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CCTA 2017
Technical Program

Technical Program for Monday August 28, 2017

MP1 Hale Hoaloha Pavilion

Opportunities and Challenges in Integration of Renewable Generation in Electric Grids (Plenary Session)

Chair: Rotea, Mario — Univ. of Texas at Dallas

Co-Chair: Spong, Mark W. — Univ. of Texas at Dallas

08:30-09:30 MP1.1

*Opportunities and Challenges in Integration of Renewable Generation in Electric Grids**

Khargonekar, Pramod — Univ. of California, Irvine

MA1 Puna

Nonlinear Systems I (Regular Session)

Chair: Rösmann, Christoph — TU Dortmund

Co-Chair: Drakunov, Sergey — Embry-Riddle Aeronautical Univ

10:00-10:20 MA1.1

A Dynamic Neural Network-Based Sliding Mode Observer Method for a Class of Uncertain Dynamic Systems, pp. 1-6

Stebler, Shane — Embry-Riddle Aeronautical Univ

MacKunis, William — Embry-Riddle Aeronautical Univ

Ramos-Pedroza, Natalie — Embry-Riddle Aeronautical Univ

Reyhanoglu, Mahmut — Embry Riddle Aeronautical Univ

A dynamic neural network (DNN)-based observer design is presented, which amalgamates an adaptive neural network-based technique with a finite-time sliding mode estimation method. The proposed observer design is motivated by practical quadrotor unmanned aerial vehicle tracking control applications, where direct sensor measurements of translational and rotational rates are not available for feedback. While sliding mode estimation strategies are well established as an effective means to compensate for bounded disturbances and dynamic model uncertainty, the proposed observer design employs a feedforward adaptive DNN-based estimation term in addition to a robust, high-gain feedback sliding mode element. The use of the DNN-based term in the estimator design is motivated by the desire to improve transient performance and reduce steady state error. In addition, the proposed sliding mode estimator design is proven to compensate for input-multiplicative parametric model uncertainty. To the best of the authors' knowledge, this is the first DNN-based sliding mode estimator result to rigorously prove asymptotic state estimation in the presence of parametric actuator uncertainty. A Lyapunov-based stability analysis is utilized to prove that the proposed DNN-based observer achieves asymptotic estimation of the quadrotor altitude and attitude rates in the presence of model uncertainty and bounded disturbances (e.g., sensor noise). Numerical simulation results are also provided to demonstrate the improved performance that is achieved by incorporating the adaptive DNN in the observer.

10:20-10:40 MA1.2

Active Flow Control under Actuator Uncertainty Using a Sliding Mode Estimation Strategy, pp. 7-12

Kidambi, Krishna Bhavithavya — Embry-Riddle Aeronautical Univ

MacKunis, William — Embry-Riddle Aeronautical Univ

Ramos-Pedroza, Natalie — Embry-Riddle Aeronautical Univ

Drakunov, Sergey V. — Embry-Riddle Aeronautical Univ

This paper presents a synthetic jet actuator (SJA)-based closed-loop active flow control and estimation method, which compensates for the parametric uncertainty inherent in SJAs. A proper orthogonal decomposition (POD)-based model reduction technique is first utilized to recast the Navier-Stokes partial differential equation as a set of ordinary differential equations in terms of the unknown Galerkin coefficients. The POD-based reduced-order model is then expressed in a control-oriented form, which incorporates the parametric uncertainty inherent in the SJA actuator model. A novel sliding mode estimator is designed to estimate the unknown Galerkin coefficients in the uncertain SJA-based reduced-order model. To the best of the authors' knowledge, this is the first time that a sliding mode estimation strategy is rigorously proven to achieve finite-time state estimation for a flow system in the presence of input-multiplicative parametric uncertainty. A rigorous proof of finite-time state estimation is provided, and the estimates are used in a nonlinear control law, which achieves asymptotic regulation of a fluid flow field to a desired time-varying velocity profile. A Lyapunov-based stability analysis is utilized to prove asymptotic regulation of the flow field velocity, and numerical simulation results are provided to demonstrate the performance of the proposed closed-loop active flow control system.

10:40-11:00 MA1.3

Constrained SPICE in Volterra-Laguerre Modeling of Human Smooth Pursuit, pp. 13-18

Bro, Viktor — Uppsala Univ

Medvedev, Alexander V. — Uppsala Univ

The Volterra model is a well-established option in nonlinear black-box system identification. However, the estimated model is often over-parametrized. This paper presents an approach to reducing the number of parameters of a Volterra model with the kernels parametrized in the orthonormal basis of Laguerre functions by estimating it with a sparse estimation algorithm subject to constraints. The resulting parameter estimates are scrutinized for parameter redundancy and functional dependence by principal component analysis. The benefits of this approach are illustrated by identifying the human smooth pursuit system. Previous studies have suggested that the Volterra model structure is suitable for modeling the human smooth pursuit system both in health and disease. The data sets are obtained by eye tracking in a study performed on 7 test subjects diagnosed with Parkinson's disease and 22 healthy control subjects. In terms of output error, the reduced model has similar performance to that of the full model.

11:00-11:20 MA1.4

Time-Optimal Nonlinear Model Predictive Control with Minimal Control Interventions, pp. 19-24

Rösmann, Christoph — TU Dortmund

Makarow, Artemi — TU Dortmund

Hoffmann, Frank — TU Dortmund

Bertram, Torsten — TU Dortmund

This paper presents a novel approach for time-optimal model predictive control. In contrast to a global uniform time scaling, the underlying optimal control problem rests upon a dynamic, local temporal discretization of the shooting grid. The approach seeks for a grid partition with minimum overall transition time. Furthermore, a multi-stage optimization iteratively adapts the number of grid points during runtime to achieve a minimum number of control interventions. A comparative analysis with previous approaches for three nonlinear control problems demonstrates the superiority of the proposed scheme. The feasibility is experimentally demonstrated for position control of a servo drive operated at 200 Hz.

11:20-11:40 MA1.5

Robust High-Gain Control of Nonlinear Reactive Sputter Processes, pp. 25-30

Woelfel, Christian Tobias — Ruhr-Univ. Bochum
Awakowicz, Peter — Ruhr-Univ. Bochum
Lunze, Jan — Ruhr-Univ. Bochum

A model-based control design method is developed for nonlinear reactive sputter processes that can be modelled by a nonlinear ordinary differential equation with linear input and stable and unstable equilibrium states. The controller shall robustly stabilize the unstable working points. Lyapunov's direct method is used to formulate stability conditions that respect possible uncertainties in the process model. It is shown that reactive sputter processes can be stabilized by robust high-gain control. The theoretical results are sustained by experiments for the validation of the developed control structure and to evaluate the agreement of the predicted closed-loop behavior with the measured behavior.

MA2 Hilo

Communication Networks (Regular Session)

Chair: Zhang, Fumin — Georgia Inst. of Tech
Co-Chair: Park, Kyung-Joon — DGIST

10:00-10:20 MA2.1

A Multi-Carrier Protocol for In-Band Control of Tactical Data Network Systems, pp. 31-36

Riley, Robert — Air Force Res. Lab
Domm, Maryanne — Northrop Grumman (current Affiliation: General Atomics)

Network management requires both awareness of the status of the network and the ability to manage key systems to maintain full network efficiency. OrderNet is an application layer protocol which rides within existing message sets to manage heterogeneous networks. This paper summarizes the analysis of alternatives performed that selected OrderNet as a promising technology for the monitoring, management, and control of tactical data networks. This paper also describes selection of the OrderNet message carriers, the OrderNet protocol design and preliminary performance analysis.

10:20-10:40 MA2.2

Extending a Routing Protocol for Mobile Robot Mesh Networking, pp. 37-42

Maxon, Sean — Georgia Inst. of Tech
Zhang, Fumin — Georgia Inst. of Tech

Mobile ad hoc mesh networks can involve a highly dynamic routing topology, characterized by rapidly changing link qualities. Existing routing protocols under-perform in this environment, yet this is precisely the situation faced by highly mobile robots operating without access to existing network infrastructure. We develop an outage probability estimation framework to compute a link quality metric within the B.A.T.M.A.N. routing protocol. This results in a unified data fusion process capable of incorporating diverse kinds of measurements in a single metric and can act as a drop-in replacement for the metric in the existing routing protocol. Our formulation exploits robot position information along with probing packet measurements and a radio signal strength model for fast link quality estimation of rapidly changing links.

10:40-11:00 MA2.3

Observer-Based Triggering Mechanism for Leader-Following Consensus of Multi-Agent Systems with Time-Varying Communication Delay, pp. 43-48

Wang, Xue-Fang — Dalian Univ. of Tech
Sun, Xi-Ming — Dalian Univ. of Tech
Du, Shengli — Dalian Univ. of Tech
Wang, Wei — Dalian Univ. of Tech

This paper investigates the leader-following consensus for general linear multi-agent systems with time-varying delay. The observer-based distributed triggering mechanism is first proposed to solve this problem. For each agent, the update of the designed distributed event-triggered controller only requires the knowledge of their neighbors' states at its own event time instants. Then a sufficient condition based on Lyapunov functional is presented to show that the consensus of the leader-following multi-agent systems can be reached exponentially. Moreover, the Zeno behavior of triggering time sequences is excluded naturally. Finally, the effectiveness of the proposed control schemes is illustrated by a numerical example along with the simulation results.

11:00-11:20 MA2.4

W-Simplex: Resilient Network and Control Co-Design under Wireless Channel Uncertainty in Cyber-Physical Systems, pp. 49-54

Kim, Dohwan — DGIST
Won, Yuchang — DGIST
Eun, Yongsoon — DGIST
Park, Kyung-Joon — DGIST

In this paper, we propose a resilient network and control co-design architecture, Wireless-Simplex (W-Simplex), which can guarantee control performance by adaptively tuning the network and control parameters against wireless channel uncertainty in cyber-physical systems (CPS). To the best of our knowledge, there has been no study on resilient network and control co-design in response to the unreliable wireless channel. Our key observation is that rate adaptation may cause significant degradation in control performance or even system instability. This performance degradation is contrary to the intuition that rate adaptation provides a reliable link under wireless channel uncertainty. We explain the cause of this phenomenon and resolve the situation by proposing a resilient co-design algorithm in an optimization framework. Our simulation study with ns-2 shows the effectiveness of the proposed scheme for providing resilience of CPS against wireless channel uncertainty.

11:20-11:40 MA2.5

Controllability and Stabilizability Analysis of Signed Consensus Networks, pp. 55-60

Alemzadeh, Siavash — Univ. of Washington
Hudoba de Badyn, Mathias — Univ. of Washington
Mesbahi, Mehran — Univ. of Washington

Signed networks have been a topic of recent interest in the network control community as they allow the study of antagonistic interactions in multi-agent systems. Although the dynamical characteristics of signed networks have been wellstudied, notions such as controllability and stabilizability for signed networks for protocols such as consensus are missing in the literature. Classically, graph automorphisms with respect to the input nodes have been used to characterize uncontrollability of consensus networks. In this paper, we show that in addition to the graph symmetry, the topological property of structural balance is also required to provide analogous sufficient conditions for uncontrollability. In particular, we provide an analysis which shows that a gauge transformation induced by structural balance allows symmetry arguments to hold for signed consensus networks. Lastly, we use new fractional automophism tools to extend these results to output controllability and stabilizability of signed consensus networks.

11:40-12:00 MA2.6

Evaluation of Asynchronous Average Consensus Algorithms in Pure Broadcasting Infrastructure-Free Networks, pp. 61-66

Orostica Navarrete, Boris Enrique — Pontificia Univ. Católica de Chile
Núñez, Felipe — Pontificia Univ. Católica de Chile

Distributed and cooperative algorithms are of preponderant importance for the correct operation of multi-agent systems. In

particular, average consensus algorithms represent an appealing alternative for combining measurements in large-scale networks of low-capable sensors, due to their low computational cost and strong convergence properties. However, the actual performance of average consensus algorithms in real scenarios, where the interaction between agents involves a communication network introducing stochastic delays, sequential transmissions and receptions, and unreliability in the information exchanging process, is yet to be investigated. This work presents an evaluation on a pure broadcasting infrastructure-free sensor network of two popular average consensus strategies: the broadcast gossip algorithm (which can be regarded as an asynchronous version of the discrete-time average consensus algorithm), and the push-sum algorithm (also known as double linear iterations). To understand the operating principles behind the algorithms, a hybrid model is first introduced that is used to conduct numerical simulations. An implementation in microprocessor-based development boards is then presented to evaluate the performance in a real environment. Results of the evaluation show that the push-sum algorithm outperforms the broadcast gossip algorithm for practical values of the reception probability.

MA3 Hamakua

Modeling I (Regular Session)

Chair: Shastri, Subramanian — Univ. of San Diego

Co-Chair: Klug, Silas — Robert Bosch GmbH

10:00-10:20 MA3.1

On-The-Go Throughput Prediction in a Combine Harvester Using Sensor Fusion, pp. 67-72

Hermann, Dan — Tech. Univ. of Denmark

Ravn, Ole — Tech. Univ. of Denmark

Andersen, Nils A. — Tech. Univ. of Denmark

The paper addresses design of a clean grain throughput observer for a combine harvester, i.e. delay free yield sensing. The aim is to predict grain throughput changes using the forward speed and a throughput sensor in the feederhouse. By utilising a grain flow model and sensor fusion an estimate of the current grain throughput is obtained, hence the effect from the lag in the momentary yield sensor reading due to material transport delays can be reduced. Statistical change detection is used to detect feederhouse load condition as well as sensor discrepancies using the observer innovation signal. The system is able to predict changes originating from forward speed and local crop density variations. Also temporary sensor discrepancies are detected and compensated in the grain flow estimate.

10:20-10:40 MA3.2

Propeller Thrust and Drag in Forward Flight, pp. 73-79

Gill, Rajan — ETH Zurich

D'Andrea, Raffaello — ETH Zurich

This paper presents a methodology for modelling the thrust, drag, and torque of propellers used in unmanned-aerial-vehicle (UAV) applications. The model can be used in wide flight regimes from hover to high speed forward flight and is derived from first-principles using Blade Element Theory (BET), Blade Element Momentum Theory (BEMT), and a parameter fitting procedure to determine aerodynamic parameters. The methodology is applied to three different types of propellers to showcase its versatility, and experiments show that the procedure can accurately predict the rotor forces. Wind tunnel measurements are also included to serve as an additional basis for comparison. A comparison to static thrust models typically used by roboticists is also shown.

10:40-11:00 MA3.3

Adaptive Pressure Control Experiment: Controller Design and Implementation, pp. 80-85

Alan, Anil — Bilkent Univ

Yildiz, Yildiray — Bilkent Univ

Poyraz, Umit — Roketsan INC

In this paper, closed loop reference model adaptive controller is implemented for the pressure control of an industrial grade cold air test setup which is ubiquitously used to conduct experiments to test and validate the throttleable ducted rocket subsystems. The objective is to control the gas pressure of a closed chamber with two ports, one entrance and one discharge. Discharge port has a control valve to manipulate the throat area. It is demonstrated that closed-loop reference model adaptive control provides improved tracking performance compared to both constant gain proportional-plusintegral controller and classical model reference adaptive controller, by suppressing the oscillations and overshoots observed for more demanding pressure commands.

11:00-11:20 MA3.4

Control-Oriented Modeling and Validation of Bicycle Curve Dynamics with Focus on Lateral Tire Parameters, pp. 86-93

Klug, Silas — Robert Bosch GmbH

Moia, Alessandro — Pol. Di Milano

Verhagen, Armin — Robert Bosch GmbH

Görges, Daniel — Univ. of Kaiserslautern

Savaresi, Sergio M. — Pol. Di Milano

Under the objective of modeling, simulating and controlling the dynamics of bicycles in dangerous situations, such as wheel slippage, an accurate tire model is essential. Especially the lateral tire behavior is crucial since it is fundamental for stability in both rectilinear and curve maneuvers. So far, various test bench measurements are available in literature that describe lateral tire forces and moments under different load, sideslip and camber angle. The most recent measurements that study the behavior of common bicycle tires that are still available on the market come to very different results, even for identical tires. Anyhow, test bench measurements almost always imply conditions that differ from field application of bicycles on actual road surface. The aim of this paper is to use lateral tire parameters extracted from literature and include them into a multibody model of lateral bicycle dynamics. The simulation result is then compared to measurements recorded in a realistic environment. Therefore a bicycle is equipped with sensors to provide a large set of relevant variables of lateral vehicle dynamics. The validation process identifies a set of tire parameters that allows good model accuracy. Also for different tires at different inflation pressure model validity can be shown using tire parameters extracted from test-bench measurements.

11:20-11:40 MA3.5

Grey-Box Modeling of an Offshore Deoiling Hydrocyclone System, pp. 94-98

Bram, Mads Valentin — Aalborg Univ

Hansen, Leif — Aalborg Univ

Hansen, Dennis Severin — Aalborg Univ

Yang, Zhenyu — Aalborg Univ

The increasing water cut from offshore production wells render optimization of the deoiling process vital for continuous oil and gas production. Hydrocyclones are commonly used as the last stage of the deoiling process and must therefore keep the oil content in the produced water below 30ppm to comply with the local legislation. Optimizing the performance of hydrocyclones is a balance between separation efficiency and reject flow rate. Thus, it is essential to exploit the freedom within the system which may be found by means of analyzing the internal fluid mechanics of the hydrocyclones. This work investigates the establishment of a control-oriented grey-box model of a hydrocyclone as an extension of a previously defined droplet trajectory-based model. The model parameters were estimated using numerical optimization by fitting the model outputs to experimental data. This work proposes a method to estimate how the hydrocyclone pressures are related to its flow rates by means of virtual orifice equations. The experimental results prove that the proposed model is able to estimate the relationship between pressures and flow rates with good accuracy and can be extended in

future works to include dynamic properties

11:40-12:00 MA3.6

Modeling the Thermal Dynamics Inside a Ceria-Coated Gasoline Particulate Filter, pp. 99-105

Arunachalam, Harikesh — Clemson Univ
Pozzato, Gabriele — Clemson Univ
Hoffman, Mark — Clemson Univ
Onori, Simona — Clemson Univ

This work presents the first-ever control oriented model to predict the thermal dynamics inside a ceria-coated Gasoline Particulate Filter (GPF). By incorporating catalytic reaction kinetics in addition to the carbon to CO_2 oxidation reactions, the proposed model predicts the internal GPF temperature during nominal operation and regeneration events. The model utilizes the GPF inlet exhaust gas temperature to predict the internal GPF temperature. Parameter identification and model validation are performed using data obtained from experiments with a ceria-coated GPF installed on a vehicle using a direct injection engine operated in a chassis dynamometer laboratory. It is demonstrated in this work that the model predicts ceria-coated GPF thermal dynamics for different initial soot loadings and engine operating conditions within a root mean square error of 5%.

MA4 — Kohala

Mechatronic Systems I (Regular Session)

Chair: Moheimani, S.O. Reza — Univ. of Texas at Dallas
Co-Chair: Petersen, Ian R. — Univ. of New South Wales at the Australian Defence Force Acad

10:00-10:20 MA4.1

A Self-Tuning Controller for High-Performance Scanning Tunneling Microscopy, pp. 106-110

Tajaddodianfar, Farid — Univ. of Texas at Dallas
Moheimani, S.O. Reza — Univ. of Texas at Dallas
Owen, James — Zyvex Labs LLC
Randall, John N. — Zyvex Labs

The loop gain in feedback control system of a Scanning Tunneling Microscope (STM) is proportional to a quantum mechanical property of the STM tip and sample, known as the Local Barrier Height (LBH). Variations in LBH can negatively affect the stability of feedback loop and increase the risk of tip-sample crash. In this paper, we propose a method for online estimation of the LBH and accordingly tuning the gains of a proportional-integral (PI) controller. Experimental results confirm enhanced stability of the STM with the tuning algorithm in effect.

10:20-10:40 MA4.2

An Application of the Fast Gradient Method to Model Predictive Control of an Atomic Force Microscope X-Y Stage, pp. 111-116

Braker, Roger A — Univ. of Colorado, Boulder
Pao, Lucy Y. — Univ. of Colorado, Boulder

Random sub-sampling imaging methods in Atomic Force Microscopy require the piezo X-Y stage to track a sequence of step inputs. Control slew-rate limits combined with linear feedback methods have been shown to limit achievable performance in this scenario. Due to its natural ability to account for actuation constraints, we consider the application of Model Predictive Control. By recasting the problem in an incremental form, the arising quadratic program takes a form that can be solved efficiently. Specifically, we solve an input constrained Model Predictive Control problem with 50 states, a control horizon of 12 samples, and a sample frequency of 25~kHz using the Fast Gradient Method. We present experimental results using the method applied to a nano-positioning stage.

10:40-11:00 MA4.3

Design and Application of a Data Driven Controller Using the Small-Gain Constraint for Positioning Control of a Nano-Positioner, pp. 117-122

Das Gupta, Tanmoy — Univ. of New South Wales
Habibullah, Habibullah — Univ. of New South Wales
Pota, Hemanshu R. — Univ. of New South Wales
Petersen, Ian R. — Univ. of New South Wales at the Australian Defence Force Acad

In this paper, the design of a data driven controller using a small-gain theorem approach for improving the positioning accuracy of a piezoelectric tube scanner (PTS) is demonstrated. Open-loop frequency responses of both the X-PTS and Y-PTS are measured using a band-limited sweep sine signal and are used as primary data for this control design. The frequency response of the controllers is synthesized by the application of the small-gain theorem constraints over the entire frequency range for both the axes. The experimental implementation of this feedback data driven controller provides significant vibration reduction, with 19 dB and 15 dB damping at the resonance frequencies of the X and Y-axes of the PTS, respectively. A comparison between the open-loop and closed-loop tracking performance for triangular signals shows significant improvement up to the scanning frequency of 150 Hz. Moreover, the design of this data driven controller is less complex than conventional controller design methods as it does not need a system model.

11:00-11:20 MA4.4

Q Control of a Microfabricated Piezoelectric Cantilever with On-Chip Feedthrough Cancellation, pp. 123-128

Fowler, Anthony — Univ. of Texas at Dallas
Coskun, M. Bulut — Univ. of Texas at Dallas
Moheimani, S.O. Reza — Univ. of Texas at Dallas

One of the major prerequisites to obtaining high-speed tapping-mode atomic force microscopy (AFM) is a controllable quality (Q) factor. This can be achieved through the use of self-sensing cantilevers that utilize piezoelectric actuation. However, such cantilever configurations commonly feature significant levels of feedthrough from the actuation signal to the sensing signal that buries the dynamics of the cantilever, and correspondingly increases the complexity of the control implementation, especially for higher imaging modes. Here we demonstrate a novel active AFM cantilever fabricated with a separate piezoelectric actuator and sensor, together with an electrode configuration that is designed to significantly reduce feedthrough. This enables a simplified approach to controlling the cantilever's dynamics, which is demonstrated through the implementation of an effective Q control method for high-speed AFM scanning.

11:20-11:40 MA4.5

Tracking of Constant-Linear-Velocity Spiral Trajectories by Approximate Internal Model Control, pp. 129-134

Bazaei, Ali — Univ. of Newcastle, Australia
Maroufi, Mohammad — Univ. of Texas at Dallas
Moheimani, S.O. Reza — Univ. of Texas at Dallas

We report an Approximate Internal Model Control (AIMC) method for tracking of the reference signals by which a constant-linear-velocity (CLV) spiral scan pattern is generated. In contrast to the constant-angular-velocity (CAV) spiral pattern, the instantaneous frequency of the CLV sinusoidal references considerably varies over the scan period. In addition, the reference amplitude is a nonlinear function of time, making the tracking of a CLV spiral reference a more challenging control objective. Considerable improvement in the tracking performance of the proposed time-varying controller is demonstrated compared to a recently developed LQG method for spiral trajectories. Experimental implementation on a MEMS nanopositioner further illustrates applicability of the proposed control approach.

11:40-12:00 MA4.6

Design Method for Power Enhancement of Piezo Actuators with Displacement Amplification Using Rolling Transmission, pp. 135-141

Tsuchiya, Koki — Sumitomo Heavy Industries, Ltd

Tsukahara, Shinichiro — Sumitomo Heavy Industries, Ltd

The mechanical stiffness of piezoelectric actuators restrains the output property and suppresses the output energy in general. We aimed to enhance the output energy of displacement amplified piezoelectric actuators (DAPAs). We have employed rolling joint mechanisms for DAPAs due to its high energy transmissibility. By using the proposed design method for the shape of the rolling joints, we developed a novel output property of DAPA. In the new design, the influence of stiffness on the output force of DAPAs was significantly cancelled. In this paper we show the design method and the novel output characteristics of DAPAs. In addition, we suggest the great potential of the design to enhance the utilization of the piezoelectric energy in DAPAs.

MA5 Ballroom I

Robotics I (Regular Session)

Chair: Pettersen, Kristin Y. — Norwegian Univ. of Science and Tech

Co-Chair: Nakashima, Akira — Nanzan Univ

10:00-10:20 MA5.1

Kinematic Singularity Avoidance for Robot Manipulators Using Set-Based Manipulability Tasks, pp. 142-149

Sverdrup-Thygeson, Jørgen — Norwegian Univ. of Science and Tech

Moe, Signe — Norwegian Univ. of Science and Tech

Pettersen, Kristin Y. — Norwegian Univ. of Science and Tech

Gravdahl, Jan Tommy — Norwegian Univ. of Science and Tech

This paper proposes a novel method for kinematic singularity avoidance for robot manipulators. Using set-based singularity avoidance tasks within the singularity-robust multiple task priority framework, avoidance of kinematic singularities is guaranteed without interfering with the convergence of compatible equality tasks. Non-compatible equality tasks will still be fulfilled to the extent possible. In addition, the method can be used to reconfigure the robot into a more dexterous configuration. The proposed method is applicable to both redundant and non-redundant robots, with both fixed base and floating base. The implementation is generic and independent of the type and number of tasks. Although also applicable for non-redundant fixed base robot manipulators, this novel approach is particularly well suited for highly redundant and/or floating base manipulators, since the robot configuration can be changed to improve the dexterity of the manipulator arm. We demonstrate the method by applying it to an underwater swimming manipulator, which is an innovative and highly redundant underwater floating base manipulator. Furthermore, simulation results are presented that illustrate and validate the proposed method.

10:20-10:40 MA5.2

Design of Robustly Stabilizing Low Order, Stable Controllers for Two-Link Underactuated Planar Robots, pp. 150-154

Yücesoy, Veysel — Aselsan Res. Center

Ozbay, Hitay — Bilkent Univ

This study is aimed to find low order, stable and proper controllers for the linearized models of two well known underactuated robots i.e. Acrobot and Pendubot around their upright equilibrium points in order to maximize the robustness of the feedback loop to uncertainties. The proposed method makes use of the robust stabilization of finite dimensional plants by Nevanlinna-Pick interpolation problem. This method does not necessarily yield a stable controller and also the resulting controller is not proper if boundary interpolation conditions are not taken into account. In this paper, additional simple constraints are defined to handle these problems to find a stable and proper controller for Acrobot and Pendubot. Third order stable controllers for these robots are designed with improvements in the robustness margin when compared to other relevant controllers from the literature. Also the integral action controller design is revisited and fourth order, stable, proper controllers are designed in this manner.

10:40-11:00 MA5.3

Modeling, Design and Control of Low-Cost Differential-Drive Robotic Ground Vehicles: Part I - Single Vehicle Study, pp. 155-160

Rodriguez, Armando A. — Arizona State Univ

Puttannaiah, Karan — Arizona State Univ

Lin, Zhenyu — Univ. of Maryland, Coll. Park

Aldaco, Jesus — Arizona State Univ

Li, Zhichao — Univ. of California San Diego

Lu, Xianglong — Changan US R&D Center

Mondal, Kaustav — Arizona State Univ

Sonawani, Shubham — Arizona State Univ

Ravishankar, Nikhilesh — Arizona State Univ

Das, Nirangkush — Arizona State Univ

Pradhan, Pragyan — Arizona State Univ

Toward the ambitious long-term goal of a fleet of cooperating Flexible Autonomous Machines operating in an uncertain Environment (FAME), this two part paper addresses several critical modeling, design and control objectives for ground vehicles. One central objective was to show how off-the-shelf (low-cost) remote-control (RC) “toy” vehicles can be converted into “intelligent” multi-capability robotic-platforms for conducting FAME research. This was done for 13 differential drive RC vehicles called Thunder Tumbler (DDT2). Each DDT2-vehicle was augmented with a suite of sensor-computing-communication devices in order to provide a substantive suite of capabilities. Part I of this two part paper, focusing on a single vehicle, examines the associated non-holonomic dynamical model (including motor dynamics) for the DDT2 vehicle under consideration. We shed light on how vehicle coupling impacts control design – a topic not well addressed within the robotics community. Because our vehicle exhibits little coupling, we are able to use classical decentralized control to design a wheel speed inner-loop controller. This controller is used for all of our outer-loop control modes: (speed-direction) cruise control along a curve, planar Cartesian (x,y) stabilization and minimum-time optimal-control around an oval race track. Empirically collected data is shown to agree well with simulation results. Reasons for observed differences are provided. Within Part II, focus is on control laws for the coordination of multiple vehicles. In short, many capabilities that are critical for reaching the longer-term FAME goal are demonstrated within this two part paper.

11:00-11:20 MA5.4

Modeling, Design and Control of Low-Cost Differential-Drive Robotic Ground Vehicles: Part II - Multiple Vehicle Study, pp. 161-166

Rodriguez, Armando A. — Arizona State Univ

Puttannaiah, Karan — Arizona State Univ

Lin, Zhenyu — Univ. of Maryland, Coll. Park

Aldaco, Jesus — Arizona State Univ

Li, Zhichao — Univ. of California San Diego

Lu, Xianglong — Changan US R&D Center

Mondal, Kaustav — Arizona State Univ

Sonawani, Shubham — Arizona State Univ

Ravishankar, Nikhilesh — Arizona State Univ

Das, Nirangkush — Arizona State Univ

Pradhan, Pragyan — Arizona State Univ

Toward the ambitious long-term goal of a fleet of cooperating Flexible Autonomous Machines operating in an uncertain Environment (FAME), this two part paper addresses several critical modeling, design and control objectives for ground vehicles. Within Part I of this paper, a low-cost differential drive robotic vehicle was introduced for FAME research. Suitable nonlinear/linear-models were used to develop inner/outer-loop control laws for a single vehicle; e.g. wheel (and vehicle translational/rotational) velocity inner-loop control, etc. Part II of this paper focusses on the coordination of multiple vehicles. The (faster) inner-loop control law discussed within Part I is used for all (slower) outer-loop control modes demonstrated within Part II. We specifically demonstrate (via simulations and hardware) the following specific outer-loop control laws: (1) Delta_x-theta separation-direction control, (2) collision avoidance, (3) separation control for a longitudinal platoon of vehicles. Empirically collected data is shown to agree well with simulation results. Reasons for observed differences are provided. The simple separation-direction control structure is adequate because of the (higher bandwidth) inner-loop control law. We observed (and expected) that (1) collision avoidance works well as long as the controlled vehicle is not traveling too fast with respect to obstacles. (2) with respect to platoon control, we demonstrated that feedforward of leader speed information significantly and uniformly improves separation performance as we move rearward in the platoon. In short, many capabilities that are critical for reaching the longer-term FAME goal are demonstrated within this two part paper.

11:20-11:40 MA5.5

A Motion Planning for Grasp and Manipulation System Based on Rolling Motion, pp. 167-174

Nakashima, Akira — Nanzan Univ

This paper proposes a motion planning method to manipulate a grasped object by a two-fingered robot hand based on the holonomy of the rolling contacts. A grasped rectangular object is regulated to a target configuration through regulating the contact coordinates between the fingers and object using the holonomy generated by closed paths on semi-spherical finger-tips. The parameters of the closed paths are determined by solving an optimization problem with the constraints which consist of the limitations on the finger-tip surfaces and configurations. The proposed method is verified by a numerical simulation.

11:40-12:00 MA5.6

Comparative Analysis of Energy-Based Criteria for Dynamics-Based Robot Motion Optimization, pp. 175-180

Hong, Youngsuk — Seoul National Univ
Kim, Jinkyu — Seoul National Univ
Park, Frank — Seoul National Univ

We perform a comparative analysis of energy-based performance criteria for the dynamics-based optimization of robot trajectories. The performance criteria considered include minimum torque, electrical power loss, approximation to mechanical work, and energy loss due to friction. Our dynamics model takes into account rotor inertias and gearing, and also considers robots subject to a range of motion types and payloads. High fidelity numerical simulation experiments are performed and compared for the various performance criteria. Our analysis and findings refute some commonly held assumptions about dynamics-based robot motion optimization, and offer practical insights on how to effectively leverage robot dynamic models and optimization into industrial robot trajectory generation.

MA6 — Ballroom II

Energy Systems I (Regular Session)

Chair: Beghi, Alessandro — Univ. Di Padova
Co-Chair: Bashash, Saeid — San Jose State Univ

10:00-10:20 MA6.1

Energy-Efficient Management of a Wood Industry Facility, pp. 181-186

Beghi, Alessandro — Univ. Di Padova
Lionello, Michele — Univ. of Padova
Rampazzo, Mirco — Univ. Di Padova

The energy-efficient management of complex industrial plants is a non-trivial task. While the traditional approach to improve energy systems efficiency is based on advanced hardware design, it is nowadays known that advanced management systems offer a unique opportunity to significantly enhance both efficiency and performance by mostly acting on software components. In this paper we consider the problem of managing a wood industry facility from an energy point of view. This kind of complex plant for processing and drying wood makes use of CHP and boiler units, renewable energy sources, and the electrical grid to meet its energy needs. Specifically, a model-based, repeated optimization scheme is applied, that exploits CHP and boiler efficiency models coupled with a nature-inspired numerical optimization algorithm. The proposed method is employed in a Matlab-based simulation environment. The simulation results show that the identified strategy maximizes profit while meeting the plant energy needs.

10:20-10:40 MA6.2

On Parameter Identification of an Equivalent Circuit Model for Lithium-Ion Batteries, pp. 187-192

Tian, Ning — Univ. of Kansas
Wang, Yebin — Mitsubishi Electric Res. Labs
Chen, Jian — Zhejiang Univ
Fang, Huazhen — Univ. of Kansas

This paper focuses on nonlinear parameter identification of an equivalent circuit model for lithium-ion batteries (LiBs). A Thevenin's model is considered, which consists of a voltage source based on the battery's open-circuit voltage (OCV), an Ohmic resistor and two RC circuits connected in series. The objective is to identify all the parameters in the voltage source and circuits at once from the current-voltage data collected from a battery under constant-current discharging. Based on the voltage response, identifiability of the parameters is analyzed using the sensitivity analysis, and it is verified that the parameters are locally identifiable. An optimization problem based on nonlinear least squares is formulated to address identification, to which parameter bounds are imposed to limit the search space. The identification is then achieved by a trust region method. An evaluation based on experimental data illustrates the effectiveness of the proposed results. Differing from the existing work, this approach does not require an explicit relationship between the OCV and the battery's state-of-charge (SoC). Its application hence requires much less effort. Furthermore, the success in parameter identification can potentially contribute to parameter-analysis-based aging prognostics of LiBs.

10:40-11:00 MA6.3

An ODE-Based Design of Spatial Charging/Discharging Patterns of In-Vehicle Batteries for Provision of Ancillary Service, pp. 193-198

Mizuta, Naoto — Osaka Prefecture Univ
Susuki, Yoshihiko — Osaka Prefecture Univ
Ota, Yutaka — Tokyo City Univ
Ishigame, Atsushi — Osaka Prefecture Univ

We develop a framework for designing a spatial pattern of charging/discharging operations of in-vehicle batteries for provision of Ancillary Service (AS) in a rudimentary power distribution grid. The

method is based on the ODE (Ordinary Differential Equation) model of distribution voltage profile that has been recently introduced. In this paper, firstly, we derive analytical solutions of the ODE model for a single straight-line feeder through a partial linearization, thereby providing a physical insight to the impact of spatial EV charging/discharging to the distribution voltage profile. Second, based on the analytical solutions, we propose an algorithm for determining values of charging/discharging power by in-vehicle batteries in the single feeder grid, so that power demanded as AS (e.g. regulation signal for primary and secondary frequency controls) is provided by EVs, and the deviation of distribution voltage from a nominal value is reduced in the grid. Effectiveness of the analytical solution and algorithm is established with numerical simulations.

11:00-11:20 MA6.4

Data-Driven Distributionally Robust Control of Energy Storage to Manage Wind Power Fluctuations, pp. 199-204

Samuelson, Samantha — Univ. of Southern California
Yang, Insoon — Univ. of Southern California

Energy storage is an important resource that can balance fluctuations in energy generation from renewable energy sources, such as wind, to increase their penetration. Many existing storage control methods require perfect information about the probability distribution of uncertainties. In practice, however, the distribution of renewable energy production is difficult to reliably estimate. To resolve this challenge, we develop a new storage operation method, based on the theory of distributionally robust stochastic control, which has the following advantages. First, our controller is robust against errors in the distribution of uncertainties such as power generated from a wind farm. Second, the proposed method is effective even with a small number of data samples. Third, the construction of our controller is computationally tractable due to the proposed duality-based dynamic programming method that converts infinite-dimensional minimax optimization problems into semi-infinite programs. The performance of the proposed method is demonstrated using data about energy production levels at wind farms in the Pennsylvania-Jersey-Maryland interconnection (PJM) area.

11:20-11:40 MA6.5

Dynamic Programming-Based Approximate Real-Time Control Policies for Plug in Hybrid Electric Vehicles, pp. 205-210

Abbaszadeh Chekan, Jafar — Virginia Tech
Bashash, Saeid — San Jose State Univ

This paper examines the application of dynamic programming (DP) to the development of parametric real-time power management policies for the plug-in hybrid electric vehicles (PHEVs). First, a representative power-split PHEV powertrain model is introduced, followed by a DP formulation for obtaining the cost-optimal powertrain trajectories. The obtained optimal trajectories are then used to train a set of control policies for the powertrain control inputs through a least-squares linear regression process. The proposed controller receives the demanded propulsion force and the powertrain variables as inputs, and generates the torque commands for the engine and the electric drivetrain system. Numerical simulations indicate that the proposed control policy is able to approximate the optimal trajectories closely using the real-time powertrain system information for the training drive cycle data. To maintain the battery state-of-charge (SOC) above a certain lower bound for arbitrary test data, a switching logic is implemented to transition to a conservative control policy when the battery SOC drops below a certain threshold. Simulation results indicate the effectiveness of the proposed approach in achieving near-optimal performance while maintaining the SOC within the desired range.

11:40-12:00 MA6.6

Synthesis and Real-Time Simulation of Reactive Controller for Hot-Water Supply in a Safety-Critical Hospital Environment, pp. 211-216

Susuki, Yoshihiko — Osaka Prefecture Univ
Saito, Tsukasa — Kyoto Univ
Hoshino, Hikaru — Kyoto Univ
Hikihara, Takashi — Kyoto Univ

We report synthesis of reactive controller for a hot-water supply system in a medical institution for dialysis treatment using formal method and its real-time simulation based on measurement data in a practical hospital. Dialysis treatment requires heat to warm a large amount of water to the body temperature. Thus, synthesizing a controller guaranteeing the correctness of heat supply is of critical importance. The hot-water supply system considered in this paper includes heat generation equipments, hot-water storage tanks, and heat loads. We synthesize a reactive controller that reacts to changes of environment of the system affecting the supply such as failure and restarting of equipments, and achieves the continuous supply of heat to a critical load for dialysis treatment. Also, we experimentally demonstrate the synthesized controller with a real-time simulator that can interact with a dynamic analog environment. For this, a dynamic model of the hot-water supply system is developed through the measurement data. We then show that the synthesized reactive controller works effectively while reacting to the analog environment.

MA7 Ballroom III

Applications of Control Technologies in the Marine Environment (Invited Session)

Chair: Chyba, Monique — Univ. of Hawaii
Co-Chair: Smith, Ryan N. — Fort Lewis Coll
Organizer: Smith, Ryan N. — Fort Lewis Coll
Organizer: Chyba, Monique — Univ. of Hawaii
Organizer: Mileyko, Yuriy — Univ. of Hawaii

10:00-10:20 MA7.1

An Energy-Casimir Approach to Underwater Vehicle Depth and Heading Regulation in Short Crested Waves (I), pp. 217-222

Battista, Thomas — Virginia Tech
Jung, Seyong — Virginia Tech
Woolsey, Craig — Virginia Tech
Paterson, Eric — Virginia Tech

Conventional underwater vehicle models neglect wave excitation forces and free surface effects, since the vessel is most often deeply submerged where these effects are negligible. For near-surface operations, wave excitation forces significantly affect vessel motion. This paper focuses on depth and heading regulation for a fully actuated underwater vehicle operating in the wave-affected zone. We first construct a non-canonical Hamiltonian model for the nominal system dynamics. We then employ the energy-Casimir method to construct a control law, together with a Lyapunov function, which renders the desired motion asymptotically stable. Finally, using a disturbance model developed in an earlier work, we study the effects of the Froude-Krylov excitation forces on the closed-loop system response.

10:20-10:40 MA7.2

Energy-Efficient Control Strategies for Updating an Augmented Terrain-Based Navigation Map for Autonomous Underwater Navigation (I), pp. 223-228

Smith, Ryan N. — Fort Lewis Coll
Chyba, Monique — Univ. of Hawaii
Mileyko, Yuriy — Univ. of Hawaii
Reis, Gregory — Florida International Univ

Accurate and energy-efficient navigation and localization methods for autonomous underwater vehicles continues to be an active area of research. As we increase the endurance of autonomous underwater vehicles, we will require navigation and localization solutions that are robust over the entire deployment duration. Rather than look at expensive and high-energy instrumentation, we examine the utility of maps created from data gathered in the region of interest. In this

paper, we present a formulation of a terrain map for applications in traditional terrain-based navigation, and then examine control strategies for energy-efficient paths that update this map for successive deployments over time. Results from field deployments are used to motivate and constrain the optimal control problem.

10:40-11:00 MA7.3

Analysis of Efficient Strokes for Multi-Legged Microswimmers (I), pp. 229-234

Chyba, Monique — Univ. of Hawaii
Takagi, Daisuke — Univ. of Hawaii
Kravchenko, Yuliia — Univ. of Hawaii
Markovichenko, Oleksandr — Univ. of Hawaii

We consider efficient controls for swimming with multiple rigid legs at low Reynolds number. We derive equations governing the translation and rotation of a general class of multi-legged swimmers, and we formulate energy-efficient controls of symmetric swimmers as a problem in geometric control theory. We then focus on the case of symmetric swimmers with multi pairs of legs. In the framework of sub-Riemannian geometry, abnormal geodescics are analyzed and shown to depend on the number of pairs of legs. Inspired by larval copepods possessing three pairs of legs, we compute various swimming strokes and explore optimal controls in that specific situation. We also compare our results to experimental measurements of larval copepod.

11:00-11:20 MA7.4

Adaptive Receding Horizon Control for a High-Speed Autonomous Surface Vehicle in Narrow Waterways (I), pp. 235-240

Dunbabin, Matthew — Queensland Univ. of Tech
Lamont, Riki — Queensland Univ. of Tech

This paper presents an adaptive receding horizon controller for a high-speed, jet-powered catamaran Autonomous Surface Vehicle (ASV) operating in narrow and cluttered natural waterways. Using an integrated vision and laser-based sensor system for real-time shoreline classification and obstacle detection, the control reference trajectories and planning horizons are adapted based on the estimated obstacle/shoreline position uncertainty and the predicted waterway trajectory. Simulation and experimental results demonstrate the performance of the proposed shoreline detector, planner and controller on an ASV in a cluttered and narrow waterway environment.

11:20-11:40 MA7.5

Set-Based Line-Of-Sight (LOS) Path Following with Collision Avoidance for Underactuated Unmanned Surface Vessels under the Influence of Ocean Currents, pp. 241-248

Moe, Signe — Norwegian Univ. of Science and Tech
Pettersen, Kristin Y. — Norwegian Univ. of Science and Tech

An essential ability of an autonomous unmanned surface vessel (USV) is to follow a predefined path in the presence of unknown ocean currents while avoiding collisions with both stationary and dynamic obstacles. This paper combines recent results for path following and collision avoidance for USVs, resulting in a switched guidance system with a designated path following and a collision avoidance mode. The closed-loop system relies on absolute velocity measurements only, and it is shown that a previously suggested guidance law for collision avoidance guarantees tracking of a safe radius about a dynamic obstacle also under the influence of unknown ocean currents. The guidance law is constructed to ensure collision avoidance while following the International Regulations for Preventing Collisions at Sea (COLREGs). Note that this set-based approach is highly generic and may be applied with any combination of methods for path following and collision avoidance. It is proven that the USV evades the obstacles in a COLREGs compliant manner and converges to the desired path in path following mode. Simulations results validate the theoretical results.

11:40-12:00 MA7.6

Communications Aware Decentralized Model Predictive Control for Path Planning within UUV Swarms, pp. 249-254

DiLeo, Nicholas — Lockheed Martin Advanced Tech. Lab
Abad, Alexandra — Lockheed Martin
Fregene, Kingsley C. — Lockheed Martin Advanced Tech. Lab

We describe a decentralized model predictive control (DMPC) algorithm to control teams of unmanned underwater vehicles (UUVs) that simultaneously optimizes vehicle control inputs in a manner that explicitly accounts for the limitations of operating underwater, which include low bandwidth communications. Rather than treating the challenges of operating a swarm underwater, such as swarm communications and collision avoidance, as constraints to be satisfied, we formulate these factors as sub-objectives and include them directly in the optimization problem. This ensures that vehicles find a solution to the optimization problem and allows vehicles to dynamically prioritize sub-objectives in situ. Swarm formations are therefore able to autonomously converge closer together in the presence of higher environmental noise. We also use a network graph to facilitate communications throughout the swarm. In contrast to existing methods that prescribe a maximum distance between all neighboring vehicles, our algorithm allows each vehicle to determine when it must limit its movement to keep communications throughout the swarm and when it can move more freely because it is less critical to the swarm's network graph. We also introduce the notion of a “critical node” within the swarm, which is a swarm member whose movement is restricted to keep in communication with its neighbors, maintaining a fully connected network graph. We demonstrate this scheme in several example scenarios where a team of UUVs works collaboratively to accomplish tasks while simultaneously addressing competing sub-objectives.

MA8 Ballroom IV

Automotive Applications I (Regular Session)

Chair: Shen, Tielong — Sophia Univ
Co-Chair: Beal, Craig — Bucknell Univ

10:00-10:20 MA8.1

Active Noise Cancellation in Passenger Cars Using the Electrical Power Steering Motor, pp. 255-260

Schubert, Dominik — Univ. of Applied Sciences Munich
Henneberger, Robert — Univ. of Applied Sciences Munich
Hecker, Simon — Univ. of Applied Sciences Munich
Sentpali, Stefan — Univ. of Applied Sciences Munich
Marburg, Steffen — Tech. Univ. of Munich

The paper describes the usage of the electrical power steering (EPS) motor as an actuator to perform active noise cancellation in passenger cars. Therefore, the existing field oriented controller for the motor current is modified and the demanded currents required for the power steering are superimposed with additional signals e.g., sinusoidal signals with frequencies of 50-500Hz that generate vibrations of the motor. These vibrations are transferred as sound and vibration to the driver's cabin. Adaptive filters are used to shape the steering motor vibrations such that they cancel narrowband disturbance sounds at the position of the driver's ear. The concept is experimentally validated in a vehicle where a narrowband acoustic disturbance generated by a shaker on the front axle carrier is canceled.

10:20-10:40 MA8.2

Design and Development of Traffic-In-Loop Powertrain Simulation, pp. 261-266

Vallur Rajendran, Avinash — Ohio State Univ
Hegde, Bharatkumar — Ohio State Univ
Ahmed, Qadeer — Ohio State Univ
Rizzoni, Giorgio — Ohio State Univ

This paper presents a traffic integrated powertrain simulation framework. The co-simulation environment aims at mimicking real-world driving, by combining microscopic traffic simulation with a detailed mathematical powertrain model in Simulink. The co-simulation is capable of emulating onboard sensors, V2X communication and capturing causal behavior of the real-world scenarios, results pertaining to which have been presented. It marks a departure from the popular cycle-based simulation for powertrain analysis. Statically validated simulation results show upto 15% variation in fuel economy due to variation in onroad traffic of constant density. The environment also offers a method to develop, calibrate and validate controllers in a real-world like simulation scenario hence accelerating the design process for powertrain and safety controllers.

10:40-11:00 MA8.3

Lane Centering Assistance System Design for Large Speed Variation and Curved Roads, pp. 267-273

Ballesteros Tolosana, Iris — Centrale-Supèlec-Univ. Paris XI
Rodriguez-Ayerbe, Pedro — Centrale-Supèlec
Olaru, Sorin — Centrale-Supèlec
Deborne, Renaud — Renault SAS
PITA, Guillermo — Renault SAS

The present paper is dedicated to the Advanced Driving Assistance Systems (ADAS). The first goal is to offer an outlook of ADAS which represents a widespread feature of the modern vehicles. After this general perspective, the attention is focused on one of the lateral dynamics control systems, the Lane Centering Assistance system. A Linear Parameter-Varying (LPV) model comprising the most relevant system dynamics is considered with the curvature of the road representing a bounded parameter-varying disturbance. This model will be used for the design of an input-to-state stable LPV observer-based controller within the Linear Matrix Inequality (LMI) framework, ensuring systems' performance in the presence of speed variation and curved roads. In addition, constraint satisfaction and the maximization of the domain of attraction are considered, in order to provide a certified region of operation. As a last part of the study, in order to reduce the conservativeness introduced by large parameter variations, a discontinuous multiple parameter-dependent design is proposed, and stability of the LPV closed-loop switching system is proved by exploiting the dwell time conditions inherited from the hysteresis implementation.

11:00-11:20 MA8.4

Slip-Ratio-Based Torque Distribution Control Strategy for Electric Vehicles Over Split Friction Regions, pp. 274-280

Ji, Yue-Han — National Cheng Kung Univ
Liu, Yen-Chen — National Cheng Kung Univ

This paper addresses a novel slip-ratio-based torque distribution strategy for electric vehicles (EVs) to avoid slippage when driving over split friction surface. With the combination to an upper and middle controller, the desired driving force and yaw moment can be distributed to four driving wheels by utilizing the proposed lower controller. Stability analysis by using Lyapunov theorem is presented to show that the distribution method can equalize the slip ratios for the wheels on the same side of EVs. In addition, we also propose two torque distribution parameters for driving force KF and moment KM so that it is more flexible and easier to design a lower controller for EVs. This distribution method is able to equalize the slip ratios for wheels on the same side of EVs, so that the slipping motion can be avoided. Simulation results by using CarSim and MATLAB/Simulink are presented to show the performance of the proposed methods.

11:20-11:40 MA8.5

Experimental Evaluation of Cooperative Adaptive Cruise Control with Autonomous Mobile Robots, pp. 281-286

Lin, Yuan — Virginia Tech
Eskandarian, Azim — Virginia Tech

Cooperative Adaptive Cruise Control (CACC) is made possible with connected vehicles to achieve tight vehicle following. Vehicle-to-vehicle wireless communication can provide information that is not present using available in-vehicle sensors and can aid the development of better control strategies for following. Current theoretical and experimental studies have shown that CACC systems reduce the inter-vehicle headway as compared to Adaptive Cruise Control (ACC) systems while guaranteeing string stability, i.e., gap-keeping error doesn't propagate throughout the platoon. This paper focuses on implementation of a CACC system on unmanned ground robots. The step response for the transfer function of the CACC system equals a step input and thus demands zero rise time. Our robot platooning experiment results have demonstrated the advantages of CACC over ACC in maintaining a small inter-vehicle headway.

11:40-12:00 MA8.6

On-Board Map Learning-Based Combustion Phase Control in Spark Ignition Engines, pp. 287-292

Zhang, Yahui — Sophia Univ
Shen, Tielong — Sophia Univ

The combustion phase control is a significant research topic in spark ignition (SI) engines since it affects the fuel efficiency, combustion variability and knocking. Managing the combustion phase, which can be set in the crank angle of 50% mass burnt (CA50), at the optimal reference value where the maximal thermal efficiency can be obtained is challenging due to the engine transient operation, the cyclic variability of combustion process and the optimal operation point drift caused by engine aging, fuel quality, etc. This research addresses this problem in two loops: an outer loop providing the optimal CA50 reference (CA50*) and an inner loop tracking CA50* by managing the spark advance (SA).CA50* is obtained by looking up a 3-dimensional map that can be updated by the stochastic gradient-based on-board map learning algorithm. Then a SA feedforward-feedback controller is designed to track CA50*. The closed loop is of benefit to the fast response of transient operation condition and the on-board learning loop compensates the map drift. Experimental validations of the proposed scheme have been carried out on a six-cylinder SI gasoline engine test bench at transient operation mode.

MB1 Puna

Nonlinear Systems II (Regular Session)

Chair: Tsubakino, Daisuke — Nagoya Univ
Co-Chair: Jabbari, Faryar — Univ. of California, Irvine

13:30-13:50 MB1.1

Stabilization of Nonlinear Systems by Adding State-Dependent Rough Signals, pp. 293-298

Nishimura, Yuki — Kagoshima Univ
Tsubakino, Daisuke — Nagoya Univ

This paper provides a stabilization strategy for input-affine systems by adding state-dependent rough signals, a particular kind of continuous processes having unbounded variations. The effective use of rough path analysis enables state-feedbacks to gain entrance to the mechanism of rough signals. The results demonstrate that the addition of rough signals also invocates ``hidden control inputs'' that make the systems controllable using Lie derivatives. This implies that control Lie algebra can be constructed by Lie derivatives instead of Lie brackets.

13:50-14:10 MB1.2

Position and Attitude Control of Two-Wheeled Mobile Robot Using Multilayer Minimum Projection Method, pp. 299-304

Kimura, Shunsuke — Tokyo Inst. of Tech
Nakamura, Hisakazu — Tokyo Univ. of Science
Shudai, Hiroki — Tokyo Univ. of Science
Ibuki, Tatsuya — Tokyo Inst. of Tech
Sampei, Mitsuji — Tokyo Inst. of Tech

For robotics navigation, artificial potential functions are commonly utilized. As a kind of these functions, control Lyapunov functions (CLFs) guarantee stability of nonlinear autonomous systems. Particularly, the vehicles such as a two-wheeled mobile robot are major application for navigation problem. However, it is difficult to stabilize due to their nonholonomic constraint. This paper presents a controller designed based on a non-smooth CLF. The controller achieves the origin of the two-wheeled mobile robot in a complex workspace. For the complex workspace, the multilayer minimum projection method can generate a CLF. The method requires a CLF for an unconstrained system and a smooth mapping. This paper proposes a composite mapping constructed by smooth mappings. The composite mapping is adopted to be combined with a non-smooth CLF. The non-smooth CLF manages theoretical difficulty from the nonholonomic constraint of the two-wheeled mobile robot. The approach is validated in computer simulation. The result demonstrates the effectiveness of the presented method.

14:10-14:30 MB1.3

Input Predictive Shaping for Vibration Control of Flexible Systems, pp. 305-310

Grazioso, Stanislao — CREATE / Univ. Degli Studi Di Napoli Federico II
Di Gironimo, Giuseppe — CREATE / Univ. Degli Studi Di Napoli Federico II
Singhose, William — Georgia Inst. of Tech
Siciliano, Bruno — Univ. Degli Studi Di Napoli Federico II

This paper presents the foundation of a new class of input shapers, designed using a predictive approach. The method is used to control the transient and residual vibrations in flexible nonlinear systems with time-varying parameters. The motivation is the development of simple algorithms and architectures for controlling the motion in flexible nonlinear systems with minimal modeling effort. The approach trains an artificial neural network to obtain closed-form expressions used for calculating, in real time, the amplitudes and the time locations of the impulses required by a common input-shaping technique. In this work we use this idea to design a command shaper for controlling the motion of the simplest flexible nonlinear system, an overhead crane with a suspended payload. We validate the approach using simulations and experiments. The benefits of such a control system will, in the end, enable using this method for controlling the motion of complex nonlinear systems, resulting in almost zero vibrations.

14:30-14:50 MB1.4

Thermal Control of SOFC: An Anti-Windup Approach for Maximizing Usable Power, pp. 311-316

Sadeghi Reineh, Maryam — Univ. of California, Irvine
Fardadi, Mahshid — Univ. of California, Irvine
Jabbari, Faryar — Univ. of California, Irvine

A Solid Oxide Fuel Cell (SOFC) integrated with a variable speed blower is studied. The idea is to maximize the usable power of the fuel cell, by artificially bounding the inlet flow rate, thus, avoiding the overshoots in the blower power. Anti-windup techniques are then incorporated in order to guarantee the stability and provide a satisfactory performance. Significant temperature drops in cathode inlet (second actuator signal) caused by AW are also avoided in order to minimize the temperature gradients along the cell.

14:50-15:10 MB1.5

An Evaluation Framework for Inverse Hysteresis Models, pp. 317-322

Mohan, Rishi — Eindhoven Univ. of Tech
Gaasbeek, Rolf — Eindhoven Univ. of Tech
de Jager, Bram — Eindhoven Univ. of Tech

Control schemes employing inverse-based hysteresis compensation are successful in accurate position control of smart material actuators. However, the effectiveness of the inverse hysteresis model in cancelling hysteresis is not addressed in the evaluation of these control schemes. Classical methods rely on closed-loop tracking error analysis which does not allow evaluation of the inverse model independent of the controller. This leads to lack of a deterministic measure of the amount of hysteresis cancelled by the model, while the influence of an inaccurate model on the overall tracking error also remains unclear. This paper proposes a framework to verify the effectiveness and accuracy of inverse hysteresis models by quantifying the hysteresis non-linearities remaining after hysteresis compensation. Further, by estimating the linear and residual non-linear dynamics, valuable information is provided for controller design. The framework is experimentally validated for a Shape Memory Alloy (SMA) actuator. The framework can be seen as a tool to explore and compare different inverse hysteresis models prior to controller design.

15:10-15:30 MB1.6

A Ship Heading and Speed Control Concept Inherently Satisfying Actuator Constraints, pp. 323-330

Sørensen, Mikkel Eske Nørgaard — Norwegian Univ. of Science and Tech
Breivik, Morten — Norwegian Univ. of Science and Tech
Eriksen, Bjørn-Olav Holtung — Norwegian Univ. of Science and Tech

Satisfying actuator constraints is often not considered in the academic literature on the design of ship heading and speed controllers. This paper considers the use of a simplified dynamic window algorithm as a way to ensure that actuator constraints are satisfied. To accomplish this, we use the simplified dynamic window algorithm as a dynamic window-based controller (DWC) to guarantee that the velocities remain within a set of feasible boundaries, while simultaneously respecting the actuator constraints. We also develop a modified nonlinear ship model on which to test the proposed concept. The DWC is compared with a more traditional ship heading and speed controller, using performance metrics which consider both control accuracy and energy use.

MB2 Hilo

Cooperative Control (Regular Session)

Chair: Sekiguchi, Kazuma — Tokyo City Univ
Co-Chair: Cai, Kai — Osaka City Univ

13:30-13:50 MB2.1

Interference Suppression Control for Interaction of Two Quad Copters by Model Predictive Control Using the Disturbance Map, pp. 331-336

Suyama, Takahiro — Tokyo City Univ
Sekiguchi, Kazuma — Tokyo City Univ
Nonaka, Kenichiro — Tokyo City Univ

This study presents the interaction suppression control of multi-copter using MPC that considers the disturbance map. The influence of wind by propellers to another quad copter is estimated beforehand and the disturbance map made from the information. The disturbance map stores the estimated disturbance value corresponding to a relative position. Also, the disturbance map is implemented in the control model for model predictive control. Hence, it is possible that the controller explicitly considers the future expected disturbance via a disturbance map. This paper performs the disturbance suppression control experiments with actual quad copters. and shows the

effectiveness of the proposed method.

13:50-14:10 MB2.2

Pinning Cluster Synchronization of Lur'e Dynamical Networks: A Convex Domain Method, pp. 337-342

Tang, Ze — Yeungnam Univ
Park, Ju H. — Yeungnam Univ
Jung, Ho-Youl — Yeungnam Univ

This paper discusses the cluster synchronization problem of complex dynamical networks consisted of Lur'e systems. Since the special topology structure of the complex network and the existence of stochastic phenomena, a kind of randomly occurring pinning controller is designed which not only synchronizes all Lur'e systems in the same cluster but also decreases the influence among different clusters. Based on the extended integral inequality, the convex combination theorem and S-procedure, the conditions for successful cluster synchronization of identical Lur'e networks are derived in a convex domain. Finally, we present a numerical example to demonstrate the validity of the control scheme and the theoretical analysis.

14:10-14:30 MB2.3

Cooperative Surveillance in the Presence of Time Sensitive Data, pp. 343-348

Manyam, Satyanarayana Gupta — Air Force Res. Lab
Sundar, Kaarthik — Texas A & M Univ
Casbeer, David W. — Air Force Res. Lab

We consider a cooperative vehicle routing problem for surveillance and reconnaissance missions using an aerial and a ground vehicle, where the collected data needs to be processed in real-time or near real-time. The proposed framework assumes that the ground vehicle has the ability to communicate long range and the aerial vehicle has limited communication range. The vehicles' paths are constrained such that the aerial vehicle remains in contact with the ground vehicle when the aerial vehicle is surveilling a target. Under this constraint, as the aerial vehicle collects data from the targets, this data can then be transmitted in real-time to the base station via the ground vehicle relay. We present a mixed-integer linear programming formulation and develop a branch-and-cut algorithm to solve the resulting cooperative routing problem involving the two vehicles. The novelty of the algorithm is the ability to maintain communication between the ground vehicle and UAV, while allowing the ground vehicle to move as the UAV is deployed. The effectiveness of the proposed approach is corroborated through extensive computational experiments on several randomly generated instances.

14:30-14:50 MB2.4

Performance Analysis of Visual Feedback Leader-Following Pose Synchronization with Stochastic Uncertain Leader in Three Dimensions, pp. 349-354

Yamauchi, Junya — Tokyo Inst. of Tech
Kizaki, Kazuhiro — Tokyo Inst. of Tech
Ibuki, Tatsuya — Tokyo Inst. of Tech
Hatanaka, Takeshi — Tokyo Inst. of Tech
Satoh, Satoshi — Hiroshima Univ
Fujita, Masayuki — Tokyo Inst. of Tech

This paper presents the performance analysis of visual feedback leader-following pose synchronization, where the leader motion is supposed to contain stochastic factors. Then, the problem is reformulated in stochastic system form and stochastic stability analyses are provided. Here, time evolution of the control error system produced by the present visual feedback control is given by stochastic differential equations on SE(3). In the control error analysis, the notion of practically stochastic input-to-state stability is introduced. Moreover, L_2 norm inequalities are employed for tracking performance evaluation. Finally, simulation verification is conducted, and the visual feedback control is implemented in a testbed.

14:50-15:10 MB2.5

From Reeds-Shepp's Paths to Continuous Curvature Paths--Part I: Transition Schemes and Algorithms, pp. 355-362

Dai, Jin — Univ. of Notre Dame
Wang, Yebin — Mitsubishi Electric Res. Labs
Bortoff, Scott A. — Mitsubishi Electric Res. Labs
Burns, Daniel — Mitsubishi Electric Res. Labs

Reeds-Shepp's (RS) based path planning remains unmatched in terms of computation efficiency and reliability when compared with continuous curvature (CC) path planning. This work considers real-time CC path planning for car-like robots, by processing collision-free RS paths. Specifically, all discontinuous curvature junctions in RS paths are processed to yield CC paths. Constraints on velocities along CC paths are determined to ensure that they do not leave neighborhoods of RS paths and thus meet the obstacle clearance requirement. To ensure reliability and computational efficiency of post-process, geometric insights casted by μ-tangency conditions are fully employed to devise processing schemes and algorithms. The proposed schemes, though sub-optimal, are straightforward, and result in CC path planning with guaranteed completeness at the negligible increase of computation. Effectiveness of proposed schemes and algorithms is validated by numerical simulations. In another companion paper, we focus on methods to process entire RS paths, analysis, and validation.

15:10-15:30 MB2.6

A Cycle-Free Coordinated Traffic Intersection Policy Using Time-Inconsistent Wait-Time Functions, pp. 363-368

Gravelle, Evan — Univ. of California at San Diego
Martinez, Sonia — Univ. of California at San Diego

Sensing and computing capabilities of modern traffic intersections have greatly improved in recent years, but current control policies do not fully utilize these capabilities. In this paper, we present a novel intersection control algorithm based on an objective function that accounts for drivers' time preferences. In particular, the intersection places greater importance on a vehicle which has been waiting at an intersection over one that just arrived. Coordination between intersections is achieved through adding a term to the objective function using the green wave idea. Under this policy and a macroscopic dynamical model, we provide a sufficient condition for the controller to maintain uniformly bounded weighted queues at an intersection given sufficiently small spawn rates. We test our algorithm and results extensively in a realistic microscopic simulation, through measuring queue stability and various performance metrics.

MB3 Hamakua

Modeling II (Regular Session)

Chair: Iwase, Masami — Tokyo Denki Univ
Co-Chair: Pyta, Lorenz — RWTH Aachen Univ

13:30-13:50 MB3.1

Precise Bicycle Modeling and Model-Based Stabilization Control on State Dependent Riccati Equation, pp. 369-376

Hatano, Ryuma — Tokyo Denki Univ
Tani, Takuya — Tokyo Denki Univ
Wada, Takayuki — Tokyo Denki Univ
Iwase, Masami — Tokyo Denki Univ

In this paper, we aim to develop a precise bicycle model which captures characteristic of bicycle behavior such as contact point motion on a surface, front fork effect and centrifugal force, which affects bicycle stability especially in the low-speed or high-speed case. From a historical viewpoint, some of them have been often neglected in the conventional modeling process, and they have caused instability in the low and/or high speed range even though a stabilizing control based on each model has been applied to the bicycle. State Dependent Riccati Equation control scheme utilizes the

precise bicycle model to realize a nonlinear controller working sufficiently in low/high speed range. The effectiveness of the proposed method is verified through numerical simulation and comparison of the conventional ``Whipple model'' with respect to the region of attraction.

13:50-14:10 MB3.2

Thermal Modeling and Decentralized Control of Mold Temperature for a Vulcanization Test Bench, pp. 377-382

Bosselmann, Steffen — Leibniz Univ. Hannover
Frank, Tobias — Inst. of Mechatronic Systems
Wielitzka, Mark — Leibniz Univ. Hannover
Dagen, Matthias — Leibniz Univ. Hannover
Ortmaier, Tobias — Leibniz Univ. Hannover

Mold temperature is a decisive process parameter during vulcanization of rubber articles. Hence, ensuring a homogeneous temperature distribution over the entire mold surface throughout the curing process is a crucial requirement. Therefore, we present a model-based approach to analyze heat propagation within the mold and to design a controller for mold surface temperature. The thermal model of the process was build by means of the heat equation utilizing spatial discretization. Simulations indicated, that the order of the resulting model can be reduced by moment-matching methods maintaining sufficient accuracy. Subsequently, a decentralized PI-controller was designed based on the reduced thermal process model. Reference tracking and disturbance rejection were investigated in simulation and experiment for a vulcanization test bench. The evaluated controller setup allows for fast wide range reference changes and proper compensation of disturbances and eventually, desired homogeneity in mold surface temperature distribution is achieved.

14:10-14:30 MB3.3

Space-Selective Nonlinear Reduced-Order Models for Turbulent Boundary Layer Drag Reduction, pp. 383-388

Pyta, Lorenz — RWTH Aachen Univ
Meysonnat, Pascal Sylvain — Inst.of Aerodynamics, RWTH Aachen Univ
Schröder, Wolfgang — Inst. of Aerodynamics, RWTH Aachen Univ
Abel, Dirk — RWTH Aachen Univ

Reduced-Order Models (ROMs) for 3D-turbulent flows based on Galerkin projection usually suffer from a large number of necessary basis functions to capture the relevant system dynamics. In this paper a new method to build a ROM for turbulent boundary layers is presented. Therefore the authors combine the Laplacian Eigenmaps as nonlinear dimensionality reduction method with the Galerkin projection. The neighborhood appearing in the Laplacian Eigenmaps is defined by a space-selective weighting approach, which moves the focus to the wall-near structures and thus enables to catch the control-relevant dynamics. As example turbulent boundary layer drag reduction by spanwise traveling waves is investigated using high-resolved CFD simulations.

14:30-14:50 MB3.4

Reduced-Order Multi-Modal Model of SEI Layer Growth for Management and Control of Lithium-Ion Batteries, pp. 389-395

Plett, Gregory L. — Univ. of Colorado at Colorado Springs

Battery-management systems (BMS) seek to maximize battery-pack performance while extending life by optimizing dynamic operational power limits. To do so in a meaningful way, the BMS must have computationally simple yet accurate models of degradation to use in the optimization. As the growth of a solid--electrolyte interphase (SEI) layer on negative-electrode particles in lithium-ion cells is the dominant aging mechanism leading to capacity loss and resistance rise, we propose a reduced-order model of diffusion- or kinetics-limited SEI growth that could be used in an embedded optimization framework. This model approximates a full-order partial-differential-equation (PDE) model in the literature with less than 1% relative error, at a speedup of more than 19 000 : 1.

14:50-15:10 MB3.5

Analysis of Control Structures for a Petlyuk Distillation Column by Partial Relative Gains, pp. 396-401

Häggblom, Kurt E. — Åbo Akademi Univ

In multiloop SISO control, decentralized integral controllability (DIC) is usually a desired feature. Necessary conditions for DIC can be expressed by the relative gains of the full system and its various subsystems. The author has previously introduced a controllability measure, the partial relative gain (PRG), that defines relative gains for partially controlled systems, i.e., situations when part of the system is under closed-loop integral control. Thus, this measure directly addresses the desired DIC properties. The measure is more reliable for variable pairing than the conventional relative gain array (RGA). In addition, it can be inferred from the PRG analysis when block-decentralized (or full MIMO) control should be considered. A review of relevant controllability measures for DIC is given in the paper. The PRG is applied to the analysis of control structures for a Petlyuk distillation column.

15:10-15:30 MB3.6

Feedback Control Systems with Cyber Fault-Management Mechanisms: Modeling and Tradeoff Analysis for Simple Examples, pp. 402-407

Roy, Sandip — Washington State Univ
Hahn, Adam — Washington State Univ
Xue, Mengran — Washington State Univ

The impacts of cyber- fault resolution techniques on the dynamics of feedback control systems are explored, using simple case studies. Specifically, for a three-state DC motor model, simple control schemes implemented using embedded microcontrollers are modeled as being subject to freeze faults, which are resolved using watchdog-timer technologies. Simulations are undertaken to characterize the impacts of the faults and fault-resolution mechanisms. Also, a formal analysis of freeze faults and fault resolution is undertaken for a single-pole plant with proportional control. It is found that watchdog timers can reduce severe impacts of faults occurring during the control system's transient, but may increase susceptibility to other faults.

MB4 Kohala

Mechatronic Systems II (Regular Session)

Chair: Maroufi, Mohammad — Univ. of Texas at Dallas
Co-Chair: Bashash, Saeid — San Jose State Univ

13:30-13:50 MB4.1

Simultaneous Frequency and Depth Adaptation of Notch Filter for Controlling Damped Vibrations, pp. 408-413

Park, Jiho — Seoul National Univ
Kim, Tae-Il — Seoul National Univ
Han, Ji-Seok — Seoul National Univ
Oh, Tae-Ho — Seoul National Univ
Lee, Jee-Hyung — RS Automation
Kim, Sang-Oh — RS Automation
Lee, Sang-Sub — RS Automation
Lee, Sang-Hoon — RS Automation
Cho, Dong-il — Seoul National Univ

Manufacturing demands have increased in recent years, requiring a tack time a few tens of milliseconds to assembly machines with vibrational modes of less than a couple of hundreds of Hz. For typical high-frequency range (approximately 800 Hz) vibrations, notch filters with a depth of 1.0 are successfully used for vibration suppression.

However, low-frequency range (approximately 200 Hz) vibrations typically result from the viscoelasticity of couplings and cannot be compensated for using a typical notch filter with a depth of 1.0. In addition, the damping levels can change significantly depending on specific application types as well as load and environment conditions, which in turn makes pre-implementation, off-line tests impractical. Therefore, it is desired to identify in real-time the damping conditions and adjust the notch filter depth, as well as the center frequency of the notch filter. Many methods are available for estimating the center frequency and the damping ratio in real-time, but the well-known zero-vibration derivative (ZVD) method to estimate the damping ratio cannot be applied in real-time. This paper develops a new real-time method to adaptively change the notch filter depth, using the methods of random decrement and peak detection. Experiments on an actual industrial servo system are used to demonstrate that damped vibrations are successfully compensated for by the proposed method.

13:50-14:10 MB4.2

Application of Discrete Derivative Method with a New Frequency Mapping Technique for Adaptive-Notch-Filter Based Vibration Control in Industrial Servo Systems, pp. 414-419

Kim, Tae-Il	Seoul National Univ
Han, Ji-Seok	Seoul National Univ
Park, Jiho	Seoul National Univ
Oh, Tae-Ho	Seoul National Univ
Lee, Jee-Hyung	RS Automation
Kim, Sang-Oh	RS Automation
Lee, Sang-Sub	RS Automation
Lee, Sang-Hoon	RS Automation
Cho, Dong-il	Seoul National Univ

This paper presents an application of a discrete derivative method with a new frequency mapping technique for adaptive-notch-filter (ANF) based resonance suppression in an actual industrial servo system. An ANF includes a frequency estimator which estimates the frequency of input signal in real time. A new discrete derivative method, which utilizes a modified bilinear transform, was recently developed to improve the frequency estimation performance of ANF and applied to computer simulation cases. The frequency estimation performance in steady state is improved, especially in high frequency ranges by using this derivative method. However the previous method can cause large estimation errors when estimated frequency varies rapidly. This paper develops a new frequency mapping technique which compensates for the frequency warping of the modified bilinear transform, and applies it with the discrete derivative method to implement an ANF. This method shows improved frequency estimation performance even when the estimated frequency varies rapidly. Numerical simulations are performed for the cases which an adaptation gain, the amplitude of an input signal, or the frequency of an input signal is high, respectively. Note that the rapid change of estimated frequency occurs in these cases. Experiments using an industrial servo system are also performed to show the improved frequency estimation performance of the developed ANF.

14:10-14:30 MB4.3

Vibration Compensation of Display Contents in Smart Devices Using Accelerometer Feedback, pp. 420-425

Mounesisohi, Alireza	San Jose State Univ
Bashash, Saeid	San Jose State Univ

This paper examines a filtering and control algorithm for stabilizing the electronic display contents under external shocks and vibrations to reduce eye strain and discomfort. A cascade of a first order high-pass filter and a stable second order double-integrator-like filter is used to generate a stable position estimate from the real-time accelerometer data. The estimated position signal is then used to compensate the high-frequency movements of the frame by offsetting the display contents in the opposite direction of the motion. Analyzing the error dynamics indicates there is a low-frequency error amplification range as a result of high-frequency disturbance rejection, suggesting the strength of the proposed method is in rejecting higher frequency disturbances. To validate the design, an experimental test bed comprising a microcontroller equipped with an accelerometer and an LCD screen is developed. Using an image processing algorithm, the movements of the display contents with and without the proposed controller were quantified and analyzed. Experimental results show that the vibrations of the display contents can be reduced by up to 70% at 4 Hz excitation frequency. The proposed method is expected to provide significant eye strain relief for users with motion sicknesses and hand tremor if successfully deployed in smart devices.

14:30-14:50 MB4.4

Force Regulation for Pick-And-Place Units by Use of Adaptive Impedance Control, pp. 426-431

Kronthaler, Phillip	Univ. for Health Sciences, Medical Informatics and Tech
Bachler, Simon	Univ. for Health Sciences, Medical Informatics and Tech
Woittennek, Frank	UMIT

Force regulation is an important topic in pick-and-place applications. To this end, a novel control concept for a setup consisting of two serially and co-linearly mounted axes is proposed. The position trajectory of the larger axis is tracked by a standard PD-controller. The feedback-law for the second and smaller axis mounted on the slide of the larger one is designed as an impedance control. A particular adaptive configuration of the proposed setup allows to achieve different tasks without changing the principal structure of the control algorithm. Firstly, tracking the position of the end effector rigidly mounted at the second drive may be achieved as long as no obstacle is hit. Secondly, a desired force trajectory to be imposed by the end effector may be tracked after collision. Finally, a sudden collapse of the obstacle, as it may happen in the considered application, can be dealt without any change of the control law. The efficiency of the proposed algorithms is shown on the basis of simulation results taking into account both, nonlinear friction models and parameter uncertainties.

14:50-15:10 MB4.5

Torque-Modulated Backstepping Control for Two-Dimensional Electromagnetic Scanners, pp. 432-437

Lee, Youngwoo	Hanyang Univ
Jeong, Ji Young	Hanyang Univ
Chung, Chung Choo	Hanyang Univ

In this paper, we propose torque-modulated backstepping control for uniform tracking errors in the vertical motion of two-dimensional electromagnetic scanners using only output measurement. Due to manufacturing tolerance, there are parameter uncertainties of two-dimensional electromagnetic scanners so that it is not easy to obtain uniform tracking error performance for the motion control of scanners. In order to resolve the problem, the proposed control law was designed with proportional feedback control with back-stepping approach. We firstly introduce the state-space model of an electromagnetic scanner. The torque-modulated backstepping control was designed for the vertical motion of the mechanical system with only position measurement. Then current tracking controller was implemented with virtual references for the states. We investigated its robust performance via frequency domain analysis with root-locus and sensitivity function. Simulations and experimental results are provided to show the effectiveness of the proposed method.

15:10-15:30 MB4.6

A Closed-Loop MEMS Force Sensor with Adjustable Stiffness, pp. 438-443

Maroufi, Mohammad	Univ. of Texas at Dallas
Alemansour, Hamed	Univ. of Texas at Dallas
Moheimani, S.O. Reza	Univ. of Texas at Dallas

This paper presents the design, implementation, and control of a novel microelectromechanical system (MEMS) force sensor. The

device features bidirectional electrostatic actuators and on-chip piezoresistive displacement sensors. For the fabrication, a standard silicon-on-insulator process is used. Due to the bidirectional geometry, the probe is able to perform force measurement in both push and pull directions. An electrostatic structure is also incorporated for in-situ tuning of the sensor's mechanical stiffness. This stiffness-adjusting mechanism offers an additional control parameter, enabling the sensor to be adaptable on various input force conditions. Exploiting the stiffness-adjusting mechanism, a variation in the resonant frequency from 3kHz to about 4.4kHz is experimentally demonstrated which translates to a stiffness variation within a factor of two. By implementing a resonant controller together with integral action, the adverse effect of flexural nonlinearities on the precision of the force measurement is mitigated. The performance of the closed-loop system is also evaluated by exerting a disturbance signal to the closed-loop system simulating an external input force. Finally, the resolution and the measurement range of the sensor in the open-loop and the closed-loop are compared and discussed.

MB5 Ballroom I

Robotics II (Regular Session)

Chair: Roehrig, Christof — Univ. of Applied Sciences and Arts Dortmund

Co-Chair: Tzes, Anthony — New York Univ. Abu Dhabi

13:30-13:50 MB5.1

Motion Controller Design for a Mecanum Wheeled Mobile Manipulator, pp. 444-449

Roehrig, Christof — Univ. of Applied Sciences and Arts Dortmund

Hess, Daniel — Univ. of Applied Sciences and Arts in Dortmund

Kuenemund, Frank — Univ. of Applied Sciences and Arts Dortmund

Mobile manipulators extend the workspace of manipulators by mounting them on mobile platforms. The paper presents the design of a motion controller for a mobile manipulator. The mobile manipulator consists of a mobile platform driven by Mecanum wheels and a robotic arm with 6 degrees of freedom. A Mecanum wheeled platform provides 3 degrees of freedom in motion. Such a platform is usually driven by 4 or more Mecanum wheels, which are mounted in a fixed position at the platform. If a mobile platform is driven by more than 3 wheels, it builds an over-actuated and over-sensed driving system. The paper develops a compact and easy applicable kinematic model of over-actuated Mecanum wheeled mobile platforms that includes the kinematic motion constraints of the system. The kinematic model is described by a single Jacobi matrix, which is invertible and therefore can be used in the forward and inverse kinematic model. Furthermore the paper describes the overall controller structure for our mobile manipulator emph{OmnMan} including the real-time synchronization of platform and manipulator. The motion controller of the platform includes a coupling controller that controls the kinematic motion constraints. Experimental results evaluates the effectiveness of the coupling controller.

13:50-14:10 MB5.2

Mid-Level MPC and 6 DOF Output Path Following for Robotic Manipulators, pp. 450-456

Hauan Arbo, Mathias — Norwegian Univ. of Science and Tech

Grøtli, Esten Ingar — Sintef Ict

Gravdahl, Jan Tommy — Norwegian Univ. of Science and Tech

In this article we discuss some of the benefits of using an MPC as a mid-level controller between the path generator and the low-level joint controller of a robot system. The MPC handles rudimentary runtime constraints that are not considered during path generation. We compare two task space oriented controllers: the model predictive path following controller and the model predictive trajectory tracking controller. We describe a 6 degrees of freedom reference path in terms of three points, and use this to experimentally verify the results with a UR5 robot and a UR3 robot.

14:10-14:30 MB5.3

Cooperative Operation between a Human and a Robot Based on Real-Time Measurement of Location and Posture of Target Object by High-Speed Vision, pp. 457-462

Matsui, Yutaro — The Univ. of Tokyo

Yamakawa, Yuji — The Univ. of Tokyo

Ishikawa, Masatoshi — The Univ. of Tokyo

The objective of this research is to realize a cooperative task in which a robot follows a human user's moves for various degrees of freedom using a high-speed hand and a high-speed camera. We constructed a system that makes the robot follow the direction in which the human wants to move a board while keeping it horizontal by holding it at one end with the human and at the other end with the robot hand, by controlling the robot hand based on high-speed visual feedback. We propose an image processing algorithm for estimating the object state (position and angles) and the inverse kinematics of the robot hand to control the hand based on the object state. We show experimental results for the task using the proposed strategy, image processing, and robot hand control. The experiment confirmed that this task was successfully completed using the proposed method.

14:30-14:50 MB5.4

Design and Experimental Evaluation of a Tendon-Driven Minimally Invasive Surgical Robotic Tool with Antagonistic Control, pp. 463-467

Evangeliou, Nikolaos — Univ. of Patras

Dimitrakakis, Emmanouil — Univ. of Patras

Tzes, Anthony — New York Univ. Abu Dhabi

The design, implementation and experimental evaluation of a minimally invasive surgical robotic instrument is presented in this article. The tool is constructed using rapid prototyping techniques and each degree-of-freedom is actuated via an antagonistic tendon driven mechanism using servo motors. The accompanying software runs under the Robot Operating System framework. The kinematics of the tool are discussed and the efficiency of the system is investigated in experimental studies, which are showcased in order to assess its potential use in a clinical environment.

14:50-15:10 MB5.5

Modeling and Control of a Cable Driven Modular Snake Robot, pp. 468-473

Racioppo, Peter — Virginia Tech

Ben-Tzvi, Pinhas — Virginia Tech

This paper presents the modeling and control of a planar snake robot composed of modular, single degree of freedom bending units. The goal of this research is to design a snake robot that minimizes the number of degrees of freedom necessary for planar serpentine locomotion, while closely approximating the idealized sinusoidal shape of a moving snake. The use of an underactuated, multi-link module as the snake's basic functional unit aims at simplifying the control of snake robots while retaining the advantages of highly articulated designs. The design and dynamic model of the snake robot are presented, and a controller is developed that demonstrates path following between waypoints and disturbance rejection, under viscous and Coulomb frictional models. Controller design for the reduced-DOF snake is presented and related to the control of snake robots that independently actuate all of their joints. Key control and design parameters are then optimized to produce curvature profiles that maximize the robot's forward speed.

15:10-15:30 MB5.6

Winding Manipulator Based on High-Speed Visual Feedback Control, pp. 474-480

Ito, Koichiro — The Univ. of Tokyo

Yamakawa, Yuji — The Univ. of Tokyo
Ishikawa, Masatoshi — The Univ. of Tokyo

Controlling a robot to manipulate objects dexterously is an important research field in robotics. In particular, casting manipulation is a manipulation in which an end effector is attached to a robot, and the robot projects it in order to grasp a distant object. With this technique, manipulation beyond the original operating range of the robot is expected. In research on conventional casting manipulations, modeling of flexible objects manipulated by robots and feedforward control based on parameter identification are the mainstream approaches. In this research, we propose casting manipulation based on high-speed visual feedback control with a whip. We aim to realize object grasping by manipulating the whip with dexterity by utilizing its deformation. The tip speed of the whip is very high, and it is difficult to properly control. Thus, in addition to the trajectory design of the robot arm using the whip as a manipulator, we captured the winding motion of the whip around the object with a high-speed vision system and made use of visual feedback to achieve robust winding of the whip . In the experiment, we constructed a flexible manipulator system consisting of a robot arm, a whip, and a high-speed vision system, and we controlled the trajectory of the robot by visual feedback based on how the whip winds around the object. We confirmed that the whip can successfully be wound around the object.

MB6 — Ballroom II

Energy Systems II (Regular Session)

Chair: Hara, Naoyuki — Osaka Prefecture Univ
Co-Chair: De Tommasi, Gianmaria — Univ. Degli Studi Di Napoli Federico II

13:30-13:50 — MB6.1

Blade Pitch Control for Floating Wind Turbines: Design and Experiments Using a Scale Model, pp. 481-486

Hara, Naoyuki — Osaka Prefecture Univ
Nihei, Yasunori — Osaka Prefecture Univ
Iijima, Kazuhiro — Osaka Univ
Konishi, Keiji — Osaka Prefecture Univ

We present experimental results for blade pitch control in a scale model of a floating wind turbine. The blade pitch controller was designed using an H^{∞} loop-shaping design procedure and its performance was evaluated by using an actual scale model. The experimental results show that the controller has good performance in regulating rotor speed and reducing the platform's pitching motion.

13:50-14:10 — MB6.2

Exploiting Refrigerant Distribution for Predictive Control of Multi-Evaporator Vapor Compression Systems, pp. 487-492

Burns, Daniel — Mitsubishi Electric Res. Labs
Bortoff, Scott A. — Mitsubishi Electric Res. Labs

An observed behavior of refrigerant mass distribution in multi-path heat exchangers is exploited for control purposes. In this paper, we describe the following empirical property exploited for control: as the inlet valve is decreased, refrigerant mass flow rate entering the heat exchanger is reduced, and for some flow rates, refrigerant is shown to preferentially flow in some paths more than others, causing maldistribution. This uneven refrigerant distribution is repeatable, reduces the capacity in a continuous manner and can be exploited with feedback controllers to regulate the per-zone cooling.

A controller is designed to provide stability and robustness to per-zone conditions and setpoints for this controller that relate per-path superheat temperature to overall evaporator capacity is created in such a way as to be robust to changes in local zone temperatures and the overall system evaporating temperature. This strategy provides zone decoupling and ultimately creates a virtual control input for a model predictive controller. Experiments demonstrate the effectiveness of this approach on a two-zone air conditioner in laboratory tests.

14:10-14:30 — MB6.3

Fuel Optimization in Multiple Diesel Driven Generator Power Plants, pp. 493-498

Knudsen, Jesper — Aalborg Univ
Bendtsen, Jan Dimon — Aalborg Univ
Andersen, Palle — Aalborg Univ
Madsen, Kjeld — Deif A/s
Sterregaard, Claes — Deif A/s
Rossiter, John Anthony — Univ. of Sheffield

This paper presents two fuel optimization approaches for independent power producer (IPP) power plants consisting of multiple diesel driven generator sets (DGs). The optimization approaches utilize assumed information about the fuel consumption characteristics of each DG in an effort to demonstrate the potential benefits of acquiring such information. Reasonable variations in fuel consumption characteristics are based on measurements of a DG during restricted air filter flow operation. The two approaches are: (i) a gradient search approach capable of finding the optimal power generation for each DG in a fixed selection of DGs accommodating a given plant power reference and (ii) a genetic algorithm approach further capable of determining the optimal selection of DGs to operate in an IPP power plant. Both approaches show notable potential benefits, in terms of fuel savings, compared to current market-leading solutions.

14:30-14:50 — MB6.4

Load Sharing Optimization for Parallel and Serial Compressor Stations, pp. 499-504

Kumar, Sant — IDSC, ETH Zürich
Cortinovis, Andrea — ABB Corp. Res

Natural gas pipelines are powered by compressor stations which usually consist of multiple interconnected compressors units ensuring the required operational flexibility. The aim of load sharing optimization is to operate these compressor units in an energy efficient way while at the same time satisfying varying demands. This paper uses a two-step approach to first identify individual compressor performances and secondly to optimize the load distribution among the active set of machines given the up-to-date performance models. The impact of different cost functions on the saving potentials is investigated and the standard parallel arrangement is extended to the case of a serial compressor station. Results are obtained by a simulation case study covering a gas-turbine driven parallel and a serial compressor station with varying gas demands. The optimization results indicate that significant fuel saving potentials are expected for both cases with an improvement of up to almost 5%.

14:50-15:10 — MB6.5

Fused Local-Global Control of Spatiotemporally-Varying Systems: A Case Study in Airborne Wind Energy, pp. 505-510

Bafandeh, Alireza — Univ. of North Carolina at Charlotte
Bin-Karim, Shamir — Univ. of North Carolina at Charlotte
Vermillion, Christopher — Univ. of North Carolina at Charlotte

This paper presents a real-time altitude optimization technique for airborne wind energy (AWE) systems that fuses a coarse, global optimization with a fine, local optimization. The ultimate goal is to maximize net energy consumption by operating at an altitude where the wind speed is closest to the turbine's rated wind speed. Without the use of auxiliary wind profiling equipment, this results in a challenging real-time optimization that must be performed over a spatiotemporally varying, partially observable environment. As a result of computational complexity, global optimization techniques must be performed over a very coarse grid. Local optimization techniques alone, on the other hand, are unlikely to yield convergence to the globally-optimal altitude trajectory. The fused

control strategy proposed in this work overcomes the limitations that both strategies pose when used in isolation. Unlike traditional hierarchical control architectures, where the upper-level controller prescribes a setpoint to the lower-level, our proposed upper-level controller passes an emph{advisory} input to the lower level. This advisory input prevents the AWE system from getting stuck in non-global optima while still giving the lower level controller freedom to explore. We demonstrate the effectiveness of the proposed controller using real wind data.

15:10-15:30 MB6.6

On Plasma Vertical Stabilization at EAST Tokamak, pp. 511-516

De Tommasi, Gianmaria — Univ. Degli Studi Di Napoli Federico II

Mele, Adriano — Univ. Degli Studi Di Napoli Federico II

Luo, Zhengping — Inst. of Plasma Physics, Chinese Acad. of Sciences

Pironti, Alfredo — Univ. Degli Studi Di Napoli Federico II

Xiao, B. J. — Inst. of Plasma Physics, Chinese Acad. of Sciences

In this paper we discuss the problem of plasma vertical stabilization at the EAST tokamak. By exploiting a plasma/circuit linearized model, we show that the plant cannot be strongly stabilized by using the in-vessel coils and a single-input-single-output controller that feeds back only the plasma vertical speed $\dot{z}_p$ (i.e. without integral action on z_p). Moreover, a stable multi-input-single-output controller that stabilizes the plant without the need of feeding back the plasma vertical position is presented. The proposed solution permits to achieve stabilization of the EAST plant without coupling the vertical stabilization system with the plasma shape controller. Such decoupling is a key requirement to enable advanced design approaches for plasma shape controller.

MB7 Ballroom III

Biosystems (Regular Session)

Chair: Medvedev, Alexander V. — Uppsala Univ

Co-Chair: Pare, Philip E. — Univ. of Illinois at Urbana-Champaign

13:30-13:50 MB7.1

Semi-Individualized Electrical Models in Deep Brain Stimulation: A Variability Analysis, pp. 517-522

Cubo, Ruben — Uppsala Univ

Fahlström, Markus — Uppsala Univ. Hospital

Jiltsova, Elena — Uppsala Univ. Hospital

Andersson, Helena — Uppsala Univ

Medvedev, Alexander V. — Uppsala Univ

Deep Brain Stimulation (DBS) is a well-established treatment in neurodegenerative diseases, e.g. Parkinson's Disease. It consists of delivering electrical stimuli to a target in the brain via a chronically implanted lead. To expedite the tuning of DBS stimuli to best therapeutical effect, mathematical models have been developed during recent years. The electric field produced by the stimuli in the brain for a given lead position is evaluated by numerically solving a Partial Differential Equation with the medium conductivity as a parameter. The latter is patient- and target-specific but difficult to measure in vivo. Estimating brain tissue conductivity through medical imaging is feasible but time consuming due to registration, segmentation and post-processing. On the other hand, brain atlases are readily available and processed. This study analyzes how alternations in the conductivity due to inter-patient variability or lead position uncertainties affect both the stimulation shape and the activation of a given target. Results suggest that stimulation shapes are similar, with a Dice's Coefficient between 93.2% and 98.8%, with a higher similarity at lower depths. On the other hand, activation shows a significant variation of 17 percentage points, with most of it being at deeper positions as well. It is concluded that, as long as the lead is not too deep, atlases can be used for conductivity maps with acceptable accuracy instead of fully individualized though medical imaging models.

13:50-14:10 MB7.2

Modeling and Accelerated CO_2 Control for Photosynthesis Measurements, pp. 523-528

Pare, Philip E. — Univ. of Illinois at Urbana-Champaign

McGrath, Justin M. — Univ. of Illinois, Urbana-Champaign

Walker, Berkley James — Heinrich-Heine Univ. of Düsseldorf

Beck, Carolyn L. — Univ. of Illinois, Urbana-Champaign

Measurements of the response of leaf photosynthesis to CO_2 are vital for understanding the response of our planet to climate change and developing novel strategies for improving food production. The speed of these measurements are often limited by the ability of the leaf gas-exchange analysis instrumentation to reach and maintain a desired set point. This paper develops a biophysical model of a leaf and the measurement instrument that incorporates the plant physiology and the physics of gas flow in the instrument. This model is then parameterized for a commonly-used device for measuring photosynthesis of leaves. A standard feedback controller and a feedback linearization controller are applied to this model to reduce waiting time in these measurements. The model is validated by comparison to real measurement data from the instrument. The controllers are implemented on the actual instrument. The result is control algorithms built from first-order principles governing the exchange of gas between a leaf and its environment. To the best of our knowledge, this is the first attempt at developing such algorithms for controlling CO_2 in these systems.

14:10-14:30 MB7.3

Meal Detection Based on Non-Individualized Moving Horizon Estimation and Classification, pp. 529-535

Kölle, Konstanze — Norwegian Univ. of Science and Tech

Fougner, Anders Lyngvi — Norwegian Univ. of Science and Tech

Stavdahl, Øyvind — Norwegian Univ. of Science and Tech

Meals are one of the greatest challenges to glucose regulation in diabetes mellitus type 1. Several times each day, food causes heavily elevated blood glucose concentrations that may result in long-term complications. Meal-time insulin boluses are administered to mitigate these hyperglycemic periods. Sporadic omissions of prandial boluses impair the outcome of the insulin therapy by leading to significant variations in blood glucose levels. As continuous glucose monitoring (CGM) becomes more common, an automated detection based on CGM data could support patients by reminding about missed boluses. In fully automated systems, meal detection could temporarily modify controller parameters until the meal is mitigated. In the present study, moving horizon estimation (MHE) and linear discriminant analysis (LDA), abbreviated “MHE+LDA”, are proposed for meal detection. An augmented version of Bergman's minimal model is used for the estimator model. Neither the model parameters nor the MHE tuning are individualized. The method is tested in simulations on the UVa/Padova simulator and its performance is compared to two other methods, namely threshold checking of the current estimated glucose appearance and the GRID algorithm. All meals are detected by MHE+LDA within 35min while the two comparative methods do not detect the smallest simulated meal. The combination of MHE and LDA outperforms the two other methods also with respect to time of detection. The MHE+LDA method's ability to identify even smaller meals without the need for individual tuning suggests that the method should be further investigated.

14:30-14:50 MB7.4

Model Predictive Control with Event-Triggered Communication for an Embedded Artificial Pancreas, pp. 536-541

Chakrabarty, Ankush — Harvard Univ
Zavitsanou, Stamatina — Harvard Univ
Doyle III, Francis J. — Harvard Univ
Dassau, Eyal — Harvard Univ

Embedded or wearable artificial pancreas (AP) systems must be capable of low energy operation to ameliorate battery depletion and reduce the need for frequent recharge cycles. One of the major contributors to energy drain of such embedded AP systems is the power utilized for wireless communication among the components of the AP: the continuous glucose monitor (CGM), control module, insulin pump, and mobile app for display. In this paper, an event-triggered communication algorithm is proposed for reducing sensor-to-controller transmissions. Concretely, a CGM value is not transmitted to the controller if the current and predicted glucose trajectory of the patient resides in a safe zone in the glucose space. An observer-based model predictive control (MPC) algorithm is subsequently deployed to regulate glucose with aperiodic, event-triggered CGM transmissions. Simulations on ten in-silico patients using the UVA/Padova metabolic simulator reveals that the proposed algorithm is capable of reducing the sensor-controller transmissions by around 50%. In spite of statistically significant communication reduction, the MPC with ETC maintains glucose values (mean +/- standard deviation) in the clinically accepted range of 70--180 mg/dL for 70.3 +/- 7.9% of the time in closed-loop, whereas a standard MPC maintains glucose in the euglycemic range for a comparable 71.8 +/- 7.9% with large, unannounced meals and nocturnal hypoglycemia. Furthermore, the proposed formalism exhibits lower time than the standard MPC in the hypoglycemic (<70 mg/dL) range. Thus, the proposed approach communicates efficaciously without compromising patient safety.

14:50-15:10 MB7.5

Tremor Quantification through Event-Based Movement Trajectory Modeling, pp. 542-547

Dimitrakopoulos, Konstantinos — Uppsala Univ
Ellmer, Christoph — Uppsala Univ
Lindström, Martin — Uppsala Univ
Medvedev, Alexander V. — Uppsala Univ

A simple non-intrusive approach to tremor quantification utilizing the repetitive nature of the phenomenon is proposed and implemented on a portable device equipped with a fused off-the-shelf sensor platform measuring 3D acceleration. The device can be automatically activated when picked up from a stationary position and acceleration measurements are performed for a certain time interval. This usage scenario naturally arises e.g. when a person lifts the cellular phone from a surface to the ear to make or answer a call. The relatively slow and damped voluntary movement is separated by filtering from the involuntary and repetitive tremor manifestations in the device position. Extreme points of the tremor signal are detected and the time stamps of the corresponding events are used to estimate of the momentary tremor amplitude and frequency. Kalman filtering of the estimates is applied further to obtain their smoothed versions.

15:10-15:30 MB7.6

Improvement of Glycemic Control in Critically Ill Patients Using Online Identification of Insulin Sensitivity, pp. 548-553

Wu, Sha — Kyoto Univ
Furutani, Eiko — Kyoto Univ

Hyperglycemia is common in critically ill patients and leads to several severe complications and even death. Although it is shown that keeping blood glucose within the range of 80--110 mg/dL (4.4--6.1 mmol/L) reduces mortality and morbidity in intensive care unit, it is not easy to maintain glycemia within that range due to the time variability of insulin sensitivity in critically ill patients. In this paper, first, we modify a glycometabolism model developed in our previous study and add a compartment of small intestinal glucose absorption to enable an enteral glucose infusion. Second, we construct a glycemic control system using nonlinear model predictive control based on the model to normalize blood glucose in critically ill patients, in which we implement an insulin sensitivity online identification algorithm that updates insulin sensitivity parameter value hourly using the previous four-hour data of blood glucose, glucose and insulin infusions. Simulation results show that our system keeps 70% of BG measurements within the range of 80--110 mg/dL without any severe hypoglycemic incidents, which indicates the effectiveness and safety of the system.

MB8 — Ballroom IV

Automotive Applications II (Regular Session)

Chair: Beal, Craig — Bucknell Univ
Co-Chair: Tashiro, Tsutomu — Osaka Sangyo Univ

13:30-13:50 MB8.1

Range Extension for Electric Vehicles by Optimal Velocity Planning Considering Different Driver Types, pp. 554-559

Morlock, Florian — Univ. of Stuttgart
Heppeler, Gunter — Univ. of Stuttgart
Wohlhaupter, Uli — Daimler AG
Sawodny, Oliver — Univ. of Stuttgart

In recent years, stricter regulation of vehicle emissions, increasing fuel prices and government grants have lead to a rapidly growing interest in electrical mobility. However, potential customers are discouraged by the limited range of electric vehicles involving reduced flexibility. This paper presents a modern, real-time capable approach using road data obtained from an advanced navigation system to compute optimized velocity trajectories in order to increase the range of an electric vehicle. This eco-driving strategy can be imagined as an intelligent cruise controller utilizing information on legal speed limit and road topology. The potential for energy savings is estimated using characterizing longitudinal driving parameters derived from expectations on a system of three different driver types.

13:50-14:10 MB8.2

Global Optimization of Local Weights in Mixed-Cost MPC for Minimum Time Vehicle Maneuvering, pp. 560-565

Anderson, Jeffery — Clemson Univ
Ayalew, Beshah — Clemson Univ

In this paper a Model Predictive Control (MPC) strategy is utilized to model a professional driver negotiating a set driving circuit in minimum time. MPC is inherently suboptimal because not all future information is incorporated into each horizon of the control scheme. Motivated by how professional drivers learn race circuits in order to best exploit its features, we will alleviate some of the suboptimality inherent to MPC by optimizing the local cost function of each MPC horizon. This will allows objectives over a local segment to be properly adjusted such that the global goal of minimizing maneuvering time over a full maneuver is approximated. This problem is solved utilizing a cascaded optimization structure with the inner loop recursively solving the MPC problem around the track and the outer loop optimizing the weights of the local MPC horizons. It will be shown that by varying weights at key locations on a particular maneuver, performance gains can be realized compared to a traditional time optimal MPC strategy.

14:10-14:30 MB8.3

Feed-Forward Lateral Dynamics Control of Over-Actuated Vehicles Considering Actuator Dynamics, pp. 566-571

Gienger, Andreas — Univ. of Stuttgart
Henning, Kay-Uwe — Univ. of Stuttgart
Sawodny, Oliver — Univ. of Stuttgart

In this paper an integrated feed-forward lateral dynamics controller, which considers the actuator dynamics and input delays, is presented. The proposed approach uses an optimization based

model inversion of a nonlinear two-track model with magic formula tire model to describe the vehicle dynamics. The model is extended by the actuator models containing delays, which are identified with measurement data. A compensation of the input delays is achieved by a prediction of the driver demand, which is used for the generation of the desired output trajectory with a linear single-track model. The control allocation is formulated as a quadratic optimization problem by using the linearized dynamics of the vehicle model. A control allocation algorithm which is suitable for the application in production vehicles is presented and compared with the solution of a quadratic programming solver in a simulation study with recorded handling maneuvers. The simulation study shows, that the consideration of the actuator dynamics as well as the prediction of the driver demand yield extensive improvements of the driving dynamics and the proposed control allocation algorithm leads to accurate results for the constrained optimization problem.

14:30-14:50 MB8.4

Simultaneous Control of Soot Emissions and Pressure Rise Rate in Gasoline PPC Engine, pp. 572-577

Yang, Tianhao — Dalian Univ. of Tech
Yin, Lianhao — Lund Univ
Ingesson, Gabriel — Lund Univ
Tunestål, Per — Lund Univ
Johansson, Rolf — Lund Univ
Long, Wuqiang — Dalian Univ. of Tech

Partially Premixed Combustion (PPC) is an advanced combustion concept resulting in high efficiencies and low emission levels by the use of high levels of EGR and pilot injections. The main limitation of PPC to use in practice lies in the high pressure rise rate, which causes issues on engine noise and durability. In addition, soot emissions face with the overshoot problem during the transient operations. This paper proposes an approach to simultaneously control soot emissions and maximum pressure rise rate. The controller presented in this paper consists of measured cylinder pressure, a control-oriented soot model, a set of feedforward PI controllers for combustion phasing and engine load, and a set of gain-scheduled PI controllers for soot and pressure rise rate. The controller was implemented on a Scania D13 heavy-duty engine, and evaluated during a load transient operation. By manipulating the pilot injection strategy, soot emissions were able to meet the Euro 6 heavy-duty emission standard without an aftertreatment system, and pressure rise rate was limited to a relatively low level without too much compromising the engine efficiency.

14:50-15:10 MB8.5

A Risk Constrained Control Approach for Adaptive Cruise Control, pp. 578-583

Moser, Dominik — Johannes Kepler Univ. Linz
Del Re, Luigi — Johannes Kepler Univ. Linz
Jones, Stephen — AVL List GmbH, Graz

This work investigates the incorporation of a risk metric based on time to collision for Adaptive Cruise Control applications on multi-lane motorways. To improve the fuel-efficiency and safety, a stochastic model predictive control approach is suggested that limits the violation probability of the imposed risk metric. For this reason, a Bayesian network is used to predict the probability distributions of the surrounding vehicles' future motion based on actual measurements. Subsequently, these distribution functions are incorporated into a stochastic model predictive control algorithm. The novel strategy is evaluated in simulation using an artificial evaluation cycle and shows significant improvements in terms of fuel efficiency and safety in comparison to conventional Adaptive Cruise Control when sharp cut-off maneuvers occur.

15:10-15:30 MB8.6

Traction Control Design Using Model Predictive Control with Fuel Cut Method for an Internal Combustion Engine, pp. 584-589

Tashiro, Tsutomu — Osaka Sangyo Univ
Maruyama, Takashi — Osaka Sangyo Univ

This paper proposes a design method of traction control with model predictive control (MPC) by fuel cut of an internal combustion engine (ICE). Traction control on production cars usually operates an electronic throttle within the ICE. However, there are cases where traction control is performed by fuel cut in the motor sport field. For example, as a manufacturing cost is one of the evaluation factors in Formula SAE, many teams withhold installing an electronic throttle to achieve a better score. In such cases, fuel cut is one of the applicable methods. Since traction control by fuel cut cannot continuously control ICE torque, it might disturb vehicle status and worsen drivability. To avoid these problems, it is necessary to ensure traction control utilizing the dynamics of the powertrain, wheel and vehicle longitudinal motion. In this paper, the dynamics are modeled as a hybrid dynamical system, and traction control by fuel cut is achieved by MPC. The effectiveness of the control is demonstrated by Hardware-In-the-Loop -Simulation (HILS) comprising an electronic control unit (ECU) and a simulation model.

MC1 Puna

Sliding Modes (Regular Session)

Chair: Fekih, Afef — Univ. of Louisiana at Lafayette
Co-Chair: Oliveira, Tiago Roux — State Univ. of Rio De Janeiro

16:00-16:20 MC1.1

Hardware-In-The-Loop Evaluation of an LPV Sliding Mode Fixed Control Allocation Scheme on the MuPAL-Alpha Research Aircraft, pp. 590-595

Chen, Lejun — Univ. of Exeter
Alwi, Halim — Univ. of Exeter
Edwards, Christopher — Univ. of Exeter
Sato, Masayuki — Japan Aerospace Exploration Agency

This paper develops a sliding mode fault tolerant control scheme based on an LPV system representation of the plant. The scheme involves a control allocation component, which is capable of fully utilizing the available actuators in the face of actuator faults. In this paper, information about the actuator faults is assumed not to be available and therefore a fixed control allocation structure is utilised in the event of faults. The proposed scheme is validated using the Japanese Aerospace Exploration Agency's Multi-Purpose Aviation Laboratory (MuPAL-alpha) research aircraft. This paper describes initial hardware-in-the-loop (HIL) tests which serve as a precursor to upcoming real test flights. The validation results show good lateral-directional state tracking performance in the fault free case with no visible performance degradation in the presence of (rudder and aileron) faults. Successful HIL tests demonstrate the potential of the proposed scheme which will be flight tested later this year.

16:20-16:40 MC1.2

A Fault Tolerant Control Approach for a Quadrotor UAV Subject to Time Varying Disturbances and Actuator Faults, pp. 596-601

Mallavalli, Seema — Univ. of Louisiana at Lafayette
Fekih, Afef — Univ. of Louisiana at Lafayette

A fault tolerant control approach is proposed in this paper for quadrotor Unmanned Aerial Vehicle (UAV) subject to time varying disturbances and actuator faults. The approach is based on a Super-Twisting (STW) control algorithm and a Higher Order Sliding Mode Observer (HOSMO). The HOSMO generates the exact estimates of the unmeasured states and time varying disturbances without any filtration that cause time delays and errors. A continuous control law that eliminates chattering is derived using the STW controller. Asymptotic stability of the control approach is analyzed using the Lyapunov theory. The controller is implemented on a quadrotor and is tested under nominal conditions, time varying disturbances and faulty scenarios. The results confirm the robustness and chattering free tracking performance of the proposed approach.

16:40-17:00 MC1.3

Adaptive Gain Parabolic Sliding Mode Filter Augmented with Vibration Observer, pp. 602-607

Lin Paing, Soe — Yangon Tech. Univ
Myo Thant Sin, Aung — Yangon Tech. Univ
Kikuuwe, Ryo — Kyushu Univ

This paper presents a new sliding-mode-based noise filter for removing high frequency noise. It is based on Jin et al.'s (2012) parabolic sliding mode filter (J-PSMF). In the new filter, the gain of J-PSMF is adapted according to the level of noise in the input signal, which is defined by using Lecours et. al.'s (2016) vibration observer. Compared to both secondorder linear low-pass filter (2-LPF) and J-PSMF, the new filter achieves better balance between noise mitigation and signal preservation. Due to implicit (backward) Euler discretization, the new filter does not suffer from chattering. The proposed filter was validated experimentally by using a DC servo motor equipped with an optical encoder. The proposed filter was implemented in a positioning system under PDD2 (proportional, derivative and second derivative) control and shown that both noise attenuation and non-overshooting response are achieved simultaneously.

17:00-17:20 MC1.4

Monitoring Function for Switching Adaptation in Control and Estimation Schemes with Sliding Modes, pp. 608-613

Rodrigues, Victor Hugo Pereira — State Univ. of Rio De Janeiro
Oliveira, Tiago Roux — State Univ. of Rio De Janeiro

A novel strategy for gain adaptation of higher-order sliding mode (HOSM) based differentiators is developed, considering that the upper bound for the higher time-derivatives of the output tracking error exist but they are unknown. Differently of earlier approaches, the proposed adaptive method is based on switching monitoring functions, which assures global stability and exact tracking when applied to output feedback. The challenging class of uncertain nonlinear plants of arbitrary relative degree handled in the paper includes time-varying and state-dependent disturbances with unknown bounds as well as unknown control directions. The unmeasured state is norm bounded through an adaptive state-norm estimator with hybrid dynamics. Simulations illustrate the potential applicability for control design and estimation in sliding mode schemes.

17:20-17:40 MC1.5

Second Order Integral Terminal Sliding Mode Control for Voltage Sag Mitigation in DFIG-Based Wind Turbines, pp. 614-619

Morshed, Mohammad Javad — Univ. of Louisiana at Lafayette
Fekih, Afef — Univ. of Louisiana at Lafayette

A second order integral terminal sliding mode control (SOITSMC) is proposed in this paper for a rotor side converter (RSC) of a DFIG-based wind turbine. The design is based on a novel sliding manifold and aims at improving the turbine's performance while minimizing chattering. The controller performance and its robustness were studied under voltage sag conditions and parameter variations. Simulation results, carried out using realistic scenarios, confirmed the system robustness against parameter variations and its effectiveness in mitigating voltage sags. The performance of the proposed approach was further compared to that of a standard SMC approach in terms of voltage sag mitigation abilities and chattering alleviation. While both SMC approaches were able to mitigate the effects of voltage sags and protect the rotor circuit against over-currents, the proposed ITSMC was shown to be more effective than CSMC in mitigating deep voltage sags and reducing the chattering effect.

17:40-18:00 MC1.6

Yaw Rotation Control of a Twin Wind Turbines Structure: Super-Twisting Strategy, pp. 620-625

Guenoune, Ibrahim — Ec. Centrale De Nantes
Plestan, Franck — Ec. Centrale De Nantes-LS2N
Chermitti, Ali — Univ. of Tlemcen

This paper presents a novel strategy for controlling the yaw rotation of a new twin wind turbines structure without a dedicated actuator. The idea of such strategy is to create a difference between the powers produced by the wind turbines, by modifying the generators torques, in order to force the structure face the wind. Given that the wind turbine performance is affected by the wind variation, a super-twisting controller is applied to optimize the produced power, by keeping the structure facing the wind, and to reduce the oscillations on the shaft coupling between turbine and generator. The performances of the proposed controller are compared to those obtained by standard sliding mode approach, for several scenarios.

MC2 Hilo

Optimization (Regular Session)

Chair: Doan, Thinh T. — Univ. of Illinois Urbana Champaign
Co-Chair: Singh, Tarunraj — State Univ. of New York at Buffalo

16:00-16:20 MC2.1

Adjoint Based Hessians for Optimization Problems in System Identification, pp. 626-631

Nandi, Souransu — State Univ. of New York at Buffalo
Singh, Tarunraj — State Univ. of New York at Buffalo

An adjoint sensitivity based approach to determine the gradient and Hessian of cost functions for system identification is presented. The motivation is the development of a computationally efficient approach relative to the direct differentiation technique and which overcomes the challenges of the step size selection in finite difference approaches. The discrete time measurements result in discontinuities in the Lagrange multipliers. The proposed approach is illustrated on the Lorenz 63 model where part of the initial conditions and model parameters are estimated.

16:20-16:40 MC2.2

Weight Design of Distributed Approximate Newton Algorithms for Constrained Optimization, pp. 632-637

Anderson, Tor — Univ. of California, San Diego
Chang, Chin-Yao — Univ. of California, San Diego
Martinez, Sonia — Univ. of California, San Diego

This paper presents a distributed algorithm to solve an economic dispatch problem, which takes the form of a linearly-constrained resource allocation problem. Distributed gradient-based methods are commonly used to solve problems of this form, which inherit slow convergence. The Newton method is a centralized alternative which uses second-order information to provide faster convergence. However, computing a Newton step is difficult in distributed settings and typically requires all-to-all agent communication. In this paper, we propose Distributed Approximate Newton Descent, a novel algorithm to approximate the Newton step with only distributed communication. The convergence of this algorithm is discussed and rigorously analyzed. In addition, we aim to address the problem of designing communication topologies and weightings that are optimal for second-order methods. To this end, we propose an effective approximation which is loosely based on completing the square to address the NP-hard bilinear optimization involved in the design. Simulations demonstrate that our proposed weight design applied to the Distributed Approximate Newton Descent Algorithm has a superior convergence property compared to existing gradient-inspired weight design applied to the Distributed Gradient Descent method.

16:40-17:00 MC2.3

Observer-Based Continuous-Time Robust Scaled-H_∞ Controller Design with Simultaneous Optimization of Scaling Matrices, pp. 638-643

Sato, Masayuki — Japan Aerospace Exploration Agency

This paper addresses the design problem of robust scaled-H_∞ controllers composed of state observers and state-feedback controllers for polytopic systems with time-invariant parameters. Even when designing robust H_∞ controllers for time-invariant polytopic systems, multiple uncertainty blocks are often introduced to represent various design requirements, in particular, frequency domain requirements. Then, scaling matrices should be introduced to reduce the conservatism due to the multiple uncertainty blocks. The problem in which H_∞ output feedback controllers and scaling matrices are both to be designed is, in general, a non-convex problem. On this issue, we propose a design method in which controller matrices, i.e. state-transition matrix, observer gain and state-feedback gain, as well as scaling matrix are all optimized simultaneously by using dilated Linear Matrix Inequality (LMI) technique. A numerical example demonstrates the effectiveness of our method with respect to the simultaneous optimization of controller gains and scaling matrices.

17:00-17:20 MC2.4

Receding Horizon Control with Ilqg Method Considering Computational Delay and Its Application to Nonholonomic Systems, pp. 644-649

Qian, Yun — Osaka Univ

Ushio, Toshimitsu — Osaka Univ

Receding Horizon Control (RHC) is a method that determines the control inputs for a plant by repeatedly solving a finite-horizon optimal control problem. We propose RHC considering a delay for the computation of the control input. The optimal control problem for each step is solved by the trajectory optimization, which calculates an optimal sequence of control inputs and its corresponding state trajectory that minimizes a given cost function. We apply the proposed method to a four-wheeled vehicle to perform a driving task. The simulation result shows the vehicle heading towards the target position along an acceptable path.

17:20-17:40 MC2.5

Distributed Lagrangian Methods for Network Resource Allocation, pp. 650-655

Doan, Thinh T. — Univ. of Illinois Urbana Champaign

Beck, Carolyn L. — Univ. of Illinois Urbana Champaign

Motivated by broad applications in various fields of engineering, we study network resource allocation problems where the goal is to optimally allocate a fixed portion of resources over a network of nodes. In these problems, due to the large scale of the network and complicated inter-connections between nodes, any solution must be implemented in parallel and based only on local data resulting in a need for distributed algorithms. In this paper, we propose a distributed Lagrangian method, which requires only local computation and communication. Our focus is to understand the performance of this algorithm on the underlying network topology. Specifically, we obtain an upper bound on the rate of convergence of the algorithm as a function of the size and the topology of the underlying network. The effectiveness and applicability of the proposed method is demonstrated by its use in solving the important economic dispatch problem in power systems, specifically on the benchmark IEEE-14 and IEEE-118 bus test systems.

17:40-18:00 MC2.6

A Novel Distributed Particle Swarm Optimization Algorithm for the Optimal Power Flow Problem, pp. 656-661

Gionfra, Nicolo — CentraleSupélec, Univ. Paris-Saclay

Sandou, Guillaume — CentraleSupélec, Univ. Paris-Saclay

Siguerdidjane, Houria — CentraleSupélec, Univ. Paris-Saclay

Loevenbruck, Philippe — Electricité De France

Faille, Damien — Electricité De France

The distributed optimal power flow problem is addressed. No assumptions on the problem cost function, and network topology are needed to solve the optimization problem. A distributed particle swarm optimization algorithm is proposed, based on Deb's rule to handle hard constraints. Moreover, the approach enables to treat a class of distributed optimization problems in which the agents share a common optimization variable. Under mild communication assumptions, agents are only required to know local variables, cost function, and constraints to solve a common optimization problem. A simulation example is provided, based on a 5-bus electric grid.

MC3 Hamakua

Estimation and Filtering (Regular Session)

Chair: Roascio, Danilo — Massachusetts Inst. of Tech

Co-Chair: Zhang, Xueji — Czech Tech. Univ. in Prague / Siemens Industry Software NV

16:00-16:20 MC3.1

Concurrent Adaptive Control and Parameter Estimation through Composite Adaptation Using Model Reference Adaptive Control/Kalman Filter Methods, pp. 662-667

Teran Espinoza, Antonio — Massachusetts Inst. of Tech

Roascio, Danilo — Massachusetts Inst. of Tech

Given their intrinsic characteristics, space missions' objectives such as on-orbit inspection, robotic servicing and assembly, autonomous reconfiguration maneuvers, and the disposal of orbital debris need to deal with unknown system and model parameters (e.g., dealing with uncooperative/unfamiliar targets, modified mass properties due to tugging/docking, etc). If an accurate value of the unknown quantities is warranted, system identification techniques are employed to characterize the system using parameter estimation algorithms, whereas if the characteristics are of no particular interest, adaptation methods are utilized to perform on-the-fly learning on a need to know basis. A common framework in which to implement parameter estimation algorithms is the Kalman Filter (KF), while Model Reference Adaptive Controllers (MRAC) can be used to accomplish parameter adaptation. The purpose of this work is to leverage the two frameworks to simultaneously exert control actions and perform inference on unknown parameter values using both sources of information, and assess the obtained performance. A simulation of a simple free floating mass example will be shown to demonstrate the approach.

16:20-16:40 MC3.2

Estimation of Parameters and Basic Reproductive Ratio for Japanese Encephalitis Transmission in the Philippines Using a Sequential Monte Carlo Filter, pp. 668-673

Riad, Md Mahbubul Huq — Kansas State Univ

Scoglio, Caterina — Kansas State Univ

McVey, David.. Scott — USDA ARS

Cohnstaedt, Lee W. — USDA

We developed a sequential Monte Carlo filter to estimate the states and the parameters in a stochastic model of Japanese Encephalitis (JE) spread in the Philippines. This method is particularly important for its adaptability to the availability of new incidence data. This method can also capture the variability in the incidence through time which is dependent upon various factors relating to the host species and the weather. Parameters estimated from the particle filter simulations show seasonal as well as yearly variations. The basic reproductive ratio fluctuations are in compliance with the endemicity of JE in the Philippines. The estimated basic reproductive ratio is comparable with other similar mosquito transmitted disease like Zika, dengue, and West Nile viruses.

16:40-17:00 MC3.3

Consensus-Based Distributed Sensor Fusion Over a Network, pp. 674-679

Zhang, Xueji — Czech Tech. Univ. in Prague /

	Siemens Industry Software
Hengster-Movric, Kristian	Czech Tech. Univ. in Prague, FEL
Sebek, Michael	Czech Tech. Univ. in Prague
Desmet, Wim	KU Leuven
Faria, Cassio	Siemens Industry Software NV

This paper studies the distributed filtering of noisy measurements of one scalar quantity. The considered network is composed of two sets of nodes: sensing nodes which perform the measuring task and non-sensing nodes which mediate between the sensing nodes. Inspired by Bayesian sensor fusion, three consensus-based algorithms are proposed. In the algorithms, graph edge weights in effect are determined based on variances of measurements of all the sensors. Evolution dynamics of the expected values and covariances of the state estimates throughout the network is analyzed. Numerical simulations are given to examine the fusion performance of the proposed scheme. The results are fairly consistent with the analytical solution regarding the statistical properties of the steady-state state estimates in the network.

17:00-17:20 MC3.4

Experimental Validation of Three-Stage Position Filter Based on Long Baseline Measurements with Unknown Wave Speed, pp. 680-686

Jørgensen, Erlend Kvinge	Norwegian Univ. of Science and Tech
Stovner, Bård	Norwegian Univ. of Science and Tech
Schjølberg, ingrid	Norwegian Univ. of Science and Tech

This paper provides experimental validation of a new globally convergent position- and velocity estimator with close-to-optimal noise properties using hydro-acoustic long baseline measurements. The estimator is compared to an Extended Kalman Filter, based on experiments conducted in a pool laboratory. Results suggest that the Three-stage Filter has similar stationary performance as the Extended Kalman Filter, but faster convergence when subjected to inaccurate initial estimates. Furthermore, the Three-stage Filter is globally convergent, whereas the Extended Kalman Filter does not have guaranteed stability. This is apparent in the experiment, in which the Extended Kalman Filter diverges for a time period.

17:20-17:40 MC3.5

Exponential Convergence Bounds in Least Squares Estimation: Identification of Viscoelastic Properties in Atomic Force Microscopy, pp. 687-694

Ragazzon, Michael Remo Palmén	Norwegian Univ. of Science and Tech
Gravdahl, Jan Tommy	Norwegian Univ. of Science and Tech
Pettersen, Kristin Y.	Norwegian Univ. of Science and Tech

Using atomic force microscopy (AFM) for studying soft, biological material has become increasingly popular in recent years. New approaches allow the use of recursive least squares estimation to identify the viscoelastic properties of a sample in AFM. As long as the regressor vector is persistently exciting (PE), exponential convergence of the parameters to be identified can be guaranteed. However, even exponential convergence can be slow. In this article, upper bounds on the parameter convergence is found, completely determined by the PE properties and least squares update law parameters. Furthermore, for a parameter vector which is piecewise constant at regular intervals, the time interval necessary for the error to converge to any specified upper limit is determined. For a soft sample in AFM, the viscoelastic properties can be spatially inhomogeneous. These properties can be spatially resolved by periodically tapping at discrete points along the sample. The results of this article then allows us to determine the time interval necessary at each tap in order to guarantee convergence to any specified fraction of the step-change in the parameters. Simulation results are presented, demonstrating the applicability of the approach.

MC4 Kohala

Mechatronic Systems III (Regular Session)

Chair: Barton, Kira	Univ. of Michigan
Co-Chair: Nittinger, Johannes Alexander	RWTH Aachen Univ

16:00-16:20 MC4.1

Hybrid Modeling and Identification of Jetting Dynamics in Electrohydrodynamic Jet Printing, pp. 695-701

Spiegel, Isaac	Univ. of Michigan Ann Arbor
Kovalenko, Ilya	Univ. of Michigan
Hoelzle, David	Univ. of Notre Dame
Sammons, Patrick	Missouri Univ. of Science and Tech
Barton, Kira	Univ. of Michigan

Electrohydrodynamic jet printing (e-jet) is a micro additive manufacturing process in which polarizable liquid inks are extracted from a microcapillary nozzle by an electric field and deposited onto a substrate. This process can be broken into two discrete phases: build up to jetting, and jetting of material. This decomposition allows e-jet to be modeled as a hybrid dynamical system. In order to develop a single model with both discrete phases, knowledge of their continuous dynamics and the transition condition between them is needed. This paper proposes and empirically verifies a physics-based inequality on cone angle for modeling the transitions between phases. Additionally, a practical model of the continuous jetting dynamics is generated from measurements taken using high speed video of the e-jet process.

16:20-16:40 MC4.2

Piezoelectric Composite Subordinate Oscillator Arrays and Frequency Response Shaping for Passive Vibration Attenuation, pp. 702-707

Paruchuri, Sai Tej	Virginia Tech
Sterling, John	Catholic Univ. of America
Kurdila, Andrew J.	Virginia Tech
Vignola, Joseph	Catholic Univ. of America

Subordinate Oscillator Arrays (SOAs) can be shown theoretically to provide vibration attenuation that is characterized by a frequency response function with a magnitude that is approximately flat over a finite bandwidth. However, the actual performance of SOA designs can suffer due to uncertainties in the structural parameters of the host and SOA. In this paper, we describe a piezoelectric composite SOA that can be used either actively or passively to account or correct for uncertainties in structural parameters that result from fabrication. This paper uses thermodynamic variational principles to derive the equations of motion for the active SOA formed using piezoelectric composites. We discuss techniques to optimize vibration attenuation for the SOA with fabrication errors using the piezoelectric appendages in the SOA.

16:40-17:00 MC4.3

Structural Sparsity for Active Control Design in Civil Engineering, pp. 708-713

Flórez Martínez, Alvaro Javier	Univ. de Los Andes
Giraldo, Luis Felipe	Univ. de Los Andes
Reyes Ortiz, Juan Carlos	Univ. de Los Andes

An active control system in civil engineering is a structure that mitigates the effect of external forces such as winds and earthquakes by applying counteracting control forces. Although they are able to adapt for a broad spectrum of conditions and structures, they involve significant increases in costs due to hardware such as actuators, sensors, and communication devices. There is a need of control strategies that lead to not only safe but also economical designs that

take into account the physical structural properties of the system. In this paper we use the concept of structural sparsity to propose a mathematical framework for the design of control strategies that involve less information to compute a control action, considering prior information about the inherent structural relations between the components of the system to be controlled. We formulate the control design process as the solution of an optimization problem driven by a component associated with the performance of the controlled civil structure along with a norm that is built to induce structural sparsity in the parameters of the controller. As a study case of the proposed control design strategy we consider the model of a structure with magnetorheological (MR) dampers whose action is determined by a state feedback controller. The criterion used to design the parameters of the controller is the H_2 norm along with a structural sparsity-inducing norm that is built to encode the relations within and between stories through a hierarchical configuration. Simulations show that the resulting controller is able to reduce the story drift with a performance close to that of a non-sparse controller, requiring less information to compute the control action, and keeping physical consistency of the controlled system.

17:00-17:20 MC4.4

Control and Path Planning Method for Simultaneous Manufacturing with Robot and Milling Machine, pp. 714-719

Brecher, Christian RWTH Aachen Univ

Nittinger, Johannes A. RWTH Aachen Univ

For automation of machining centers such as milling machines a common approach is to integrate robots for tasks like (un)loading workpieces. However, the controllers of machine tool and robot are usually not integrated. This limits the possibilities for a close cooperation between machine and robot significantly. This paper describes a milling machine that has been integrated with a robot both mechanically and on the controller level. To allow for robot and milling spindle to machine on the same workpiece at the same time, the control concept is extended and a concept for a path planning method is developed. The path planning module is evaluated for the process combinations of milling and robot based deburring. The paths of robot and machine are first planned sequentially and then fed into the planning module. The planning module splits up the paths and performs collision simulations to find possible combinations of process steps that can be executed simultaneously. The result is a collision matrix that allows selecting collision free path combinations for simultaneous operations.

17:20-17:40 MC4.5

A Cornea Holding Device for Transplantation Surgery Using Negative Pressure, pp. 720-725

Kanno, Takahiro Tokyo Medical and Dental Univ

Ito, Norihiko Tottori Univ. Veterinary Medical Center

Kawashima, Kenji Tokyo Medical and Dental Univ

Cornea transplantation surgery needs a highly skilled ophthalmologist due to the requirement of precise positioning and the plasticity of a cornea. In this paper, we propose a cornea holding device, which fixes the relative position between a donor cornea and a patient cornea. The proposed device prevents the slipping or deformation of the corneas during transplantation surgery. The cornea holder has two sets of fluid channels, one for vacuuming donor cornea and the other for the patient cornea. We also constructed a compact fluid control system using a microcomputer, moreover, an on-off control is introduced for negative pressure and vacuum break control using high response solenoid valves. A preliminary experiment determines a proper negative pressure value without damaging the cornea. We conducted in-vitro experiments using a porcine eye and gathered several comments by an eye surgeon.

17:40-18:00 MC4.6

Predictive-Model-Based MIMO Motion Control of an Unstable 6-DoF Hexapod Stage for Overlay Measurements, pp. 726-731

Witvoet, Gert TNO Tech. Sciences

Kuiper, Stefan TU Delft

Kramer, Geerten TNO

Baeten, Max TNO

Correct functionality of semiconductor devices depends on the overlay performance between device layers. Future smaller device features consequently require more accurate overlay metrology tools. In this paper we present a large dynamic range AFM overlay tool to directly measure marker-to-feature distances, and focus on the controller design of the large stroke 6-DoF hexapod motion stage which is at the heart of this tool. The stage is open-loop unstable due to magnetic gravity compensation, which calls for an initial model-based MIMO controller design, which is based on a finite-element modal analysis, geometric decoupling and SISO loop shaping. This controller is successfully validated in experiments; further controller improvements after closed-loop system identification yield a closed-loop position error of just 1nm RMS.

MC5 Ballroom I

Robotics III (Regular Session)

Chair: Pettersen, Kristin Y. Norwegian Univ. of Science and Tech

Co-Chair: Eriksen, Bjørn-Olav Holtung Norwegian Univ. of Science and Tech

16:00-16:20 MC5.1

Spiral Path Planning for Docking of Underactuated Vehicles with Limited FOV, pp. 732-739

Sans-Muntadas, Albert Norwegian Univ. of Science and Tech

Kelasidi, Eleni Norwegian Univ. of Science and Tech

Pettersen, Kristin Y. Norwegian Univ. of Science and Tech

Brekke, Edmund Norwegian Univ. of Science and Tech

This paper proposes a novel approach for constructing a docking path for underwater vehicles, using a new spiral resulting of combining the Fermat and logarithmic spirals. The proposed spiral path has two properties that will help solve some of the challenges of docking autonomous underactuated vehicles (AUVs). The first property is that the spiral path reaches the entrance of the docking station without curvature, allowing a smooth transition when entering the docking station. The second is that the AUV never exceeds a certain bearing angle with respect to docking station. This last feature allows AUVs equipped with navigation sensors which have a reduced field of view (FOV), such as cameras or acoustic positioning systems, to always preserve the docking station inside the FOV. Furthermore, the paper presents an interpolation of the spiral using waypoints that are connected with segments of logarithmic spirals. This makes it possible to apply existing guidance laws to follow the docking spiral. The proposed spiral docking path has been experimentally tested using an autonomous underwater vehicle.

16:20-16:40 MC5.2

Design of Singularity-Robust and Task-Priority Primitive Controllers for Cooperative Manipulation Using Dual Quaternion Representation, pp. 740-745

Miranda de Farias, Cristiana Univ. De Brasília

Goncalves Rocha, Yuri Univ. of Brasilia

Figueredo, Luis Felipe Cruz Univ. of Brasília

Bernardes, Mariana Costa Univ. of Brasilia

This paper revises and extends the problem of robust singularity and joint limits avoidance to the cooperative task-space using unit dual quaternion framework—ensuring singularity-free coupled representation of the cooperative space. The research is paramount to cooperative control applications within flexible manufacturing systems and poorly structured environments where robustness and reactiveness play a significant role. Singularity-robust techniques are proposed to control cooperative task primitives while dynamically avoiding kinematic singularities for redundant and non-redundant cooperative task trajectories. A task self-motion, which uses the nullspace of the cooperative task, is also exploited to avoid joint limits or singularities and to define task-priority controllers. Simulated and experimental results illustrate the effectiveness of the proposed singularity-robust and task-priority primitive controllers and the usefulness of singularity-robust solutions and joint limits avoidance in the cooperative task-space.

16:40-17:00 mc5.3

deformable robot behavior based on the standard linear solid model, pp. 746-751

Senoo, Taku univ. of tokyo

Murakami, Kenichi Univ. of Tokyo

Ishikawa, Masatoshi Univ. of Tokyo

This study describes the design and realization of passive dynamic control for a manipulator. The control strategy is based on the idea that the shift in position and posture of an end effector attributable to an external force is regarded as the deformation of a robot. Control methods are constructed from the standard linear solid model, which describes the combination of plastic and elastic deformation. Two types of control methods are proposed in terms of the model's expression. Physical simulations with a robotic arm were executed to validate and analyze the proposed control laws.

17:00-17:20 MC5.4

Velocity and Orientation Control of Underwater Snake Robots Using Absolute Velocity Feedback, pp. 752-759

Kohl, Anna M. Norwegian Univ. of Science and Tech

Pettersen, Kristin Y. Norwegian Univ. of Science and Tech

Gravdahl, Jan Tommy Norwegian Univ. of Science and Tech

This article presents a control system for velocity and orientation control of underwater snake robots using absolute velocity feedback. The control system is structured in a hierarchical way, where the highest priority is to enforce virtual constraints encoding a planar gait on the body shape of the robot. To this end, we propose an adaptive joint controller and show that it asymptotically stabilizes the constraint manifold. The virtual constraints are parametrized by the states of two dynamic compensators, which can be used to control the velocity and the orientation of the robot, the second and third control priority. We design an adaptive controller that asymptotically stabilizes the forward velocity to a reference and an orientation controller that utilizes the current estimate of the velocity controller. It is shown that the zero dynamics of the closed-loop system remains bounded, and we present simulation results that demonstrate the performance of the controller.

17:20-17:40 MC5.5

Stability of Line-Of-Sight Based Trajectory-Tracking in Two Dimensions, pp. 760-765

Flåten, Andreas Lindahl Norwegian Univ. of Science and Tech

Brekke, Edmund Norwegian Univ. of Science and Tech

This paper addresses the trajectory tracking problem for general trajectories in two dimensions, where a desired time-parametrized trajectory has been specified. Specifically we investigate the use of a Line-Of-Sight guidance algorithm with a modified definition of the path tangential angle, which requires specification of a lookahead time as opposed to a lookahead distance. The modified definition is simple, and provides a convenient way of proving exponential convergence and ultimate boundedness to straight and general trajectories respectively. This is proved using Lyapunov perturbation theory for the guidance law error dynamics, and verified in simulation for an underactuated marine vehicle.

17:40-18:00 MC5.6

MPC-Based Mid-Level Collision Avoidance for ASVs Using Nonlinear Programming, pp. 766-772

Eriksen, Bjørn-Olav Holtung Norwegian Univ. of Science and Tech

Breivik, Morten Norwegian Univ. of Science and Tech

In this paper, we present a mid-level collision avoidance algorithm for autonomous surface vehicles (ASVs) based on model predictive control (MPC) using nonlinear programming. The algorithm enables avoidance of both static and moving obstacles, and following of a desired nominal trajectory if there is no danger of collision. We compare two alternative objective functions, where one is a quadratic function and the other is a nonlinear function designed to produce maneuvers observable for other vessels in compliance with rule 8 of the International Regulations for Preventing Collisions at Sea (COLREGS). The algorithm is implemented in the CASADI framework and uses the IPOPT solver. The performance of the algorithm is evaluated through simulations which show promising results. Furthermore, the algorithm is considered computationally feasible to run in real time. This algorithm serves as a base algorithm for further development in order to ensure full COLREGS compliance.

MC6 Ballroom II

Energy Systems III (Regular Session)

Chair: Cortinovis, Andrea ABB Corp. Res

Co-Chair: Beck, Carolyn L. Univ. of Illinois, Urbana-Champaign

16:00-16:20 MC6.1

Modeling and Maximizing Power in Wind Turbine Arrays, pp. 773-778

Buccafusca, Lucas Univ. of Illinois, Urbana-Champaign

Beck, Carolyn L. Univ. of Illinois, Urbana-Champaign

Dullerud, Geir E. Univ. of Illinois, Urbana-Champaign

This paper considers a specific application domain, that of wind turbine arrays, and explores algorithms for determining individual axial induction factors that optimize overall energy extraction. Large wind turbine arrays, or wind farms, can be viewed as large coupled networks, for which the application of traditional optimization techniques are impractical. We consider a dynamic programming approach to maximize power extraction under the condition of uniform wind. Recent work has used a dynamic programming approach for a near-field approximate solution. In this paper we present a heuristic method to find solutions to both the near-field and the far-field problems. Simulation results are discussed, which demonstrate our algorithm provides improved performance compared to prior work on near-field approaches. Ongoing work involves modeling and control for the true dynamic nature of the problem, including applications of recent distributed feedback control methods.

16:20-16:40 MC6.2

Optimal Control of a Wave Energy Converter, pp. 779-786

Hendrikx, Bob — Eindhoven Univ. of Tech
Leth, John — Aalborg Univ
Andersen, Palle — Aalborg Univ
Heemels, W.P.M.H. — Eindhoven Univ. of Tech

The optimal control strategy for a wave energy converter (WEC) with constraints on the control torque is investigated. The goal is to optimize the total energy delivered to the electricity grid. Using Pontryagin's maximum principle, the solution is found to be singular-bang. Using higher order conditions, the optimal control on the singular arc is found as a function of the state and costate trajectories. Furthermore, it is shown that the transitions between bang and singular subarcs are discontinuous. Based on these findings the results of a numerical direct method are validated. Finally, the optimal control is used to benchmark an existing MPC strategy. It is found that for active control torque constraints the MPC strategy does not result in the discontinuous singular-bang transitions. However, the difference in harvested power is small.

16:40-17:00 MC6.3

Voltage Uncertainties in the Presence of Photovoltaic Systems, N/A

Zeinalzadeh, Ashkan — Univ. of Notre Dame
Hughes, Katherine — Hawaii Data Analytics LLP

In grids with high penetration of photovoltaic (PV) systems, voltage fluctuations can occur at the distribution systems, resulting in inverter tripping and insufficient power to meet the load. We obtain a linear model for voltage rise as a function of PV system output power. This model can be used to study the effect of increasing PV system capacities on distribution system voltages. It is observed that voltage fluctuations have greater correlation with the location of the PV systems on the grid than with the PV system capacities, i.e., more randomness and disorder in voltage behavior occurs with PV systems with larger line impedance.

17:00-17:20 MC6.4

Battery Energy Storage Operation with Adaptive Droop Control, pp. 793-798

Zhang, Jimmy — AESO

With more renewable resources integrated to the grid, energy storage is expected to rise to the challenge of the grid caused by the characteristics of the intermittent renewable sources. This paper presents an innovative battery energy storage system (BESS) combined with the decoupled PQ control and adaptive capacity-based droop control for both grid-connected operation and stand-alone operation. When the system is islanded, such BESS synchronizes to form a reliable frequency source which does not collapse when member BESS fail. The flexibility of the proposed control method enables the BESS to adjust the power output according to its available capacity respectively so that the decentralized autonomous frequency control with load sharing is achieved without violating the stability limit. The paper also highlights the significant role of the Phase Lock Loop for the proposed control principles.

17:20-17:40 MC6.5

Energy Management System for Charging Stations with Regenerative Supply and Battery Storage Based on Hybrid Model Predictive Control, pp. 799-805

Lepold, Tobias — Univ. of Kaiserslautern
Görges, Daniel — Univ. of Kaiserslautern

This paper introduces a comprehensive approach to smart charging at a charging station supported by a vanadium redox flow buffer battery and supplied by a photovoltaic panel. Both increasing photovoltaic power and fast charging of electric vehicles induce challenges for grid management. Smart charging in conjunction with the buffer battery increases efficiency and reduces strain on the grid. Improved yet simple models for vanadium redox flow batteries and the electric vehicle charging processes are developed. The component models for control design are formulated as mixed logical dynamical system to accommodate the limitations of the charging process imposed by IEC 61851. From the models a hybrid model predictive control scheme is derived and evaluated in a test scenario.

17:40-18:00 MC6.6

Power Consumption Optimization for Multiple Parallel Centrifugal Pumps, pp. 806-811

Jepsen, Kasper — Aalborg Univ
Hansen, Leif — Aalborg Univ
Mai, Christian — Aalborg Univ
Yang, Zhenyu — Aalborg Univ

Large amounts of energy is being used in a wide range of applications to transport liquid. This paper proposes a generic solution for minimizing power consumption of a generic pumping station equipped with identical variable speed pumps. The proposed solution consists of two sequential steps; firstly, the energy consumption for a pre-selected set of active pumps are formulated as a convex optimization problem and that can be solved analytically. Secondly, the problem of choosing the number of active pumps are formulated and solved using a convex solver subject to constraints. The proposed solution is compared with a conventional affinity-law based solution. The experimental analysis showed that the proposed solution and method lead to more precise pump modeling and simplicity in solving this type of pump optimization problem.

MC7 — Ballroom III

Robotic Locomotion Control (Invited Session)

Chair: Gregg, Robert D. — Univ. of Texas at Dallas
Co-Chair: Mohammadi, Alireza — Univ. of Texas at Dallas
Organizer: Mohammadi, Alireza — Univ. of Texas at Dallas
Organizer: Gregg, Robert D. — Univ. of Texas at Dallas

16:00-16:20 MC7.1

Automatic Tuning of Virtual Constraint-Based Control Algorithms for Powered Knee-Ankle Prostheses (I), pp. 812-818

Kumar, Saurav — Univ. of Texas at Dallas
Mohammadi, Alireza — Univ. of Texas at Dallas
Gans, Nicholas — Univ. of Texas at Dallas
Gregg, Robert D. — Univ. of Texas at Dallas

State-of-art powered prosthetic legs are often controlled using a collection of joint impedance controllers designed for different phases of a walking cycle. Consequently, finite state machines are used to control transitions between different phases. This approach requires a large number of impedance parameters and switching rules to be tuned. Since one set of control parameters cannot be used across different amputees, clinicians spend enormous time tuning these gains for each patient. This paper proposes a virtual constraint-based control scheme with a smaller set of control parameters, which are automatically tuned in real-time using an extremum seeking controller (ESC). ESC, being a model-free control method, assumes no prior knowledge of either the prosthesis or human. Using a singular perturbation analysis, we prove that the virtual constraint tracking errors are small and the PD gains remain bounded. Simulations demonstrate that our ESC-based method is capable of adapting the virtual-constraint based control parameters for amputees with different masses.

16:20-16:40 MC7.2

Modeling and Propulsion Methods of Underwater Snake Robots (I), pp. 819-826

Kelasidi, Eleni	Norwegian Univ. of Science and Tech
Pettersen, Kristin Y.	Norwegian Univ. of Science and Tech
Gravdahl, Jan Tommy	Norwegian Univ. of Science & Tech
Strømsøyen, Simen	Department of Marine Tech. at NTNU
Sorensen, Asgeir Johan	Norwegian Univ. of Sci and Tech

In this paper we consider underwater snake robots (USRs) that may be equipped with additional added effectors along their body, including caudal, dorsal and pectoral fins, tunnel thrusters and/or a stern propeller. We propose a mathematical model for USRs swimming in a 2D plane, which includes the extra propulsion forces acting on each link from the added effectors. The resulting model is in closed form, making it well-suited for control design and analysis. We then consider the particular case when fins are added to one or more links to provide lift forces. We develop a quasi-static model for an oscillating and rotating foil, which is then combined with the model of the USR to provide a model of an USR with one or more fins along its body. This makes it possible to make a simulation-based comparison of the USR energy efficiency with and without fins. Simulation results presented in this paper show that there is a significant improvement in propulsion efficiency for the USR with a caudal (tail) fin compared to the results obtained for the USR without a caudal fin.

16:40-17:00 MC7.3

Moving Target Localization Method Using Foot Mounted Acceleration Sensor for Autonomous Following Robot, pp. 827-833

Tasaki, Ryosuke	Toyohashi Univ. of Tech
Sakurai, Hiroto	Toyohashi Univ. of Tech
Terashima, Kazuhiko	Toyohashi Univ. of Tech

Development of the autonomous mobile robot system has expanded its application fields in various such as medical service support, automatic vehicle operation, and delivery business. In recent years, we have developed a mobile robot which is responsible for task to follow the medical doctor from arbitrary starting point to the patient room in hospital and to manage medical resources and patient's electronic information. The robot follows with the position being a few meters behind the moving target person or the medical doctor. Here, when there is a blocking object between the following target and the observation sensor, the robot stops because it loses the target position. Obstacles for these robots are passers-by in straight corridors and corner walls in turns. In this research, we propose a moving target localization method that directly measures or indirectly estimates the position of the robot's following target, in assuming a movement environment where the presence or absence of occlusion that is impossible to directly detect the following target by some obstacles from the robot is switchingly occurred. The wearable acceleration sensor is attached to the one-leg of the following target person and self-localization with high accuracy can be estimated by our proposed calculation algorithm based on the inertial navigation information. As the compensation for position error accumulated with the time proceeds, estimation calculation is processed according to correction information of the standing leg judgment by acceleration sensor and the target's moving direction by LRF during straight walking. Construction of the estimation compensation algorithm, its implementation on the mobile robot and trial experiment of robot following a specified human are mentioned.

17:00-17:20 MC7.4

Removing Phase Variables from Biped Robot Parametric Gaits (I), pp. 834-840

Mohammadi, Alireza	Univ. of Texas at Dallas
Horn, Jonathan	Texas A & M Univ
Gregg, Robert D.	Univ. of Texas at Dallas

Hybrid zero dynamics-based control is a promising framework for controlling underactuated biped robots and powered prosthetic legs. In this control paradigm, stable walking gaits are implicitly encoded in polynomial output functions of the robot configuration variables, which are to be zeroed via feedback. The biped output functions are parameterized by a suitable mechanical phasing variable whose evolution determines the biped gait progression during each step. Determining a proper phase variable, however, might not always be a trivial task. In this paper, we present a method for generating output functions from given parametric walking gaits without any explicit knowledge of the phase variable. Our elimination method is based on computing the resultant of polynomials, an algebraic tool widely used in computer algebra.

17:20-17:40 MC7.5

Autopilot Design for a Class of Miniature Autonomous Blimps (I), pp. 841-846

CHO, SUNGJIN	Georgia Inst. of Tech
Mishra, Vivek	Georgia Inst. of Tech
Tao, Qiuyang	Georgia Inst. of Tech
Varnell, Paul	Georgia Inst. of Tech
King-Smith, Matt	The Coll. of Wooster
Muni, Aneri	Georgia Inst. of Tech
Smallwood, Weston	Georgia Inst. of Tech
Zhang, Fumin	Georgia Inst. of Tech

The Georgia Tech Miniature Autonomous Blimp (GT-MAB) is developed as an indoor testbed for robotics research. Compared with existing platforms, the GT-MAB features longer flight times and safer human-robot interactions. The influence of aerodynamics on the blimp is significant and must be considered to achieve autonomous flying behaviors. This paper presents the mathematical modeling, system identification, and controller design for the GT-MAB, which leads to a set of motion primitives that can be combined for autonomous waypoint-following. Especially, an altitude controller incorporating a scheduling algorithm is proposed to address uncertainties of propeller efficiency. Experiments have demonstrated that the GT-MAB is able to perform 3D sampling and mapping of a light intensity field in an indoor environment.

17:40-18:00 MC7.6

Real-Time Continuous Gait Phase and Speed Estimation from a Single Sensor (I), pp. 847-852

Quintero, David	Univ. of Texas at Dallas
Lambert, Daniel	Univ. of Texas at Dallas
Villarreal, Dario J.	Univ. of Texas at Dallas
Gregg, Robert D.	Univ. of Texas at Dallas

Human gait involves a repetitive cycle of movements, and the phase of gait represents the location in this cycle. Gait phase is measured across many areas of study (e.g., for analyzing gait and controlling powered lower-limb prosthetic and orthotic devices). Current gait phase detection methods measure discrete gait events (e.g., heel strike, flat foot, toe off, etc.) by placing multiple sensors on the subject's lower-limbs. Using multiple sensors can create difficulty in experimental setup and real-time data processing. In addition, detecting only discrete events during the gait cycle limits the amount of information available during locomotion. In this paper we propose a real-time and continuous measurement of gait phase parameterized by a mechanical variable (i.e., phase variable) from a single sensor measuring the human thigh motion. Human subject experiments demonstrate the ability of the phase variable to accurately

parameterize gait progression for different walking/running speeds (1 to 9 miles/hour). Our results show that this real-time method can also estimate gait speed from the same sensor.

MC8	Ballroom IV
Modeling, Control and Optimization of Powertrain Systems (Invited Session)	
Chair: Onori, Simona	Clemson Univ
Co-Chair: Ahmed, Qadeer	Ohio State Univ
Organizer: Onori, Simona	Clemson Univ
Organizer: Ahmed, Qadeer	Ohio State Univ

16:00-16:20 MC8.1

Genetic Algorithms Optimized Multi-Objective Controller for an Induction Machine Based Electrified Powertrain (I), pp. 853-858

Hanif, Athar — COMSATS Inst. of Information Tech. Lahore Campus, Lah

Ahmed, Qadeer — Ohio State Univ

Bhatti, Aamer Iqbal — Capital Univ. of Engineering and Tech

Rizzoni, Giorgio — Ohio State Univ

In electrified powertrain control, meeting the torque demands and ensuring efficient Electrical Machine (EM) operations are two essential but conflicting demands. A multi-objective Linear Parameters Varying (LPV) controller is proposed to address the problem of these conflicting objectives. The synthesis of multi-objective controller is based on the selection of optimal weighting functions optimized by Genetic Algorithm (GA). The effectiveness of the proposed controller is tested and evaluated for an electrified powertrain operating in a standard urban driving cycles. The stability of the proposed Multi-Objective Controller (MOC) is established. The nonlinear simulation of the proposed controller delivers the robust performance and better efficiency of an EV Induction Machine (IM) based electric drive over the entire driving cycle.

16:20-16:40 MC8.2

Modeling and Experimental Validation of Series Connected Battery Pack Modules (I), pp. 859-865

Guo, Lin-L — Supply Chain Development, Home Depot U.S.A., Inc

Ramaswamy, Manish — Ford Motor Company

Pyne, Moinak — Univ. of Texas at Dallas

Yurkovich, BJ — Ohio State Univ

Yurkovich, Stephen — Univ. of Texas at Dallas

For applications such as electrified automotive powertrains, which require high power density and operating voltages, the lithium-ion battery is an ideal candidate. When individual batteries are combined into packs, a battery management system is needed to safely operate packs consisting of hundreds of cells in series and parallel configurations. While much attention has been given to modeling and analysis of single cells, there has been less attention given to modeling and analysis of pack configurations regarding voltages and currents in the strings that make up the pack. Such analyses have an impact on investigations regarding pack balancing. Moreover, relatively little research has appeared in the open literature regarding experimental validation of models with regard to voltage and current characteristics in pack configurations. In this article we present a dynamic model for a lithium-ion series battery pack based on the voltage-current relationship of individual cells in various operating scenarios such as charge balancing. Resulting models are validated in the lab using a special purpose battery pack by comparing the simulated pack model with the bench top battery pack.

16:40-17:00 MC8.3

An Alternate Control Framework Development for Atkinson Cycle Engine Using Variable Late Intake Valve (I), pp. 866-871

Murtaza, Ghulam — Mohammad Ali Jinnah Univ. Islamabad, Pakistan

Ahmed, Qadeer — Ohio State Univ

Bhatti, Aamer Iqbal — Capital Univ. of Engineering and Tech

Rizzoni, Giorgio — Ohio State Univ

A new control framework for VCR Atkinson cycle VVT engine with an unconventional Late Intake Valve Closing (LIVC) strategy instead of the throttle, is developed to ascertain its better fuel economy in comparison with the conventional Otto cycle engine. In this context, the authors have already proposed a control-oriented Extended Mean Value Engine Model (EMVEM) of the Atkinson cycle engine with variable intake valve actuation. The proposed control strategy is developed on the same model evaluated for the standard Urban driving cycles at medium and higher operating conditions in the fuel economy perspective. It has the potential to deal better with the engine throttling effect and to enhance its thermal efficiency that will result in significant improvement in performance, fuel economy and emissions reduction. The controllability analysis of the EMVEM model in viewpoint of control design is carried out with respect to the alternative control input. The simulation results exhibit the better thermal efficiency and reduction in the engine part load losses. Consequently, significant enhancement in the fuel economy of the Atkinson cycle VVT engine with the proposed control input is achieved over Otto cycle engine.

17:00-17:20 MC8.4

Capacity Fade Estimation Using Supervised Learning (I), pp. 872-878

Pyne, Moinak — Univ. of Texas at Dallas

Yurkovich, BJ — Ohio State Univ

Yurkovich, Stephen — Univ. of Texas at Dallas

Reliability of energy storage systems, for stationary as well as mobile applications, is crucial for their stable long term operation. Among all the components that are susceptible to failure, modules made up of individual batteries determine the useful life of such a system. Hence, estimating health quotients of battery packs in typical energy storage systems takes on a high priority. The computational complexity and large volumes of data required in such calculations are well documented. In this article we present an approach for trend prediction of capacity fade while reducing the amount of test data required. This is accomplished through the use of clustering techniques and a supervised learning system, further reducing computation with the use of a recurrent neural network based system. Data for training and validation, mimicking drive cycle data with multiple current pulses, is provided by extensive charge and discharge experimentation in the lab on a commercially available battery pack.

17:20-17:40 MC8.5

Monte Carlo Simulation for Optimization of Hybrid Fuel Cell Bus Powertrain Components (I), pp. 879-885

Freudiger, Danny — Ohio State Univ

Bigelow, Erik — CTE

Yurkovich, BJ — Ohio State Univ

This paper presents a Monte Carlo approach for determining optimal component sizing for several different classes of fuel cell transit buses. Real world bus routes were collected and used in simulation for a large set of bus powertrain configurations, and then each case was evaluated using a defined set of pass/fail criterion. Each passing case was further evaluated using a defined set of metrics based on route difficulty and vehicle performance. Using these results, optimal powertrain configurations were determined for the various route profiles. Finally, a set of optimal configurations are proposed for fuel cell transit buses over a range of varying driving vocations.

17:40-18:00 MC8.6

Reduced Order Model Design for Three Way Catalytic Converters (I), pp. 886-891

Godi, Romit — Clemson Univ
Onori, Simona — Clemson Univ

This paper presents a reduced order model for three way catalyst (TWC) temperature dynamics developed using Proper Orthogonal Decomposition (POD) and Galerkin projection method. The TWC thermal dynamics are described using a set of coupled, non-linear partial differential equations (PDEs). The Galerkin projection method is applied to the PDEmodel to construct a set of ordinary differential equations (ODEs) to describe the dynamics of the system. POD extracts a low dimensional basis functions from a high dimensional data set obtained by numerical simulation of the system. This is achieved by performing singular value decomposition (SVD) on the data set and selecting the basis functions corresponding to the most dominant eigenvalues of the system. Using the POD basis functions along with Galerkin projection leads to a low order ODE system that captures the system dynamics described by the physics based model. The results obtained indicate that a three state reduced-order model obtained using POD-Galerkin is able to capture the thermal dynamics with satisfactory accuracy. The development of the newly proposed control oriented model for TWC thermal dynamics is carried out using experimental data collected from a TWC running on the Federal Test Protocol (FTP) driving cycle.

ME1 — Hale Hoaloha Pavilion

Managing Innovation in Control Technology and Applications: Insights from Industry and Academia (Industry/Academia Panel Session)

Panel Chair: Samad, Tariq — Univ. of Minnesota

18:15-19:45 — TP1.1

Industry/Academia Panel Session
*Managing Innovation in Control Technology and Applications: Insights from Industry and Academia**

Panelists

Ganguli, Ankur — General Motors
Kelkar, Atul — National Science Foundation and Iowa State Univ
Marcos, Andres — Univ. of Bristol
Spong, Mark W. — Univ. of Texas at Dallas

Technical Program for Tuesday August 29, 2017

TP1	Hale Hoaloha Pavilion
Connected Vehicles: Closing the Loop with the Highway (Keynote Address)	
Chair: Spong, Mark W.	Univ. of Texas at Dallas
Co-Chair: Yurkovich, Stephen	Univ. of Texas at Dallas

08:30-09:30 TP1.1

*Connected Vehicles: Closing the Loop with the Highway**

Ioannou, Petros A. — Univ. of Southern California

TA1	Puna
Hybrid and Switched Systems (Regular Session)	
Chair: Plestan, Franck	Ec. Centrale De Nantes-IRCCyN
Co-Chair: Sanfelice, Ricardo G.	Univ. of California at Santa Cruz

10:30-10:50 TA1.1

Third Order Sliding Mode Control with a Predefined Convergence Time: Application to an Electropneumatic Actuator, pp. 892-897

Chalanga, Asif — Ec. Centrale De Nantes

Plestan, Franck — Ec. Centrale De Nantes-LS2N

This paper presents the practical implementation of a new robust third order sliding mode controller for an electropneumatic actuator with a predefined convergence time. The controllerí robustness is discussed with respect to external disturbances. Implementation results on an electropneumatic actuator setup show the effectiveness of the controller.

10:50-11:10 TA1.2

Optimal Switching Surface Design for Switching LPV Control and Its Application to Air-Fuel Ratio Control of an Automotive Engine, pp. 898-903

Zhao, Pan — Univ. of British Columbia

Nagamune, Ryozo — Univ. of British Columbia

This paper formulates and solves the problem of optimizing switching surfaces (SSs) in switching LPV (SLPV) controller design to further enhance the control performance. The conditions for the SLPV controller synthesis under fixed SSs are first presented, which involves a finite number of linear matrix inequalities. The SS design problem is then formulated as an optimization problem where the cost function is evaluated by solving problems of SLPV controller synthesis under fixed SSs. An algorithm based on particle swarm optimization (PSO) is proposed to solve the SS design problem. The effectiveness of the proposed method is demonstrated on the air-fuel ratio control of a spark ignition engine in automobiles.

11:10-11:30 TA1.3

A Hybrid Predictive Control Algorithm for Tracking in a Single-Phase DC/AC Inverter, pp. 904-909

Torquati, Luca — Univ. of Trento

Sanfelice, Ricardo G. — Univ. of California at Santa Cruz

Zaccarian, Luca — LAAS-CNRS and Univ. of Trento

In this paper we design a hybrid predictive controller for the tracking of a sinusoidal reference signal. The stability and forward invariance of a set of points around the reference state, named the tracking ellipse, is established by using tools for hybrid dynamical systems. Moreover, prediction of solutions for a finite number of switching events is used to minimize the number of switches. The control algorithm is shown to be robust to small perturbations and input disturbances. Simulations illustrating the main results are included.

11:30-11:50 TA1.4

Input-To-State Stability of Discrete-Time Switched Systems and Switching Supervisory Control, pp. 910-915

Huang, Miao — Ningbo Inst. of Tech., Zhejiang Univ

Ma, Longhua — Ningbo Inst. of Tech., Zhejiang Univ

Guangzhou, Zhao — Ningbo Inst. of Tech., Zhejiang Univ

Wang, Xin — Shanghai Jiao Tong Univ

Wang, Zhenlei — East China Univ. of Science and Tech

In this paper, a discrete-time switched nonlinear system is proved to have an input-to-state stable (ISS) property under mode-dependent average dwell-time switching signals if each constituent subsystem is ISS. This result is then applied to stabilization of uncertain discrete-time nonlinear systems via an improved switching supervisory control scheme. The states of the closed-loop system are proved to be bounded in the presence of bounded disturbances when the candidate controllers provide ISS properties regarding the estimation errors. Simulation results are provided to illustrate the effectiveness of the proposed stabilization method.

11:50-12:10 TA1.5

Control Lyapunov Function Design for Nonholonomic Systems on Noncontractible Manifold Via Revived Transformation, pp. 916-921

Ikeda, Hayato — Tokyo Univ. of Science

Nakamura, Hisakazu — Tokyo Univ. of Science

Kimura, Shunsuke — Tokyo Inst. of Tech

The control Lyapunov function (CLF) plays an important role in feedback control design. Nakamura et al. proposed the minimum method for designing CLFs on noncontractible manifolds. However, as yet, there are no methods of designing CLFs for nonholonomic systems on noncontractible manifolds. In this paper, we design such a CLF by combining a revived transformation and the minimum projection method. The effectiveness of this method is confirmed by computer simulation.

TA2	Hilo
Observers (Regular Session)	
Chair: Polis, Michael P.	Oakland Univ
Co-Chair: Michalska, Hannah H.	McGill Univ

10:30-10:50 TA2.1

Double-Sided Kernel Observer for Linear Time-Varying Systems, pp. 922-927

Ghoshal, Debarshi Patanjali — McGill Univ

Michalska, Hannah H. — McGill Univ

A double-sided input-output kernel functional representation is developed for the class of totally observable linear time-varying systems with inputs. The double-sided kernel representation is immediately applicable as part of a non-asymptotic state observer for observable LTV systems. In the absence of output measurement noise the observer provides exact state values of the system state in arbitrarily short time. It also shares the usual superior features of algebraic observers such as independence of the initial conditions of the system and good noise attenuation properties. Other advantages of the double-sided input-output kernel functional representation of linear systems are elucidated as the concept can be employed to construct state and parameter estimators for flat nonlinear systems.

10:50-11:10 TA2.2

A Direct Coupling Coherent Quantum Observer for an Oscillatory Quantum Plant, pp. 928-932

Petersen, Ian R. — Univ. of New South Wales at the Australian Defence Force Acad

A direct coupling coherent observer is constructed for a linear quantum plant which has oscillatory solutions. It is shown that a finite time moving average of the quantum observer output can provide an estimate of the quantum plant output without disturbing this plant signal. By choosing a sufficiently small averaging time and a sufficiently large observer gain, the observer tracking error can be made arbitrarily small.

11:10-11:30 TA2.3

State-Of-Charge Estimation of Rechargeable Battery with Hysteresis Characteristics Using Robust Gain-Scheduled Observer, pp. 933-938

hattaha, kenichi — Keio Univ
Inoue, Masaki — Keio Univ
Kawaguchi, Takahiro — Keio Univ
Osamura, Kensuke — Calsonic Knsei
Adachi, Shuichi — Keio Univ

In this paper, we consider model-based state-of-charge (SOC) estimation of a rechargeable battery with hysteresis characteristics. A standard approach is to describe the battery system as an approximated linear time-invariant model and to apply a linear estimator such as the robust observer or Kalman filter. However, this cannot achieve sufficient estimation accuracy due to the nonlinearity of the hysteresis characteristics. We propose to describe the battery system as a linear-parameter-varying (LPV) model, which does not require the approximation. Furthermore, parameter uncertainties are taken into account to derive robust gain-scheduled observer design. The effectiveness of the proposed method is illustrated through numerical experiments.

11:30-11:50 TA2.4

Unknown Input Observer for a Robot Arm Using TS Fuzzy Descriptor Models, pp. 939-944

Nagy, Zoltan — Tech. Univ. of Cluj Napoca
Pall, Elod — Tech. Univ. of Cluj-Napoca
Lendek, Zsofia — Tech. Univ. of Cluj-Napoca

This paper presents an unknown input observer for a two-link robot arm. To handle the inherent nonlinearities, a Takagi-Sugeno fuzzy model in descriptor form is used. The design conditions are given as linear matrix inequalities, which can be efficiently solved. The observer is tested both in simulation and on experimental, measured data.

11:50-12:10 TA2.5

Cascade Attitude Observer for the SLAM Filtering Problem, pp. 945-952

Bjørne, Elias — Norwegian Univ. of Science and Tech
Brekke, Edmund — Norwegian Univ. of Science and Tech
Johansen, Tor Arne — Norwegian Univ. of Science and Tech

This article presents an attitude observer that exploits both bearing and range measurements from landmarks, in addition to reference vectors such as magnetometer and accelerometer. It is a gyro bias observer in cascade with a simplified complementary filter, driven by a gyro measurement, in which the gyro bias is estimated by comparing the bearing dynamics with the gyro measurements. The observer is compared to a full complimentary filter, and it is shown that it is more robust to initial gyro bias estimation error compared to the complimentary filter. The article also reveals how this new observer handles magnetometer failure and can use landmarks as reference vectors.

TA3 Hamakua

Topics in Systems and Computational Biology (Invited Session)

Chair: Vidyasagar, Mathukumalli — Univ. of Texas at Dallas
Co-Chair: Achanta, Hema — GE Global Res
Organizer: Vidyasagar, Mathukumalli — Univ. of Texas at Dallas

10:30-10:50 TA3.1

Finding the Steady-State Solution of the Chemical Master Equation (I), pp. 953-954

Gupta, Ankit — ETH Zürich
Khammash, Mustafa H. — ETH Zurich

In Systems Biology, the chemical master equation (CME) is often used to understand the effects of randomness that is generated by reactions involving biomolecular species with low copy-numbers. The CME is a system of ordinary differential equations (ODEs) describing the dynamics of the probability distribution of the underlying Markov chain. For many examples, the state-space of this Markov chain is infinite, and hence the CME cannot be directly solved. In such cases, approximate solutions of the CME can be found by truncating the state-space and using the Finite State Projection (FSP) algorithm, developed by Munsky and Khammash (Jour. Chem. Phys. 2006). The FSP is only applicable for finite time-periods and it cannot estimate the stationary solutions of CME which are often of interest in biological applications. In this paper we present a version of FSP which enables accurate estimation of the stationary CME solution. We illustrate our approach using a simple example.

10:50-11:10 TA3.2

Integrating Biological Data across Multiple Platforms Using Importance-Weighted Transfer Learning and Applications to Breast Cancer Data Sets (I), pp. 955-960

Achanta, Hema — GE Global Res
Misganaw, Burook — Univ. of Texas at Dallas
Vidyasagar, Mathukumalli — Univ. of Texas at Dallas

Traditional machine learning approaches are based on the premise that the training and testing samples come from a common probability distribution. Transfer learning refers to situations where this assumption does not necessarily hold. Integrating biological data measured on diverse platforms is a major challenge. Transfer learning is a natural candidate for achieving such integration. In this paper, we adapt the l_1 -norm SVM using the importance weighting approach to fit into the paradigm of Transfer Learning under Covariate Shift, with the aim of integrating biological data sources from diverse platforms. The conditional probability of the testing data with respect to the training data is estimated using a small number of testing samples. The weights of the l_1 -norm SVM are adapted using this estimated conditional probability, also known as the importance weight.

To validate our approach, we applied the proposed algorithm to the problem of classifying breast cancer tumors as ER-positive or ER-negative, which is the first step in personalizing therapy to the patient. Then we compared it against conversion to Z -scores, which is the current best practice. The l_1 -norm SVM modified via importance weighting shows better performance than using Z-scores, on five different test data sets.

11:10-11:30 TA3.3

Utilizing Biomarkers to Forecast Quantitative Metabolite Concentration Profiles in Human Red Blood Cells (I), pp. 961-966

Yurkovich, James — Univ. of California, San Diego
Yang, Laurence — Univ. of Toronto
Palsson, Bernhard — Univ. of California, San Diego

One of the major limitations in making experimental measurements of biological systems is the complexity of the network being investigated. Major efforts have been made to identify a subset of measurements ("biomarkers") that can be used to provide information about the rest of the system. For red blood cells under cold storage conditions in a blood bank, a set of metabolite biomarkers have been identified that can reliably define the qualitative trend of cellular metabolism. Recently, it was shown that these biomarkers could also be used to train a model that quantitatively predicts the concentrations of other metabolites in the network over a 45 day time course. Here, we extend the utility of these methods by using a linear black-box model to forecast future values of these concentrations. We show that 57 of the 70 metabolites measured in the red blood cell metabolic network (81%) can be accurately forecasted after 8 days of storage (5 time points) with a global median error of 18.36%. The ability to forecast metabolite profiles by only requiring a subset of measurements for the first few days of storage makes these methods immediately applicable in a clinical setting to assess the metabolic health of stored blood.

11:30-11:50 TA3.4

Robust Moment Closure Method for the Chemical Master Equation (I), pp. 967-972

Naghnaeian, Mohammad — Massachusetts Inst. of Tech
Del Vecchio, Domitilla — Massachusetts Inst. of Tech

The Chemical Master Equation (CME) is used to stochastically model biochemical reaction networks, under the Markovian assumption. The low-order statistical moments induced by the CME are often the key quantities that one is interested in. However, in most cases, the moments equation is not closed; in the sense that the first n moments depend on the higher order moments, for any positive integer n. In this paper, we develop a moment closure technique in which the higher order moments are approximated by an affine function of the lower order moments. We refer to such functions as the affine Moment Closure Functions (MCF) and prove that they are optimal in the worst-case context, in which no a priori information on the probability distribution is available. Furthermore, we cast the problem of finding the optimal affine MCF as a linear program, which is tractable. We utilize the affine MCFs to derive a finite dimensional linear system that approximates the low-order moments. We quantify the approximation error in terms of the l_∞ induced norm of some linear system. Our results can be effectively used to approximate the low-order moments and characterize the noise properties of the biochemical network under study.

11:50-12:10 TA3.5

Design of a Bistable Network Using the CRISPR/Cas System (I), pp. 973-978

Cuba Samaniego, Christian — Univ. of California at Riverside
Subramanian, Hari — Univ. of California - Riverside
Franco, Elisa — Univ. of California at Riverside

The CRISPR/Cas-based genome editing system has provided a powerful tool for control of gene activity within cells. Here, we model an experimentally plausible architecture harnessing the power of CRISPR/Cas to create a biomolecular bistable switch. The designed in vitro circuit is based on mutual repression of two genes together with two other activator genes. The repression is generated by the binding of catalytically dead endonuclease (dCas9) to the target gene mediated by a guide RNA. The activation is accomplished by use of an anti- guide RNA partially complementary to the guide RNA. Using mathematical analysis of the model, we show that the proposed scheme is capable of exhibiting bistability. We further discuss ultrasensitivity of the regulatory modules, and their capacity to manage competition for dCas9 and downstream load.

TA4 — Kohala

Predictive Control I (Regular Session)

Chair: Zhang, Fan — Southeast Univ
Co-Chair: Liao-McPherson, Dominic — Univ. of Michigan

10:30-10:50 TA4.1

A Cascaded Economic Model Predictive Control Strategy for a Diesel Engine Using a Non-Uniform Prediction Horizon Discretization, pp. 979-986

Liao-McPherson, Dominic — Univ. of Michigan
Kim, Shinhoon — The DAKO Group
Butts, Kenneth R. — Toyota Tech. Center
Kolmanovsky, Ilya V. — Univ. of Michigan

This paper presents an economic model predictive control (eMPC) controller for the diesel engine airpath. The control objective is to maximize fuel economy while maintaining drivability and reducing emissions by manipulating the exhaust gas recirculation (EGR) valve, throttle, variable geometry turbine (VGT), and the fueling rate. This is achieved using a cascaded architecture wherein an upper level economic MPC controller controls the fueling rate and generates EGR rate and intake manifold pressure setpoints for a lower level nonlinear MPC airpath controller which manipulates the actuators. A non-uniform prediction horizon discretization is used to manage computational complexity while capturing dynamics with multiple timescales. Simulation results demonstrating emission constraint satisfaction and stable operation over drivecycles are presented.

10:50-11:10 TA4.2

Local Trajectory Planning and Control for Autonomous Vehicles Using the Adaptive Potential Field, pp. 987-993

Kim, Dongchan — Hanyang Univ
Kim, Hayoung — Hanyang Univ
Huh, Kunsoo — Hanyang Univ

In this paper, a new potential field approach is proposed for trajectory planning and control in autonomous vehicles. The potential field of the surrounding environment is generated including vehicles, road boundaries and lane centers. Based on the predicted positions of the vehicles, the location of the ego vehicle and the surrounding potentials are synchronized. In addition, the potential fields of the surrounding vehicles are adaptively modified in shape depending on the relative velocity of the surrounding vehicles. The longitudinal distance required for the lateral avoidance is mathematically calculated and reflected in the potential field. Based on the proposed potential field, the trajectory of the autonomous vehicle is selected as the suboptimal path and the MPC (Model Predictive Control) method is applied for tracking control and the lateral stability of the vehicle. The performance of the proposed algorithm is verified in simulations under various conditions.

11:10-11:30 TA4.3

Control of Ultra-Supercritical Once-Through Boiler-Turbine Unit Using MPC and ESO Approaches, pp. 994-999

Zhang, Fan — Southeast Univ
Zhang, Yi — Southeast Univ
Wu, Xiao — Southeast Univ
Shen, Jiong — Southeast Univ
Lee, Kwang Y. — Baylor Univ

In order to meet the wide-range load tracking requirement and overcome unknown disturbance issues of ultra-supercritical (USC) boiler-turbine unit, an extended state observer based fuzzy model predictive controller is proposed using the techniques of fuzzy

scheduling, model predictive control and extended state observer. Local state-space models are established on the basis of nonlinearity analysis. Then a fuzzy stable model predictive controller is devised on the fuzzy model using output cost function for the purpose of wide-range load tracking. An improved linear extended state observer, which can estimate plant behavior variations and unknown disturbances regardless of the direct feedthrough characteristic of the boiler-turbine unit, is synthesized with the predictive controller to enhance its disturbance rejection capability. The simulation results on a 1000MW USC boiler-turbine unit model verify the merits of the proposed strategy in achieving the satisfactory wide-range load tracking and disturbance rejection performance.

11:30-11:50 TA4.4

Implementation and Validation of an Event-Based Real-Time Nonlinear Model Predictive Control Framework with ROS Interface for Single and Multi-Robot Systems, pp. 1000-1006

Dentler, Jan SnT, Univ. of Luxembourg
Kannan, Somasundar SnT, Univ. of Luxembourg
Olivares-Mendez, Miguel A. SnT, Univ. of Luxembourg
Voos, Holger SnT, Univ. of Luxembourg

This paper presents the implementation and experimental validation of a central control framework. The presented framework addresses the need for a controller, which provides high performance combined with a low-computational load while being on-line adaptable to changes in the control scenario. Examples for such scenarios are cooperative control, task-based control and fault-tolerant control, where the system's topology, dynamics, objectives and constraints are changing. The framework combines a fast Nonlinear Model Predictive Control (NMPC), a communication interface with the Robot Operating System (ROS) [1] as well as a modularization that allows an event-based change of the NMPC scenario. To experimentally validate performance and event-based adaptability of the framework, this paper is using a cooperative control scenario of Unmanned Aerial Vehicles (UAVs). The source code of the proposed framework is available under [2].

11:50-12:10 TA4.5

Convex Optimization-Based Control of Sustainable Communities with On-Site Photovoltaic (PV) and Batteries, pp. 1007-1012

Cai, Jie Purdue Univ
Zhang, Hao Purdue Univ
Kim, Donghun Purdue Univ
Braun, James E. Purdue Univ
Hu, Jianghai Purdue Univ

This paper presents a convex optimization-based control method for sustainable communities with multiple buildings served by a central cooling plant and with on-site solar generation and batteries. A model predictive control (MPC) approach is used to optimally schedule the energy flows among the different energy sources, on-site battery and building end users to achieve the minimum operation cost. A convex formulation is derived for the MPC problem which is then solved with a convex programming package. With the optimal operation strategy, a 9.4% energy cost savings and a 35.6% demand cost savings were achieved compared to a baseline control strategy, for a case study with three buildings and an on-site PV and battery system.

TA5 Ballroom I

Robotics IV (Regular Session)

Chair: Tabuada, Paulo Univ. of California at Los Angeles
Co-Chair: Milutinovic, Dejan Univ. of California, Santa Cruz

10:30-10:50 TA5.1

Prescribed Performance Function Based Control for Trajectory Tracking of Nonholonomic Mobile Robots with Collision Avoidance, pp. 1013-1018

Park, Bong Seok Kongju National Univ

This paper proposes a prescribed performance function based control method for trajectory tracking of nonholonomic mobile robots with collision avoidance. To design a simple controller, the prescribed performance function based algorithm that does not require the adaptive or the intelligent method to compensate the uncertainties is used. For the collision avoidance, the virtual heading angle which is derived through coordinate transformation is proposed. Since this angle is switched according to the presence of the obstacles, the lowpass filters are adopted to reduce the chattering phenomenon. Finally, the torque controller is designed using Lyapunov and backstepping methods.

10:50-11:10 TA5.2

Development of a Prototype Electrically-Driven Four-Arm Four-Flipper Disaster Response Robot OCTOPUS, pp. 1019-1024

Kamezaki, Mitsuhiro Waseda Univ
Chen, Kui Waseda Univ
Azuma, Kohga Waseda Univ
Katano, Takahiro Waseda Univ
Kaneko, Taisei Waseda Univ
Ishida, Tatsuzo Waseda Univ
Nakayama, Masayuki Kikuchi Seisakusho Co., Ltd
Seki, Masatoshi Kikuchi Seisakusho Co., Ltd
Ichiryu, Ken Kikuchi Seisakusho Co., Ltd
Sugano, Shigeki Waseda Univ

In a previous study, we have developed a four-arm four-crawler disaster response robot called ‘OCTOPUS'. Advanced disaster response robots are expected to be capable of both mobility, such as entering narrow spaces over unstructured ground, and workability, such as preforming complex debris-removal work. We have confirmed experimentally that the four arms could make the robot perform complex tasks while ensuring stabilization when climbing steps while the four flippers could make it traverse rough terrain while avoiding toppling over when conducting manipulation task. OCTOPUS, renamed as H-OCTOPUS, is oil-hydraulically driven to perform outdoor demolition of heavy debris, and is teleoperated by two operators. In this study, we develop a prototype electrically-driven OCTOPUS, called E-OCTOPUS, to manipulate various light-objects mainly indoors such as valve operations in nuclear power plants. For reducing the size and weight while maximizing task performance, we introduced a mutual complementary strategy between its arms and flippers. To validate the capability of E-OCTOPUS, we performed preliminary experiments involving climbing high steps and manipulating and cutting wires by cooperating the four arms and four flippers. The results indicated that E-OCTOPUS could complete the tasks by coordinating its four arms and four flippers.

11:10-11:30 TA5.3

Using Recurrent Neural Networks (RNNs) As Planners for Bio-Inspired Robotic Motion, pp. 1025-1030

Khan, Ayesha Georgia Inst. of Tech
Zhang, Fumin Georgia Inst. of Tech

In this paper, we propose using Long Short Term Memory Networks (LSTM) to serve as planners for bio-inspired robotic motion. LSTMs can learn long and short dependencies on sequential data and hence can be used to model complex temporal data. Using LSTM networks, we implement a motion planner taking inspiration from simulated fish trajectories. The path planning unit can then be implemented on robots such that they can operate without localization in an autonomous setting. Simulation results show that the planned path demonstrates characteristics which are similar to simulated fish trajectories. Hence, the proposed approach can be used to learn animal behavior and formulate bio-inspired path planners for robots to operate in unknown environments.

11:30-11:50 TA5.4

A Stochastic Approach to Small UAV Feedback Control for Target Tracking and Blind Spot Avoidance, pp. 1031-1037

Milutinovic, Dejan — Univ. of California, Santa Cruz
Casbeer, David W. — Air Force Res. Lab
Kingston, Derek B. — Air Force Res. Lab
Rasmussen, Steven — Miami Valley Aerospace LLC

This paper presents a stochastic optimal control approach suitable for implementation on small unmanned aerial vehicles (UAV). The controller provides tracking of a target at a desired distance, keeps the target away from the sector of blind spots and prevents flying over the target to avoid the flipping images in the camera's recorded sequence. The controller is based on a two-dimensional stochastic kinematic model which accounts for uncertainty and its interference with the control problem nonlinearities. Consequently, the computed controller is a two-dimensional lookup table which can be stored in the memory of the UAV's on-board computer and executed at high rates. The results are illustrated by both numerical simulations and flight test data with a small UAV.

11:50-12:10 TA5.5

Pose Estimation Scheme Based on the Motion of a Monocular Vision System - Preliminary Results and First Experimentations, pp. 1038-1043

Rouquet, Sebastien — Ec. Centrale De Nantes
Plestan, Franck — Ec. Centrale De Nantes-LS2N
Chriette, Abdelhamid — Ec. Centrale De Nantes, IRCCyN
Ghanes, Malek — Ec. Centrale De Nantes
Hamon, Arnaud — Ec. Centrale De Nantes
Gibert, Victor — Airbus

In this paper, a new scheme for pose estimation in vision system is presented and evaluated on a serial robot. A nonlinear observer is proposed for online estimation of the deviations of the embedded camera with respect to the ground reference without knowledge of the geometric features of the scene. This observer is based on high-gain strategy. The presented results consist in using feature and observation scheme to guarantee the observability and efficiency of the estimation. Experimentation results, which are the first of such observers, are presented in a controlled environment of a KUKA robot.

TA6 Ballroom II

Distributed Energy Management towards Clean and Energy Efficient Society (Invited Session)

Chair: Hatanaka, Takeshi — Tokyo Inst. of Tech
Co-Chair: Wasa, Yasuaki — Waseda Univ
Organizer: Hatanaka, Takeshi — Tokyo Inst. of Tech
Organizer: Imura, Jun-ichi — Tokyo Inst. of Tech

10:30-10:50 TA6.1

Differential Game-Based Load Frequency Control for Power Networks and Its Integration with Electricity Market Mechanisms (I), pp. 1044-1049

Wasa, Yasuaki — Waseda Univ
Sakata, Kengo — Waseda Univ
Hirata, Kenji — Nagaoka Univ. of Tech
Uchida, Kenko — Waseda Univ

This paper proposes a novel load frequency control architecture based on differential games in energy supply-demand network integrating power networks and real-time electricity regulation markets. In order to establish the control architecture that each area minimizes his own cost independently on not only the electricity market layer but also the physical layer, we first present a novel load frequency control in power networks, where set-point signals from electricity markets depend on competitive bidding among utilities in each area and they are regarded as stationary disturbances in power networks. Then, we show that the control problem can be reduced to a finite-horizon differential game and the solution of the differential game control problem is analytically given by a feedback Nash equilibrium. The effectiveness of the proposed control mechanism is finally demonstrated through simulations with two-area power and electricity market network model.

10:50-11:10 TA6.2

An Integrated Design of Optimization and Physical Dynamics for Energy Efficient Buildings: A Passivity Approach (I), pp. 1050-1057

Hatanaka, Takeshi — Tokyo Inst. of Tech
Zhang, Xuan — Harvard Univ
Shi, Wenbo — Harvard Univ
Zhu, Minghui — Pennsylvania State Univ
Li, Na — Harvard Univ

In this paper, we address energy management for heating, ventilation, and air-conditioning (HVAC) systems in buildings, and present a novel combined optimization and control approach. We first formulate a thermal dynamics and an associated optimization problem. An optimization dynamics is then designed based on a standard primal-dual algorithm, and its strict passivity is proved. We then design a local controller and prove that the physical dynamics with the controller is ensured to be passivity-short. Based on these passivity results, we interconnect the optimization and physical dynamics, and prove convergence of the room temperatures to the optimal ones defined for unmeasurable disturbances. Finally, we demonstrate the present algorithms through simulation.

11:10-11:30 TA6.3

Fast Parallel Calculation for Optimal Power Demand Control in Multi-Layer Smart Grids (I), pp. 1058-1063

Nishida, Gou — Nihon Univ
Imura, Jun-ichi — Tokyo Inst. of Tech
Ohtake, Hideaki — National Inst. of Advanced Industrial Science and Tech

This paper presents an optimal method for controlling power demand probabilities in a negawatt trading between aggregators in a multi-layer smart grid. The calculation algorithm can be parallelized by using the multi-layer structure; therefore, we can avoid computational effort explosions. In the power demand control, according to a cost distribution representing maximum probabilities at assumed total power demands of aggregators in a lower-layer, an independent system operator in the top layer can optimally allocate some desired variation of the distribution to each aggregator. The allocated distributions may be offered to aggregators as peak shifts and/or power restrictions with their benefits.

11:30-11:50 TA6.4

Analyzing the Effects of Transmission Line Fault on the Stochastic Model Predictive Controlled IEEE 30-Bus System with Uncertain Environment (I), pp. 1064-1069

Ohki, Kentaro — Kyoto Univ
kakehashi, Takuya — Kyoto Univ
Sugihara, Hideharu — Osaka Univ
Kashima, Kenji — Kyoto Univ
Ohta, Yoshito — Kyoto Univ

Unpredictable accidents and uncertain environment make the management of the power systems difficult, which may increase the cost of power generation. In this paper, we apply a stochastic model predictive control to maintain the demand-and-supply balance in the IEEE 30-bus system and analyze how much a transmission line fault with uncertain weather forecast raises the generation costs. Since the temperatures of the transmission lines are greatly affected by the accuracy of the weather forecast, the effects of the accuracy on the generation costs are also analyzed.

11:50-12:10 TA6.5

Simultaneous Optimization of Assignment, Reallocation and Charging of Electric Vehicles in Sharing Services (I), pp. 1070-1076

Kawashima, Akihiko — Nagoya Univ
Makino, Naoki — Nagoya Univ
Inagaki, Shinkichi — Nagoya Univ
Suzuki, Tatsuya — Nagoya Univ
Shimizu, Osamu — Nagoya Univ

Electric vehicles (EVs) are being used in car sharing services to reduce CO 2 emission and complement transportation in regional societies. To achieve this purpose more effectively, the power used for driving EVs should be provided by renewable energy such a photovoltaic unit, and charging of in-vehicle batteries also should be scheduled optimally considering customers' requests and renewable generation. This means that all EVs and those State-of-Charge (SoC) must be managed individually. In one-way trip services, however, conventional researchers have focused on the management of distribution of EVs without individual SoC management. This paper presents a simultaneous optimization of vehicle assignment, reallocation and charging for one-way EV sharing services considering individual states of all EVs and PV generation. Through computational experiments, usefulness of the proposed method is verified from viewpoint of computational cost.

TA7 Ballroom III

Estimation and Sensing (Regular Session)

Chair: Bai, He — Oklahoma State Univ
Co-Chair: Andersson, Leif Erik — Norwegian Univ. of Science and Tech

10:30-10:50 TA7.1

Interval State Observer Based on a Time-Variant Transformation for LPV Systems and Application to Induction Machines, pp. 1077-1084

Krebs, Stefan — Inst. of Control Systems, Karlsruhe Inst. of Tech
Fugel, Sebastian — KIT, Inst. of Control Systems
Hohmann, Soeren — KIT

For the state estimation of safety-critical systems, interval observers are an emerging alternative to classical state estimation methods due to their provision of guaranteed information on unmeasurable quantities. One possible application of interval observers are induction machines used as a traction drive whose common models belong to the class of linear parameter-varying (LPV) systems. To overcome the design conditions of existing interval observers for LPV systems, which are too strict for an application to the aforementioned system, we propose a new interval observer design based on a time-variant transformation. The effectiveness of the method is shown by experimental results of an induction machine.

10:50-11:10 TA7.2

Real-Time Identification and Compensation of Asymmetric Friction Using Unscented Kalman Filter, pp. 1085-1090

Fukui, Jun'ya — Nanzan Univ
Yamamoto, Takayuki — Nippon Electric Glass Company, Limited
Chen, Gan — Nanzan Univ
Takami, Isao — Nanzan Univ

This paper presents a method to design the contour control of the ball screw system. The friction is one of the main factors to deteriorate the positioning performance. There exists the nonlinearity in the friction such as the Stribeck effect and the hysteresis property. The friction has the position dependent and asymmetric characteristics which change the friction size depending on the position and the direction of the object. In addition, the friction varies depending on temperature and wear. From the above, it is necessary to successively estimate the friction. In these conditions, we propose the method to estimate and compensate the friction in real time. The LuGre model is applied to describe the dynamics of friction, which is able to represent the characteristics by a few parameters. The unscented Kalman filter is used to estimate the friction which is applicable to nonlinear systems. The estimated variables are used to compensate the friction in real time. The effectiveness is illustrated by simulations and experiments.

11:10-11:30 TA7.3

Orbiting Intruder Passive Ranging for Small UAS Detect-And-Avoid, pp. 1091-1096

Daugherty, Jordan — Oklahoma State Univ
Bai, He — Oklahoma State Univ
Avadhanam, Sharath — UtopiaCompression

We investigate the orbiting intruder passive ranging problem, where an ownship aircraft is moving with a constant velocity and the intruding aircraft is conducting an orbiting maneuver. We assume that the ownship measures the bearing angles to the intruder aircraft. We approach the problem by utilizing a filter bank algorithm parameterized with respect to the range, the heading of the intruder, and the angular velocity. We examine the performance of the filter bank algorithm using two different system models. The first system model comprises of the relative position between the two aircraft in Cartesian coordinates and the velocities of the intruding aircraft in polar coordinates. The second system model is the modified polar coordinates. We conduct Monte Carlo simulations and utilize the root mean square error over time to determine the best parameterization of the filter algorithm for both system models. The results show that the system model in Cartesian coordinates performs better when estimating the range while the modified polar coordinates achieves better estimates for the heading of the intruder. We find that the filter in the modified polar coordinates exhibits more divergent behavior than the system in Cartesian coordinates.

11:30-11:50 TA7.4

Forecasting Using Multivariate Empirical Mode Decomposition - Applied to Iceberg Drift Forecast, pp. 1097-1103

Andersson, Leif Erik — Norwegian Univ. of Science and Tech
Aftab, Muhammad Faisal — NTNU
Scibilia, Francesco — Statoil ASA
Imsland, Lars — Norwegian Univ. of Science and Tech

The prediction of the movement of a floating object, such as an iceberg, in the ocean is a challenging problem. Large uncertainties in the driving forces and possibly in the geometry of the object itself prevent accurate forecasts. However, if an observation of the past trajectory of the object is available the forecast can be improved considerably. This article proposes an adaptive data-driven forecast algorithm using multivariate empirical mode decomposition to handle these kind of forecast problems. The algorithm identifies the common oscillation groups and noise between the velocity of the floating object and its driving forces. Afterwards it decides which group contributes to the movement and how the future movement of each oscillation group can be predicted best with the available information. The efficacy of the proposed forecast algorithm is shown on a real iceberg drift data set.

11:50-12:10 TA7.5

Efficiency Investigation of an Offshore Deoiling Hydrocyclone Using Real-Time Fluorescence and Microscopy-Based Monitors, pp. 1104-1109

Hansen, Dennis Severin — Aalborg Univ
Bram, Mads Valentin — Aalborg Univ
Yang, Zhenyu — Aalborg Univ

Offshore oil & gas production is facing an increasing challenge as the water fraction from the production wells rises over time. It is not

uncommon that the extracted mixture contains a water-cut of more than 90%. The current North Sea discharge legislation states that the dispersed oil concentration in water must be less than 30 parts per million (ppm). Consequently, the discharge ports are sampled two times per day and analyzed using the OSPAR recommended GC-FID method. However, the variations of Oil-in-Water (OiW) concentration between sampling time points are unknown and could exceed the regulatory limits. This sampling method is commonly used since the current real-time OiW monitoring technology is still quite open and immature. This work focuses on experimental investigation of reliability and accuracy of selected real-time OiW measuring technologies based on two available commercial products. The obtained results indicate that the instrument based on fluorescence technology can provide reasonably fast, reliable, and accurate OiW concentration measurement, while the instrument based on microscopy technology can provide fast and reasonable measurement of the oil droplet's size distribution. This work indicates that it is beneficial to combine both technologies for real-time OiW monitoring before and after the hydrocyclone.

TA8 Ballroom IV

NSF CAREER Awardees: Emerging Research in Smart Grid (Invited Session)

Chair: Baheti, Radhakisan — National Science Foundation

Organizer: Baheti, Radhakisan — National Science Foundation

10:30-10:50 TA8.1

Infusing Autonomy in Power Distribution Networks Using Smart Transformers (I), pp. 1110-1116

Chakrabortty, Aranya — North Carolina State Univ

In this tutorial we describe a list of analytical methods from optimization, control theory, and machine learning that can be used for infusing autonomy in large-scale interconnected networks of microgrids with as little human intervention in their control loops as possible. The cornerstone medium for promoting this autonomy is smart transformers made out of solid-state technology, which serve the dual role of a power-electronic transformer with very fast switching capability, and, hence, with significantly smaller size than conventional magnetic transformers, as well as of a powerful computer or logic-machine that can make intelligent decisions via communication. Solid-state transformers (SSTs) are, in fact, being anticipated to be the backbone of tomorrow's modern distribution grid. Microgrids typically have three layers of controllers - namely, primary control (for switching and circuit-breaking decisions), secondary control (for voltage and frequency regulation, and synchronization), and tertiary control (where a centralized supervisory controller communicates with energy management centers for updating set points according to load demands, and other changes in the circuit). Operating these control layers in today's microgrids require professional knowledge of the system, and calls for the operators to manually configure each of the components. With technology advancing to low-cost microprocessor driven devices such as SSTs, we propose a suite of new control and learning approaches that exploit different 'Internet of things' functionalities embedded inside the SSTs, and thereby guarantee at-scale resilience, reliability, fault-tolerance, and autonomy for tomorrow's distribution networks.

10:50-11:10 TA8.2

*High-Performance Optimization Methods and Distributed Control Techniques for Power Systems: Theory, Algorithms, and Case Studies (I)**

Lavaei, Javad — Univ. of California, Berkeley

11:10-11:30 TA8.3

*Decentralized Coordination of Distributed Energy Resources at Scale (I)**

Bitar, Eilyan — Cornell Univ.

11:30-11:50 TA8.4

*NSF Programs in Control, Robotics, Smart Grid, and Cyber-Physical Systems (I)**

Baheti, Radhakisan — National Science Foundation

TB1 Puna

Linear Systems (Regular Session)

Chair: Mumm, Nils — TU Munchen

Co-Chair: Shafai, Bahram — Northeastern Univ

13:30-13:50 TB1.1

Vertical Speed Command Performance Improvement of a Load Factor Command Based Autopilot for Automatic Landing by Shaping the Desired Command During Flare, pp. 1117-1122

Mumm, Nils — Tech. Univ. München

Holzapfel, Florian — Tech. Univ. München

In this paper the design methods for a flare controller for a general aviation aircraft Diamond DA42 are presented. The flare maneuver utilizes an existing vertical speed command controller, but increases its performance by applying a command filter as well as an additional feed forward command. The approach ensures a significant reduction of the system's rise time by approximately 45% and therefore a better tracking performance in respect to a desired continuous vertical speed command during flare. The advantage of modifying the command input is that the original vertical speed controller is not changed and verification and validation processes have not to be repeated for the existing system. The design process presented in this paper covers the design of a linear vertical speed command filter as well as an additional corresponding feed forward command.

13:50-14:10 TB1.2

Manipulative Zero-Stealthy Attacks in Cyber-Physical Systems: Existence Space of Feasible Attack Objectives, pp. 1123-1128

Shinohara, Takumi — Keio Univ

Namerikawa, Toru — Keio Univ

In this paper, we analyze the vulnerabilities due to novel integrity cyber attacks in CPS, which are modeled as a stochastic Linear Time-Invariant (LTI) system equipped with a Kalman filter, an LQG controller, and a chi-squared failure detector from an attacker's standpoint. The attacks are designed by a sophisticated attacker so that the measurement residual of the compromised system coincides with the healthy one. Additionally, the attacked system state is manipulated to an objective which is designed by the adversary. First, we show an existence condition and a design procedure of the stealthy attacks using invariant subspace property. Second, we formulate the stealthy attacks with a malicious objective, and the condition of the feasible objectives is derived. Finally, the dangerousness of the attacks is verified through a numerical simulation.

14:10-14:30 TB1.3

Controllability of Linear Ensemble Systems with Constant Drift and Linear Parameter Variation, pp. 1129-1134

Tie, Lin — Beihang Univ. (Beijing Univ. of Aeronautics and Astron

Zhang, Wei — Washington Univ. in St. Louis

Li, Jr-Shin — Washington Univ. in St. Louis

Control of population systems is an indispensable task in many cutting-edge applications from nuclear magnetic resonance spectroscopy and imaging to deep brain stimulation for treatment of

neurological disorders. Characterizing the fundamental limit of the ability to control such large-scale systems is critical towards the understanding of their functionality and dynamical structures. In this paper, we study controllability of time-invariant linear ensemble systems whose natural and control dynamics form a linear variety of the system parameter. We derive explicit controllability conditions in terms of the rank of the system and control matrices, and show that ensemble controllability is highly dependent on the spectrum structure of the parameter-dependent system matrix.

14:30-14:50 TB1.4

Simultaneous Rejection of Signals below and above the Nyquist Frequency, pp. 1135-1139

Yamamoto, Kaoru — Lund Univ
Yamamoto, Yutaka — Kyoto Univ
Nagahara, Masaaki — The Univ. of Kitakyushu

This paper studies the disturbance rejection problem for sampled-data control systems, where disturbance signal occurs below and above the Nyquist frequency simultaneously. Two discrete-time controllers are designed via H^∞ optimal control in two steps; at first a controller is designed to reject the low-frequency components, and then we construct the generalized plant including the first controller to design the second controller, which has the capability of rejecting the high-frequency components. In view of the well-known sampling theorem, one recognizes that any high-frequency components may be detected only as an alias in the low base band, and hence it is impossible to recover or detect such frequency components. The authors recently showed in [Yamamoto et al. 2016] that this assumption depends crucially on the underlying analog model, and it is indeed possible to track or reject such frequency components by introducing multirate signal processing techniques. This paper aims to make this design technique applicable to the case in which the target frequencies lie both below and above the Nyquist frequency. Detailed analysis of multirate closed-loop systems are given. It is shown via examples that rejection of lower- and higher-frequency signals than the Nyquist frequency can be achieved.

14:50-15:10 TB1.5

Positive Stabilization of Singular Systems by Proportional Derivative State Feedback, pp. 1140-1146

Shafai, Bahram — Northeastern Univ
Li, Cheng — Northeastern Univ

This paper considers the problem of positive stabilization of linear continuous-time singular systems by both proportional and proportional derivative state feedback. First, we provide conditions for a singular system to be admissible (stable, regular, and impulse-free). Then, with the aid of these conditions, we show that the well-known positive stabilization technique based on LMI for conventional linear systems can be applied to singular systems represented by its standard decomposition form. Two design strategies are given for positive stabilization by proportional derivative state feedback with the aid of normalization of singular systems. Numerical examples are provided to support the theoretical results.

15:10-15:30 TB1.6

Convex Optimization of a Spacecraft Stabilization with a Double-Gimbal Variable-Speed Control Moment Gyro Actuator: Geometric Approach, pp. 1147-1152

Sasaki, Takahiro — Osaka Prefecture Univ
Shimomura, Takashi — Osaka Prefecture Univ
Schaub, Hanspeter — Univ. of Colorado

This paper applies the linear parameter-varying (LPV) control theory to the attitude stabilization problem for a spacecraft with a double-gimbal variable-speed control moment gyro (DGVSCMG). The LPV control theory can provide an optimal gain-scheduled (GS) controller by using linear matrix inequalities (LMIs) with regional pole placement constraints. When LMIs are solved, most studies select a common Lyapunov function for the whole operating range. However, selecting a common Lyapunov function leads to conservatism of design. The scheduling parameters in the LPV model of a spacecraft with a DGVSCMG have an interesting property. By using this property, this paper proposes the method to geometrically reduce the number of vertices in the convex hull to cover the LPV system. Through numerical examples, the proposed method can reduce the conservatism of design.

TB2 Hilo

Identification I (Regular Session)

Chair: Regruto, Diego — Pol. Di Torino
Co-Chair: Dumont, Guy A. — Univ. of British Columbia

13:30-13:50 TB2.1

Computational Geometric Identification for Quadrotor Dynamics in Wind Fields, pp. 1153-1158

Bisheban, Mahdis — George Washington Univ
Lee, Taeyoung — George Washington Univ

This paper presents a computational framework to identify the effects of wind on the dynamics of a quadrotor unmanned aerial vehicle. Then, using the identified model, the strength and the direction of the wind are estimated with the inertial measurements. The proposed approach is based on a geometric numerical integrator on the special Euclidean group, referred to as a Lie group variational integrator such that singularities or complexities associated with the local coordinates or quaternions are completely avoided. We illustrate through numerical examples that the presented methods successfully identify the effects of the wind even for the challenging case of large initial estimation errors.

13:50-14:10 TB2.2

Set-Membership Identification of a Dry-Clutch Transmission Model, pp. 1159-1164

Cerone, Vito — Pol. Di Torino
Regruto, Diego — Pol. Di Torino
Abuabiah, Mohammad I.F. — Pol. Di Torino

This paper deals with the problem of identifying the mathematical model of a dry-clutch transmission system, from input-output data experimentally collected on a real vehicle. The proposed identification procedure is based on a set-membership identification approach, where a-priori information on the structure of the physical model are taken into account in the selection of the model class. Parameter uncertainty intervals and the Chebyshev center of the feasible parameter set are computed by applying suitable convex relaxation schemes. The quality of the obtained model is tested on several validation data sets.

14:10-14:30 TB2.3

Closed-Loop Instrumental Variable Identification of Propofol Anesthesia, pp. 1165-1170

van Heusden, Klaske — Univ. of British Columbia
Ansermino, John Mark — Univ. of British Columbia
Dumont, Guy A. — Univ. of British Columbia

One of the challenges in the development of high-performance closed-loop anesthetic drug delivery systems is the lack of accurate models. Physiological models have limited accuracy and drug effect varies largely between patients, while data-driven modeling of individual responses is challenging due to limited excitation and disturbances. This paper proposes a multi-input single-output (MISO) approach to deal with the effect of disturbances by identifying a plant model as well as a disturbance model. Furthermore, a MISO extension to closed-loop instrumental variable (IV) identification is proposed. Closed-loop IV methods are consistent without the need for identification of intermediate variables or noise-model parameters. Identification of fewer parameters is expected to be advantageous in this application where excitation is limited. The proposed approach is compared to closed-loop prediction-error methods. IV estimation achieved similar performance to a tailor-made parametrization. Bias

in direct output-error (OE) estimates due to noise is limited. Closed-loop methods that require a controller description or that introduce additional computational complexity do not significantly improve model accuracy compared to direct OE estimation in this application.

14:30-14:50 TB2.4

A Relay Feedback Structure for Processes under Static Disturbances or Drift, pp. 1171-1176

da Silva, Moisés T. Univ. Federal De Campina Grande

Barros, Pericles Rezende Univ. Federal De Campina Grande

The standard relay feedback method cannot provide a stable oscillation under large static disturbances or drift. In this paper, it is proposed a relay feedback structure to overcome this limitation. This structure is composed by a block to remove static disturbance or drift followed by a relay. The block consists of a simple high-pass filter followed by a relay plus an integrator. Describing function analysis shows that the proposed structure is similar to the standard relay. Case studies illustrate that the proposed relay structure results in a symmetric oscillation of the process output.

14:50-15:10 TB2.5

Structure Identification in Layered Precedence Networks, pp. 1177-1182

Kong, Seo Taek Univ. of Illinois at Urbana-Champaign

Katselis, Dimitrios Univ. of Illinois, Urbana-Champaign

Beck, Carolyn L. Univ. of Illinois, Urbana-Champaign

Srikant, R Univ. of Illinois, Urbana-Champaign

We consider the problem of identifying the structure of a network when precedence constraints are present. The associated graph is assumed to be directed, layered and with edges that exist only between successive layers. Such precedence networks arise in manufacturing processes resulting from a necessary or desirable sequencing of subassembly tasks to be completed in order to assemble the final product. Each node in the graph corresponds to a task and each edge represents a precedence constraint. We provide a simple and natural algorithm that can identify the network structure. We study the corresponding sample complexity as a function of the number of layers L, the maximum number of nodes, D, per layer and the maximum node in-degree M in the network. We show that, for networks that are *start-time synchronized*, i.e., networks in which all tasks per layer are coordinated to start simultaneously, the sample complexity scales linearly with M and logarithmically with the product $(L\text{-}2)MD$.

15:10-15:30 TB2.6

Identification of Inverse Generalized Asymmetric Prandtl-Ishlinskii Model for Compensation of Hysteresis Nonlinearities, pp. 1183-1188

Ko, Young-Rae Chung-Ang Univ

Chun, Semin Chung-Ang Univ

Kim, Tae-Hyoung Chung-Ang Univ

This study presents an identification-based construction of the inverse generalized Prandtl–Ishlinskii (P–I) model to facilitate inverse model-based feedforward compensation of asymmetric hysteresis nonlinearities. Compared with the derivation of the inverse model analytically from a generalized P-I model, this direct modeling approach has the following advantages. First, direct inverse model identification is formulated as a nonlinear optimization problem, which is not subject to the constraint condition on the generalized P–I model's threshold and density functions, where this is indispensable for the analytical model inversion procedure. Second, this approach may be a simple and attractive alternative when the identification precision of a generalized P–I model is limited by the constraint condition, which necessarily results in insufficient hysteresis compensation functionality for the analytically derived inverse model. Finally, direct inverse model identification can overcome the drawbacks of the analytical inversion method, including the accumulation of parameter estimation errors in an analytical inverse model because these parameters are computed from the generalized P–I model's parameters in a recursive manner.

TB3 Hamakua

Control Applications I (Regular Session)

Chair: Vaughan, Joshua Univ. of Louisiana at Lafayette

Co-Chair: Bachler, Simon Univ. for Health Sciences, Medical Informatics and Tech. (UMIT)

13:30-13:50 TB3.1

Command Shaping of a Boom Crane Subject to Nonzero Initial Conditions, pp. 1189-1194

Newman, Daniel Univ. of Louisiana at Lafayette

Vaughan, Joshua Univ. of Louisiana at Lafayette

Input shaping is an open-loop command shaping method that has been used on a wide variety of flexible systems. It has been shown to be particularly useful in the control of cranes. However, most previous research on the use of input shaping has been limited to rest-to-rest commands. Because input shaping is open-loop, it is inherently incapable of eliminating existing, unknown vibration in a system. This paper will expand on prior research that has shown the feasibility of using input shaping to eliminate nonzero initial conditions. Particularly, the elimination of these conditions from a boom crane will be considered. Computer simulations support the effectiveness of a simple input shaping technique to accomplish nonzero initial condition elimination from a planar boom crane undergoing a luff command.

13:50-14:10 TB3.2

Sliding Mode Observer for Fluid Flow, pp. 1195-1200

Kamran, Niloofar Cornell Coll

Drakunov, Sergey V. Embry-Riddle Aeronautical Univ

Many phenomena in science and engineering are described using partial differential equations. However, for the systems modeled by PDEs, having access to the states of the system can be challenging due to technical difficulties such as lacking enough sensors in the system. In this paper the problem of estimating the parameters of fluid flow described by distributed parameter systems is considered. Two simplified versions of Navier-Stokes equations, Burgers' and advection equations, are practiced to model the fluid dynamics. Using the principles of sliding mode control theory, the distributed parameter observer is designed in order estimate the parameters of the system having only limited number of measurements available.

14:10-14:30 TB3.3

On the Application of Distributed Control Structure for Medium-Voltage DC Shipboard Power System, pp. 1201-1206

Zohrabi, Nasibeh Mississippi State Univ

Abdelwahed, Sherif Mississippi State Univ

In this paper, a distributed control structure is presented for a nonlinear Medium-Voltage DC (MVDC) Shipboard Power System (SPS). Distributed control architecture has the advantages of less computational burden, high flexibility, and a good error tolerance. In this framework, each subsystem is controlled by a model predictive controller using local state variables and parameters, and also interaction variables from other subsystems shared through a coordinator. In the coordinator level, an optimization problem is iteratively solved to update a Lagrange multiplier vector to have a global optimal solution. The effectiveness of the proposed distributed control structure for a partitioned MVDC model is demonstrated by the simulation results. The performance analysis is accomplished by comparing centralized and distributed control methods on the global and partitioned models and considering different specifications in the MVDC system.

14:30-14:50 TB3.4

Control of Cooling Loops with Large and Variable Delays, pp. 1207-1212

Bachler, Simon — Univ. for Health Sciences, Medical Informatics and Tech
Huber, Johannes — GE Jenbacher Gmbh & Co OG
Kopecek, Herbert — GE
Woittennek, Frank — UMIT

This paper deals with the control design for large cooling loops with large and time varying delays and measured disturbances. A control oriented model is presented and a two-degree-of-freedom control strategy is introduced. The feedforward part of the controller is designed using input-output linearization techniques. The control performance with respect to trajectory tracking and disturbance rejection is discussed on the basis of measurements on a scaled test rig.

14:50-15:10 TB3.5

Stable Inversion Design for Binaural Reproduction Over Loudspeakers, pp. 1213-1217

Mori, Shohei — Keio Univ
Inoue, Masaki — Keio Univ
Matsui, Kentaro — NHK Science and Tech. Res. Lab
Adachi, Shuichi — Keio Univ

This paper is devoted to designing a transaural sound reproduction system, which is a virtual realization of three-dimensional audio using multi-channel loudspeakers. The transaural sound reproduction requires the inverse model of a reproduced sound field. It is known that any transfer function model of the sound field includes unstable zeros that are originated from the inherent propagation delay. The complete inversion of the sound field is inevitably unstable and cannot be implemented to actual systems. To overcome this problem, we propose a design method of a stable feedforward inversion based on the mathcal{H}$_\infty$model matching problem. In the method, low gain specification is imposed on the inversion, which is important for improving robustness to the modeling error in the reproduced sound field. Then, the design method is applied to actual experimental data of a reproduced sound field to show its effectiveness.

15:10-15:30 TB3.6

Automatic Level and Bender Control for Hot Finishing Mill Using Flatness Measurement of Steel Strip, pp. 1218-1222

Noh, Ilhwan — POSCO

This paper introduces an automation method for the level and the bender control of hot finishing mill process in the steel industry, and its application. The flatness measurement system containing the area cameras and the multi-line laser is designed to measure the strip flatness at the delivery of roll stand. The flatness data measured by this system stands for the relative elongation rate of each width section of the steel strip. And a wave controller is developed to enhance the strip flatness by adjusting the level and bender of the roll stand. The bender deals with the symmetrical flatness defect like the edge wave and the center buckle, and the level controls asymmetric one side edge wave. The wave controller calculates the optimal compensation of the level and the bender from the flatness data and other operating information. This approach has been applied on a real plant of POSCO, and its results contribute to improving stability and productivity of the plant.

TB4 Kohala

Predictive Control II (Regular Session)

Chair: Bitmead, Robert — Univ. of California, San Diego
Co-Chair: Kristoffersen, Torstein Thode — Norwegian Univ. of Science and Tech

13:30-13:50 TB4.1

Tractable Dual Optimal Stochastic Model Predictive Control: An Example in Healthcare, pp. 1223-1228

Sehr, Martin A — Univ. of California, San Diego
Bitmead, Robert — Univ. of California, San Diego

Output-Feedback Stochastic Model Predictive Control based on Stochastic Optimal Control for nonlinear systems is computationally intractable because of the need to solve a Finite Horizon Stochastic Optimal Control Problem. However, solving this problem leads to a control law possessing optimal probing properties, called dual control, which trades off benefits of exploration and exploitation. In practice, intractability of Stochastic Model Predictive Control is typically overcome by replacement of the underlying Stochastic Optimal Control problem by more amenable approximate surrogate problems, which however come at a loss of the optimal probing nature of the control signals. While probing can be superimposed in some approaches, this is done sub-optimally. In this paper, we examine approximation of the system dynamics by a Partially Observable Markov Decision Process with its own Finite Horizon Stochastic Optimal Control Problem, which can be solved for an optimal control policy, implemented in receding horizon fashion. This procedure enables maintaining probing in the control actions. We further discuss a numerical example in healthcare decision making, highlighting the duality in stochastic optimal receding horizon control.

13:50-14:10 TB4.2

Model Predictive Trajectory Set Control for a Proportional Directional Control Valve, pp. 1229-1234

Makarow, Artemi — TU Dortmund
Keller, Martin — TU Dortmund
Rösmann, Christoph — TU Dortmund
Bertram, Torsten — TU Dortmund
Schoppel, Georg — Bosch Rexroth AG
Glowatzky, Ingo — Bosch Rexroth AG

In practice, high quality control for mechatronic systems is often achieved by augmenting classical control architectures like PID controllers with numerous tailored nonlinear characteristic parameter curves and cascades. This complexity can be significantly reduced by utilizing advanced model predictive controllers (MPC). Furthermore, desired objectives like minimum control error and effort can be realized while explicitly adhering to state and control constraints. However, MPC is subject to iterative gradient-based online optimization algorithms which are computationally expensive. Hence, their application to mechatronic systems with fast dynamics is limited. It is worth mentioning that industrial systems often utilize low cost computational hardware. Accordingly, this contribution presents a model predictive trajectory set control (MPTSC) scheme that mimics a sub-optimal MPC by a rough discretization of the control input domain. A comparative analysis with a linear quadratic regulator demonstrates its ability to provide a sufficiently high control performance compared to the optimal reference. Furthermore, the approach is experimentally evaluated on a proportional directional control valve with a sample rate of 10 kHz. In addition to its efficiency the implementation of MPTSC is less complex and error-prone in comparison to MPC which is a reasonable advantage especially in industrial applications.

14:10-14:30 TB4.3

Smooth Operator: Control Using the Smooth Robustness of Temporal Logic, pp. 1235-1240

Pant, Yash Vardhan — Univ. of Pennsylvania
Abbas, Houssam — Univ. of Pennsylvania

Mangharam, Rahul — Univ. of Pennsylvania

Modern control systems, like controllers for swarms of quadrotors, must satisfy complex control objectives while withstanding a wide range of disturbances, from bugs in their software to attacks on their sensors and changes in their environments. These requirements go beyond stability and tracking, and involve temporal and sequencing constraints on system response to various events. This work formalizes the requirements as formulas in Metric Temporal Logic (MTL), and designs a controller that maximizes the robustness of the MTL formula. Formally, if the system satisfies the formula with robustness r, then any disturbance of size less than r cannot cause it to violate the formula. Because robustness is not differentiable, this work provides arbitrarily precise, infinitely differentiable, approximations of it, thus enabling the use of powerful gradient descent optimizers. Experiments on a temperature control example and a two-quadrotor system demonstrate that this approach to controller design outperforms existing approaches to robustness maximization based on Mixed Integer Linear Programming and stochastic heuristics. Moreover, it is not constrained to linear systems.

14:30-14:50 TB4.4

Dispatching Active Distribution Networks through Electrochemical Storage Systems and Demand Side Management, pp. 1241-1247

Fabietti, Luca	École Pol. Fédérale De Lausanne
Gorecki, Tomasz Tadeusz	École Pol. Fédérale De Lausanne
Namor, Emil	École Pol. Fédérale De Lausanne
Sossan, Fabrizio	École Pol. Fédérale De Lausanne
Paolone, Mario	École Pol. Fédérale De Lausanne
Jones, Colin N.	École Pol. Fédérale De Lausanne

In this paper, the problem of dispatching the operation of a distribution feeder comprising a set of heterogeneous resources is investigated. In particular, the main objective is to track a 5-minute resolution trajectory, called the textit{dispatch plan} that is computed one day before the beginning of operation. During real-time operation, due to the stochasticity of part of the resources in the feeder portfolio, tracking errors need to be absorbed in order to track the committed dispatch plan. This is achieved by modulating the power consumption of a grid-connected battery energy storage system (BESS) and of the HVAC system of a commercial controllable building (CB). To this end, a hierarchical multi-time-scale controller is designed to coordinate the two entities while requiring a minimal communication infrastructure.

The effectiveness of the proposed control framework is demonstrated by means of a set of full-day experimental results on the 20kV distribution feeder of the EPFL campus that is comprised of: 1) a set of uncontrollable resources represented by 5 office buildings (350kWp) and a roof-top PV installation (90kWp) 2) a set of controllable resources, namely, a grid-connected BESS (720kVA-500kWh), and a fully-occupied multi-zone office building (45 kWp).

14:50-15:10 TB4.5

Model Predictive Control and Extended Kalman Filter for a Gas-Liquid Cylindrical Cyclone, pp. 1248-1255

Kristoffersen, Torstein Thode	Norwegian Univ. of Science and Tech
Holden, Christian	Norwegian Univ. of Science and Tech

Gas-liquid cylindrical cyclone separators are widely used in several applications, including bulk separation of hydrocarbons. Recently, these separators have been considered for subsea separation because of their low weight and compact design. However, disadvantages associated with their design are the resulting fast dynamics and small operational volume, which make them highly sensitive to flow variations. There are two possible approaches for dealing with this problem: (1) increasing the operational volume or (2) improved control. The fast dynamics necessitates a fast and computationally inexpensive control algorithm. Therefore, in this paper, we consider a newly proposed nonlinear dynamic model containing unmeasured parameters to design a model predictive control algorithm for real-time offset-free optimal control, i.e., improved transient handling and product quality optimization. Offset-free optimal control is achieved by augmenting the states with integral error states of the controlled variables. The MPC algorithm with and without state feedback from the estimator is compared in simulations, both achieving offset-free optimal control.

15:10-15:30 TB4.6

Online Parameter Estimation for MPC Model Uncertainties Based on LSCR Approach, pp. 1256-1261

Kalmuk, Alexander	Saint-Petersburg State Univ
Tyushev, Kirill	Saint-Petersburg State Univ
Granichin, Oleg	Saint Petersburg State Univ
Yuchi, Ming	Huazhong Univ. of Science and Tech

The paper discusses a novel probabilistic approach for online parameter estimation of the predictor model used in an MPC (Model Predictive Control) setting in the presence of model uncertainties and external disturbances. Model uncertainty makes it hard to compute an optimal control in general case, because it is needed to take into account all possible values of model parameters. Therefore, it is a good way for optimisation to shrink a set of possible model parameters. The proposed method iteratively estimates model parameters using randomized control strategy and algorithm based on LSCR (Leave-out Sign-dominant Correlation Regions) and computes a new control for the estimated parameters using robust MPC. The theoretical results are demonstrated via a model simulation example with two unknown parameters.

TB5 — Ballroom I

Robotics V (Regular Session)

Chair: Ambrose, Eric	California Inst. of Tech
Co-Chair: Tomizuka, Masayoshi	Univ. of California, Berkeley

13:30-13:50 TB5.1

Stabilization of 3D Underactuated Biped Robots: Using Posture Adjustment and Gait Libraries to Reject Velocity Disturbances, pp. 1262-1269

Hartley, Ross	Univ. of Michigan
Da, Xingye	Univ. of Michigan
Grizzle, Jessy W.	Univ. of Michigan

This paper presents a systematic, two-stage optimization process for the design and stabilization of periodic walking gaits based on the full 3D dynamic model of a robot. After designing a nominal periodic walking motion, a parametric means of adjusting the robot's posture is introduced to achieve exponential orbital stability. The parameters are determined through a finite-horizon optimization problem that emphasizes gait robustness to perturbations. This gait design and stabilization process is used to generate a library of gaits over a grid of longitudinal and lateral velocities. The discrete set of gaits is then unified through bilinear interpolation to create a single continuously defined control policy. This policy extends the controller's region of attraction, allowing the robot to handle perturbations much larger than those presented during the initial optimization. The resulting controller allows the simulated robot to recover from velocity disturbances of up to 1.4 m/s longitudinally and 0.7 m/s laterally. Preliminary experimental results are shown on an underactuated Atrias-series robot.

13:50-14:10 TB5.2

Toward Benchmarking Locomotion Economy across Design Configurations on the Modular Robot: AMBER-3M, pp. 1270-1276

Ambrose, Eric	California Inst. of Tech
Ma, Wenlong	California Inst. of Tech
Hubicki, Christian	Georgia Tech. Univ

Ames, Aaron D. California Inst. of Tech

Making conclusive performance comparisons of bipedal locomotion behaviors can be difficult when working with different robots. This is particularly true in the case of comparing energy economy, which is highly dependent on mechanical, electrical and control components. As a means of controlling for these disparities in methodical testing, we built a modular bipedal robot platform, AMBER-3M. Three leg configurations were designed for this purpose: actuated flat foot, rigid point-foot, and compliant point-foot. As a proof of concept for the mechanical, electrical, and algorithmic modularity, we present walking experiments with all three AMBER-3M configurations, using the same control methods and experimental procedures. As a pilot study for investigating locomotion economy, we performed further systematic experiments of point-foot walking with the purpose of examining the effects of speed on the cost of transport (COT). We optimized 36 walking gaits for maximum locomotion economy at various transport velocities. Walking performance data was collected from these gaits spanning a speed range of 0.34 to 0.94 m/s. An apparent Pareto-optimal frontier was observed in the data, showing that mechanical cost of transport increases with speed; ranging from 0.22 up to 0.36. Conversely, the electrical cost of transport decreased at higher walking speeds.

14:10-14:30 TB5.3

Joint Trajectory Generation and Motion Control of a Wearable Robot for Complete Paraplegics Based on Forward Inflection Walking, pp. 1277-1281

Choi, Jungsu Sogang Univ
Na, Byeonghun Sogang Univ
Jung, Pyeong-Gook Sogang Univ
Rha, Dong-wook Yonsei Univ. Coll. of Medicine
Kong, Kyoungchul Sogang Univ

Wearable robots are regarded as a new transportation system in daily living for complete paraplegics due to spinal cord injury (SCI). For the motion control of a wearable robot, the normal gait pattern of people without disabilities is often applied as a reference input. When the natural dynamics of the human body can be utilized and the displacement of center of gravity (CoG) is possible, the normal gait pattern is effective to increase the gait speed with the minimal energy consumption. Complete paraplegics with high SCI level (i.e., above thoracic spine level), however, are able to voluntarily move neither the legs nor their waist, and thus they cannot control the CoG at all. Consequently, the normal gait pattern is not necessarily the best option for such complete paraplegics. In addition, the degree of freedom (DoF) of wearable robots is less than that of the human body; therefore, it is difficult to expect that the complete paraplegics naturally control the CoG even with the help of wearable robots. In this paper, a new gait pattern, called forward inflection walking (FIW), is proposed for the motion control of a wearable robot for complete paraplegics. The proposed FIW method enables to transfer the CoG to the leg ahead by modification and optimization of the joint angle trajectories for effective walking. Therefore, the FIW method intentionally moves the CoG of complete paraplegics with wearable robots according to the gait phase (i.e., stance and swing). The proposed method is verified by clinical experiments.

14:30-14:50 TB5.4

Generalized Momentum Based-Observer for Robot Impact Detection - Insights and Guidelines under Characterized Uncertainties, pp. 1282-1287

Briquet-Kerestedjian, Nolwenn L2S CentraleSupélec-CNRS
Makarov, Maria L2S CentraleSupélec-CNRS
Grossard, Mathieu CEA LIST Interactive Robotics Lab
Rodriguez-Ayerbe, Pedro L2S CentraleSupélec-CNRS

In the context of human-robot interaction, detecting an impact between a serial robot manipulator and the human operator or its environment efficiently and at the earliest is essential for safe and efficient operations. This work relies on the generalized momentum based-observer for robot impact detection using only motor/joint information and characterizes the uncertainties to quantify the expected sensitivity of detection. Indeed, modeling uncertainties affect the external torque estimation in the same structural way as external disturbances and no structural decoupling is reachable between both. For this purpose in this study, modeling uncertainties are divided into parametric and numerical differentiation errors. Their contribution in process and measurement noises is detailed and then approximated by a white noise of characterized variance for the observer design. High-level tuning guidelines are provided for the design parameters depending on the expected speed and sensitivity of detection. This approach is applied experimentally on the CEA robot arm manipulator.

14:50-15:10 TB5.5

The Effect of Remote-Signal Feedback Architectures on the Stability of Human-In-The-Loop Telerobotics in the Presence of Time-Delays, pp. 1288-1293

Yousefi, Ehsan Bilkent Univ
Yildiz, Yildiray Bilkent Univ
Sipahi, Rifat Northeastern Univ
Yucelen, Tansel Univ. of South Florida

In this paper, stability properties of three different human-in-the-loop telerobotic system architectures are comparatively investigated, in the presence of human reaction time-delay and communication time-delays. The challenging problem of stability characterization of systems with multiple time-delays is addressed by implementing rigorous stability analysis tools, and the results are verified via numerical illustrations. Practical insights about the results of the stability investigations are also provided.

15:10-15:30 TB5.6

Real-Time Collision Avoidance Algorithm on Industrial Manipulators, pp. 1294-1299

Lin, Hsien-Chung Univ. of California, Berkeley
Liu, Changliu Univ. of California, Berkeley
Fan, Yongxiang Univ. of California, Berkeley
Tomizuka, Masayoshi Univ. of California, Berkeley

Safety is a fundamental issue in robotics, especially in the growing application of human-robot interaction (HRI), where collision avoidance is an important consideration. In this paper, a novel real-time velocity based collision avoidance planner is presented to address this problem. The proposed algorithm provides a solution to deal with both collision avoidance and reference tracking simultaneously. An invariant safe set is introduced to exclude the dangerous states that may lead to collision, and a smoothing function is introduced to adapt different reference commands and to preserve the invariant property of the safe set. A real-time experiment with a moving obstacle is conducted on FANUC LR Mate 200iD/7L.

TB6 Ballroom II

Security and Privacy in Control Systems (Invited Session)

Chair: Mestha, Lalit K. GE Global Res
Co-Chair: Cardenas, Alvaro Univ. of Texas at Dallas
Organizer: Mestha, Lalit K. GE Global Res
Organizer: Cardenas, Alvaro Univ. of Texas at Dallas

13:30-13:50 TB6.1

Methods of State Estimation Resilient against Sensor Attacks and Robust against Exogenous Disturbances (I), pp. 1300-1305

Na, Gyujin DGIST
Seo, Dongmin DGIST
Eun, Yongsoon DGIST

Control systems that are resilient against malicious attacks have

recently become one of the important research topics. This is due to the fact that many critical infrastructures in our society such as power grid, nuclear facility, and public transportation, rely on feedback control technology, and that malfunction of said systems due to attack could be disastrous. Malicious attacks on control systems indeed occurred in recent years. The problem of resilient state estimation against sensor attacks, which is concerned of correctly estimating plant state despite of sensor attacks, have been previously addressed. Existing methods, however, lose the accuracy of the estimation if external disturbance exists. In this paper, we investigate the problem of resilient state estimation that are robust against external disturbance. Specifically, unknown input observer based state estimation has been developed to eliminate the effect of external disturbance on the state estimation that are resilient against malicious attacks on sensors. Associated design conditions have been derived. Additionally, disturbance observer based state estimation method has been developed. Validation of the proposed methods is provided through experiments.

13:50-14:10 TB6.2

Active Detection for Exposing Intelligent Attacks in Control Systems (I), pp. 1306-1312

Weerakkody, Sean — Carnegie Mellon Univ
Ozel, Omur — Carnegie Mellon Univ
Griffioen, Paul — Carnegie Mellon Univ
Sinopoli, Bruno — Carnegie Mellon Univ

In this paper, we consider approaches for detecting integrity attacks carried out by intelligent and resourceful adversaries in control systems. Passive detection techniques are often incorporated to identify malicious behavior. Here, the defender utilizes finely-tuned algorithms to process information and make a binary decision, whether the system is healthy or under attack. We demonstrate that passive detection can be ineffective against adversaries with model knowledge and access to a set of input/output channels. We then propose active detection as a tool to detect attacks. In active detection, the defender leverages degrees of freedom he has in the system to detect the adversary. Specifically, the defender will introduce a physical secret kept hidden from the adversary, which can be utilized to authenticate the dynamics. In this regard, we carefully review two approaches for active detection: physical watermarking at the control input, and a moving target approach for generating system dynamics. We examine practical considerations for implementing these technologies and discuss future research directions.

14:10-14:30 TB6.3

Security and Privacy Trade-Offs in CPS by Leveraging Inherent Differential Privacy (I), pp. 1313-1318

Giraldo, Jairo — Univ. of Texas at Dallas
Cardenas, Alvaro — Univ. of Texas at Dallas
Kantarcioglu, Murat — Univ. of Texas at Dallas

Cyber-physical systems are subject to natural uncertainties and sensor noise that can be amplified/attenuated due to feedback. In this work, we want to leverage these properties in order to define the inherent differential privacy of feedback-control systems without the addition of an external differential privacy noise. If larger levels of privacy are required, we introduce a methodology to add an external differential privacy mechanism that injects the minimum amount of noise that is needed. On the other hand, we show how the combination of inherent and external noise affects system security in terms of the impact that integrity attacks can impose over the system while remaining undetected. We formulate a bilevel optimization problem to redesign the control parameters in order to minimize the attack impact for a desired level of inherent privacy.

14:30-14:50 TB6.4

Secure Reference-Tracking with Resource-Constrained UAVs (I), pp. 1319-1325

Katewa, Vaibhav — Univ. of California, Riverside
Anguluri, Rajasekhar — Univ. of California, Riverside
Ganlath, Akila — Univ. of California, Riverside
Pasqualetti, Fabio — Univ. of California, Riverside

In this paper we study a security problem for resource-constrained autonomous systems. We consider a UAV tasked with tracking a reference trajectory, and an attacker capable of compromising the measurements taken at certain sensors. We consider a probabilistic attack model, where the attacker executes denial of service attacks against a subset of sensors based on a Bernoulli process. We assume that sensors have different accuracy, reliability, and require different computational times to be activated. Our approach is based on the formalism of Markov Jump Linear Systems. We develop and numerically validate an optimal security countermeasure that probabilistically selects which sensor to use at different time instants, so as to balance performance and security, and ultimately minimize the UAV's expected tracking error.

14:50-15:10 TB6.5

Cyber-Attack Detection and Accommodation Algorithm for Energy Delivery Systems (I), pp. 1326-1331

Mestha, Lalit K. — GE Global Res
Anubi, Olugbenga — General Electric
Abbaszadeh, Masoud — Univ. of Alberta

Cyber-attack accommodation in a cyber-physical system is to ensure system operation, integrity and availability while maintaining a reasonable operational performance under attack. In this paper, we present a novel cyber-attack accommodation algorithm by estimating the true operational states of the system with new boundary & performance constrained resilient estimators while the system is continuously operating and is under attack. Our approach is based on combining data driven machine learning and physics based domain knowledge with traditional resilient estimation. The results were evaluated using a high fidelity model-based simulation environment.

TB7 Ballroom III

Estimation (Regular Session)

Chair: Bridgeman, Leila Jasmine — Duke Univ
Co-Chair: Takegami, Tomoki — Mitsubishi Electric Corp

13:30-13:50 TB7.1

State-Of-Charge and Parameter Estimation of Lithium-Ion Battery Using Dual Adaptive Filter, pp. 1332-1337

Takegami, Tomoki — Mitsubishi Electric Corp
Wada, Toshihiro — Mitsubishi Electric Corp

In this paper, we propose a cross-referring approach using a dual adaptive filter to estimate the state-of-charge (SOC), full charge capacity (FCC), and resistance of a battery in a real-time manner. Although conventional SOC estimation methods such as the Coulomb counting and the open-circuit voltage (OCV) estimation are commonly used for battery systems, accuracy of their SOC estimates are deteriorated by the presence of errors on the current and voltage measurements of the battery. Moreover, the methods depend on parameters such as the FCC and resistance, both of them gradually vary as the battery degrades, resulting in large SOC estimation errors. In our approach, the FCC and current sensor offset in the Coulomb counting method are estimated by referring the OCV estimation method, while the resistance in the OCV estimation method is estimated by referring the Coulomb counting method, resulting in accurate SOC estimation. The performance of the proposed method is verified through numerical examples based on both simulated and experimental data of a lithium-ion battery (LIB).

13:50-14:10 TB7.2

Kernel-Based Adaptive Multiple Model Target Tracking, pp. 1338-1343

Ghoshal, Debarshi Patanjali — McGill Univ
Gopalakrishnan, Kumar Vishwanath — McGill Univ
Michalska, Hannah H. — McGill Univ

The novel adaptive multiple-model target tracking algorithm presented here employs a non-asymptotic state and parameter estimator whose design hinges on a non-standard integral system representation. The same estimator can be used for target maneuver detection and isolation and hence constitutes the principal ingredient of the tracking algorithm. The algorithm does not maintain a model bank, but creates and identifies new models in an attempt to best track the measurement data. Such an approach is rendered uniquely possible by the fact that the state and parameter estimator is essentially dead-beat. Practical model identifiability, persistent excitation condition for the measured signal are discussed. Although this first version of the algorithm is deterministic and employs threshold-based maneuver detection, it exhibits good robustness with respect to Gaussian measurement noise.

14:10-14:30 TB7.3

Applying a Passive Network Reconstruction Technique to Twitter Data in Order to Identify Trend Setters, pp. 1344-1349

Chetty, Vasu — Brigham Young Univ
Woodbury, Nathan Scott — Brigham Young Univ
Brewer, Jacob — Brigham Young Univ
Lee, Chin Hong Kenneth — Brigham Young Univ. - Hawaii
Warnick, Sean — Brigham Young Univ

In this work we apply a systems-theoretic approach to identifying trend setters on Twitter. A network reconstruction algorithm was applied to Twitter data to determine causal relationships among topics discussed by popular Twitter users. Causal relationships in this context means that the topics tweeted by a single user influences the topics tweeted by another user, regardless of sentiment. A user that causally influences other users, without themselves being strongly influenced is identified as a trendsetter. This work seeks to identify potential trendsetters among popular Twitter users and demonstrating that causal influence does not always directly correlate with a user's popularity in terms of followers–demonstrating that popularity alone may not be sufficient for identifying trendsetters on Twitter.

14:30-14:50 TB7.4

Robust State Estimation and Online Outlier Detection Using Eccentricity Analysis, pp. 1350-1355

Lee, Kyuman — Georgia Inst. of Tech
Johnson, Eric N. — Georgia Inst. of Tech

Both state propagation and sensor measurements are often corrupted by unmodeled non-Gaussian or heavy-tailed noise. Without dealing with such outliers, the accuracy of a estimator significantly degrades, and control systems that rely on high-quality estimation lose stability. To estimate the states of dynamic systems in which both types of outliers occur, we propose a novel approach that combines a real-time outlier detection technique with an extended version of an outlier robust Kalman filter (ORKF). Unlike the ORKF for only measurement outliers, the technique, the extended ORKF (EORKF), also handles situations in which propagation outliers arise; that is, to approximately compute the optimal precision matrices of process outliers, we derive equations and algorithms using the variational inference method. Hence, the EORKF does not restrict noise at either a constant or Gaussian level. Furthermore, for lower computational effort and memory uses, our approach employs the typicality and eccentricity data analysis (TEDA), which provides information about the time when outliers occur and runs the EORKF whenever the TEDA detects outliers. The results of Monte Carlo simulations show that our approach leads to greater improvement in robustness and lower computational complexity than existing methods.

14:50-15:10 TB7.5

Norm and Linear-Inequality-Constrained State Estimation: An LMI Approach, pp. 1356-1361

Chee, Stephen — McGill Univ
Bridgeman, Leila Jasmine — Duke Robotics
Forbes, James Richard — McGill Univ

This paper proposes a method for state estimation that incorporates norm- and linear-inequality constraints using Linear Matrix Inequalities (LMIs). This is accomplished by adopting a prediction-correction filter form and calculating the observer gain matrix by solving a convex optimization problem with LMI constraints where the state constraints are expressed as LMIs. The state constraints considered in this study include norm and linear inequalities. Simulation results are included to assess the performance of the proposed filter in a scenario involving a mobile robot moving within a constrained area taking range and bearing measurements of known landmarks. The filter's performance is compared with a traditional EKF.

15:10-15:30 TB7.6

3D Surface Registration Using Estimated Local Shape Variation, pp. 1362-1367

Ono, Keiko — Ryukoku Univ
Ono, Ryuji — Ryukoku Univ
Hanada, Yoshiko — Kansai Univ

We address the problem of 3D image registration without pre-registration based on features extracted from point clouds. 3D image registration is currently receiving a great deal of attention as we can get 3D image data easier than before for developing a portable depth camera such as Kinect and Xtion. The Iterative Closest Point (ICP) algorithm is often used to register between current and next frames or meshes during capturing by using a depth camera, and is utilized into a lot of 3D processing softwares as the state-of-art method. However, the ICP algorithm needs pre-registration by hand to register images when there are distance and differences in image size between target images. It is known that, in this case, there are multiple local minima in the design space of this problem, and it is difficult to estimate each appropriate position. When scanned multivew images are available and they are roughly the same size, a multiview matching technique can be adopted and estimate an approximate rigid transformation without pre-registration. However, multiview images are not always available. We in this paper propose a method to register 3D images automatically without multiview images, which estimates correspondence points based on local gradient information within neighborhood. For two different 3D images, we demonstrate that the proposed approach does not converge to local minima and shows good performance in terms of 3D image registration.

TB8 — Ballroom IV

NSF CAREER Awardees: Emerging Areas in Systems and Control (Invited Session)

Chair: Baheti, Radhakisan — National Science Foundation
Organizer: Baheti, Radhakisan — National Science Foundation

13:30-13:50 TB8.1

Studies on Mechanisms for Robust Social Influence (I), pp. 1368-1369

Brown, Philip N. — Univ. of California, Santa Barbara
Marden, Jason R. — Univ. of California, Santa Barbara

An important goal in engineering design is to ensure that infrastructure systems are utilized efficiently by the public. One example is a transportation network which exhibits congestion effects due to self-interested routing choices by drivers. We study the use of road tolls to positively influence routing choices, focusing on deriving pricing mechanisms which are robust to mischaracterizations of network topology and driver price-sensitivity. We show that robust

taxation is possible, but only if road taxes are allowed to vary with traffic loads.

13:50-14:10 TB8.2

*An Overview of Recent Advances and Future Challenges in Hybrid Feedback Control Design (I)**

Sanfelice, Ricardo G. Univ. of California at Santa Cruz

14:10-14:30 TB8.3

Scalable Microscopic and Macroscopic Control of Traffic Systems (I), N/A

Savla, Ketan Univ. of Southern California

Increasing sensing, autonomy and connectivity are presenting novel opportunities for control in traffic systems, ranging from feedback traffic signal, ramp metering and variable speed limit control at the macroscopic scale, to influencing microscopic interaction rules for autonomous vehicles, such as car-following and lane-changing. While such possibilities have the potential to increase the efficiency and resiliency of traffic systems, the large number of control points, either fixed to the infrastructure or on-board vehicles, poses severe computational challenges. Extensions of existing scalable analysis, control and optimization methodologies for networked systems to nonlinear traffic dynamics, and to relevant performance metrics such as throughput and travel time, are challenging. In this talk, we present our contributions in addressing these challenges.

We consider three canonical problems. First, we describe a computationally efficient simulation-free gradient-based algorithm for joint optimal control of green time splits and offsets for arterial networks of signalized intersections. This is based on a novel approach for accurate objective function evaluation at given traffic signal control values. Second, we discuss optimal control of traffic flow for freeway networks. We provide distributed algorithms with provable convergence guarantees to compute optimal finite time open loop control, and identify sufficient conditions on the cost function and traffic flow dynamics, under which the optimal closed-loop control exhibits spatio-temporal sparsity. Third, we study horizontal traffic queues that explicitly model inter-vehicle motion coupling. We provide throughput and travel time analysis for such queues under standard parameterizations of coupled dynamics in terms of car-following behavior and inter-vehicle communication network.

We supplement our analytical results with case studies developed in a microscopic traffic simulator for scenarios calibrated for the Los Angeles area. We conclude by commenting on the integration of the proposed methodologies with driver decisions under algorithmic information structure design.

14:30-14:50 TB8.4

Fragility in Brain Networks: From Irrational Decision Making to Seizures (I), N/A

Sarma, Sridevi Johns Hopkins Univ

In this talk, I will discuss how small perturbations in neuronal populations cause abnormal brain activity and behavior. First, I will describe a study wherein human subjects, implanted with depth electrodes for clinical purposes, gamble virtual money. We model the decision making system of each subject from behavioral data and link model components to neural activity. The model identifies anatomical substrates of components that drive irrational decisions, making the system fragile. I then describe a second study, wherein structured perturbation theory is applied to invasive EEG recordings collected from epilepsy patients to localize where seizures originate - the epileptogenic zone (EZ). Our hypothesis is that the most fragile nodes in the brain network, as defined by the smallest perturbation one can apply to a node's influence on its neighbors to destabilize the network, form the EZ. Our theory allows localization without having to observe a single seizure event and is remarkably aligned with clinical annotations which require several seizure events to be observed.

14:50-15:10 TB8.5

*Panel Discussion (I)**

Baheti, Radhakisan National Science Foundation

TC1 Puna

Delay Systems (Regular Session)

Chair: Figueredo, Luis Felipe Cruz Univ. of Brasília

Co-Chair: Oliveira, Tiago Roux State Univ. of Rio De Janeiro

16:00-16:20 TC1.1

Input Selection for Return Temperature Estimation in Mixing Loops Using Partial Mutual Information with Flow Variable Delay, pp. 1372-1377

Overgaard, Anders Aalborg Univ

Kallesøe, Carsten Skovmose Aalborg Univ

Bendtsen, Jan Dimon Aalborg Univ

Nielsen, Brian Grundfos Management A/S

In hydronic heating systems for buildings a mixing loop is often used to control the temperature and pressure. An important task of a mixing loop is to control or constrain the return temperature since this leads to energy savings by reducing heat loss and energy consumed by the pump. With increased access to data, it is desirable to create a data driven model for control. Due to the abundance of data available a method for input variable selection (IVS) is used called partial mutual information (PMI). The paper introduces a method to include flow variable delay into the PMI framework. Data from an office building in Bjerringbro, Denmark is used for the analysis. It is shown that mutual information and performance of a generalized regression neural network (GRNN) is improved by using flow variable delay compared to constant delay.

16:20-16:40 TC1.2

Cascade Observers for Output-Feedback Control of Uncertain Systems with Arbitrary Sensor Delays, pp. 1378-1383

Marques, Ionara Oliveira State Univ. of Rio De Janeiro

Cunha, José Paulo V. S. State Univ. of Rio De Janeiro

Oliveira, Tiago Roux State Univ. of Rio De Janeiro

An output-feedback control system for uncertain single-input-single-output linear systems with arbitrary delay in the output signal is developed. The state of the system is estimated by observers connected in cascade. Unlike previous works, parametric uncertainties are allowed. Their effects are analyzed by using the Small-Gain Theorem. The proposed control strategy guarantees global stability of the closed-loop system. A numerical example illustrates the effectiveness of the proposed control strategy applied to compensate arbitrary delays and bounded uncertainties.

16:40-17:00 TC1.3

Novel Stability Analysis of Delayed LFC Power Systems by Infinite-Series-Based Integral Inequality, pp. 1384-1389

Yang, Feisheng Northwestern Pol. Univ

He, Jing Northwestern Pol. Univ

Wang, Jing Northwestern Pol. Univ

A new method is proposed for the stability problem of delay system model applied for one-area load frequency control (LFC) scheme with fixed and time-varying delay cases included in the current article. Novel stability conditions with delay dependency in terms of linear matrix inequalities for LFC systems are derived by an augmented Lyapunov-Krasovski (L-K) functional. Our proof deployment for system stability of power grid applies the further improved integral inequality in the form of infinite series which turns out to be less conservative than Wirtinger's inequality that encompasses Jensen inequality. A simulation case study is carried out to show the

effectiveness and superiority of the presented delay-dependent PI-type LFC design technology.

17:00-17:20 TC1.4

H∞ Control for Networked Control Systems with Dynamic Controllers in the Feedback Loop, pp. 1390-1395

Cavalcanti, Joao — Massachusetts Inst. of Tech
Figueredo, Luis Felipe Cruz — Univ. of Brasília
Ishihara, Joao Y. — Univ. of Brasília

Although paramount contributions have been made to networked control systems (NCS) theory concerning both stability analysis and controller design, results regarding general purpose dynamic controllers are still scarce. Indeed, controller dynamics induce complex closed-loop behavior, making the adaption of previous techniques troublesome. This paper introduces sufficient conditions which assure stability and guaranteed H_∞ performance for NCSs with dynamic controllers in the feedback loop. The theorem is combined with simulated annealing algorithm to obtain dynamic controllers with superior disturbance rejection.

17:20-17:40 TC1.5

Design of Coupling Strengths for Consensus with Time-Varying Delays, pp. 1396-1401

Savino, Heitor Judiss — Federal Univ. of Alagoas
Souza, Fernando de Oliveira — Univ. Federal De Minas Gerais
Pimenta, Luciano — Univ. Federal De Minas Gerais

This paper proposes a method to design the coupling strengths in a multi-agent system in order to achieve consensus in arbitrary directed networks in the presence of input time-varying delays. A model transformation is carried out to convert the consensus problem into a stability one. Then, based on an appropriate Lyapunov–Krasovskii functional, sufficient conditions for consensus in multi-agent systems are derived, where the coupling strengths are given as variables of Linear Matrix Inequalities (LMI). The designed coupling strengths may enable consensus and also meet a specified convergence rate. Numerical simulations are provided to demonstrate the effectiveness of the proposed results.

17:40-18:00 TC1.6

State and Parameter Estimation Using Measurements with Unknown Time Delays, pp. 1402-1407

Lee, Kyuman — Georgia Inst. of Tech
Johnson, Eric N. — Georgia Inst. of Tech

Standard Kalman filtering does not handle time-delayed measurements, and if the delay is significant, large estimation errors may accumulate over time. Furthermore, the delay value is typically unknown and variable in many real applications. To fuse measurements with unknown time delays, this study incorporates a parameter estimation technique into state estimation. In the combined parameter-state estimator, we directly estimate the delay value as an additional state and simultaneously obtain refined state estimates in the modified Kalman filter that compensates for delayed measurements. Since estimated delay value has some constraints, the estimator requires both interpolation and the truncation of the probability density function. Monte Carlo simulation results of this study show that this approach is more reliable than existing approaches for state estimation using measurements with unknown time delays.

TC2 Hilo

Identification II (Regular Session)

Chair: Diepolder, Johannes — Tech. Univ. of Munich
Co-Chair: Adachi, Shuichi — Keio Univ

16:00-16:20 TC2.1

System Identification and State Estimation under Lebesgue Sampling: Use of Inter-Sample Information, pp. 1408-1413

Kawaguchi, Takahiro — Keio Univ
Inoue, Masaki — Keio Univ
Maruta, Ichiro — Kyoto Univ
Adachi, Shuichi — Keio Univ

In conventional system identification and state estimation problems, it is commonly assumed that the output signal of a dynamical system is sampled at every regular time interval. This paper addresses the identification and estimation problems under the Lebesgue sampling, which is a type of eventtriggered sampling such that the output signal is sampled only when it crosses a specific threshold. In this paper, it is assumed that the output signal is sampled under the Lebesgue sampling rule. Then, the time interval between two samples possesses information such that the signal crosses none of the thresholds during the interval. The inter-sample information plays a key role to improve the accuracy of modeling and estimation. The problems utilizing the information are formulated. We propose likelihood-based methods of both system identification and state estimation to solve the problems. The effectiveness of the methods are illustrated in numerical examples.

16:20-16:40 TC2.2

Efficient PSO-Based Algorithm for Parameter Estimation of McKibben PAM Model, pp. 1414-1419

Okabe, Atsushi — The Univ. of Electro-Communications
Ishikawa, Takahiro — The Univ. of Electro-Communications
Kogiso, Kiminao — The Univ. of Electro-Communications
Nishiyama, Yu — The Univ. of Electro-Communications

This study considers the parameter estimation problem for an elaborate nonlinear hybrid model of a McKibben pneumatic artificial muscle (PAM) actuated by a proportional-directional control valve and proposes an efficient particle-swarm-optimization-based algorithm to find adequate model parameters in terms of model accuracy and computation time. A novel approach to making an algorithm more efficient is to focus on the parameter space of the PAM model and to use a support vector machine (SVM) to specify a subset in the parameter space. The inertia of the PSO algorithm is erased to the extent that the particles are allowed to search intensively in the subset region. Furthermore, this study validates the efficiency of the proposed algorithm using three different practical PAM products.

16:40-17:00 TC2.3

A Novel Zonotope-Based Set-Membership Identification Approach for Uncertain System, pp. 1420-1425

Wang, Di — Southeast Univ. School of Energy and Environment
Wu, Xiao — Southeast Univ
Pan, Lei — Southeast Univ
Shen, Jiong — Southeast Univ
Lee, Kwang Y. — Baylor Univ

As a Minkowski summation of several linear segments in the real space, zonotopes have been widely used in set-membership identification (SMI) for uncertain system because of its advantages, such as higher accuracy, compactness of representation and less complexity. A new SMI approach is proposed in this paper to develop a control oriented model based on zonotope, with which complex

mathematical calculation of feasible system set (FSS) can be avoided. The main contributions of this work are that we obtain a zonotope-based uncertainty model in an iterative form, via minimizing a new criterion representing the accuracy of the nominal model and the size of uncertainty. To circumvent the problem that the order of identified zonotope increases persistently during iteration and to reduce the computational effort, a novel approach is proposed to keep the order of zonotope constant without losing optimality, which is a contrast to the conventional approach that reduces the order after performing the optimization. The proposed zonotope-based SMI approach can be directly extended for multi-input multi-output (MIMO) system identification using decomposition-composition rule. The effectiveness of the proposed approach is demonstrated by two illustrative examples.

17:00-17:20 TC2.4

Experimental Study on Sparse Modeling of a Diesel Engine Air Path System, pp. 1426-1431

Shimizu, Kazuhiro — Graduate School of Informatics, Kyoto Univ
Nakada, Hayato — Toyota Motor Corp
Kashima, Kenji — Kyoto Univ

Toward model-based development of automotive engines, it is crucial to develop an effective method to construct their accurate and low-complexity models. In this paper, we conduct an experimental study on sparse modeling of a diesel engine air path system. First, we apply two standard methods and examine their trade-offs; the Gaussian process regression that can provide a confidence interval; the l1-regularized regression that can reduce the number of basis functions. Next, we attempt to take advantages of both methods via the so-called Relevant Vector Machine.

17:20-17:40 TC2.5

Optimal Control Based Flight Control Law Testing with Parameter Uncertainties, pp. 1432-1437

Diepolder, Johannes — Tech. Univ. München
Göttlicher, Christoph — Tech. Univ. München
Grüter, Benedikt — Tech. Univ. München
Akman, Tugba — Tech. Univ. München
Holzapfel, Florian — Tech. Univ. München
Ben-Asher, Joseph Z. — Tech. Univ. München

In the present paper we investigate a novel approach for optimal control based testing of flight control laws with respect to worst case pilot inputs, disturbances, such as wind gusts, and worst case parameter combinations. For the latter we consider parameters with fixed bounds, such as aircraft mass and statistically distributed parameters for the aerodynamic data set. In order to determine appropriate bounds on the statistically distributed parameters, first a maximum likelihood estimation problem is solved, utilizing measurements obtained via flight tests. This yields estimates of the considered parameters' mean and covariance matrix. Based on these quantities, the admissible set of the uncertain parameters for flight control law testing is then constrained to the respective 95% confidence region. This allows for the consideration of uncertainty due to the estimation algorithm by excluding unlikely parameter values in the optimal control problem. Furthermore, pilot inputs, wind gusts and parameters with fixed bounds are introduced as optimization variables. The approach is illustrated by testing the Angle-of-Attack protection of a modern twin engine aircraft w.r.t. worst case pilot load factor commands, wind gusts, and parametric uncertainties.

17:40-18:00 TC2.6

Selection of Residual Generators in Structural Analysis for Fault Diagnosis Using a Diagnosability Index, pp. 1438-1445

Rizzoni, Giorgio — Ohio State Univ
Zhang, Jiyu — Ohio State Univ

Structural analysis for fault detection and isolation (FDI) is an efficient method for designing structured residual generators for model-based diagnosis. It generates a number of diagnostic test candidates, whose number may be large in case of complex systems. This paper proposes a method for selecting residual generators from a possibly large number of candidate equation sets using a diagnosability index that measures the degree of diagnosability in a diagnostic system. The selection process of residual generators is aimed at reducing the solution sets for achieving the optimal diagnostic performance, i.e, maximizing the detectability and isolability of various faults. The approach for selecting residual generators is applied to a permanent magnet synchronous machine (PMSM) drive system in an electrified vehicle to show that the proposed methodology is effective in automatically downsizing the candidate equation sets for diagnostic tests from a relatively larger number of choices derived from the structural analysis algorithms.

TC3 Hamakua

Control Applications II (Regular Session)

Chair: Low, Chang Boon — DSO National Lab
Co-Chair: Schuster, Eugenio — Lehigh Univ

16:00-16:20 TC3.1

Tele-Rehabilitation System for Human Lower Limb Using Electrical Stimulation Based on Bilateral Teleoperation, pp. 1446-1451

Kawai, Yasunori — National Inst. of Tech. Ishikawa Coll
Honda, Kenya — National Inst. of Tech. Ishikawa Coll
Kawai, Hiroyuki — Kanazawa Inst. of Tech
Miyoshi, Takanori — Toyohashi Univ. of Tech
Fujita, Masayuki — Tokyo Inst. of Tech

This paper considers tele-rehabilitation system by using the electrical stimulation based on the bilateral teleoperation for a human lower limb. The tele-rehabilitation means that a physical therapist rehabilitates a patient who is away from the physical therapist. When the therapist cannot check the condition of the patient directly, the haptic interface is used to feel the condition by the haptic sense. And the therapist moves the patient's lower limb by using the electrical stimulation indirectly through the haptic interface. In this way, the system that both the therapist side and the patient side are controlled each other is called as the bilateral teleoperation. However, the time delays of the communication cause the instability for the bilateral teleoperation. First, the mathematical model of a human lower limb is considered by using the linearization, the phase-lead filter is designed. Next, the paddle system as a haptic interface is modeled, the feedback controller is proposed. The scattering transformations and wave filters are constructed. Finally, the proposed tele-rehabilitation system is verified with respect to the stabilization and the control performance in the simulation and the experiment. As a result, the stability is compensated, the position error between the paddle and human lower limb is small.

16:20-16:40 TC3.2

Design, Implementation, and Experimental Validation of a Cascaded Trajectory Tracking Controller for Nonholonomic Car-Like Wheeled Mobile Robots with Velocity and Steering Controllers in the Loops, pp. 1452-1459

Low, Chang Boon — DSO National Lab

This paper presents a cascaded trajectory tracking controller and a control gains selection procedure for nonholonomic car-like wheeled mobile robots with velocity and steering controllers in the tracking control loops. The trajectory tracking controller enables the mobile robots to stably follow the reference trajectories in the presence of the robot's velocity and steering control latencies. Also, the proposed tracking control solution provides a systematic approach to implementing the tracking controller onto the real car-like mobile robots without requiring any dynamical model of the robot's velocity and steering control systems. This feature avoids the need for ad-hoc

control parameters tuning when implementing the tracking controller. The trajectory tracking controller was validated in both simulations and experimentations. The tracking controller has been applied on a car-like pickup truck for experimentations in both on-road and off-road environments. The controller was tested up to the speed of 5.4m/sec in off-road environments. The obtained results confirm the effectiveness of the proposed tracking controller.

16:40-17:00 TC3.3

Central Safety Factor Control in DIII-D Using Neutral Beam Injection and Electron Cyclotron Launchers in Zero Input-Torque Scenarios, pp. 1460-1465

Pajares, Andres — Lehigh Univ
Schuster, Eugenio — Lehigh Univ

The tokamak is a torus-shaped machine whose final purpose is generating energy from nuclear fusion reactions. In order to achieve this goal, a reactant plasma is confined inside the tokamak by means of magnetic fields. For a tokamak to be commercially competitive, operation for long periods of time at high-performance operating points will be needed. Those high-performance scenarios are characterized by a steady-state, stable plasma operation in which the safety factor, a property of the plasma that measures the pitch of the magnetic field lines, plays a decisive role. In particular, control of the central safety factor, which is the value of the safety factor at the tokamak magnetic axis, is one of the crucial aspects to the success of tokamak devices due to its close relationship to magnetohydrodynamic stability. Therefore, control algorithms for the central safety factor in tokamaks will be required. In the present work, a linear controller is proposed for the regulation of the central safety factor using neutral beam injection and electron cyclotron launchers. This controller is designed to guarantee a zero input torque delivered by the neutral beam injection system. The controller performance is tested via a simulation study in a DIII-D scenario.

17:00-17:20 TC3.4

A Data-Driven Approach to Power Converter Control Via Convex Optimization, pp. 1466-1471

Nicoletti, Achille — École Pol. Fédérale De Lausanne
Martino, Michele — CERN
Karimi, Alireza — École Pol. Fédérale De Lausanne

A new model reference data-driven approach is presented for synthesizing controllers for the CERN power converter control system. This method uses the frequency response function (FRF) of a system in order to avoid the problem of unmodeled dynamics associated with low-order parametric models. For this particular application, it is shown that a convex optimization problem can be formulated (in either the H_∞ or H_2 sense) to shape the closed-loop FRF while guaranteeing the closed-loop stability. This optimization problem is realized by linearizing a non-convex constraint around a stabilizing operating point. The effectiveness of the method is illustrated by designing a controller for the SATURN power converter which is used in the Large Hadron Collider, in injector machines, and for pulsed applications at CERN. Experimental validation in the frequency-domain is also presented.

17:20-17:40 TC3.5

Robust & Anti-Windup Disturbance Feedback Control for Water Chiller Systems, pp. 1472-1479

Kawai, Fukiko — Aalborg Univ
Vinther, Kasper — Aalborg Univ
Andersen, Palle — Aalborg Univ
Bendtsen, Jan Dimon — Aalborg Univ

Disturbance Feedback Control (DFC) is a technique in which an existing controller is augmented with an additional loop. It was originally proposed by Fuji Electric in 1980, and has been applied in Factory Automation (FA). This paper proposes a robust DFC including the anti-windup controllers for process control. The proposed method is designed in two steps; firstly, the robust DFC without saturation is designed by Linear Matrix Inequality (LMI) approach, and then LMI technique are used again for stabilizing the closed loop system with anti-windup compensator. The simulation results for the water chiller system shows the improvements of control performances, and keeps stability of the system when the saturation blocks are introduced.

17:40-18:00 TC3.6

Suppression of Cable Suspended Parallel Manipulator Vibration Utilizing Input Shaping, pp. 1480-1485

Montgomery, Forrest — Univ. of Louisiana at Lafayette
Vaughan, Joshua — Univ. of Louisiana at Lafayette

Cable Suspended Parallel Manipulators (CSPMs) are a class of cable robots that are held in tension by the end-effector weight. Controlling the complex CSPM motion requires advanced knowledge of the equilibrium positions and the system dynamics. Additionally, the changing cable lengths alter the natural frequencies of the manipulator as it moves around the workspace. This paper presents the modeling and control of a large scale CSPM with an extendable end-effector. The dominant dynamics were used to design a control system to limit the end-effector vibration. The simulated results are compared to a full-scale experimental setup to verify the key findings.

TC4 — Kohala

Process Control (Regular Session)

Chair: Al-Dabbagh, Ahmad — Univ. of Alberta
Co-Chair: Bouslikhane, Salim — Univ. of Lorraine

16:00-16:20 TC4.1

Pairwise Discriminate Analysis Based Minimax Probability Machine (PDA-MPM) Approach for Fault Diagnosis, pp. 1486-1491

Jiang, Benben — Beijing Univ. of Chemical Tech
Guo, Zhifeng — Beijing Univ. of Chemical Tech
Zhu, Qunxiong — Beijing Univ. of Chemical Tech

Fault diagnosis is crucial to maintain safe and efficient operations of industrial processes. In this paper, a minimax probability machine (MPM) approach based on the framework of probabilistic representations is put forward for diagnosing process faults, without imposing any assumptions on data distributions. Moreover, a technique of pairwise discriminate analysis is incorporated to handle the classification of multiple faulty datasets. In addition to the enhanced handling of imbalanced distribution of datasets, the proposed MPM-based approach can also bring the benefits for fault diagnosis, owning to the utilization of an objective function in the form of summation of the pairwise separation probabilities between each pair of faulty datasets. The effectiveness of the proposed approach is demonstrated on the benchmark of Tennessee Eastman process.

16:20-16:40 TC4.2

Convergent Cross Mapping (CCM) Based Approach for Isolating the Source of Plant-Wide Disturbances, pp. 1492-1498

Aftab, Muhammad Faisal — Norwegian Univ. of Sci and Tech
Hovd, Morten — Norwegian Univ. of Sci and Tech
Sivalingam, Selvanathan — Norwegian Univ. of Sci and Tech

Disturbances originating in one control loop of a large industrial plant can propagate far from the source, giving rise to plant-wide oscillations. The underlying interactions among the different control loops make it hard to identify the origin of such large scale disturbances. This paper studies the application of the convergent cross mapping (CCM) based technique to isolate the source of a plant-wide disturbance. The proposed scheme exploits the cause and effect relationships among the affected variables to find the source of disturbance. The states of the causative factors are estimated from the effect variable and the directionality of information flow is established using the correlation between the original and estimated signal. The method is applied to the industrial case study and is

shown to be effective in isolating the disturbance origin.

16:40-17:00 TC4.3

Virtual Inflow Monitoring for a Three Phase Gravity Separator, pp. 1499-1504

Backi, Christoph Josef — Norwegian Univ. of Science and Tech

Skogestad, Sigurd — Norwegian Univ. of Science and Tech

This paper presents a virtual monitoring approach for a gravity separator. It is used to separate the three phases oil, water and gas. The monitored variables are thereby the gaseous and liquid inflows as well as the effective split ratio of oil and water entering the continuous water phase. Measurements for these variables are either expensive, unreliable or even impossible to take (as for the split ratio). Therefore, an Extended Kalman Filter is designed, which can estimate the inflows and the split factor based on a model of the dynamic system. The performance is shown in simulations, where the gravity separator's states are controlled by PI controllers.

17:00-17:20 TC4.4

Practical Evaluation of a Novel Multivariable Relay Autotuner with Short and Efficient Excitation, pp. 1505-1510

Berner, Josefin — Lund Univ

Soltesz, Kristian — Lund Univ

Astrom, Karl J. — Lund Univ

Hagglund, Tore — Lund Univ

In this paper we propose an autotuning method that combines a setup for decentralized relay autotuning of two-input two-output systems with an identification method that uses short experiments to estimate up to second-order time-delayed systems. A small modification of the experiment gives better low-frequency excitation and improved models. The method is successfully demonstrated in simulations and on a quadruple tank process.

17:20-17:40 TC4.5

An Optimal Integrated Maintenance for a Closed-Loop System under Carbon Emission Tax, N/A

Bouslikhane, Salim — Univ. of Lorraine

Zied, Hajej — Univ. De Metz

Rezg, Nidhal — Univ. of Lorraine

An optimal integrated maintenance under environmental concerns is proposed for a manufacturing and remanufacturing system. The production system is composed by a principal unit producing a single type of product and subjected to random failures and a second machine for remanufacturing the returned products. The aim of this paper is to propose an optimal production and maintenance strategies under the emission carbon constraint. Taking into account the correlation of the manufacturing unit with its production rates and the definite maintenance planning of the remanufacturing unit, we determine the ideal production plans of both units as well as the emission carbon quantities and the optimal plan of maintenance by minimizing the total cost of production, inventory, Carbone emission and maintenance.

17:40-18:00 TC4.6

Fractional Order Modeling and Control of a Smart Beam, pp. 1517-1523

Muresan, Cristina-Ioana — Tech. Univ. of Cluj-Napoca

Folea, Silviu — Tech. Univ. of Cluj-Napoca

Birs, Isabela — Tech. Univ. of Cluj-Napoca

Ionescu, Clara — Ghent Univ

Smart beams are one of the most frequently used means of studying vibrations in airplane wings. Their mathematical models have been so far solely based on classical approaches that ultimately involve integer order transfer functions. In this paper, a different approach towards modeling such smart beams is considered, an approach that is based on fractional calculus. In this way, a fractional order model of the smart beam is obtained, which is able to better capture the dynamics of the system. Based on this novel fractional order model, a fractional order PD^mu controller is then tuned according to a set of three design constraints. This design leads to a closed loop system that exhibits a much smaller resonant peak compared to the uncompensated smart beam system. Experimental results are provided, considering both passive and active control responses of the smart beam, showing that a significant improvement of the closed loop behavior is obtained using the designed controller.

TC5 Ballroom I

UAS/UAV Control Systems Complexity (Invited Session)

Chair: Chong, Edwin K. P. — Colorado State Univ

Co-Chair: Krakow, Lucas W. — Colorado State Univ

Organizer: Krakow, Lucas W. — Colorado State Univ

Organizer: Chong, Edwin K. P. — Colorado State Univ

16:00-16:20 TC5.1

Autonomous UAV Control: Balancing Target Tracking and Persistent Surveillance (I), pp. 1524-1529

Krakow, Lucas W. — Colorado State Univ

Chong, Edwin K. P. — Colorado State Univ

Persistent surveillance and target tracking are often accomplished through the use of unmanned aerial vehicles (UAVs). In many scenarios both tasks are concurrently required, but are disparate in their area investigation techniques; surveillance requires global exploration, whereas tracking takes a local target-centric view. Thus, the two tend to require different actions when controlling UAVs tasked with their respective objectives. We propose formulating the UAV control problem for concurrent surveillance and target tracking as a partially observable Markov decision process (POMDP) applying a Q-value approximation technique called nominal belief-state optimization (NBO). Using the Probability Hypothesis Density (PHD) filter as the tracking algorithm, we are able to exploit the birth-intensity components combined with non-myopic action selection inspiring the desired accompanying surveillance behaviors.

16:20-16:40 TC5.2

Robust UAV Path Planning Using POMDP with Limited FOV Sensor (I), pp. 1530-1535

Eaton, Christopher — Colorado State Univ

Chong, Edwin K. P. — Colorado State Univ

Maciejewski, Anthony A — Colorado State Univ

Significant development in path planning algorithms for unmanned aerial vehicles (UAVs) has been performed using numerous different methods. One such method, Partially Observable Markov Decision Processes (POMDP), has been used effectively for tracking fixed and moving targets. One limitation of those efforts has been the assumption that the UAVs could always see the targets, with a few unique exceptions, e.g., building obscuration. In reality, there will be times when a vehicle will not be able to observe a target due to constraints such as turn requirements or tracking multiple targets that are not within a single field of view (FOV). The POMDP formulation proposed in this paper is robust enough to handle those missed observations. Monte Carlo runs of 1000 iterations per configuration are run to provide statistical confidence in the performance of the algorithm. UAV altitude and sensor configuration are varied to show robustness across multiple configurations. A sensor with a limited FOV is assumed and changes in fixed look angle are evaluated. Changes in altitude provide results equivalent to changes in sensor window or focal length. Results show that the POMDP algorithm is capable of tracking single and multiple moving targets successfully with limited FOV sensors across a range of conditions.

16:40-17:00 TC5.3

Energy-Aware Aircraft Trajectory Generation Using Pseudospectral Methods with Differential Flatness (I), pp. 1536-1541

Mills, Andrew B. Univ. of Colorado Boulder
Kim, Daniel Univ. of Colorado Boulder
Frew, Eric W. Univ. of Colorado, Bolder

A path optimization strategy for generating energy-aware soaring trajectories for small Unmanned Aerial Systems (sUAS) is presented. Soaring paths are generated using a point-mass dynamics model and deterministic local wind field. The dynamics model, periodic constraints, and an energy-aware cost function are combined into a nonlinear program (NLP) framework to generate energy optimal paths. A dynamics model is derived which is differentially flat. This property, combined with a Legendre pseudospectral approximation facilitates the formulation of a novel and efficient energy-aware path planning optimization algorithm. The algorithm's ability to generate energy optimal trajectories is demonstrated for loiter and travel patterns in a linear wind gradient.

17:00-17:20 TC5.4

A Controller Design Framework for a NextGen Circulation Control Based UAV (I), pp. 1542-1549

Michailidis, Michail Univ. of Denver
Agha, Mohammed Univ. of Denver
Kanistras, Konstantinos Univ. of Denver
Rutherford, Matthew Univ. of Denver
Valavanis, Kimon Univ. of Denver

Circulation Control (CC) is an active flow blowing technique that can be used on small scale fixed-wing Unmanned Aerial Vehicles (UAVs) to enhance lift and aerodynamic efficiency, resulting in enhanced payload capabilities. This paper presents a novel, newly introduced controller design for what could be the next generation UAV, the Unmanned Circulation Control Aerial Vehicle (UCCAV). Controller design for the UCCAV is a challenging task mainly due to the unknown effect of the CC system on the aircraft flight dynamics. This challenge is tackled by using and implementing mu-Analysis and additive uncertainty weighting functions. The general control system architecture of the UCCAV consists of two parts: a dynamic inversion inner-loop control law and a mu-synthesis outer- loop controller. Preliminary results for the proposed control scheme show that the technique can be used for efficient tracking of desired reference signals.

17:20-17:40 TC5.5

Robust Hybrid Control for Swinging-Up and Balancing an Inverted Pendulum Attached to a UAV (I), pp. 1550-1555

Hintz, Christoph Univ. of New Mexico
Ahmad, Shakeeb Univ. of New Mexico
Kloeppel, Joseph Univ. of New Mexico
Fierro, Rafael Univ. of New Mexico

The problem of balancing a flying inverted pendulum on an unmanned aerial vehicle (UAV) has been solved using linear and nonlinear control approaches. However, to the best of our knowledge, the problem of swinging-up a flying pendulum has not been addressed in the literature. In this paper, we solve the general problem of swinging-up and balancing an inverted pendulum attached to a quadrotor using robust hybrid control approaches. Moreover, we take advantage of the quadrotor dynamics and show that this system can be implemented without any modifications to a universal (i.e., linear and rotary) inverted pendulum. We demonstrate the performance of the proposed controller through a set of realistic simulation studies.

17:40-18:00 TC5.6

Edge Potential Residuals in Low-Complexity Aggregation Behaviors, pp. 1556-1561

Pierpaoli, Pietro Univ. of Miami
Vu, Thanh Univ. of Miami
Rahmani, Amir Jet Propulsion Lab

In multiagent robotics, formation control problems usually address the maintenance of inter-agent distances equal to a set of predefined values. This problem requires either agents to be distinguishable or some combinatorial optimization to be solved in order to find the most convenient target-to-agent assignment. However, in many applications or mission stages, group connectivity and collision free trajectories are in fact the only desired requirements, while the robots themselves are allowed to freely generate their spatial distribution. To this end, the simplest possible case corresponds to all agents trying to maintain the same relative scalar distance. However, since it is not possible to have more than d+1 equally separated points in a d-dimensional space, we investigate solutions where inter- agent distances are as close as possible to desired one. We introduce a quadratic potential proportional to the error from the desired distance and equilibrium with non-null potentials are investigated. Stability of the behavior resulting from our protocol is described using elements from rigidity theory and final results are presented in form of numerical simulations.

TC6 Ballroom II

Systems and Control Methods for Smart Cities - from Mobility to Social Networks (Invited Session)

Chair: Cassandras, Christos G. Boston Univ
Co-Chair: Su, Rong Nanyang Tech. Univ
Organizer: Cassandras, Christos G. Boston Univ
Organizer: Su, Rong Nanyang Tech. Univ

16:00-16:20 TC6.1

Supervisory Control Synthesis for a Waterway Lock (I), pp. 1562-1568

Reijnen, Ferdie Eindhoven Univ. of Tech
Goorden, Martijn Angelo Eindhoven Univ. of Tech
van de Mortel-Fronczak, Joanna Eindhoven Univ. of Tech
Rooda, J.E. Eindhoven Univ. of Tech

Formal methods help in coping with the growing functionality and complexity, time-to-market and costs in cyber-physical systems (CPSs). Supervisory control synthesis (SCS) is such a method. It can be used to synthesize a controller for a CPS from the uncontrolled system model (plant) and the specification model (requirements). While SCS is an active research topic, reports on industrial applications are rare. In this paper, we show the applicability of SCS to the design of controllers for waterway locks. The following steps in the development process are discussed: modeling the plant and the requirements, synthesizing the supervisor, validating the supervisor, generating a real-time controller and implementing this controller on a PLC. Following this way of working, a supervisory controller for a real waterway lock has been successfully developed and analyzed. The real-time controller is implemented in an experimental set-up. The state-space size of the uncontrolled plant is 6.0x10^32 and the number of state-based requirements involved in the specification is 234. The synthesized controller is automatically translated into 1.2x10^4 lines of structured text, executable by a PLC. This case study delivers a proof of concept for the applicability of the procedure for supervisor synthesis and automatic PLC code generation to industrial-size systems.

16:20-16:40 TC6.2

On the Modeling of Neural Cognition for Social Network Applications (I), pp. 1569-1574

Wei, Jieqiang — Royal Inst. of Tech
Wu, Junfeng — Royal Inst. of Tech
Molinari, Marco — Royal Inst. of Tech
Cvetkovic, Vladimir — Royal Inst. of Tech
Johansson, Karl H. — Royal Inst. of Tech

In this paper, we study neural cognition in social network. A stochastic model is introduced and shown to incorporate two well-known models in Pavlovian conditioning and social networks as special case, namely Rescorla-Wagner model and Friedkin-Johnsen model. The interpretation and comparison of these model are discussed. We consider two cases when the disturbance is independent identically distributed for all time and when the distribution of the random variable evolves according to a markov chain. We show that the systems for both cases are mean square stable and the expectation of the states converges to consensus.

16:40-17:00 TC6.3

Vehicle-In-The-Loop (VIL) Verification of a Smart City Intersection Control Scheme for Autonomous Vehicles (I), pp. 1575-1580

Fayazi, S. AliReza — Clemson Univ
Vahidi, Ardalan — Clemson Univ

In this paper, an implementation of a traffic management scheme is presented for autonomous vehicles at intersections. Using bi-directional communication provided by a cellular network, the intersection controller is capable of receiving the status of the approaching vehicles, calculating an optimal arrival schedule, and sending the obtained schedule to individual vehicles. The proposed algorithm eliminates the need for physical traffic signals in an all autonomous driving environment. A vehicle-in-the-loop (VIL) simulation environment is implemented in order to evaluate our proposed traffic management scheme in reducing stops and energy consumption while ensuring safety. The test environment is configurable and reproducible to incorporate most of the real time signal control methods. This environment can assist the developers to validate their smart city projects.

17:00-17:20 TC6.4

Modelling and Traffic Signal Control of a Heterogeneous Traffic Network with Signalized and Non-Signalized Intersections (I), pp. 1581-1586

Zhang, Yicheng — Nanyang Tech. Univ
Su, Rong — Nanyang Tech. Univ
Sun, Chunyang — Nanyang Tech. Univ
Zhang, Yi — Nanyang Tech. Univ

An urban traffic system is a heterogeneous system, which consists of different types of intersections and dynamics. In this paper, we focus on one type of heterogeneous traffic network, which consists of signalized intersections and nonsignalized ones, where in the latter case vehicles usually follow the first-come-first-serve (FCFS) principle. We propose a novel model describing the dynamic behaviors of such a system and validate it via simulations in VISSIM. Upon such a new model, a signal control problem for a heterogeneous traffic network is formulated as a mixed integer programming problem. Comparisons between a homogeneous traffic system and a heterogeneous one are provided, which leaves the door open for developing a systematic planning approach on deciding what traffic intersections require signal control to ensure a good traffic control performance, thus, have a great social and economic potentials, considering that it is rather expensive to introduce signal control in an urban area.

17:20-17:40 TC6.5

A Receding Horizon Routing Controller for Inventory Replenishment Agents in Bike Sharing Systems with Time-Varying Demand (I), pp. 1587-1592

Swaszek, Rebecca — Boston Univ
Cassandras, Christos G. — Boston Univ

A Bike Sharing System (BSS) may be modeled as a graph with two node types: stations with finite bike inventory subject to time-varying demand and intersections to represent the underlying transportation network. Mobile agents (replenishment trucks) travel on the arcs of the graph to reset station inventories and make routing decisions at intersections. One-way rides create inventory imbalances across the system. Inventory control via rebalancing trucks has two main facets: selecting the number of bikes to load/unload between the truck and a station and routing decisions for the truck based on daily demand patterns. This paper focuses on the latter and introduces a Receding Horizon Controller which minimizes a user dissatisfaction metric defined as the expected number of users unable to rent or return a bike due to a station being empty or full, respectively. We model stations as M/M/1/K queues subject to time-varying birth and death rates based on the time of day. The controller proceeds in an event-driven manner and determines at each event the optimal routes over a finite planning horizon, with the control applied over a shorter action horizon. The proposed controller is applied to a simulated BSS with station and demand parameters extracted from the data sets of Hubway, the BSS in Boston MA.

17:40-18:00 TC6.6

Traffic Light Scheduling for Pedestrians and Vehicles (I), pp. 1593-1598

Zhang, Yi — Nanyang Tech. Univ
Su, Rong — Nanyang Tech. Univ
Gao, Kaizhou — Nanyang Tech. Univ
Zhang, Yicheng — Nanyang Tech. Univ

This paper presents a traffic signal scheduling strategy with consideration of both pedestrians and vehicles in the urban traffic system. Firstly, a novel mathematical model consisting of several logic constraints is proposed to describe the pedestrian flow in the urban traffic network and its dynamics are developed based on the crossing rules. Secondly, a mathematical model about the vehicle traffic network is introduced. Thirdly, a traffic light scheduling strategy to minimize the trade-off of the delays between pedestrians and vehicles is proposed. Finally, we translate this traffic signal scheduling problem to a mixed integer quadratic programming (MIQP) problem which can be solved by several existing tools, e.g., GUROBI. Numerical simulation results are provided to illustrate the effectiveness of our real-time traffic light scheduling for pedestrian movement and the potential impact to the vehicle traffic flows by the pedestrian movement.

TC7 Ballroom III

Software and Computational Methods (Regular Session)

Chair: Rutten, Eric — INRIA Grenoble - Rhone-Alpes

Co-Chair: Bhattacharyya, Shankar P. — Texas A & M Univ

16:00-16:20 TC7.1

Logico-Numerical Control for Software Components Reconfiguration (I), pp. 1599-1606

Berthier, Nicolas — Univ. of Liverpool

Alvares, Frederico — IMT Atlantique, LS2N, Inria

Marchand, Herve — INRIA Rennes - Bretagne Atlantique

Delaval, Gwenaël — LIG/Univ. Joseph Fourier

Rutten, Eric — INRIA Grenoble - Rhone-Alpes

We target the problem of the safe control of reconfigurations in component-based software systems, where strategies of adaptation to variations in both their environment and internal resource demands need to be enforced. In this context, the computing system involves software components that are subject to control decisions. We approach this problem under the angle of Discrete Event Systems (DES), involving properties on events observed during the execution (e.g., requests of computing tasks, work overload), and a state space representing different configurations such as activity or assemblies of components. We consider in particular the potential of applying novel logico-numerical control techniques to extend the expressivity of control models and objectives, thereby extending the application of DES in component-based software systems. We elaborate methodological guidelines for the application of logico-numerical control based on a case-study, and validate the result experimentally.

16:20-16:40 TC7.2

Constrained Multi-Objective Nonlinear Optimization for Tuning a Helicopter Controller, pp. 1607-1612

Bichlmeier, Magnus — Tech. Univ. of Munich

A helicopter controller with a large number of tuning variables is presented. To automate the tuning process at least partially, a nonlinear optimization procedure is suggested, which is designed to be compatible to noisy data from real flight tests. This involves the definition of a cost function based on desired and real frequency responses of the helicopter to satisfy multiple simultaneous objectives. For minimizing the value of this cost function, an exemplary sequence of quadratic programming and an exemplary evolutionary algorithm are shown.

16:40-17:00 TC7.3

Planning Near Time-Optimal Trajectories in 3D, pp. 1613-1618

Mayer, Annika — Univ. of Stuttgart

Sonntag, Marcus Christian — Univ. of Stuttgart

Sawodny, Oliver — Univ. of Stuttgart

In context of human-machine-interaction trajectories need to be rerouted or re-planned with reduced dynamical constraints in order to avoid collisions. This requires online feasible algorithm for trajectory planning in space. In this paper a new method for planning time-optimal trajectories subject to dynamic and geometrical constraints is proposed. Distinctively to other work, both spatial and temporal variables are subject to optimization. Further the optimization can be performed on the fly and the computational complexity increases only linear with respect to the total number of waypoints. The dynamic constraints are deduced from safety concerns, it is assumed that those limits are stricter than those originating from the limits of the robot's dynamic, which are therefore neglected. The proposed concept relies on two components, on one hand a projection module which reduces the N-point trajectory planning problem in space to a sequence of 3-point problems in a plane and on the other hand a nonlinear two-phase model predictive control problem to solve the simplified sub-problems. A proof-of-concept shows that trajectories can be planned for a wide range of dynamical constraints in reasonable calculation times.

17:00-17:20 TC7.4

Computationally Efficient Velocity and Power Split Control of Hybrid Electric Vehicles, pp. 1619-1624

Uebel, Stephan — Tech. Univ. Dresden

Murgovski, Nikolce — Chalmers Univ. of Tech

Tempelhahn, Conny — Tech. Univ. Dresden

Bäker, Bernard — Tech. Univ. Dresden

An assessment study is presented for online optimal control of hybrid electric vehicles (HEV), based on the Pontryagin's Maximum Principle. A parallel HEV is used as an example, where states in the optimal control problem are the electric energy storage, kinetic energy and travel time. The solution quality and computational effort of the proposed method are assessed by comparing the results with a benchmark method that yields optimal performance. It is illustrated that the proposed method yields a good solution by solving the optimal control problem over 50 times faster than the benchmark method. Additionally, the novel approach brings up to 16 % decline in fuel consumption compared to a simple velocity trajectory which a human driver would choose.

17:20-17:40 TC7.5

Motion Planning with Invariant Set Trees, pp. 1625-1630

Weiss, Avishai — Mitsubishi Electric Res. Labs

Danielson, Claus — Mitsubishi Electric Res. Labs

Berntorp, Karl — Mitsubishi Electric Res. Labs

Kolmanovsky, Ilya V. — Univ. of Michigan

Di Cairano, Stefano — Mitsubishi Electric Res. Labs

This paper introduces the planning algorithm SafeRRT, which extends the rapidly-exploring random tree (RRT) algorithm by using feedback control and positively invariant sets to guarantee collision-free closed-loop path tracking. The SafeRRT algorithm steers the output of a system from a feasible initial value to a desired goal, while satisfying input constraints and non-convex output constraints. The algorithm constructs a tree of local state-feedback controllers, each with a randomly sampled reference equilibrium and corresponding positively invariant set. The positively invariant sets indicate when it is possible to safely transition from one local controller to another without violating constraints. The tree is expanded from the desired goal until it contains the initial condition, at which point traversing the tree yields a dynamically feasible and safe closed-loop trajectory. We demonstrate SafeRRT on a spacecraft rendezvous example.

17:40-18:00 TC7.6

A New Formula for the Characteristic Equation of a Matrix with Applications, pp. 1631-1636

Keel, Lee — Tennessee State Univ

Oliveira, Vilma A. — Univ. De Sao Paulo

Bhattacharyya, Shankar P. — Texas A & M Univ

In this paper, we develop a new formula for the characteristic equation of a matrix A explicitly and directly in terms of the elements of A. This contrasts with existing methods such as Leverrier's algorithm which is iterative and eigenvalue computation based methods which cannot be applied to matrices with unknown parameters. The formula is applied here to derive explicit stability conditions in terms of the matrix elements for continuous and discrete time systems. It is also shown how the characteristic equation of time-delay systems may be determined. It is expected that the formula will have myriad other uses in control theory and computational linear algebra. Illustrative application examples are included,

Technical Program for Wednesday August 30, 2017

WP1	Hale Hoaloha Pavilion
Connected and Automated Vehicle and Powertrain Control Technologies to Achieve Unprecedented Fuel Economy Gains (Plenary Session)	
Chair: Yurkovich, Stephen	Univ. of Texas at Dallas
Co-Chair: Rotea, Mario	Univ. of Texas at Dallas

08:30-09:30 WP1.1

*Connected and Automated Vehicle and Powertrain Control Technologies to Achieve Unprecedented Fuel Economy Gains**

Rizzoni, Giorgio — Ohio State Univ.

WA1	Puna
Power Systems (Regular Session)	
Chair: Nguyen, Dinh Hoa	Kyushu Univ
Co-Chair: Wang, Jianan	Beijing Inst. of Tech

10:00-10:20 WA1.1

Mitigation of Active and Reactive Demand Response Mismatches through Reactive Power Control Considering Static Load Modeling in Distribution Grids, pp. 1637-1642

Bajool, Reza — Isfahan Univ. of Tech
Shafie-khah, Miadreza — C-MAST/UBI
Shokri Gazafroudi, Amin — Univ. of Salamanca
Catalao, Joao — Univ. Porto

Demand response is known as one of the basic components of smart grids that plays an important role in shaping load curves. In most of the prior reports on applying demand response programs, reactive power and load dependency to voltage magnitude have been ignored in distribution grids. In this paper, firstly, we show that the ignorance of the mentioned phenomena can cause a mismatch between the expected value of demand response and the experimental value. This mismatch is known as the demand response mismatch (DRM), which is dependent on some parameters such as load type, load reduction percentage, and network power factor. To overcome this problem, this paper presents a reactive power control model. In addition, a mixed integer nonlinear program is proposed to find the optimal size and location of STATCOMs and the optimal transformer tap settings that minimize the DRM. In this paper, the 16-bus U.K. generic distribution system (UKGDS) is employed to prove the capability of the presented method in DRM reduction.

10:20-10:40 WA1.2

Transformer Monitoring Using Kalman Filtering, pp. 1643-1648

Shastri, Subramanian — Univ. of San Diego
Stewart, Emma — Lawrence Berkeley Lab
Roberts, Ciaran — LBL

In this paper, we present a systems-theoretic approach to real-time in-situ monitoring of operating transformers. The most significant and novel result is the estimation of partial discharge buildup in transformers. In addition, it is capable of calculating secondary side power factor, and detecting voltage fluctuations, reactive buildup and core saturation. The paper discusses critical design considerations such as sampling time, model excitation, and system order

Concerns regarding power quality, reliability and resilience are increasing in the distribution grid with the injection of power from renewables. The algorithm presented here could help mitigate these by continuously monitoring transformer health and performance during operation.

10:40-11:00 WA1.3

Optimal Distributed Coordination Control of Multiple Photovoltaic Generators in Distribution Networks, pp. 1649-1654

Wang, Jianan — Beijing Inst. of Tech
Shan, Jiayuan — Beijing Inst. of Tech

In this paper, a class of coordination control problems of power system in distribution networks is addressed. The multiple photovoltaic generators (PVs) in network are expected to be operated in a certain level, namely Fair Utilization, in order to provide reliable power of high quality. In other words, the occupancy ratios of all PVs that are determined by the current active and reactive power outputs in terms of the capacities of each PV, are required to be driven to a specified reference level. Towards this end, a totally distributed, analytical and optimal coordination strategy is proposed to achieve this goal. Comparing with the existing approaches, the distinct merit of the proposed algorithm is the sense of optimality, which really minimizes the control effort. In addition, an inverse optimal control method is elegantly adopted for this coordination control formulation and the rigorous proof of stability as well as optimality are explicitly provided. In the end, a radial distribution network simulation is carefully elaborated and the validity of proposed algorithm is examined as well.

11:00-11:20 WA1.4

A Lyapunov Approach for Transient Stability Analysis of Droop Inverter-Based Mesh Microgrids Using Line-Based Model, pp. 1655-1660

Nguyen, Dinh Hoa — Kyushu Univ
Tran, Ngoc Huynh — Toyota Tech. Inst
Kawanishi, Michihiro — Toyota Tech. Inst
Narikiyo, Tatsuo — Toyota Tech. Inst

This paper proposes a systematic approach to derive analytical and explicit certificates for transient stability analysis of inverter-based microgrids. We first derive a line-based model of microgrids with general mesh structure. Then by employing Lyapunov stability theory with a quadratic Lyapunov function, the region of attraction of any post-fault stable equilibrium point (EP) is estimated by a large domain which contains the the well-known principle region inside, if a low-dimension convex LMI problem is feasible. Accordingly, it provides a very efficient and robust transient stability certificate which can be calculated off-line, easily, and very fast. Moreover, it can be applied to microgrids with any structure. Finally, numerous tests on a microgrid are then given to illustrate the effectiveness of the proposed approach.

WA2	Hilo
PID Control (Regular Session)	
Chair: Barbieri, Enrique	Univ. of North Texas
Co-Chair: Gambier, Adrian	Fraunhofer IWES

10:00-10:20 WA2.1

Stability Margin Based Design of Multivariable Controllers, pp. 1661-1666

Diaz-Rodriguez, Ivan, D. — Univ. Autonoma de Tamaulipas
Han, Sangjin — Texas A & M Univ
Bhattacharyya, Shankar P. — Texas A & M Univ

In this paper, we describe a new approach to the design of Multi-Input Multi-Output (MIMO) controllers which attain predesigned gain and phase margins. This is achieved by considering the Smith-McMillan form of the $n \times n$ plant transfer function with diagonal elements $P_i(s)$ designing Single-Input Single-Output (SISO) controllers $C_i(s)$ for the Smith-McMillan plants with corresponding loop gain margins g_i and phase margins ϕ_i, $i = 1, 2, ..., n$. Then it is shown that the MIMO controller can be recovered in such a way that the MIMO

system achieves gain and phase margins that are the minimum of gain margins and the minimum of phase margins of the scalar unity feedback Smith-McMillan loops. These results are then applied to the design of Proportional-Integral (PI) controllers where achievable gain and phase margins can be exactly quantified. The result is illustrated by examples.

10:20-10:40 WA2.2

Constrained PID Design & Implementation: A Co-Simulation Framework, pp. 1667-1672

Tzouanas, Vassilios Univ. of Houston - Downtown
Barbieri, Enrique Univ. of North Texas

A simulation environment is presented for tuning proportional-integral-derivative (PID) controllers that optimizes a performance criterion subject to various constraints. The tuning environment is cast under a simulation-based control design or co-simulation framework not requiring elaborate analytical optimization techniques or computing platforms; it is applicable to open loop stable or unstable processes; it is independent of the PID controller type; it accommodates controllers with proportional and/or derivative action on the error or process variable; and can be applied to the simultaneous tuning of PID controllers in a series or parallel cascade structure. The method can also account for robustness in response to modeling errors by including magnitude constraints on the nominal sensitivity function. Performance is demonstrated in simulation using Microsoft Excel and its Solver function in a Plug-and-Play approach. A PID design is applied to a two-tank level laboratory system to compare experimental results against the performance obtained from classical tuning methods.

10:40-11:00 WA2.3

Parametric PID Controller Tuning for a Fast Steering Mirror, pp. 1673-1678

Csencsics, Ernst Vienna Univ. of Tech
Schitter, Georg Vienna Univ. of Tech

Even though the design and tuning of proportional-integral-derivative (PID) controllers appears to be conceptually simple it can be difficult in practice, especially when competing control objectives are present. This paper presents a tuning method for PID controllers applied to low stiffness mechatronic systems that allows a direct and intuitive trade-off between the robustness and the performance of the resulting system. With the required system bandwidth typically determined by the targeted application and an according parametrization, the controller tuning is reduced to the selection of the cross-over frequency and the variation of a single parameter alpha. It is demonstrated how the alpha-value influences the resulting system properties, while a larger alpha increases robustness but also diminishes control quality. The tuning method is experimentally verified on a fast steering mirror (FSM) system by implementing controllers with alpha-values of 2, 3 and 4.5. It is shown that the settling time for alpha = 2 is 4-times smaller than for alpha = 4.5, when applied to the nominal plant. On the other hand the stability margins for alpha = 2 are also significantly smaller, diminishing robustness and increasing oscillating transients when plant uncertainties are present. An alpha-value of 3 yields a good trade-off between robustness and performance of the closed-loop operated system.

11:00-11:20 WA2.4

Simultaneous Design of Pitch Control and Active Tower Damping of a Wind Turbine by Using Multi-Objective Optimization, pp. 1679-1684

Gambier, Adrian Fraunhofer IWES

Collective pitch control (CPC) and active tower damping control (ATDC) are currently two standard control loops of practically all commercial large-sized, variable-speed, horizontal-axis wind turbines. Both control loops are highly coupled and therefore they perform in a contradictory manner: while an optimal CPC increases loads in the first fore-aft tower frequency, the ATDC damps these loads by modifying the pitch angle, i.e. detuning the CPC. Thus, the main problem is to find controller parameters that produce the best possible compromise between both controllers. In the current work, the controllers for CPC and ATDC are designed by using a cooperative game-theoretic approach, whose solution is found by using multi-objective parametric optimization. Simulation results show that the proposed method yields satisfactory performance for both control loops.

11:20-11:40 WA2.5

Laser Beam Pointing and Stabilization by Fractional-Order PID Control : Tuning Rule and Experiments, pp. 1685-1691

Al-Alwan, Asem King Abdullah Univ. of Science and Tech. (KAUST)
Guo, Xingang King Abdullah Univ. of Science and Tech. (KAUST)
N'Doye, Ibrahima King Abdullah Univ. of Science and Tech. (KAUST)
Laleg-Kirati, Taous-Meriem King Abdullah Univ. of Science and Tech. (KAUST)

This paper studies the problem of high-precision positioning of laser beams by using a robust Fractional-Order Proportional-Integral-Derivative (FOPID) controller. The control problem addressed in laser beams aims to maintain the position of the laser beam on a Position Sensing Device (PSD) despite the effects of noise and active disturbances. The FOPID controller is well known for its simplicity with better tuning flexibility along with robustness to noise and output disturbance rejections. Thus, a control strategy based on FOPID to achieve the control objectives has been proposed. The FOPID gains and differentiation orders are optimally tuned in order to fulfill the robustness design specifications by solving a nonlinear optimization problem. A comparison to the conventional Proportional-Integral-Derivative (PID) and robust PID is also provided from simulation and experiment set-up. Due to sensor noise, practical PID controllers that filter the position signal before taking the derivative have been also proposed. Experimental results show that the requirements are totally met for the laser beam platform to be stabilized.

WA3 Hamakua

Distributed Systems (Regular Session)

Chair: Stefanovic, Margareta Univ. of Denver
Co-Chair: Schmidt, Kevin Univ. of Stuttgart

10:00-10:20 WA3.1

Distributed Stabilization of Linear Multiagent Systems with Coupled State and Input Uncertainties, pp. 1692-1697

Rezaei, Vahid Univ. of Denver
Stefanovic, Margareta Univ. of Denver

Using graph-theoretic tools, distributed control algorithms have been widely designed to manage a cooperative task among a group of individual agents. However, when agents are physically interconnected, these algorithms do not guarantee stability of the closed-loop multiagent system. In this paper, we consider a class of interconnected linear multiagent systems with state- and input-coupled modeling uncertainties. We assume that only few agents have access to their local state information, and others only provide lumped relative-state information. We propose a robust stabilization problem for an interconnected multiagent system with state- and input-coupled modeling uncertainties. By adding a virtual leader, possibly unstable, we reformulate this stabilization task to a leader-follower tracking problem. Incorporating the graph theory, we propose a linear quadratic regulator-based approach and propose a sufficient condition to systematically address this problem. Finally, we verify the feasibility of our approach through a simulation study.

10:20-10:40 WA3.2

Observer Based Leader Following Consensus for Multi-Agent Systems with Random Packet Loss, pp. 1698-1703

Huang, Zipeng Dalhousie Univ
Pan, Ya-Jun Dalhousie Univ

This paper addresses the leader-follower consensus problem of multi-agent systems (MASs) consisting of general linear agents in the event of stochastic communication link failure over the network. Bernoulli process is applied to model the packet dropout during operation while the packet dropout in communication links are assumed to be asynchronous and independent. A distributed observer-type algorithm is proposed based on the sufficient conditions using Lyapunov-based method, linear matrix inequality (LMI) techniques and the separation principle. It is shown that the sufficient conditions can be decomposed into small conditions of same dimension as a single agent, provided that the followers are symmetrically connected, which leads to efficient solutions when considering consensus problem of a large group of high-order linear agents. Numerical simulations for groups of five double-integrator agents and three linearized quadcopter agents are conducted to demonstrate the effectiveness of the proposed algorithm.

10:40-11:00 WA3.3

A Distributed Dual Algorithm for Distributed MPC with Application to Urban Traffic Control, pp. 1704-1709

Camponogara, Eduardo Federal Univ. of Santa Catarina
Silva, Ricardo Santos Federal Univ. of Santa Catarina
de Aguiar, Marco Aurélio Schmitz Federal Univ. of Santa Catarina

A linear dynamic network (LDN) is a system of interconnected subsystems that are coupled through dynamics and constraints, which can model geographically distributed systems such as urban traffic networks. For model predictive control (MPC) of LDNs, a distributed dual algorithm is proposed for optimizing control signals over a prediction horizon. While a master problem updates Lagrangian multipliers and penalty factors for the constraints, a slave problem is decomposed into a set of distributed subproblems whose variables are constrained only in sign. In an application to green-time control of an urban traffic network, the distributed algorithm was shown to produce iterates converging to the optimum.

11:00-11:20 WA3.4

Distributed Algorithms for the Average Bridge Consensus, pp. 1710-1715

Mou, Shaoshuai Purdue Univ
Garcia, Eloy Air Force Res. Lab
Casbeer, David W. Air Force Res. Lab

By considering the existence of bridge sensor nodes that lose the capability of sensing, the average bridge consensus problem aims to achieve the average of selective observations only from sensing nodes while bridge nodes play the role of relaying information. We note that traditional average consensus algorithms achieve the global average of states from all nodes in the network, which are not directly applied here. In this paper we present two distributed algorithms for solving the bridge consensus problem on fixed-tree networks in finite time and a class of time-varying networks exponentially fast, respectively. Both theoretical and numerical results are provided for validations of the proposed algorithms.

11:20-11:40 WA3.5

Efficient Simulation of Semilinear Populations Models for Age-Structured Bio Reactors, pp. 1716-1721

Schmidt, Kevin Univ. of Stuttgart
Sawodny, Oliver Univ. of Stuttgart

In this contribution, we introduce an efficient simulation scheme for a class of hyperbolic dynamic systems, which model the age-structured evolution of a microorganism population in a bio reactor. Due to the non-local boundary condition and the semilinear transient behavior, standard methods like finite-differences do not lead to satisfactory results, even at high approximation orders. This gives rise to advanced simulation schemes: The presented algorithm utilizes the framework of weighted residuals and preserves crucial properties of the PDE system. For instance, we incorporate the steady state solution of the PDE system and guarantee a vanishing steady state approximation error – independent of the order.

11:40-12:00 WA3.6

Arctic Sea Ice Temperature Profile Estimation Via Backstepping Observer Design, pp. 1722-1727

Koga, Shumon Univ. of California, San Diego
Krstic, Miroslav Univ. of California, San Diego

Recent rapid loss of the Arctic sea ice motivates the study of the Arctic sea ice thickness. Global climate model that describe the ice's thickness evolution, require an accurate temperature profile of the Arctic sea ice. However, measuring the complete temperature profile is not feasible due to a limited number of thermal sensors. Instead, measuring the ice's thickness is doable based on the acquisition of data from submarine and satellite devices. In this paper, we develop a backstepping observer algorithm to estimate temperature profile for the Arctic sea ice model via available measurements of sea ice thickness, sea ice surface temperature, and temperature gradient at the ice-ocean interface. The observer is designed in a rigorous manner to drive the temperature profile estimation error to zero, for salinity-free sea ice model. Moreover, the proposed observer is used to estimate the temperature profile of the original sea ice model with salinity via numerical simulation. In comparison with the straightforward open-loop algorithm, the simulation results illustrate that our observer design achieves faster convergence of the estimated temperature.

WA4 Kohala

Uncertain Systems I (Regular Session)

Chair: Shafique, Md Ashfaque B Arizona State Univ
Co-Chair: Piprek, Patrick Tech. Univ. München - Inst. of Flight System Dynamics

10:00-10:20 WA4.1

Control Relevant System Identification Using Multiple Short Data Sets, pp. 1728-1733

Shafique, Md Ashfaque B Arizona State Univ
joshi, Rakesh Arizona State Univ
Tsakalis, Kostas Arizona State Univ

In this paper, we develop a data-driven model of a model-sized aircraft using system identification (SysID) techniques. The emphasis is placed on multiple short data records that are used in obtaining an initial model of the system. The records are “short” with respect to the length of a “typical” identification experiment and are necessary because of the unstable nature of the open-loop system. Owing to this, our formulation can also be applied to other systems that are highly non-linear or have external influences that act over relatively longer periods of time. The length of each record is at least an order smaller than what a full-length Pseudo-Random-Binary-Sequence (PRBS) sequence would require. For the model aircraft, the lengths are a second or less and are dictated by the length of time a “novice” operator could keep the aircraft in unconstrained flight. A set of decentralized PID controllers are then tuned using robust control techniques augmented with computation of control-relevant uncertainty estimates from data. The uncertainty, together with closed loop sensitivities serve as an essential metric to evaluate the utility of the obtained model. The designed controller showed acceptable stabilization properties for the aircraft in hover mode. A second iteration of SysID using longer data records from the initial stabilized system resulted in a controller with improved bandwidth and reference tracking. Results from the experiment are presented to illustrate the sequence of operations.

10:20-10:40 WA4.2

Optimization of Parameter Matrix : Optimal Output Feedback Control and Optimal PID Control, pp. 1734-1739

Shimizu, Kiyotaka Keio Univ

This paper concerns with optimizing gain matrices in static output feedback controller and PID controller. We first study on optimization of parameter matrix in general dynamical system. The gradient function of an objective functional with respect to the parameter matrix is derived and optimality condition is presented. Next, gain matrix optimization of static output feedback controller for nonlinear system and linear MIMO system is investigated. Then, we develop optimization method for PID controller and propose an algorithm to compute optimal gain matrices for the controller by the steepest descent method.

10:40-11:00 WA4.3

Simultaneous Perturbation Stochastic Approximation for Clustering of a Gaussian Mixture Model under Unknown but Bounded Disturbances, pp. 1740-1745

Boiarov, Andrei Saint Petersburg State Univ
Granichin, Oleg Saint Petersburg State Univ
Wenguang, Hou Huazhong Univ. of Science and Tech

Multidimensional optimization holds a central role in many machine learning problems. When a model quality functional is measured with an almost arbitrary external noise, it makes sense to use randomized optimization techniques. This paper deals with the problem of clustering of a Gaussian mixture model under unknown but bounded disturbances. We introduce a stochastic approximation algorithm with randomly perturbed input (like SPSA) to solve this problem. The proposed method is appropriate for the online learning with streaming data, and it has a high speed of convergence. We study the conditions of the SPSA clustering algorithm applicability and show illustrative examples.

11:00-11:20 WA4.4

Receding Horizon H-Infinity Guaranteed Cost Control for Norm-Bounded Uncertain Systems with Actuator Saturation, pp. 1746-1750

Zhong, Jiaqi Chongqing Univ
Liang, Shan Chongqing Univ
Xiong, Qingyu Chongqing Univ
Gao, Min Chongqing Univ
Wang, Kai Chongqing Univ

This paper investigates the receding horizon H_∞ guaranteed cost control for a class of norm-bounded uncertain systems subject to actuator saturation. A sufficient condition for the existence of the controller is proposed to handle the amplitudes of control input signals and guarantee both of the H_∞ norm and quadratic cost performance for all admissible uncertainties and external disturbances. Furthermore, the optimal receding horizon controller can be obtained by on-line solving a convex optimization problem with linear matrix inequalities (LMIs) constraints. The effectiveness of the proposed controller is demonstrated with a numerical example.

11:20-11:40 WA4.5

Robust Trajectory Optimization Combining Gaussian Mixture Models with Stochastic Collocation, pp. 1751-1756

Piprek, Patrick Tech. Univ. München - Inst. of Flight System Dyna
Holzapfel, Florian Tech. Univ. München

This paper presents a method for extending the generalized polynomial chaos method with stochastic collocation, so that expansion coefficients for further continuous distributions other than the standard distributions of the generalized polynomial chaos can be calculated. This is achieved by using Gaussian mixture models to approximate the desired arbitrary continuous input distribution. This incorporation of the Gaussian mixture models basically yields a repetitive solution of only Hermite-chaos problems. The developed method was applied to a time-optimal trajectory optimization problem for a fighter aircraft using the MATLAB-based toolbox, FALCON.m [1]. Within the generalized polynomial chaos stochastic collocation framework only the repetitive solution of standard, deterministic trajectory optimization problems at Gaussian quadrature nodes were required. This makes the stochastic collocation approach very efficient for carrying out robust trajectory optimizations. The developed framework was tested against a Jacobi-chaos problem, a multi-modal Gaussian distribution, and a Weibull distribution. The latter two were validated by comparing them to Latin-Hypercube-Sampling.

11:40-12:00 WA4.6

Chance Constraint Based Design of Input Shapers, pp. 1757-1762

Nandi, Souransu State Univ. of New York at Buffalo
Singh, Tarunraj State Univ. of New York at Buffalo

The focus of this paper is on the design of input shapers for systems with uncertainties in the parameters of the vibratory modes which need to be attenuated. A probabilistic framework is proposed for the design of the robust input shaper, when the uncertain modal parameters are characterized by probability density functions. A convex chance constrained optimization problem is posed to determine the parameters of input shapers (time-delay filter) which can accommodate the users acceptable risk levels for a prescribed residual energy threshold. Robust input shapers are developed for various compact support distributions to illustrate the ability of the proposed formulation to synthesize input shapers which can satisfy a residual energy threshold with a given risk level. This problem formulation can conceivably reduce the conservative nature of worst case controllers which have to ensure that all realizations of the uncertain system have to satisfy a prescribed performance index. The chance constrained input shaper is designed for a spring-mass-dashpot system with three different distributions for the uncertain spring stiffness. Results provide encouragement for the extension of the proposed approach to multi-dimensional and multi-model uncertainties.

WA5 Ballroom I

Mobile Robots (Regular Session)

Chair: Ben-Tzvi, Pinhas Virginia Tech
Co-Chair: Liu, Yen-Chen National Cheng Kung Univ

10:00-10:20 WA5.1

Maneuvering and Stabilizing Control of a Quadrupedal Robot Using a Serpentine Robotic Tail, pp. 1763-1768

Rone, William Virginia Tech
Ben-Tzvi, Pinhas Virginia Tech

This paper analyzes the control of a mobile robotic system that utilizes a serpentine robotic tail to assist in the maneuvering and stabilization of quadrupedal locomotion. The goal of this research is to reduce the design and control complexity required in the robot's legs by providing a separate mechanism to help the mobile robot steer and recover from disturbances. The design and dynamic models for a quadrupedal robotic platform's yaw, pitch and roll are presented, along with the design and dynamic model of the roll-revolute-revolute robotic tail (R3-RT). Dynamic tail configuration controllers are designed to enable different system functionalities, including yaw-angle turning and pitch/roll-angle stabilization. Case studies are simulated in MATLAB to demonstrate the proposed functionalities.

10:20-10:40 WA5.2

Realizing Simultaneous Lane Keeping and Adaptive Speed Regulation on Accessible Mobile Robot Testbeds, pp. 1769-1775

Xu, Xiangru — Univ. of Michigan
Waters, Thomas — Georgia Inst. of Tech
Pickem, Daniel — Georgia Tech
Glotfelter, Paul — Georgia Inst. of Tech
Egerstedt, Magnus — Georgia Inst. of Tech
Tabuada, Paulo — Univ. of California at Los Angeles
Grizzle, Jessy W. — Univ. of Michigan
Ames, Aaron D. — California Inst. of Tech

This paper presents experimental results on novel robot testbeds that allow the evaluation of the simultaneous implementation of adaptive speed regulation and lane keeping in a safe, education-centric, and inexpensive manner. The underlying algorithms are based on a control Lyapunov function for performance, a control barrier function for safety, and a real-time quadratic program for mediating the conflicting demands of performance and safety. The Robotarium used for this work allows students, as well as researchers less experienced with hardware, to experiment with advanced control concepts in a safe and standardized environment.

10:40-11:00 WA5.3

A Reactive Collision Avoidance Algorithm for Nonholonomic Vehicles, pp. 1776-1783

Wiig, Martin Syre — Norwegian Univ. of Science and Tech
Pettersen, Kristin Y. — Norwegian Univ. of Science and Tech
Savkin, Andrey V. — Univ. of New South Wales

This paper presents a reactive collision avoidance algorithm for vehicles with unicycle-type nonholonomic constraints. Static and dynamic obstacles are avoided by keeping a constant avoidance angle to the obstacle. The algorithm compensates for the obstacle velocity, which can be time-varying. Conditions are derived under which successful collision avoidance is mathematically proved, and the theoretical results are supported by simulations. The proposed algorithm makes only limited sensing requirements of the vehicle. It is intuitive, has a low computational complexity and is suitable also for vehicles with a limited speed envelope or heavy linear acceleration constraints. This is demonstrated by applying the algorithm to a vehicle with a constant forward speed.

11:00-11:20 WA5.4

Direct Learning Coverage Control Based on Expectation Maximization in Wireless Sensor and Robot Network, pp. 1784-1790

Lin, Tsen-Chang — National Cheng Kung Univ
Liu, Yen-Chen — National Cheng Kung Univ

This paper proposes a direct learning controller for wireless sensor and robot network to coverage an environment by utilizing expectation maximization algorithm. In addition to sensors, including high-level and low-level sensors, mounted on mobile robots, low-level stationary sensors are considered to provide information for enhance the performance of coverage control. The main objective is to maximize the information quantity of high-level sensors from the sensing density generated by a group of low-level sensors. This direct method uses the parameter of basis function to design controller based on Expectation Maximization (EM) algorithm. Moreover, the proposed estimation and learning law are also used in indirect method for other coverage controller. Subsequently, this paper proposes a transformation method based on EM algorithm for coverage problem with complicated sensing function such as Gaussian function. Numerical examples are introduced to demonstrate the performance of the proposed direct coverage control in wireless sensor and robot network.

11:20-11:40 WA5.5

Dynamic Visual Feedback Position Tracking of Two-Wheeled Vehicles with a Target Vehicle Motion Model, pp. 1791-1796

Nakano, Satoshi — Tokyo Inst. of Tech
Ibuki, Tatsuya — Tokyo Inst. of Tech
Sampei, Mitsuji — Tokyo Inst. of Tech

This paper investigates a dynamic visual feedback position tracking of two kinds of two-wheeled vehicles with a camera or a target object for visual measurements. A problem formulation is first provided, where the dynamics of the camera vehicle is explicitly considered and the target vehicle velocity is expressed by a Fourier series expansion. Next, a passivity-based tracking control structure is explained and a visual feedback position tracking law based on the structure is proposed. Here, the present law integrates a vision-based observer to estimate the relative pose between the two vehicles and the target vehicle velocity simultaneously. This work then provides convergence analysis and simulation is finally demonstrated to verify the effectiveness of the present method.

11:40-12:00 WA5.6

Implementation and Experimental Evaluation of Flexible Formation Tracking Controllers for Car-Like Mobile Robots with Velocity and Steering Controllers in the Loops, pp. 1797-1804

Low, Chang Boon — DSO National Lab

This paper presents an implementation and an experimental validation of a virtual structure and a leader-follower flexible formation tracking controllers for car-like nonholonomic mobile robots with velocity and steering controllers in the loops. The formations are flexible in the sense that their formation configurations are defined based on curvilinear longitudinal and lateral relative separations instead of the commonly used rectilinear relative separations. The two formation controllers leverage on our recently developed cascaded nonlinear trajectory tracking controller to attain stable flexible formation control in the presence of low-level dynamical control latencies in the loops without needing any dynamical model of the robots' low-level control systems when implementing the controllers. The performances of the two controllers have been validated in both simulation and partial experimentations with satisfactory results. For the virtual structure formation controller, it was experimented in an on-road environment up to the speed of 4.1m/sec, and the leader-follower formation controller was tested in both on-road and off-road environments up to the speed of 4.5m/sec. The results provide the foundation to develop formation navigation systems for the considered nonholonomic mobile robots to navigate in a team in both on-road and off-road environments.

WA6 Ballroom II

Aerospace Applications I (Regular Session)

Chair: Pham, Khanh D. — Air Force Res. Lab
Co-Chair: Weiss, Avishai — Mitsubishi Electric Res. Labs

10:00-10:20 WA6.1

A Dynamical-Network Model with Hierarchical Controls for Cognitive Military Satellite Communications, pp. 1805-1810

Roy, Sandip — Washington State Univ
Doty, Kyle — Washington State Univ
Xue, Mengran — Washington State Univ
Pham, Khanh D. — Air Force Res. Lab

A modeling framework is developed that enables analysis and design of cognitive radio technologies for military satellite communication networks. The main components of the model are: 1) a multi-tiered queueing network that captures data transmission within the network; 2) access and routing models for primary and cognitive users, abstracted as mixed supervisory and bottom-up controls. A complete set of governing equations for the model are presented, as a starting

point for simulation and formal evaluation. Finally, a specific use case is developed, on comparing static and dynamic bandwidth allocation (supervisory control) schemes in the military satellite backbone.

10:20-10:40 WA6.2

Incorporating Periodic and Non-Periodic Natural Motion Trajectories into Constrained Invariance-Based Spacecraft Relative Motion Planning, pp. 1811-1816

Frey, Gregory — Univ. of Michigan
Petersen, Christopher — Univ. of Michigan
Leve, Frederick — AFOSR
Kolmanovsky, Ilya V. — Univ. of Michigan
Girard, Anouck — Univ. of Michigan

Spacecraft relative motion planning is concerned with the design and execution of maneuvers relative to a nominal target. These maneuvers must account for spacecraft dynamics, and possibly for constrained thrust capabilities and inclusion and exclusion zone constraints, where the latter can be non-linear and non-convex. In this paper, a scheme for generating a feasible trajectory for spacecraft relative motion based on a graph search applied to a set (virtual net) of closed (periodic) natural motion trajectories (NMTs) is extended to incorporate open (non-periodic) NMTs. This extension increases the flexibility of the scheme and can provide other advantages, such as reduced fuel use. Safe positively invariant tubes are constructed around each trajectory in the virtual net and used to determine node (vertex) adjacency and connection information such that transitions between trajectories corresponding to adjacent nodes can be executed while satisfying the imposed constraints.

10:40-11:00 WA6.3

Circular Orbit Transfer Using Approximate Higher-Order Nonlinear State Transformations and Nonlinear Feedback, pp. 1817-1822

Khosravi, Parisa — Univ. of South Florida
Bishop, Robert H — Univ. of South Florida

An approximate feedback linearization method is applied iteratively to the problem of circular orbit transfer to obtain an analytic exact solution up to the ρ -th degree for continuous thrust circular orbit transfers. The coordinate transformation and feedback parameters are computed symbolically using a one-step approach in multi-stage form. During the recursive steps, patterns were detected in the approximate solutions as they evolved illuminating a family of exact solutions to the circular orbit nonlinear feedback control problem utilizing the null space that appears as part of the computations. It is shown that applying higher-degree feedback improves the closed-loop system stability for the orbital transfer problem and at some point the performance improvement of ever increasing higher-degree approximations diminishes, hinting at convergence to an exact solution. The relationship between the ρ -th degree exact solution obtained through the recursive approximations and a known exact solution is illustrated where it is shown that two different exact solutions can have different performance in terms of fuel usage leading to the possibility of optimization considerations in selecting the desired exact solution.

11:00-11:20 WA6.4

Automated Gain Schedule Synthesis for Missile Systems, pp. 1823-1828

Dickinson, Benjamin — US Air Force Res. Lab
Valenciaga, Sandor — Univ. of Florida
Hung, Chiung — Bevilacqua Res. Corp
Hussain, Heather — Massachusetts Inst. of Tech.

Gain schedule synthesis typically involves significant manual tuning to meet various time and frequency domain design specifications. This work explores how optimization may achieve automatic tuning for missile systems. Here, vertical acceleration command tracking is considered with closed loop control of the short period dynamics. Tracking is achieved with robust servomechanism design and linear quadratic regulation. Tuning the controller is posed as an optimization problem to meet command tracking requirements subject to multiple design constraints. Sequential quadratic programming is applied to the optimization problem and provides automated tuning for individual and batch runs of controllers. A successful strategy for initial guess selection in batch runs is proposed and its importance for efficient automation is shown. These results support the viability of optimization methods for automated gain schedule synthesis in missile systems.

11:20-11:40 WA6.5

Disturbance Rejection Based Optimal Control Scheme for Landing on a Celestial Object, pp. 1829-1834

Kang, Shen — Tech. Univ. München
Wang, Jianan — Beijing Inst. of Tech
Shan, Jiayuan — Beijing Inst. of Tech

This paper presents an optimal control solution for celestial object landing problem, involving Theta−D control technique and disturbance rejection mechanism. Based on the polar coordinate system, the control objective is to enforce the probe to reach the surface of celestial object with the desirable line-of-sight angle and zero velocity while eliminating the influence of disturbances. Theta−D technique is applied in the absence of disturbances to deal with the nonlinear optimal control problem. Then, the disturbances are estimated in the fast-estimation framework with bounded estimation errors. An additional variable-structure term is added to the composite control protocol to ensure stability under the time-varying disturbances. Comparative simulation results of the proposed approach are presented at the end of this paper, demonstrating the effectiveness of the proposed control protocol.

11:40-12:00 WA6.6

MPC for Coupled Station Keeping, Attitude Control, and Momentum Management of GEO Satellites Using On-Off Electric Propulsion, pp. 1835-1840

Zlotnik, David Evan — Univ. of Michigan
Di Cairano, Stefano — Mitsubishi Electric Res. Labs
Weiss, Avishai — Mitsubishi Electric Res. Labs

This paper develops a model predictive control (MPC) policy for simultaneous station keeping, attitude control, and momentum management of a nadir-pointing geostationary satellite equipped with three reaction wheels and four on-off electric thrusters mounted on two boom assemblies attached to the anti-nadir face of the satellite. A closed-loop pulse-width modulation (PWM) scheme is implemented in conjunction with the MPC policy in order to generate on-off commands to the thrusters. The MPC policy is shown to satisfy all station keeping and attitude constraints while managing stored momentum, enforcing thruster constraints, and minimizing required delta-v.

WA7	Ballroom III
Intelligent and Cooperative UAV Systems (Invited Session)	
Chair: Peterson, Cameron	Brigham Young Univ
Co-Chair: Cao, Yongcan	Univ. of Texas, San Antonio
Organizer: Peterson, Cameron	Brigham Young Univ
Organizer: Beard, Randal W.	Brigham Young Univ

10:00-10:20 WA7.1

A Gaze Based Operator Instrumentation Approach for the Command of Multiple Autonomous Vehicles (I), pp. 1841-1846

Jessee, Michael — Johns Hopkins Univ. Applied Physics Lab

Chiou, Tzuhsiu — Johns Hopkins Univ. Applied Physics Lab

Krepps, Andrew — Johns Hopkins Univ. Applied Physics Lab

Prengaman, Brian — Johns Hopkins Univ. Applied Physics Lab

The control of multiple unmanned vehicles with higher levels of autonomy by a single operator has posed unique human systems integration challenges. To address this, previous researchers have attempted to assess aspects of human cognition in real time in order to expand the information exchange bandwidth to improve performance. Here, the accumulation of operator gaze data over a geospatial search area was used to refine a search area for a group of collaborative unmanned vehicles. This passively collected point of gaze input (instrumentation condition) was compared to a standard mouse input and multimodal input condition that required manual region of interest selection in a dual search area refinement task and target detection task. Data were collected in an immersive virtual environment with a head mounted display. Results indicated that gaze data were significantly correlated with predefined regions of interest, while workload from pupillometry data and target detection performance changed significantly across input conditions. These results are discussed in terms of visual attention allocation during scene recognition, and challenges with multimodal input that utilize point of gaze.

10:20-10:40 WA7.2

Practical Considerations for Implementing an Autonomous, Persistent, Intelligence, Surveillance, and Reconnaissance System (I), pp. 1847-1854

Rasmussen, Steven — Miami Valley Aerospace LLC

Kalyanam, Krishnamoorthy — Infoscitex Corp

Manyam, Satyanarayana Gupta — Air Force Res. Lab

Casbeer, David W. — Air Force Res. Lab

Olsen, Christopher — USAF

We are interested in the persistent surveillance of an area of interest comprised of heterogeneous tasks (or targets) that need to be completed (or visited) in a repeated manner subject to constraints on time between successive visits. The task is undertaken by a set of heterogeneous UAVs which autonomously execute the mission. In addition to geographically distributed tasks, the mission may also include a central node (control target), where data collected from the different targets need to be delivered. In this context, the performance of the system, in addition to the desired revisit rate of the tasks may also entail minimizing the delay in delivering the data collected from a target/task to the central node. We detail, in this paper, a completely autonomous Persistent, Intelligence, Surveillance and Reconnaissance (PISR) System, that addresses the mission requirements. In particular, we focus on practical considerations in terms of scalable optimization and heuristic methods that solve the underlying problem and also discuss the on-board implementation of the chosen optimization schema. We provide details on an in-house software framework that enables easy implementation of the optimization algorithms on commercial drones. To solve the problem, we consider three different optimization schemes based on branch and bound (tree search), MILP formulation and Dynamic Programming. We compare and contrast the three approaches with details on the respective benefits and pitfalls and also touch upon easily implementable heuristic methods motivated by the optimal solution.

10:40-11:00 WA7.3

Dynamic Grouping of Cooperating Vehicles Using a Receding Horizon Controller for Ground Target Search and Track Missions (I), pp. 1855-1860

Peterson, Cameron — Brigham Young Univ

Teams of unmanned vehicles are capable of accomplishing a wide variety of mission objectives, such as searching for and tracking targets. In this paper, a receding horizon control is utilized with information based reward measures to accomplish these two competing mission objectives. This approach for cooperatively searching and tracking has proven to be effective in past work. However, it is not generally scalable for large numbers of vehicles due to the computational expense required when generating joint path decisions. This paper proposes a method to dynamically group vehicles with neighbors that have intersecting decision spaces, thus reducing computational cost while still maintaining reasonable performance. Each vehicle also decides its ideal event horizon based upon inferred knowledge of the operational environment, further reducing cost.

11:00-11:20 WA7.4

Co-Optimization of Communication, Sensing, and Computation for Information Gathering Using Cloud Computing (I), pp. 1861-1867

Moon, Sangwoo — Univ. of Colorado, Boulder

Ramaswamy Pillai, Vinod — Qualcomm India

Frew, Eric W. — Univ. of Colorado, Bolder

Ahmed, Nisar — Univ. of Colorado, Boulder

This paper describes a co-optimization method for communication-aware information gathering in multi-agent systems using cloud computing. The cloud process complements the local estimate of each agent by sending more accurate information to the agent. However, using cloud computing to improve local information gathering can lead to asynchronous delays in processing estimation and sending its results to each agent. This paper describes how information flows and channel selection can be used to manage information between the cloud and the agent, as well as among agents. Since centralized optimization cannot be performed realistically due imperfect communication, this paper uses a game-theoretic distributed optimization approach when evaluating the co-optimization method. A set of simulations show that the estimates from the distributed, cloud-based approach converge to those from a single centralized estimator.

11:20-11:40 WA7.5

Multi-Objective Cooperative Search of Spatially Diverse Routes in Uncertain Environments (I), pp. 1868-1873

Votion, Johnathan — Univ. of Texas, San Antonio

Cao, Yongcan — Univ. of Texas, San Antonio

This paper focuses on developing new navigation and reconnaissance capabilities for cooperative unmanned systems in uncertain environments. The goal is to design a cooperative multi-vehicle system that can survey an unknown environment and find the most valuable route for personnel to travel. To accomplish the goal, the multi-vehicle system first explores spatially diverse routes and then selects the safest route. In particular, the proposed cooperative path planner sequentially generates a set of spatially diverse routes according to a number of factors, including travel distance, ease of travel, and uncertainty associated with the ease of travel. The planner's dependence on each of these factors is altered by a weighted score. Varying the weights changes the criteria for determining an optimum route. To penalize the selection of same paths by different vehicles, a control gain is used to increase the cost of paths that lie near the route(s) assigned to other vehicles. By

varying the control gain, the spatial diversity among routes can be accomplished. By repeatedly searching for different paths cooperatively, an optimal path can be selected that yields the most valuable route.

11:40-12:00 WA7.6

A Lagrangian UAV Swarm Formation Suitable for Monitoring Exclusive Economic Zone and for Search and Rescue, pp. 1874-1879

Kumar, Sandeep Ameet — Fiji National Univ
Vanualailai, Jito — Univ. of the South Pacific

This paper presents the velocity controllers of the simple rigid-body individuals of a 2-D Lagrangian swarm model that can take up a linear formation which could be used by unmanned aerial dynamical systems for searching large areas. The velocity controllers are derived from a Lyapunov function. The Direct method of Lyapunov guarantees the stability of the system. The velocity controllers are then applied to a swarm of unmanned aerial vehicles. Simulation results are provided to support the results obtained.

WA8 Ballroom IV

Automotive Systems Modeling and Control (Invited Session)

Chair: Onori, Simona — Clemson Univ
Co-Chair: Ahmed, Qadeer — Ohio State Univ
Organizer: Onori, Simona — Clemson Univ
Organizer: Ahmed, Qadeer — Ohio State Univ

10:00-10:20 WA8.1

Differential Braking-Based Anti-Rollover Control for Non-Tilting Narrow-Track Vehicles (I), pp. 1880-1885

Amodio, Alessandro — Pol. Di Milano
Corno, Matteo — Pol. Di Milano
Panzani, Giulio — Pol. Di Milano
Savaresi, Sergio M. — Pol. Di Milano

This paper presents an anti-rollover control system for a non-tilting narrow-track four-wheeled vehicle. The control system relies on two independent braking actuators on the rear wheels. The control system, designed to prevent rollover while limiting the reduction of speed, has two key elements: a steady state term that handles the static roll over limits and a dynamic term that intervenes during fast transients. The control system is tuned based on a control oriented model identified from a multi-body simulator of the vehicle. The paper validates the proposed control system for steady state and dynamic maneuvers and compares the results against an acausal optimal benchmark. This analysis shows that the control system prevents rollover for all velocities and, in the worst case, reduces the velocity of an additional 25% with respect to the acausal optimal benchmark.

10:20-10:40 WA8.2

Load Levelling Control for an Hydro-Pneumatic Suspension of a Tractor Cabin: Modelling, Identification and Control (I), pp. 1886-1891

colombo, tommaso — Pol. Di Milano
Panzani, Giulio — Pol. Di Milano
Lozoya Santos, Jorge de-J — Univ. de Monterrey
Savaresi, Sergio M. — Pol. Di Milano

This paper deals with the load levelling control of a tractor cabin equipped with an hydro-pneumatic suspension, controlled with on-off actuators. A model-based approach for the controller design is proposed. A dynamic physical model of the hydro-pneumatic suspension is developed and identified through a grey-box approach and a linear continuous controller is then designed, where actuation delays and model uncertainties are considered. The continuous-time controller requests are then converted into actual on-off switching valves commands through a duty-cycle modulation. Experimental results validate the overall approach showing effective closed loop performances.

10:40-11:00 WA8.3

Motorcycle Tire Rolling Radius Estimation for TPMS Applications Via GPS Sensing (I), pp. 1892-1897

Sabatini, Stefano — Pol. Di Milano
Formentin, Simone — Pol. Di Milano
Panzani, Giulio — Pol. Di Milano
Lozoya Santos, Jorge de-J — Univ. de Monterrey
Savaresi, Sergio M. — Pol. Di Milano

An accurate knowledge of the tire effective rolling radius is fundamental for many vehicle dynamics applications relying on an estimate of the vehicle speed, like ABS, stability and traction control. It may also serve as a tool to detect tire deflation and improve the safety on-board. Many algorithms for rolling radius estimation have been presented in the literature, but most of them cannot be applied on production vehicles, as they require too accurate measurements or a too high sampling rate. In this work, a signal processing procedure for on-line estimation of the rolling radius is presented, with a focus on motorcycles and pressure monitoring applications. The procedure assumes that a standard production Gps sensor is available and it is tested on a real production motorcycle.

11:00-11:20 WA8.4

Stabilization of a Vehicle Traversing a Short Low-Friction Road Segment (I), pp. 1898-1903

Beal, Craig — Bucknell Univ

In normal vehicle operation, drivers occasionally encounter low friction patches without advance warning. The sudden transitions to and from the low friction surface may destabilize the vehicle, even when the operating point on the higher friction surface is away from the handling limits. Because of these fast dynamics, an active assistance system could significantly enhance safety. This paper describes the dynamics of transition between friction surfaces and demonstrates the utility of an envelope controller that uses real-time friction estimates and a state-bounding approach. Experimental data and the controller state bounds are used to provide insight into the trade-off between estimator accuracy and response time when used for real-time control.

11:20-11:40 WA8.5

A New Air-Fuel Ratio Model Fixing the Transport Delay: Validation and Control, pp. 1904-1909

Laurain, Thomas — LAMIH (UMR CNRS 8201), Univ. of Valenciennes
Lendek, Zsofia — Tech. Univ. of Cluj-Napoca
Lauber, Jimmy — Univ. of Valenciennes and Hainaut Cambresis
Palhares, Reinaldo Martinez — Univ. Federal De Minas Gerais

Air-fuel ratio control is a crucial problem for engine control since it is one of the most important issues related to pollution reduction. The main difficulty in air-fuel ratio control is the time-varying delay. We propose a new model that includes the delay. This model is identified using real dataset from an engine test bench. The time-varying delay is made constant by using a change of domain. The nonlinearities of the model are handled with the Takagi-Sugeno representation and a linear controller is designed using the Lyapunov direct method. Simulation results highlight the efficiency of the proposed approach compared to classic maps-based controllers.

11:40-12:00 WA8.6

Active Damping for Test Benches of High Boosted Combustion Engines with Hybrid Technology, pp. 1910-1916

Kokal, Helmut — AVL List GmbH
Dank, Matthias — AVL List GmbH

This paper is concerned with the increase of the damping behavior of an engine test bed by suitable extending the control strategy of a

standard engine test bed with respect to the test of high charged, small displacement combustion engines used in modern hybrid powertrain concepts. Especially in high performance engines (e.g. such as for race cars) the outbid boosting with electrical driven turbo chargers of the combustion engine leads to distinct excitation of the 0.5th order in case of a four cylinder engine. This stimulation coming from combustion engine could be root cause for high oscillations up to damage to the mechanical setup under full load conditions during engine testing. Since these oscillations are in frequency ranges where transport delay time for the dynamometer load system of the test bed becomes significant, a controller strategy based on a First-In-First-Out memory (FIFO) approach for delay compensation is chosen. The efficiency of the control strategy is shown by results from a real test bed experiment. To archive maximum damping effect, test bed load units (dynamometer) with high dynamic are used. Up to 70.000rpm/s acceleration of the dynamometer is needed – depending on the dynamic of the combustion engine - to achieve similar dynamic of the combustion engine seen in torque oscillation level. This goal can only be achieved by the use of synchronous permanent magnet dynamometers, which are characterized by very high torque to inertia ratio compared to asynchronous dynamometers.

WB1 — Puna

Learning (Regular Session)

Chair: Masuda, Shiro — Tokyo Metropolitan Univ

Co-Chair: Macnab, Chris — Univ. of Calgary

13:30-13:50 WB1.1

A Deep Learning Framework for Model Reduction of Dynamical Systems, pp. 1917-1922

Hartman, David — Univ. of Maryland, Coll. Park

Mestha, Lalit K. — GE Global Res

A new framework is proposed for model-order reduction in which a neural network is used to learn a reduced model of a dynamical system. As technological, social, and biological models become increasingly complex, it has become necessary to find ways of reducing the number of dynamical states of a system while still maintaining model integrity. The new approach combines ideas from two existing model-order reduction methods: proper orthogonal decomposition (POD) and balanced truncation. The previously mentioned methods reduce the number of state variables by projecting the dynamics onto a linear subspace spanned by principal components of a representative data matrix. Our proposed model-reduction method has the advantage of projecting the dynamics onto a nonlinear space. The proposed method is referred to as feature decomposition," in light of the nonlinear features extracted by way of neural networks. The method is applied to both autonomous and state-space systems. In feature decomposition for state-space systems, empirical Gramians are the representative training set on which we perform the nonlinear feature learning. It is shown that under certain assumptions, feature decomposition applied to state-space systems is equivalent to balanced truncation. Finally, the method is applied to a spreading infectious disease dynamical system and the results from our reduced order model are compared to POD.

13:50-14:10 WB1.2

Iterative Data-Driven Generalized Minimum Variance Regulatory Control Via L_2-Regularization, pp. 1923-1928

Shimamoto, Yoshitada — Tokyo Metropolitan Univ

Masuda, Shiro — Tokyo Metropolitan Univ

The paper proposes iterative data-driven generalized minimum variance (GMV) regulatory control via L_2-regularization. The proposed approach reformulates the derivation of the GMV regulatory control as a L_2-regularized optimization problem and employs an iterative design approach that repeats the same routine as the one-shot GMV regulatory control via L_2-regularization. The L_2-regularization assures the uniqueness of control parameters as well as moderate high variance estimates. However, the penalty term for L_2-regularization causes bias of estimation values. The proposed method solves the problem by employing iterative design approach. The penalty term that evaluates the deviation from initial parameters is updated at each iteration, which leads to the convergence to the true GMV control parameters without any bias. The paper provides some analytical results for the convergence property. The effectiveness of the proposed method is assured through a numerical example.

14:10-14:30 WB1.3

Ultra-Wideband Range Measurement Model with Gaussian Processes, pp. 1929-1934

Ledergerber, Anton — ETH Zurich

D'Andrea, Raffaello — ETH Zurich

This paper presents an ultra-wideband range measurement model based on Gaussian processes. An analysis of the range measurement error with off-the-shelf ultra-wideband radio modules reveals a strong correlation between the reported error and the relative pose of the two ranging modules. A Gaussian process is trained for capturing this correlation and is included in the measurement model. Its effectiveness and real-time applicability are experimentally demonstrated on a quadrocopter platform.

14:30-14:50 WB1.4

Parameter Extraction for Identifying Product Type of McKibben Pneumatic Artificial Muscles, pp. 1935-1940

Ishikawa, Takahiro — The Univ. of Electro-Communications

Nishiyama, Yu — The Univ. of Electro-Communications

Kogiso, Kiminao — The Univ. of Electro-Communications

This study demonstrates that various unknown parameters used in nonlinear models of McKibben pneumatic artificial muscles (PAMs) can characterize the features of McKibben PAM products. By focusing on a parameter space in the PAM model, this study employs a support vector machine (SVM) to determine which unknown parameters characterize each PAM product. For validation, three different PAM products are analyzed to observe whether the resulting minimal combination of parameters will help to identify the product. The observation is expected to provide prior PAM knowledge that can be used to develop efficient parameter estimation and capture aging degradation, which are important for robust estimation and control in PAM systems.

14:50-15:10 WB1.5

Trajectory Generation for Networked UAVs Using Online Learning for Delay Compensation, pp. 1941-1946

Yoo, Jaehyun — Royal Inst. of Tech

Lee, Seung Jae — Seoul National Univ

Kim, H. Jin — Seoul National Univ

Johansson, Karl H. — Royal Inst. of Tech

This paper presents a trajectory generation mechanism based on machine learning for a network of unmanned aerial vehicles (UAVs). For delay compensation, we apply an online regression technique to learn a pattern of network-induced effects on UAV maneuvers. Due to online learning, the control system not only adapts to changes to the environment, but also maintains a fixed amount of training data. The proposed algorithm is evaluated on a collaborative trajectory tracking task for two UAVs. Improved tracking is achieved in comparison to a conventional linear compensation algorithm.

15:10-15:30 WB1.6

CMAC Control of a Quadrotor Helicopter Using a Stable Robust Weight-Smoothing Algorithm, pp. 1947-1953

Macnab, Chris — Univ. of Calgary

The Cerebellar Model Articulation Controller (CMAC) is a type of neural network particularly suited to real-time control applications due to fast adaptation and the ability to handle many inputs. However, the CMAC is well-known to exhibit weight (adaptive-parameter) drift when

used in adaptive control, and overlearning when applied in static learning situations. A weight smoothing algorithm originally proposed for halting the overlearning during static training has recently been modified and proposed for use in adaptive control. However, the method as proposed currently suffers from impractical computational complexity for more than one or two inputs, and does not have guarantees of stability. This paper proposes both a way to ensure computational efficiency for real-time operation and a Lyapunov-derived method of achieving uniformly ultimately bounded signals. Simulations with a quadrotor helicopter show the method significantly outperforms other robust direct adaptive control methods (deadzone and e-modification) as well as a tuned PID control.

WB2 Hilo

Adaptive Control (Regular Session)

Chair: Ohrem, Sveinung Johan — Norwegian Univ. of Science and Tech

Co-Chair: Miller, Daniel E. — Univ. of Waterloo

13:30-13:50 WB2.1

Experimental Validation of Adaptive Observers for Battery Management Systems, pp. 1954-1960

Jenkins, Benjamin — Massachusetts Inst. of Tech

Annaswamy, Anuradha M. — Massachusetts Inst. of Tech

A lithium ion battery model includes several parametric uncertainties, which need to be identified in real time in order to determine accurate estimates of State of Charge (SOC) and State of Health. Recently, an augmented adaptive observer that simultaneously estimates the parameters of the underlying linear dynamics and algebraic nonlinearities in a modified Single Particle Model (SPM) was proposed. In this paper, we validate this observer experimentally using a Panasonic cell. The algebraic nonlinearities included are both due to open circuit potential and due to over potential. Using the properties of these potential functions and experimental constraints, a novel adaptive observer was used to estimate their parameters as well as those of the underlying linear dynamics. The experimental results show that the adaptive observer results in accurate SOC estimation and parameter convergence.

13:50-14:10 WB2.2

Flight Control System Design for Wind Gust Rejection Based on an Unknown Input Observer and a Simple Adaptive Controller, pp. 1961-1966

Sofrony, Jorge Ivan — Univ. Nacional De Colombia

Turner, Matthew C. — Univ. of Leicester

This paper presents a switched control strategy for LTI systems with input constrained. The proposed state- dependent switching law is constructed such the closed-loop sys- tem is zero-input exponentially stable and ultimately bounded non-increasing under the presence of external disturbances. Unlike most approaches for switched systems with input satu- ration, the proposed technique does not impose a dwell-time and seeks to construct nested switching ellipsoidal sets via an ultimate boundedness condition. The main objective of the proposed approach is to provide performance enhancement of the saturated system of the closed-loop system by switching between high and low gain, activating the appropriate controller depending on the the size of the states.

14:10-14:30 WB2.3

Adaptive and Nonlinear Model-Based Control of Variable Displacement Pumps for Variable Loading Conditions, pp. 1967-1974

Koivumäki, Janne — Tampere Univ. of Tech

Mattila, Jouni — Tampere Univ. of Tech

Energy efficiency remains one of the most important unsolved challenges in hydraulic (robotic) systems, especially in off-highway machines and ambulatory robotic systems where the energy source(s) must be carried on board in limited space. Consequently, this paper proposes an adaptive and nonlinear model-based (NMB) controller for a discharge pressure-controlling variable displacement axial piston pump (VDAPP), to reduce the energy consumption of the hydraulic systems.

For the control design, a novel NMB control method is used. The method originates from the virtual decomposition control (VDC) approach but is developed in a novel manner. Similar to VDC, the control design is based on virtually decomposed subsystems' dynamics, rather than centralized system dynamics, while rigorously guaranteeing asymptotic convergence. The dynamic interaction among subsystems is addressed with the designed *stabilizing term* and *stability-preventing term*, which eventually cancel each other out when subsystems are coupled.

The rationale for this study is to 1) examine the novel control design method in comparison with state-of-the-art controllers for discharge pressure controlling VDAPPs and 2) design a high-performance discharge pressure-tracking controller for a VDAPP that supplies an actively controlled load valve. The latter is to obtain reductions in energy consumption compared to conventional methods. The comparative experiments demonstrate an advancement of the proposed method.

14:30-14:50 WB2.4

Classical Discrete-Time Adaptive Control Revisited: Exponential Stabilization, pp. 1975-1980

Miller, Daniel E. — Univ. of Waterloo

Classical discrete-time adaptive controllers provide asymptotic stabilization. While the original adaptive controllers did not handle noise or unmodelled dynamics well, redesigned versions were proven to have some tolerance; however, exponential stabilization and a bounded gain on the noise was rarely proven. Here we consider a classical pole placement adaptive controller using the original projection algorithm rather than the commonly modified version; we impose the assumption that the plant parameters lie in a convex, compact set and that the parameter estimates are projected onto that set at every step. We demonstrate that the closed-loop system exhibits very desireable closed-loop behaviour: there are linear-like convolution bounds on the closed loop behaviour, which confers exponential stability and a bounded noise gain. We emphasize that there is no persistent excitation requirement of any sort.

14:50-15:10 WB2.5

Adaptive Feedback Linearizing Control of a Gas Liquid Cylindrical Cyclone, pp. 1981-1987

Ohrem, Sveinung Johan — Norwegian Univ. of Science and Tech

Kristoffersen, Torstein Thode — Norwegian Univ. of Science and Tech

Holden, Christian — Norwegian Univ. of Science anf Tech

As subsea production of oil and gas reaches deeper and more remote waters, the need for more compact separation equipment arises. The gas liquid cylindrical cyclone (GLCC) is a widely used separation device in topside facilities, but has yet to reach the same popularity subsea. The GLCC separates gas and liquid by inducing a swirl on the multiphase flow. Because of its small size, the GLCC is sensitive to flow variations which may reduce separation performance. The performance of the GLCC can be improved by control. In this paper we consider a nonlinear dynamic model of a GLCC containing unmeasured variables and states. We present an adaptive feedback linearizing controller and prove that the origin of the gas pressure and liquid level error systems are locally asymptotically stable in the sense of Lyapunov on a specified domain. The model and controller are implemented in Simulink and simulations show that the controller works very well, even with uncertainties in assumed known parameters, and measurement noise.

WB3 Hamakua

Control Applications III (Regular Session)

Chair: Kang, Chul-Goo — Konkuk Univ

Co-Chair: Rezaei, Vahid — Univ. of Denver

13:30-13:50 WB3.1

Testing and Performance Enhancement of a Model-Based Designed Ground Controller for a Diamond-Shaped Unmanned Air Vehicle (UAV), pp. 1988-1994

Seiferth, David — Tech. Univ. München

Heller, Matthias — Tech. Univ. München

At the Institute of Flight System Dynamics of the Technische Universität München (TUM), a digital flight control system for a fixed wing Unmanned Air Vehicle (UAV) featuring a novel diamond-shaped configuration is designed, implemented and tested up to its first flight. The capabilities of the UAV comprises a fully automated flight, including ground control for centerline tracking and runway alignment during automatic take-off and landing. This paper presents the testing and performance enhancement of a model-based designed ground controller for the diamond-shaped UAV. The focus is set on the challenges of testing the ground controller within the framework of an existing flight software and ground control station.

13:50-14:10 WB3.2

Monitoring of Electric Contact Resistance: Application to Automotive Connectors, N/A

Farges, Christophe — Univ. of Bordeaux

Chevrié, Mathieu — Bordeaux Univ

Sabatier, Jocelyn — IMS Lab. - Bordeaux Univ

Pradere, Laetitia — PSA Peugeot-Citroën

Guillemard, Franck — PSA Peugeot-Citroën

Car manufacturers have to size Electric and Electronic Systems (EES) to avoid the risk of short circuits while at the same time ensuring a viable economic balance. In other words, the copper mass must be sufficient for safety reasons, but not excessive for cost reasons. It is thus necessary to monitor the critical points of the electric architecture in order to make an appropriate decision to maintain a high level of safety. However, due to physical and economic constraints, direct temperature measurement of these critical points is seldom possible. Moreover, temperature monitoring at these points would not allow one to determine whether the rise in temperature was related to degradation of the contact or whether it was due to the generation of thermal power by another component. The objective of the present paper is thus to propose a new method to monitor critical points of the electric architecture that does not require direct measurements. In order to achieve this objective, an electrothermal model of the architecture was developed and a diagnosis method was used. The method was applied to detect abnormal variations in the contact resistance inside a connector which is a critical point commonly encountered in the electrothermal chain of automotive vehicles. The efficiency of the algorithm was evaluated on a dedicated test bench. The proposed approach is able to detect a deviation of about 10 % in the contact resistance thus validating the proposed methodology.

14:10-14:30 WB3.3

Cascaded Bottom Hole Pressure Control in Managed Pressure Drilling, pp. 2001-2007

Stakvik, Jon Åge — Kelda Drilling Controls

Berg, Christian — Kelda Drilling Controls

Kaasa, Glenn-Ole — Kelda Drilling Controls

Aamo, Ole Morten — NTNU

Today, in search of oil resources, marginal wells with narrow pressure windows are frequently being drilled. This requires accurate and precise control to balance the bottom hole pressure (BHP) between the pore and fracture pressure of the reservoir. Managed pressure drilling (MPD) is a technique introduced to enable improved pressure control when drilling. This paper presents a cascaded control structure for BHP, choke pressure and choke position in MPD operations. Estimators for the unknown bottom hole flow and uncertain BHP are developed to improve pressure control performance. The presented method is evaluated with field operation data from drilling two 4000 m deep wells. The results show that the pressure is maintained within acceptable margins through a series of operations.

14:30-14:50 WB3.4

Achievable Optimal Superheat Temperature Control in Evaporators of HVAC Systems, pp. 2008-2014

Kianfar, Kaveh — Univ. of Windsor

Izadi-Zamanabadi, Roozbeh — Danfoss A/S

Saif, Mehrdad — Univ. of Windsor

In this paper a novel approach to minimize superheat temperature of an evaporator in real-time operation of a Heating Ventilation Air Conditioning (HVAC)-Refrigeration system is presented. Two approaches for optimal control of an evaporator superheat are presented in this paper. Both approaches use the second derivative of superheat (Tsh), w.r.t. mass flow rate of refrigerant at the outlet of an evaporator for the purpose of controlling the superheat to its near optimal value. The first approach is based on an analytical formulation of the second derivative and employs gradient descent method to drive the Tsh to its optimal point. The second approach utilizes an extremum seeking control (ESC) for optimizing higher order derivatives to drive and maintain the Tsh at its minimum stable level. The proposed approaches have been validated through simulation studies in MATLAB/Simulink environment.

14:50-15:10 WB3.5

Better Understanding of Process Operation Using Performance Metrics and Visualization Plots, pp. 2015-2020

Al-Dabbagh, Ahmad — Univ. of Alberta

Hu, Wenkai — Univ. of Alberta

Lai, Shiqi — Univ. of Alberta

Chen, Tongwen — Univ. of Alberta

Shah, Sirish L. — Univ. of Alberta

In an industrial facility, a large amount of data on the operation of the facility is collected. The data includes control variables used in monitoring and regulation, alarm variables displayed to notify operators of abnormalities, and operators' actions taken to correct abnormalities as well as to operate the facility. As the data is historized and is readily accessible, it can provide a wealth of knowledge on the operation of the facility. Thus, this paper tackles the following question: Can the historized data be used to extract information to better understand process operation? More specifically, the paper attempts to answer the question by its two contributions, namely: (i) the development of performance metrics that characterize the time and frequency relations of events, and (ii) the development of two types of visualization plots to present the performance metrics in a succinct fashion. The paper also discusses the incorporation of the performance metrics and the visualization plots into industrial automation platforms.

15:10-15:30 WB3.6

Braking Control for Wheel-Slide Protection Using HILS, pp. 2021-2026

Kang, Chul-Goo — Konkuk Univ

Lee, Nam-Jin — Hyundai-Rotem Co

During the braking of a railway vehicle, excessive slide between wheel and rail can occur due to temporarily degraded adhesion by wet or contaminated rail surface. This can damage the wheel tread, and the damaged wheel affects seriously the safety and ride comfort of the railway vehicle. To prevent from excessive slide between wheel and rail, braking control using wheel-slide protection (WSP) logic is required. In this paper, we present an effective WSP logic to maximize the usage of adhesion force, and demonstrate experimentally the validity of it using a brake HILS (hardware-in-the-

loop simulation) system developed in our laboratory.

WB4	Kohala
Uncertain Systems II (Regular Session)	
Chair: Keller, Juerg Peter	FHNW
Co-Chair: Simaan, Marwan A.	Univ. of Central Florida

13:30-13:50 WB4.1

Optimal Risk Management in Critical Infrastructures against Cyber-Adversaries, pp. 2027-2032

Barreto, Carlos — Univ. of Texas at Dallas

Cardenas, Alvaro — Univ. of Texas at Dallas

One of the biggest cyber-security problems that our critical infrastructures face is the underinvestment in cyber-security solutions by private firms operating these systems. A healthy market insurance may incentivize asset owners to invest more in cyber-security protections in order to pay lower premiums to manage their residual risk. In this paper we model the problem of optimal risk management in critical infrastructures and show conditions where insurance motivates asset owners to invest more in security, and other conditions where even government incentives for the adoption of insurance may have the opposite effect of reducing cyber-security investments.

13:50-14:10 WB4.2

Robust and Optimal H Infinity Control in LabVIEW, pp. 2033-2040

Zeugin, Pascal Michael — Univ. of Applied Sciences Northwestern Switzerland

Keller, Juerg Peter — FHNW

State of the art computer-aided control system design (CACSD) tools for robust control offer only very basic commands and consequently require a very detailed mathematical background and advanced user knowledge about syntax and data structures. Also many typical controller design problems have to be reformulated over and over. This contribution therefore aims to tackle these matters by introducing a CACSD-tool with a user-friendly graphical user interface based on LabVIEW. Although not providing quite the flexibility of common low-level design tools, it offers a set of comfortable, ready-to-use solutions for robust H_∞ controller design and implementation including the field-testing of the control system with a laboratory plant. The structure of the tool provides the possibility to solve a whole range of different MIMO H_∞ problems, without needing to do tedious algebraic calculations for each respective problem. The originality of this tool thereby lies in the fact that it allows to attain the design goals interactively, i.e. one can infer the consequences of minor changes in the control specifications on the closed-loop system immediately. This provides a deductive approach to understanding H_∞ control without the necessity to learn complicated mathematical formalisms and syntax.

14:10-14:30 WB4.3

Zero-Sum Turret Defense Differential Game with Singular Surfaces, pp. 2041-2048

Akilan, Zackariah — Wright State Univ

Fuchs, Zachariah E. — Wright State Univ

We examine a two-player, zero-sum, differential turret defense game, which consists of two players, a mobile Attacker and a stationary Defender. The Attacker is modeled as a mobile agent moving with a constant speed about an infinite, two-dimensional plane, and it is capable of making instantaneous changes in direction. The Defender is modeled as a stationary target located at the origin, and it is capable of steering a direction of focus toward the Attacker. The game terminates when the Attacker intercepts the Defender. Over the course of the game, the Attacker incurs an integral cost. The cost functional consists of a constant time penalty and a Defender generated cost based on the relative agents' positions. The goal of the Attacker is to terminate the game with minimal cost, while the Defender strives to maximize the Attacker's cost. We show that the global equilibrium solution contains three singular surfaces that divide the state space into regions with qualitatively different equilibrium control strategies for the two players.

14:30-14:50 WB4.4

Cooperative, Non-Cooperative and Greedy Pursuers Strategies in Multi-Player Pursuit-Evasion Games, pp. 2049-2056

Talebi, Shahriar — Univ. of Central Florida

Simaan, Marwan A. — Univ. of Central Florida

Qu, Zhihua — Univ. of Central Florida

In this paper we consider three different strategies for N pursuers and one evader in a multi-player Pursuit-Evasion game. Each pursuer's objective function reflects a desire to minimize the distance between itself and the evader while the evader's objective function reflects a need to escape by maximizing the distance between itself and a weighted measure of the distances between itself and the pursuers. The first strategy is characterized by pursuers who cooperate as a team in their effort to catch the evader. The resulting game is referred to as a Cooperating Pursuers Game. The second strategy is characterized by non-cooperating pursuers who act in a non-cooperative manner among themselves and the evader. The resulting game is referred to as a Non-Cooperating Pursuers Game. The third strategy is characterized by greedy pursuers who act independently and selfishly each on its own in an attempt to catch the evader. The resulting game is referred to as Greedy Pursuers Game. To treat these strategies under one common framework a general all-against-one linear quadratic dynamic game is considered and the corresponding closed-loop Nash solution is discussed. Using this framework, the three pursuers' strategies are then developed separately. Implementation of several scenarios of these games are also investigated where neither the pursuers nor the evader have knowledge of the objective functions of the other side and hence need to implement strategies that are secure against possible worst strategies by the other side. A Monte Carlo analysis over the parameters space of the objective functions is preformed to yield probabilities of capture of the evader under each of the studied scenarios. Results of the Monte Carlo simulation show that in general, pursuers do not always benefit from cooperating as a team and that acting as non-cooperating players may yield a higher probability of capturing the evader depending on what strategy the evader may use.

14:50-15:10 WB4.5

A Population-Games Application with the Balls-In-Tubes Experiment, pp. 2057-2062

Díaz, Juan Pablo — Univ. De Los Andes

Barreiro-Gomez, Julian — Univ. De Los Andes - Univ. Pol. De Catalunya

Quijano, Nicanor — Univ. De Los Andes

Many multi-agent control strategies have been implemented in simulations, but not as much in physical applications. In this paper, a design and research of multi-agent systems control strategies, under several constraints, are presented. The main contribution of this work is the implementation of evolutionary game theory into distributed control systems, throughout different tests in a real application, known as the *Balls-in-Tubes* experiment. Moreover, results regarding the performance of the closed-loop system are shown, comparing different possible strategies, under a population-games approach. A new methodology for enhancing the control performance is validated by means of various selected key performance indicators. The demonstration of optimal resource distribution with population dynamics is shown with specific designed scenarios, where the characteristics under which the dynamics perform are modified in each test. Furthermore, a comparison among distributed control strategies is presented.

15:10-15:30 WB4.6

Spectral Profiling of Writing Process, pp. 2063-2068

Kizhaeva, Natalia — Saint Petersburg State Univ
Volkovich, Zeev — ORT Braude Coll. of Engineering
Granichin, Oleg — Saint Petersburg State Univ
Granichina, Olga — Herzen State Pedagogical Univ
Kiyaev, Vladimir — Saint Petersburg State Univ

This paper discusses a novel methodology for dynamic modeling of writing process. Sequent sub-documents of a given document are described through occurrences of the suitably selected N-grams. The Mean Dependence similarity measures the association between a present sub-document and numerous preceding ones and transforms a document into a time series, which is supposed to be weak stationary if the document is created using the same writing style. A periodogram of this signal estimates its Power Spectral Density providing a spectral attribute of the style. Numerical experiments demonstrate high ability of the proposed method in authorship identification and the reveal of writing style evolution.

WB5 — Ballroom I

Aerial Robotics (Regular Session)

Chair: Hajiloo, Amir — Concordia Univ
Co-Chair: Maier, Moritz — DLR

13:30-13:50 WB5.1

Modeling and Backstepping Control of Under-Actuated Spherical UAV, pp. 2069-2074

Hajiloo, Amir — Concordia Univ
Rodrigues, Luis — Concordia Univ

The main contribution of this paper is to derive a nonlinear mathematical model and design a controller for a single rotor under-actuated spherical UAV providing asymptotic stability and trajectory tracking for the closed-loop system. A quaternion representation is first used to cast the model in two cascaded subsystems. A backstepping controller is then designed based on the nonlinear model. The performance of the controller is shown in simulation results.

13:50-14:10 WB5.2

Path Following for Quadrotors, pp. 2075-2081

Kumar, Sant — IDSC, ETH Zürich
Gill, Rajan — ETH Zurich

This paper presents a path following controller for quadrotors to follow splines in the output space. The control pipeline includes utilization of a cascaded control architecture, generation of paths using quintic spline interpolation, transformation of coordinates using Frenet-Serret (FS) frames, and decoupling controllers for the transversal and tangential sub-systems. The result is a time-invariant controller that renders the desired path invariant and attractive from arbitrary initial conditions, even when thrown into the air (shown in experiments), while maintaining a desired tangential velocity.

14:10-14:30 WB5.3

3D Trajectory Tracking Control of Quadrotor UAV with On-Line Disturbance Compensation, pp. 2082-2087

Bouzid, Yasser — IBISC Lab - Univ. Evry Val D'essonne, Univ. Paris Saclay
Siguerdidjane, Houria — Supelec
Bestaoui, Yasmina — Univ. D'evry Val D'essonne

In this paper, we propose a revisited form of the so-called Model-Free Control (MFC). Herein, the MFC principle is employed to deal with the unknown part of the plant only (i.e., unmodeled dynamics, disturbances, etc.) and occurs beside an Interconnection and Damping Assignment-Passivity Based Control (IDA-PBC) strategy that is used instead of the PID structure as done in the classical MFC form. Using the proposed formulation, it is shown that we can significantly improve the performance of the control and its robustness level. This problem is studied in the case of Multi-Inputs Multi-Outputs (MIMO) system with an application to a small Vertical Take-Off and Landing (VTOL) vehicle where a stability analysis is also provided. The numerical simulations have shown satisfactory results where an in-depth discussion with respect to the control performance is highlighted by considering several scenarios and using several metrics.

14:30-14:50 WB5.4

Application of Model Error Compensator Based on FRIT to Quadcopter, pp. 2088-2093

Endo, Hiroaki — Tokyo City Univ
Aramaki, Ryo — Tokyo City Univ
Nonaka, Kenichiro — Tokyo City Univ
Sekiguchi, Kazuma — Tokyo City Univ

We apply the method to suppress the influence of the model error to a quadcopter. Because a quadcopter is a flying object, the stability is important. Many model based controllers have been proposed and applied to a quadcopter but the control performance is deteriorated when a model error exists. The model error compensator (MEC) is applied to a model based controller as a solution of this problem. MEC is one of the 2-DOF control system. In many studies using the model based control, a linearized model is used to simplify the controller design, but model errors may change by the attitude of a quadcopter. The compensating the fluctuated model error is difficult using simple MEC. Therefore, the fictitious reference iterative tuning (FRIT) is applied to adjust the compensation gain of MEC. using the optimization calculation. The performance of the proposed controlled system is verified by experiments.

14:50-15:10 WB5.5

Robot Assisted Landing of VTOL UAVs on Ships: A Simulation Case Study of the Touch-Down Phase, pp. 2094-2101

Maier, Moritz — German Aerospace Center (DLR)
Kondak, Konstantin — German Aerospace Center (DLR)

Robot assisted landing means to use a robot manipulator to capture a vertical take-off and landing unmanned aerial vehicle (VTOL UAV) in flight and tow it to a designated landing spot. This procedure enables the VTOL UAV to land on moving surfaces and under side wind conditions. In our previous work, we neglected ship motion, the influence of the UAV on the manipulator, and the torque limits of the robot, which is only valid for light UAVs. Therefore, in this paper, we present a multibody dynamics model of a moving base robot manipulator with a VTOL UAV attached at its end-effector via a ball joint. For the robot, a task space tracking controller with base motion compensation is derived and for the UAV, an active thrust vector control law. We evaluate the effect of heavy UAVs and of base motion compensation on the trajectory tracking performance in a simulation case study using five sets of realistic VTOL UAV model parameters as well as base movements provided by a ship motion simulation at three different sea states. The results clearly show that active thrust vector control is needed in order to comply with the robots joint torque limits.

15:10-15:30 WB5.6

Nonlinear Hovering Control Laws for Small Vectored-Thrust Tail-Sitter UAVs, pp. 2102-2107

Miyazaki, Kouzi — Nagoya Univ
Tsubakino, Daisuke — Nagoya Univ

In this paper, we develop hovering control laws for a small vectored-thrust tail-sitter unmanned aerial vehicle (UAV). The UAV is equipped with propellers in a pusher configuration. The magnitude and direction of the thrust generated by the propellers are regarded as the control input. Since the state equation is not in an input-affine form, a state and an input transformation are introduced. Then, three control laws including the inverse optimal controller are derived based on the backstepping control method. Numerical simulations confirm that all the control laws successfully realize the hovering. Comparison of the

performance of these control laws is also conducted.

WB6 Ballroom II

Aerospace Applications II (Regular Session)

Chair: Kügler, Martin — Tech. Univ. of Munich

Co-Chair: Sato, Masayuki — Japan Aerospace Exploration Agency

13:30-13:50 WB6.1

Online Self-Monitoring of Automatic Take-Off and Landing Control of a Fixed-Wing UAV, pp. 2108-2113

Kügler, Martin — Tech. Univ. München

Holzapfel, Florian — Tech. Univ. München

In comparison to the pilot aboard a manned aircraft, the flight operator of an unmanned aerial vehicle (UAV) has less possibilities to supervise its automatic flight guidance and control system and intervene if necessary. This is especially critical during automatic take-off and landing (ATOL), as these phases of flight demand low reaction time and tolerate little error. This paper presents an online self-monitoring algorithm for the ATOL system of a fixed-wing UAV. It assesses systems, controllers, and flight-performance during the maneuvers and enables automatic decision to alter or abort. The algorithm has been successfully implemented in the flight control system of the SAGITTA Demonstrator UAV, the functional software of which has been developed at the Institute of Flight System Dynamics of the Technical University of Munich. Simulation results and ground testing of the SAGITTA Demonstrator have proven the concept of the self-monitoring algorithm and give an outlook to its applicability in flight.

13:50-14:10 WB6.2

Revisiting the Aircraft C Control Law: A Comparison between Classical and Structured H-Infinity Designs*, pp. 2114-2119

Marcos, Andres — Univ. of Bristol

This article presents the design and comparison of two approaches to the case of a C* control law design. This type of control laws is the standard in the commercial aviation industry, with both Airbus and Boeing flying versions of it. A baseline design is first developed following the standard, classical control technique of Root Locus, and then the structured H-infinity control technique is used. It is shown that both approaches are successful, and indeed with some design precautions the latter can maximize the knowledge from the previous design while imbuing the process with more advantageous capabilities in terms of reducing design time and accounting for model uncertainty and operational changes.

14:10-14:30 WB6.3

Allocation of Distributed Flaps for Gust Load Alleviation, pp. 2120-2125

Pusch, Manuel — German Aerospace Center (DLR)

Increasing the number and functionality of control surfaces provides great potential to improve aircraft performance. This, however, complicates the design of the control allocation system commonly used for flight control. A novel method for linear control allocation is presented which allows considering an arbitrary number of frequency dependent control objectives. The method systematically identifies principal control input directions for predefined performance channels by means of a balancing state space transformation. The effectiveness of the method is proven by designing a gust load alleviation system for a flexible aircraft with distributed trailing edge flaps.

14:30-14:50 WB6.4

Flight Management Systems for All-Electric Aircraft, pp. 2126-2131

Kaptsov, Maxim — Concordia Univ

Rodrigues, Luis — Concordia Univ

Recent years have marked a significant step forward in the development of all-electric airplanes, some of which have been built and tested recently. This paper proposes an optimal control framework for flight management systems of all-electric aircraft. The optimal control problems of economy mode and maximum endurance will be solved using Pontryagin's minimum principle. The economy mode optimization problem corresponds to the minimization of a functional parameterized by a coefficient index that performs a trade-off between the cost of the battery charge and time-related costs. The speed for maximum endurance, the maximum endurance and the maximum range were obtained as analytical solutions of the parameters. However, the speed for maximum range and the speed for economy mode are the positive real root of a polynomial equation of order eight, which can easily be obtained numerically. The Airbus E-Fan 1.0 model is used to obtain numerical results and validate the optimal solutions.

14:50-15:10 WB6.5

Flight Testing of an Structured H-Infinity Controller: An EU-Japan Collaborative Experience, pp. 2132-2137

Marcos, Andres — Univ. of Bristol

Sato, Masayuki — Japan Aerospace Exploration Agency

This article presents the results from the first flight campaign undertaken within the frame of a collaborative EU-Japan project aimed towards the technological maturation of advanced aircraft guidance, navigation and control techniques. A control design (developed and flight tested by JAXA several years ago) was selected as the baseline system and objectives. This baseline design was based on a two degrees-of-freedom structure aimed at gust suppression in the feedback part and handling qualities model-matching objectives in the feedforward part. A newly developed controller uses this legacy interconnection and objectives and applies the Structured H-infinity control design approach with the goal to demonstrate the latter's potential to fulfill the same objectives while reducing the controller's dimension. The flight tests results presented show that this was successful and that both controllers' behavior are mostly indistinguishable, but with the new controller at half the dimension of the baseline.

15:10-15:30 WB6.6

Control Strategies for an Advanced Aircraft-Cabin Temperature-System, pp. 2138-2143

Pollok, Alexander — German Aerospace Center (DLR)

Thermal regulation of aircraft cabins requires controlling the temperature of supplied fresh air. State of the art plant architectures support only a small number of temperature zones. In this paper we consider a novel architecture that allows an arbitrary number of temperature zones. This is bought at the expense of a more complex control problem. Control challenges connected to this novel architecture are identified and possible control approaches are presented. They are benchmarked against high-fidelity models in the equation-based object-oriented modelling language Modelica. Results show that control input normalization offers significant advantages for any kind of control system, while the choice between PID-based and LQG-based control is somewhat ambiguous: The former shows better performance in the nominal case, the latter exhibits better robustness.

WB7 Ballroom III

Control Applications for Renewable Integration (Invited Session)

Chair: Dong, Jin — Oak Ridge National Lab
Co-Chair: Qu, Zhihua — Univ. of Central Florida
Organizer: Taylor, Joshua A. — Univ. of Toronto
Organizer: Qu, Zhihua — Univ. of Central Florida

13:30-13:50 WB7.1

Hierarchical and Cooperative Model Predictive Control of Electrical Grids by Using Overlapping Information (I), pp. 2144-2149

Sanz i López, Víctor — Univ. Pol. De Catalunya
Namerikawa, Toru — Keio Univ

The presented study deals with hierarchical and cooperative model predictive control (MPC) of electrical grids. The aim of this study is minimizing electrical frequency deviation while ensuring power levels do not rise too much. The original system is a simply interconnected one divided in several areas and, in order to control eventually disconnected areas due to communication blackouts, an expansion of the original system to a hierarchical version of itself by overlapping original system's areas is developed.

13:50-14:10 WB7.2

Harmonic Reduction Via Optimal Power Flow and the Frequency Coupling Matrix (I), pp. 2150-2157

Tian, Yanhua — Univ. of Toronto
Li, Na — Harvard Univ
Taylor, Joshua A. — Univ. of Toronto

In this paper we propose a new optimal power flow scheme that takes into account the harmonics generated by power electronics interfaced distributed generation (DG). The objective is to minimize the cost of generation under constraints on the total harmonic distortion (THD) of voltage. The frequency coupling matrix (FCM) is used to model the harmonic current injected by a converter. Network current and voltage are modeled for each harmonic frequency. Constraints limiting the maximum voltage THD are introduced to the three- phase optimal power flow (OPF) problem. We construct a semidefinite relaxation, which can be solved using commercially available software packages. We give numerical results for the harmonic-constrained optimal power flow for two test systems.

14:10-14:30 WB7.3

Augmented Optimal Control for Buildings under High Penetration of Solar Photovoltaic Generation, pp. 2158-2163

Dong, Jin — Oak Ridge National Lab
Djouadi, Seddik, M. — Univ. of Tennessee
Kuruganti, Teja — Oak Ridge National Lab
Olama, Mohammed — Oak Ridge National Lab

This paper investigates the use of a collection of dispatchable heating, ventilation and air conditioning (HVAC) loads to absorb the slow (low-frequency) fluctuations in solar photovoltaic (PV) generation. We first formulate the buildings' thermal dynamics and the associated optimization problem. An optimization formulation is then designed based on traditional model predictive control algorithm, which provides the baseline performance. We then develop an augmented optimal control strategy to improve the solar tracking performance. To guarantee quality of service, in a fleet of residential/commercial buildings, a quadratic optimization problem is formulated to compute the optimal schedule for a given set of HVAC loads, while maintaining occupants comfort and PV generation constraints. Finally, we demonstrate the performance of the present algorithms through simulation, which validates that the proposed mechanism is able to achieve good PV tracking performance as well as obtain a minimal capacity of the required energy storage devices.

14:30-14:50 WB7.4

Blockchains for Decentralized Optimization of Energy Resources in Microgrid Networks (I), pp. 2164-2171

Munsing, Eric — Univ. of California, Berkeley
Mather, Jonathan — Univ. of California, Berkeley
Moura, Scott — Univ. of California, Berkeley

We present an architecture for peer-to-peer energy markets which can guarantee that operational constraints are respected and payments are fairly rendered, without relying on a centralized utility or microgrid aggregator. We demonstrate how to address trust, security, and transparency issues by using blockchains and smart contracts, two emerging technologies which can facilitate decentralized coordination between non-trusting agents. While blockchains are receiving considerable interest as a platform for distributed computation and data management, this is the first work to examine their use to facilitate distributed optimization and control. Using the Alternating Direction Method of Multipliers (ADMM), we pose a decentralized optimal power flow (OPF) model for scheduling a mix of batteries, shapable loads, and deferrable loads on an electricity distribution network. The DERs perform local optimization steps, and a smart contract on the blockchain serves as the ADMM coordinator, allowing the validity and optimality of the solution to be verified. The optimal schedule is securely stored on the blockchain, and payments can be automatically, securely, and trustlessly rendered without requiring a microgrid operator.

14:50-15:10 WB7.5

Stochastic Day Ahead Load Scheduling for Aggregated Distributed Energy Resources (I), pp. 2172-2179

Travacca, Bertrand — Univ. of California, Berkeley
Bae, Sangjae — Univ. of California, Berkeley
Wu, Jiacheng — Univ. of California, Berkeley
Moura, Scott — Univ. of California, Berkeley

This paper presents an optimal Day-Ahead Electricity Market (DAM) bidding strategy for an aggregator leveraging a pool of residential prosumers: residential customers with local photovoltaic (PV) production and plug-in electric vehicle (PEV) charging flexibility. The aggregator's point-of-view differs from the social planner angle that is taken in the majority of the existing literature, mainly the aggregator is considered to be a private entity (e.g. an electricity retailer). We propose a novel approach to tackling this optimization problem, by including risk management in the objective function and chance constraints on the aggregated PEV mobility constraints. In a first step, we model local system constraints and define a stochastic optimization scheme that exploits the problem structure to distribute the objective among prosumers via dual-splitting. Dual splitting is achieved with two consensus variables: a shadow price for energy and for PEV charging. In a second step, we propose a projected gradient ascent algorithm to solve the dual problem and we prove its corresponding rate of convergence (upper-bound). Finally, we implement a case study, with a model of 100 prosumers, to illustrate the convergence rate of our algorithm. We show that we reach an acceptable level of precision with less than 50 iterations.

15:10-15:30 WB7.6

Dissipativity-Based Design of Local and Wide-Area DER Controls for Large-Scale Power Systems with High Penetration of Renewables (I), pp. 2180-2187

Harvey, Roland — Univ. of Central Florida
Xu, Ying — Univ. of Central Florida
Qu, Zhihua — Univ. of Central Florida
Namerikawa, Toru — Keio Univ

In this paper, an integrated and modular control design is developed for distributed energy resources (DERs) to stabilize power systems and minimize effects of load variations and intermittent generation. Traditionally, the droop control of each generator (or virtual power plant) works as a local feedback loop to track frequency during load disturbance, whereas automatic generation control (AGC) calculates

control signals and sends them to each generator with the goal of matching the total generation and load in the overall system. The droop control and the AGC work separately, therefore the two controls often conflict each other. The proposed design enables us to modularly synthesize an integrated control for each of the DERs by using both local and wide-area measurements so that the controls work together in enhancing stability and performance of the power system. The design methodology admits the full nonlinear power flow equations, and it results in a data-driven control that in real-time takes into account the nonlinear power flow interactions (in terms of current angle measurements) and adaptively adjusts parameters of the controls that operate the DERs. The design framework uses the concept of passivity-short systems to analyze individual DERs and quantify their dynamic responses in such a way that the resulting system-wide implementation becomes plug-and-play. Simulations are done to demonstrate the effectiveness of the proposed methodology and design.

WB8 Ballroom IV

Connected and Autonomous Vehicles (Invited Session)

Chair: Ahmed, Qadeer — Ohio State Univ
Co-Chair: Onori, Simona — Clemson Univ
Organizer: Onori, Simona — Clemson Univ
Organizer: Ahmed, Qadeer — Ohio State Univ

13:30-13:50 WB8.1

Constraint Tightening for the Probabilistic Collision Avoidance of Multi-Vehicle Groups in Uncertain Traffic (I), pp. 2188-2195

Wang, Qian — Clemson Univ
Ayalew, Beshah — Clemson Univ

Future self-driving cars and current ones with advanced driver assistance systems are expected to interact with other traffic participants, which often are multiple other vehicles. To facilitate the motion planning of the autonomously controlled vehicle in collision avoidance, individual object vehicles with closeness in positions and velocities can be grouped as a single extended moving object. However, due to uncertainties from sensor imperfections and environmental disturbances, the collision avoidance conditions are often expressed as difficult to resolve probabilistic constraints in the motion planning problem. In this paper, we propose a constraint tightening method to transform the probabilistic collision avoidance condition for a vehicle group or an extended object into a deterministic form. This is done via a conservative closed-form transformation of the bivariate integral in the collision probability density function and subsequent computable approximation with logistic functions. Detailed numerical experiments are included to illustrate the workings and the performance of the proposed approach. This method can be incorporated in existing motion planning methods.

13:50-14:10 WB8.2

Absolute Driving Style Estimation for Ground Vehicles (I), pp. 2196-2201

Colombo, Tommaso — Pol. Di Milano
Panzani, Giulio — Pol. Di Milano
Savaresi, Sergio M. — Pol. Di Milano
Paparo, Pascal — Honda R&D Europe

This paper proposes a method for a real-time classification of the absolute driving style using three levels of sportiveness: calm, normal and sporty. The algorithm is based on a physical gg-plot-based approach and on a novel manouvre detection algorithm. The method makes use of standard vehicle signals which can be also provided by an external IMU+GPS system. Experimental results show the effectiveness of the proposed approach as driving style indicator.

14:10-14:30 WB8.3

Sequential Convex Programming MPC for Dynamic Vehicle Collision Avoidance (I), pp. 2202-2207

Alrifaee, Bassam — RWTH Aachen Univ
Maczijewski, Janis — RWTH Aachen Univ
Abel, Dirk — RWTH Aachen Univ

This paper presents a dynamic collision avoidance controller of a connected vehicle group using Model-based Predictive Control (MPC). The vehicles should follow a predefined reference trajectory while simultaneously avoiding collisions on this trajectory. MPC pursues the following of the reference trajectory in the objective function of the optimization problem. In order to avoid collisions, MPC defines avoidance constraints between each two vehicles. Due to the collision avoidance constraints, the feasible set of the optimization problem is non-convex. Thus, the resulting optimization problem is non-convex. This paper presents an efficient method to solve this non-convex optimization problem based on sequential convex programming.

14:30-14:50 WB8.4

Constraint-Enforcing Controller for Both Autonomous and Assisted Steering (I), pp. 2208-2213

Kalabic, Uros V. — Mitsubishi Electric Res. Labs
Berntorp, Karl — Mitsubishi Electric Res. Labs
Di Cairano, Stefano — Mitsubishi Electric Res. Labs

This paper considers the design of a controller and a constraint-enforcement scheme for application to dual-mode, autonomous and manual steering systems. A tracking controller is designed to track a desired pinion angle during autonomous operation, and to provide assistive torque during manual operation. The tracking controller is designed using H_∞ synthesis with tracking made possible via the solution to a full-information output regulation problem. A reference governor scheme is implemented in order to enforce constraints. Numerical simulations are presented corresponding to an aggressive step-steer maneuver in autonomous mode and show strict constraint enforcement.

14:50-15:10 WB8.5

Model Predictive Control with a Mixed Integer Programming for Merging Path Generation on Motor Way, pp. 2214-2219

Mukai, Masakazu — Kogakuin Univ
Natori, Hiroi — Kogakuin Univ
Fujita, Masayuki — Tokyo Inst. of Tech

This paper proposes a path generation method using model predictive control for merging of automobiles on a motor way. It is formulated as a mixed integer programming problem. The method is implemented based on receding horizon philosophy. The optimization problem is solved at each step then a first element of the optimal input is applied to system. The point of the proposed method is that it can consider a feasibility of the merging. Computer simulation is carried out to show the effectiveness of the proposed control method. Furthermore it is shown that the feasibility analysis can be employed to the gap control using adaptive cruise control and lane change control.

15:10-15:30 WB8.6

H-Infinity Control with Look-Ahead for Lane Keeping in Autonomous Vehicles, pp. 2220-2225

Roselli, Federico — Pol. Di Milano
Corno, Matteo — Pol. Di Milano
Savaresi, Sergio M. — Pol. Di Milano
Giorelli, Michele — Magneti Marelli
Azzolini, Davide — Magneti Marelli
Irilli, Alessandro — Magneti Marelli
Panzani, Giulio — Pol. Di Milano

In this paper a path tracking control for an autonomous vehicle is developed using the H_∞ technique. The lateral control problem is reformulated as the control of two variables: the lateral error and the derivative of the look-ahead error, defined as the distance between a virtual point on the vehicle longitudinal axis in front of the CoG and the reference trajectory. This approach is based on the fact that while driving on a constant curvature trajectory the derivative of the look-ahead error must be 0. The effectiveness of the proposed control strategy is demonstrated with experiments on a 2013 Dodge Dart equipped with throttle, brake and steer-by-wire system and in simulation on CarSim. A model of the vehicle is identified, validated by experimental tests and used to tune the simulator. The steering actuator dynamics is also taken into account since it significantly affects the dynamics of the total system.