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ICUAS 2017 Paper Abstracts

WeA1	Salon E
Autonomy - I	
Chair: Quagliotti, Fulvia	Pol. Di Torino
Co-Chair: Panagou, Dimitra	Univ. of Michigan

10:00-10:20 WeA1.1

3D Dynamic Coverage and Avoidance Control in Power-Constrained UAV Surveillance Networks, pp. 1-10

Bentz, William — Univ. of Michigan
Panagou, Dimitra — Univ. of Michigan

This paper considers dynamic coverage control of multiple power-constrained UAVs. The UAVs are deployed to patrol a domain until the entire space has reached a satisfactory level of coverage. This is achieved through the gathering of visual information by a forward-facing camera, modeled as an anisotropic spherical sector. Coverage and collision avoidance guarantees are met through the design of a high-level kinematic hybrid control scheme consisting of a hold state as well as three coverage modes: local, global and scan mode. Energy-aware methods are encoded into the global coverage state to shift the bulk of spatial redistribution onto less constrained agents. The efficacy of this algorithm is presented through simulation.

10:20-10:40 WeA1.2

Data Science for Decision Aiding UAV Control, pp. 11-15

Ashokkumar, Chimpalthradi — US Air Force Acad
York, George — Acad. Center for Unmanned Aircraft Systems Res

The dynamics of a human operated nonlinear unmanned aerial vehicle (NUAV) with a given controller at the inner loop is governed by the admissible nonzero initial conditions and the pilot inputs. The movements of the joystick connected to the throttle and the control surfaces in a way are the indications of the pilot decision points to operate the stabilized NUAV. If these decisions fall short to avoid an obstacle or a denied air space, data science to generate the admissible control inputs through appropriate initial conditions becomes an important problem. Such control inputs at the autonomous decision points (decisions not made by the human pilot) complement the pilot inputs and may be used to avoid the obstacles and the denied airspace. In this paper, the rules to choose these control inputs at the autonomous decision points are discussed. A three degree of freedom aircraft in pitch plane is considered for illustrations.

10:40-11:00 WeA1.3

Time Response Bounds in Nonlinear UAV Control, pp. 16-22

Ashokkumar, Chimpalthradi — US Air Force Acad
York, George — Acad. Center for Unmanned Aircraft Systems Res
Lagimoniere, Ernie — Sierra Nevada Corp

One of the intriguing problems in nonlinear unmanned aerial vehicle (NUAV) control using one of its linearized model based controllers at the inner loop is generating admissible control inputs for which the aircraft trajectories are confined to its stability region. It is an initial condition selection problem that is not necessarily applied at initial time but can be applied at any part of the flight duration where a bifurcation is needed, say, to avoid a collision with an obstacle. So, valid initial condition options at a given time instant can generate a stable constant speed maneuver tree that can be augmented to an existing autopilot and enhance autonomous characteristics at the decision points where changes in flight path directions are needed. In this paper, a procedure to select these initial conditions is presented. The time response bounds of the NUAV in its stability regions are developed. Both zero input response without pilot inputs and total response with pilot inputs and initial conditions are analyzed. A three degree of freedom NUAV in pitch plane is considered to illustrate the hierarchical initial conditions for which the time responses are bounded.

11:00-11:20 WeA1.4

Decentralized Hungarian-Based Approach for Fast and Scalable Task Allocation, pp. 23-28

Ismail, Sarah — Department of Mechanical and Aerospace Engineering, New Mexico S
Sun, Liang — New Mexico State Univ

In this paper, a novel decentralized task allocation algorithm based on the Hungarian approach is proposed. The proposed algorithm guarantees an optimal solution as long as the agent network is connected, i.e., the second smallest eigenvalue of the Laplacian matrix of the agent graph is greater than zero. In order to show the motivation of the proposed algorithm, the original centralized auction and Hungarian algorithms are compared in terms of the converging speed versus the number of agents. The result shows the superiority of the Hungarian algorithm in scalability over the auction algorithm. Then, the performance of the proposed decentralized Hungarian-Based algorithm (DHBA) is compared with the consensus-based auction algorithm (CBAA) under different situations, including different number of agents and different network topologies. The simulation results show that DHBA outperforms CBAA in all cases on the basis of the converging speed, the optimality of assignments, and computational time.

11:20-11:40 WeA1.5

Quad Rotor-UAV Stabilization by Predictor Based Control, pp. 29-35

Ordaz, Jose Jairo — CINVESTAV
Salazar, Sergio — Umi Lafmia Cinvestav
Mondie, Sabine — CINVESTAV-IPN
Lozano, Rogelio — Univ. of Tech. of Compiègne
López, Jesús Ricardo — CINVESTAV

This works deals with the problem to stabilize a Quad rotor-UAV in presence of time-delay and disturbances. The proposed controller is based on the reduction approach, i.e. the system transformation into one without delay which might be stabilized using a regular controller. Mathematical induction method allows to develop a new transformation based on the fundamental theorem of calculus. A closed-loop stability analysis based on Lyapunov theory is address to prove the feasibility of the controller. The proposed technique is applied to an experimental platform with 4 DOF (degrees of freedom) specifically designed to bring a secure and easy way to tune and test experimental controllers.

WeA2	Salon AB
Path Planning - I	
Chair: Zhang, Youmin	Concordia Univ
Co-Chair: Rathinam, Sivakumar	Texas a & M Univ

10:00-10:20 WeA2.1

Analysis of a Gesture-Based Interface for UAV Flight Path Generation, pp. 36-45

Chandarana, Meghan — Carnegie Mellon Univ
Meszaros, Erica — Univ. of Chicago
Trujillo, Anna — NASA Langley Res. Center
Allen, Bonnie Danette — NASA Langley Res. Center

Traditionally, flight paths for unmanned aerial vehicles (UAVs) are generated offline by trained pilots and engineers using assumed environmental conditions, terrain and obstacles as constraints. As new applications for UAVs emerge, their user base shifts from one of operators with knowledge of low level systems to that of non-experts. These new operators require a more intuitive method for building desired UAV flight paths such that they can leverage the full capabilities of the vehicle without needing to understand its system complexities. We present a gesture-based natural language interface for defining trajectory segments using a library of twelve simple hand gestures. A user study is presented to analyze the effectiveness, ease-of-use and accuracy of the gesture-based interface as compared to a baseline mouse interface. We explore differences seen between subjects given their hand dominance, their prior UAV flight experience (or lack

thereof), and whether they chose to sit or stand while using the gesture interface. Given limited training time, subjects were able to accurately define an average of 74.36% of trajectory segments. Overall the user study highlights the favorable potential for the use of the gesture-based interface as an alternative input modality, as well as, feedback for future interface improvements and training methods.

10:20-10:40 WeA2.2

Speech-Based Natural Language Interface for UAV Trajectory Generation, pp. 46-55

Meszaros, Erica	Univ. of Chicago
Chandarana, Meghan	Carnegie Mellon Univ
Trujillo, Anna	NASA Langley Res. Center
Allen, Bonnie Danette	NASA Langley Res. Center

In recent years, natural language machine interfaces have become increasingly common. These interfaces allow for more intuitive communication with machines, reducing the complexity of interacting with these systems and enabling their use by non-expert users. Most of these natural language interfaces rely on speech, including such well-known devices as the iPhone's Siri application, Cortana, Amazon's Alexa and Echo devices, and others. Given their intuitive functionality, natural language interfaces have also been investigated as a method for controlling unmanned aerial vehicles (UAVs), allowing non-subject matter experts to use these tools in their scientific pursuits. This paper examines a speech-based natural language interface for defining UAV trajectories. To determine the efficacy of this interface, a user study is also presented that examines how users perform with this interface compared to a traditional mouse-based interface. The results of the user study are described in order to show how accurately users were able to define trajectories as well as user preference for using the speech-based system both before and after participating in the user study. Additional data are presented on whether users had previous experience with speech-based interfaces and how long they spent training with the interface before participating in the study. The user study demonstrates the potential of speech-based interfaces for UAV trajectory generation and suggests methods for future improvement and incorporation of natural language interfaces for UAV pilots.

10:40-11:00 WeA2.3

Collision-Free Trajectory Generation for UAVs Using Markov Decision Process, pp. 56-61

Yu, Xiang	Concordia Univ
Zhou, Xiaobin	Hunan Univ
Zhang, Youmin	Concordia Univ

A collision-free trajectory generation method capable of re-planning the trajectories of an unmanned aerial vehicle (UAV) can increase flight safety and decrease the possibility of mission failure. For this purpose, a Markov decision process (MDP) based algorithm combined with backtracking method, is presented to create a safe trajectory in the case of obstacles. Subsequently, a differential flatness method is adopted to smooth the profile of the rerouted trajectory for satisfying the UAV physical constraints. Simulation results demonstrate that the UAV with the proposed strategy can avoid obstacles and track moving targets in a hostile environment.

11:00-11:20 WeA2.4

Routing Unmanned Vehicles in GPS-Denied Environments, pp. 62-71

Sundar, Kaarthik	Texas A&M Univ
Misra, Sohum	Univ. of Cincinnati
Rathinam, Sivakumar	Texas a & M Univ
Sharma, Rajnikant	Univ. of Cincinnati

Most of the routing algorithms for unmanned vehicles, that arise in data gathering and monitoring applications in the literature, rely on the Global Positioning System (GPS) information for localization. However, disruption of GPS signals either intentionally or unintentionally could potentially render these algorithms not applicable. In this article, we present a novel method to address this difficulty by combining methods from cooperative localization and routing. In particular, the article formulates a fundamental combinatorial optimization problem to plan routes for an unmanned vehicle in a GPS-restricted environment while enabling localization for the vehicle. We also develop algorithms to compute optimal paths for the vehicle using the proposed formulation. Extensive simulation results are also presented to corroborate the effectiveness and performance of the proposed formulation and algorithms.

11:20-11:40 WeA2.5

Randomized Path Optimization for the Mitigated Counter-Detection of UAVs, pp. 72-78

Heaton, Mitchell	Naval Postgraduate School
DeVries, Levi	United States Naval Acad
Kutzer, Michael	United States Naval Acad

UAVs provide exceptional capabilities and a myriad of potential mission sets, but the ability to disguise where the aircraft takes off and lands would expansively advance the abilities of UAVs. This paper describes the development of a nonlinear estimation algorithm to predict the terminal location of an aircraft and a trajectory optimization strategy to mitigate the algorithm's success. A recursive Bayesian filtering scheme is used to assimilate noisy measurements of the UAVs position to predict its terminal location. We use a blackbody radiation-based likelihood function tuned to the UAVs known endurance limitations to assimilate the position measurements. A quadratic trajectory generation method with waypoint and time variation is used to produce a parameterized family of potential aircraft trajectories. The estimation algorithm is then used to assess parameterized UAV trajectories that minimize certainty of the true terminal location. The KL divergence is used to compare the probability density of aircraft termination to a normal distribution around the true terminal location. Results show that the greatest obfuscation of path directly correlates to variations in time of flight with respect to the vehicle's maximum possible flight time.

11:40-12:00 WeA2.6

A Line-Graph Path Planner for Performance Constrained Fixed-Wing UAVs in Wind Fields, pp. 79-86

Benders, Sebastian	DLR Braunschweig
Schopferer, Simon	DLR (German Aerospace Center)

We present a runtime efficient approach to sampling-based path planning for fixed-wing unmanned aerial vehicles (UAV) based on line-graphs. Accounting for flight performance limits and the local prevailing wind, path planning is computationally expensive especially in 3D obstacle environments. A common approach is to solve the problem successively, i.e. to plan collision free paths, which are then transformed into feasible paths. However, this may compromise planning completeness if path smoothing fails. We show that line-graphs based on 3D probabilistic roadmaps can be used to effectively decouple the planning problem. The roadmap serves as a persistent free space representation of the environment and the corresponding line-graph is used to incorporate kinematic constraints to respect the fixed-wing flight performance limits in wind. Applying the A* graph-search on the line-graph instead of the 3D roadmap allows to efficiently find paths that respect these kinematic constraints without relying on path smoothing. Our results show that the presented approach can be used for near-real time multi-query planning with varying wind conditions and flight performance constraints.

WeA3 Salon CD

Control Architectures - I

Chair: Nahon, Meyer	McGill Univ
Co-Chair: Bradley, Justin	Univ. of Nebraska

10:00-10:20 WeA3.1

Nonlinear Model Predictive Control for Aerial Manipulation, pp. 87-93

Lunni, Dario	Pol. Di Milano
Santamaria-Navarro, Angel	Inst. De Robòtica I Informàtica Industrial (CSIC-UPC)
Rossi, Roberto	Pol. Di Milano
Rocco, Paolo	Pol. Di Milano

Bascetta, Luca — Pol. Di Milano
Andrade-Cetto, Juan — Inst. De Robòtica I Informàtica Industrial, CSIC-UPC

This paper presents a nonlinear model predictive controller to follow desired 3D trajectories with the end effector of an unmanned aerial manipulator (i.e., a multirotor with a serial arm attached). To the knowledge of the authors, this is the first time that such controller runs online and on board a limited computational unit to drive a kinematically augmented aerial vehicle. Besides the trajectory following target, we explore the possibility of accomplishing other tasks during flight by taking advantage of the system redundancy. We define several tasks designed for aerial manipulators and show in simulation case studies how they can be achieved by either a weighting strategy, within a main optimization process, or a hierarchical approach consisting on nested optimizations. Moreover, experiments are presented to demonstrate the performance of such controller in a real robot.

10:20-10:40 WeA3.2

Neural Network Based Nonlinear Model Reference Adaptive Controller for an Unmanned Aerial Vehicle, pp. 94-103

Noble, Deleena — Cal Pol. Pomona
Bhandari, Subodh — Cal Pol. Pomona

This paper presents a neural network based model reference adaptive controller (MRAC) for the control of a fixed-wing unmanned aerial vehicle (UAV). An adaptive neural network is trained using the error between the UAV response and the desired response as given by the reference model. The design of a suitable reference model for the desired aircraft performance is investigated and developed. Unknown nonlinearities of the vehicle dynamics not accounted for by the reference model are compensated in real-time by the adaptive neural network approximation, which also provides online adaptation during off-nominal flight conditions. The nonlinear dynamics of a twin-engine UAV are modeled in Simulink to test the controller in a software-in-the-loop simulation environment. Simulation results for a number of flight maneuvers show the feasibility and performance of the proposed controller.

10:40-11:00 WeA3.3

Autonomous Control of Agile Fixed-Wing UAVs Performing Aerobatic Maneuvers, pp. 104-113

Bulka, Eitan — McGill Univ
Nahon, Meyer — McGill Univ

In this work, we present an autonomous control system to perform aerobatic maneuvers with an agile fixed-wing UAV. The control system is strongly based on the underlying physics of the aircraft, thus allowing simple control techniques to work well through the full range of flight conditions undergone in aerobatic maneuvers. Moreover, this single control system is capable of performing a wide variety of maneuvers, including those demonstrated in this work: knife-edge, rolling Harrier, hover, and aggressive turnaround, as well as the transitions between these maneuvers. The system's performance is demonstrated in a high-fidelity simulation environment.

11:00-11:20 WeA3.4

Agile Fixed-Wing UAV Motion Planning with Knife-Edge Maneuvers, pp. 114-123

Levin, Joshua Max — McGill Univ
Paranjape, Aditya — Imperial Coll. London
Nahon, Meyer — McGill Univ

A modern class of small fixed-wing unmanned aerial vehicles are physically capable of performing exceptional aerobatic maneuvers. This paper presents a methodology for including one of the more functional of these maneuvers, the knife-edge, in motion planning. This is achieved by separating the top-level motion planner from the dynamics and control of the knife-edge maneuver. By coupling feedback laws to feedforward control policies, a control system is developed for conventional trajectory tracking, as well as transitioning into and holding constant altitude and velocity knife-edge flight. A demonstration of how the knife-edge maneuver interacts with a motion planner is provided. The motion planner is based on a modified version of the rapidly-exploring random trees (RRT) algorithm. The algorithm is designed to generate a smooth, collision-free straight-line path that is used to construct a time-dependent reference trajectory for feedback tracking. For demonstration, environments are constructed with passages near as narrow as the aircraft's wingspan, which can more safely be passed through in knife-edge flight. Simulations are conducted to display the control system's ability to track the motion plan through the environments, including during narrow passages where knife-edge is employed.

11:20-11:40 WeA3.5

Nonlinear Controller for a UAV Using Echo State Network, pp. 124-132

Pugach, Bogdan — Cal Pol. Pomona
Beallo, Brian — California State Pol. Univ. Pomona
Bement, David — Cal Pol. Pomona
Brock, Justin — Cal Pol. Pomona
Winterer, Kyle — California State Pol. Univ. Pomona
Rodriguez, Luis — California State Pol. Univ. Pomona
Miller, Noah — California State Pol. Univ. Pomona
McGough, Sean — California Pol. State Univ. Pomona
Bhandari, Subodh — Cal Pol. Pomona
Aliyazicioglu, Zekeriya — Cal Pol. Pomona
Sherman, Tristan — Cal Pol. Pomona

A nonlinear adaptive controller for an unmanned aerial vehicle (UAV) has been developed using Echo State Network (ESN), which is a form of three-layered recurrent neural network (RNN). Online learning is used to train the ESN in real-time starting from randomized weights. The ESN is integrated into ArduPilot, an open source autopilot, for complex flight simulations. Software-in-the-loop and hardware-in-the-loop simulations are performed using the FlightGear Flight Simulator. The response of the UAV using the controller based on the ESN has surpassed the performance of the traditional controllers. Noise and external disturbances are added to show the effectiveness of the controllers. A UAV test platform is designed and built to gather aircraft flight data and test the ESN.

11:40-12:00 WeA3.6

Toward a Cyber-Physical Quadrotor: Characterizing Trajectory Following Performance, pp. 133-142

Shankar, Ajay — NIMBUS Lab, Univ. of Nebraska-Lincoln
Doebbeling, Seth — NIMBUS Lab, Univ. of Nebraska Lincoln
Bradley, Justin — Univ. of Nebraska

An Unmanned Aircraft System (UAS) is a Cyber-Physical System (CPS) in which a host of real-time computational tasks contending for shared resources must be cooperatively managed to provide actuation input for control of the locomotion necessary to obtain mission objectives. Traditionally, control of the UAS is designed assuming a fixed, high sampling rate in order to maintain reliable performance and margins of stability. But emerging methods challenge this design by dynamically allocating resources to computational tasks, thereby affecting control and mission performance. To apply these emerging strategies, a characterization and understanding of the effects of timing on control and trajectory following performance is required. Going beyond traditional control evaluation techniques, in this paper we characterize the trajectory following performance, timing, and control of a quadrotor UAS under discrete linear quadratic regulator control designed at various sampling rates. We develop a direct relationship between trajectory following performance and the real-time task period (i.e. sampling rate) of the real-time control task allowing future designs to trade off UAS performance and cyber resources at the planning and/or guidance layer. We also introduce new metrics for characterizing cyber-physical quadrotor performance, and lay the groundwork for the application of CPS control methods to quadrotor UASs.

WeA4 Lummus Island

UAS Applications - I

Chair: Campoy, Pascual	Univ. Pol. Madrid
Co-Chair: Theilliol, Didier	Univ. of Lorraine

10:00-10:20 WeA4.1

Adaptive Dynamic Control for Trajectory Tracking with a Quadrotor, pp. 143-149

Santos, Milton Cesar Paes	Federal Inst. of Espirito Santo
Rosales, Claudio Dario	Univ
Sarapura, Jorge	Inst. De Automática - Univ. Nacional De San Juan
Sarcinelli-Filho, Mário	Federal Univ. of Espirito Santo
Carelli, Ricardo	Univ. Nacional De San Juan

This work proposes an adaptive dynamic controller for an unmanned aerial vehicle (UAV) to track a desired trajectory. Initially, reference velocities are generated by a controller that is based only on the kinematic model of the UAV. Subsequently, new control actions are calculated to compensate for the internal dynamics of the robot. Then the model parameters that characterize the robot dynamics are updated during navigation, characterizing an adaptive controller. In this way, the performance of the flight application with the quadrotor is improved, since the control errors are minimized. The stability of the proposed control system is proven, based on the Lyapunov theory. Finally, simulated results are presented, demonstrating the good performance of the controller even without any previous knowledge of the values of the parameters of the UAV dynamics.

10:20-10:40 WeA4.2

Attitude and Altitude Tracking of Hexacopter Via LQR with Integral Action, pp. 150-159

Suicmez, Emre Can	Middle East Tech. Univ
Kutay, Ali	Georgia Inst. of Tech

A controller is designed for hexacopter platform to achieve accurate tracking of altitude and attitude commands under the influence of severe disturbances. The main aim is designing a controller that can be tuned easily to satisfy desired performance requirements. For this purpose, multi-variable control method LQR is combined with PID structure which provides valuable physical insight in tuning process. Integral states are added to the system dynamics to have PID structure. Command generator is used to have trajectory independent optimal gain matrix which is advantageous for real time application. Time domain requirements are satisfied by tuning state and input weight matrices (Q and R) systematically. By this way, it is also possible to tune the controller for hexacopter platforms with different parameters (mass, inertia, etc.) without much effort. Controller performance is analyzed by using nonlinear dynamic model which includes a basic drag model, disturbance effects, actuator and sensor dynamics. Tracking performance and disturbance rejection properties are satisfactory according to numerical results. Controller structure is suitable for real time implementation with the help of simplified tuning process and a hexacopter platform is under construction for experimental verification.

10:40-11:00 WeA4.3

Development and Experimental Verification of a Hybrid Vertical Take-Off and Landing (VTOL) Unmanned Aerial Vehicle(UAV), pp. 160-169

Gu, Haowei	Hong Kong Univ. of Science and Tech
Lyu, Ximin	HKUST
Li, Zexiang	Hong Kong Univ. of Science & Tech
SHEN, Shaojie	Hong Kong Univ. of Science and Tech
Zhang, Fu	Hong Kong University of Science and Tech

In this paper, we present the design and verification of a hybrid vertical takeoff and landing (VTOL) unmanned aerial vehicles (UAV) of the type named dual system or extra propulsion VTOL UAV. This paper features the comprehensive system development of such VTOL UAVs from all aspects, including the aircraft design and implementation, onboard devices integration, ground station support, and long distance communication. We proceed with aerodynamic analysis, mechanical design, and controller development. Finally, we verify by experiment that this hybrid VTOL UAV has the desired aerodynamic performance, flight stability, endurance and range. In addition, with the designed flight controller, the VTOL UAV can achieve full autonomous flight in a real outdoor environment. It serves a good platform for future research, such as vision-based precise landing, motion planning and quick 3-D mapping, as well as service applications, such as medicine delivery.

11:00-11:20 WeA4.4

Towards Fully Autonomous Landing on Moving Platforms for Rotary Unmanned Aerial Vehicles, pp. 170-178

Rodríguez-Ramos, Alejandro	PhD Student at Univ. Pol. De Madrid
Sampedro, Carlos	Univ
Bavle, Hriday	PhD Student at Univ. Pol. De Madrid
Milosevic, Zorana	Univ. Pol. De Madrid
Garcia-Vaquero Velasco, Alejandro	Univ. Pol. De Madrid
Campoy, Pascual	Univ. Pol. Madrid

Fully autonomous landing on moving platforms poses a problem of importance for Unmanned Aerial Vehicles (UAVs). Current approaches are usually based on tracking and following the moving platform by means of several techniques, which frequently lack performance in real applications. The aim of this paper is to prove a simple landing strategy is able to provide practical results. The presented approach is based on three stages: estimation, prediction and fast landing. As a preliminary phase, the problem is solved for a particular case of the IMAV 2016 competition. Subsequently, it is extended to a more generic and versatile approach. A thorough evaluation has been conducted with simulated and real flight experiments. Simulations have been performed utilizing Gazebo 6 and PX4 Software-In-The-Loop (SITL) and real flight experiments have been conducted with a custom quadrotor and a moving platform in an indoor environment.

11:20-11:40 WeA4.5

SoC Estimation Using an Extended Kalman Filter for UAV Applications, pp. 179-187

Schacht Rodríguez, Ricardo	Centro Nacional De Investigacion Y Desarrollo Tecnologico
Ortiz Torres, Gerardo	CENIDET
Garcia Beltran, Carlos Daniel	Centro Nacional De Investigación Y Desarrollo Tecnológico
Astorga-Zaragoza, Carlos	TecnolÓgico Nacional De MÉxico - Cenidet
Ponsart, Jean-Christophe	Univ. De Lorraine
Theilliol, Didier	Univ. of Lorraine

Measuring or estimating adequately and accurately the state of charge (SoC) of a Li-Po battery, which powered an UAV during its flight allows to know the limits of the mission that the UAV is developing and to maximize the energy supplied by the battery. In this sense this paper presents a methodology to estimate the state of charge (SoC) of a Li-Po battery through an Extended Kalman Filter (EKF) during the flight of an UAV. By considering the mathematical model of the propulsion system of an UAV hexacopter, the power consumption is computed, and the SoC of the battery is estimated. Finally, a strategy based on estimated SoC is presented to predict the End-of-Discharge (EoD) during the development of a mission of and UAV hexacopter. The simulation results show the effectiveness of the proposed method.

11:40-12:00 WeA4.6

An Aerial Phytobiopsy System: Design, Evaluation, and Lessons Learned, pp. 188-195

Orol, Daniel	Univ. of Pennsylvania
Das, Jnaneshwar	Univ. of Pennsylvania
Vacek, Lukas	Univ. of Pennsylvania
Orr, Isabella	Univ. of Pennsylvania
Paret, Mathews	Univ. of Florida

Taylor, Camillo Jose — Univ. of Pennsylvania
Kumar, Vijay — Univ. of Pennsylvania

Early plant disease detection and treatment could dramatically increase crop yield. However, even experts cannot visually distinguish various diseases with certainty, limiting image based diagnosis. In this paper, we present a novel small unmanned aircraft system (sUAS) for Phytobiopsy. This platform can remove a leaf section with visual symptoms and transport it to a lab for precise disease analysis. We present the design of a gripper and an arm mechanism, and we discuss best practices for using the system. Results are presented from extensive experimental evaluation of the gripper assembly and 21 indoor manual flight trials, demonstrating efficacy. Our sUAS utilizes its inherent mobility and range to solve a pressing agricultural problem, improving food production and disease detection capabilities. A short video of our system can be found at https://goo.gl/xomYUO .

WeA5 — San Marco Island
UAS Navigation - I

Chair: Magree, Daniel — Georgia Inst. of Tech
Co-Chair: Ewing, Mark — Univ. of Kansas

10:00-10:20 — WeA5.1

Bio-Inspired Navigation Algorithm for GPS Denial Modes, pp. 196-205

Kolpuke, Shriniwas — Univ. of Kansas
Keshmiri, Shawn — Univ. of Kansas
Ewing, Mark — Univ. of Kansas

Abstract—The wide use of the Global Positioning System (GPS) for navigation has been persistent for a long time. However, in today's scenario when technologies are advancing the accuracy of positioning systems, there are various new threats and challenges emerging. The signal receivers for positioning systems are prone to spoofing. This external interference in the system is usually done by feeding false signals to the receiver. Though the dead reckoning method is still in use, any interference with GPS can still lead to disaster. Insects and birds are known to use solar position for guidance and it is widely accepted by researchers that some birds, such as pigeons, use solar position in their homing flight. There are similar studies performed on honeybees and monarch butterflies. The use of solar position by these insects and birds brings up the question of whether a mathematical model can be used to replicate the results for aircraft navigation, and can a bio-inspired navigation algorithm like this be implemented? Solar position algorithms are already in wide use. The solar position algorithms available calculate the azimuth and zenith/incidence angles for the solar position at any given point of time when the position of the observer is known. The objective for navigation is to find an observer's position from solar position to present an alternative to GPS for navigational use. This document proposes a method for calculating the observer's position when the azimuth and zenith/incidence angles for the solar position, attitude of aircraft and time are known. The approach proposed is that the position of the observer can be calculated by reversing the ENEA algorithm where one will be calculating the position of the observer from solar position and time.

10:20-10:40 — WeA5.2

Generalized Predictive Control for Trajectory Tracking of a Quadcopter Vehicle, pp. 206-212

Rodriguez Cortes, Hugo — CINVESTAV-IPN
Mendoza Soto, José Luis — UNAM, Inst. De Ingenieria, Mexico

This article proposes a control strategy based on the constrained generalized predictive control (GPC) in combination with a geometric attitude controller for trajectory tracking of the quadcopter vehicle. The generalized predictive control approach allows tracking time varying trajectories using optimal control actions to meet constraints on the desired trajectory. The geometric attitude controller tracks the reference attitude defined by the generalized predictive controller. The proposed controller is tested experimentally in a low-cost quadcopter instrumented with an attitude and heading reference system and an infrared camera based positioning system.

10:40-11:00 — WeA5.3

Finding Self-Cast Shadows in Aerial Camera Images, pp. 213-220

Gatter, Alexander — German Aerospace Center (DLR)
Andert, Franz — German Aerospace Center (DLR)

This paper presents a model-based shadow estimation method that aims at identifying self-cast shadows of aerial vehicles in on-board images. The self-cast shadow poses a non-negligible problem in any kind of on-board processing, e.g. remote sensing, visual odometry, or target tracking. Therefore, it often is necessary to exclude the image regions that contain this self-cast shadow. The presented method achieves this exclusion by using data from an INS (Inertial Navigation System) combined with the knowledge of the appearance of the shadow-casting object. This paper will present the self-cast shadow detection algorithm in detail. Further, the algorithm will be tested on flight data that have been recorded by an unmanned helicopter which is operated by the German Aerospace Center. The results show that it is possible to forecast the position of the shadow with an accuracy of over 95%, thus this method is capable of finding an image region where typical image motion estimation algorithms are likely to fail.

11:00-11:20 — WeA5.4

Direct Feature Correspondence in Vision-Aided Inertial Navigation for Unmanned Aerial Vehicles, pp. 221-229

Paredes Vallés, Federico — TU Delft
Magree, Daniel — Georgia Inst. of Tech
Johnson, Eric N. — Georgia Inst. of Tech

This paper proposes a novel method for corresponding visual measurements to map points in a visual-inertial navigation system. The algorithm is based on the minimization of the photometric error on sparse locations of the image region, and realizes a gain in robustness that comes from the elimination of the need of feature-extraction for correspondence. The system is compared to a standard approach based on feature extraction, within a visual-inertial EKF formulation. High-fidelity simulation results show the proposed method improves the horizontal RMS error by means of increasing the number of features corresponded by the algorithm.

11:20-11:40 — WeA5.5

Accelerated Point Mass Filter for Vision-Aided Terrain Referenced Navigation, pp. 230-236

JANG, DONGJIN — Hanseo Univ
Park, Jinyong — Hanseo Univ
Lee, Dongjin — Hanseo Univ

In this paper, a vision-aided terrain referenced navigation (VATRN) algorithm constructed by point-mass filter (PMF) is accelerated by graphic processing unit (GPU). The terrain referenced navigation algorithm estimates the vehicle's position by blending INS data with measured terrain height, and matching that data with the stored digital terrain elevation database (DTED). On the other hands, the VATRN algorithm obtains odometry data from visual sensors instead of inertial sensors. The odometry data is estimated by the homography relationship of two successive ground images of a monocular camera. Point-mass filter is one of the TRN algorithm based on the Bayesian estimation theory, and it contains convolutional integral of each points for the time update process. The convolution is the computational burden and can be accelerated by parallel computing to improve the estimation performance of PMF with sufficient point grids. GPU is employed to accelerate the PMF and numerical simulations are performed to analyze and evaluate the performance of the proposed method. The results show that the precise autonomous navigation of unmanned aircraft is achieved by the accelerated vision-based TRN algorithm.

11:40-12:00 — WeA5.6

Flight Demonstration of Multi-UAV CDGPS and Vision-Based Sensing for High Accuracy Attitude Estimation, pp. 237-246

Vetrella, Amedeo Rodi — Univ. of Naples "Federico II"
Causa, Flavia — Univ. of Naples "Federico II"
Renga, Alfredo — Univ. of Naples "Federico II"
Fasano, Giancarmine — Univ. of Naples "Federico II"

Accardo, Domenico — Univ. of Naples "Federico II"
Grassi, Michele — Univ. of Naples Federico II

This paper presents a cooperative navigation technique which exploits relative vision-based sensing and carrier-phase differential GPS (CDGPS) between antennas embarked on different flying platforms, to improve UAV attitude estimation in real time or in post-processing phase. The focus is set on outdoor environments; hence it is assumed that all vehicles are under nominal GPS coverage. The logical architecture and the main processing steps are highlighted with particular focus on the CDGPS processing. The experimental setup used to evaluate the proposed approach comprises two multi-rotors and two ground antennas. Results from flight tests are presented in which both code-based differential GPS (DGPS) and CDGPS solutions are analyzed. In addition, the attitude solution obtained by integrating CDGPS and vision (CDGPS/Vision) is compared with attitude estimates provided by the onboard autopilot system and with those obtained by adopting a DGPS/Vision approach.

WeB1 — Salon E
Autonomy - II

Chair: Sun, Liang — New Mexico State Univ
Co-Chair: Magree, Daniel — Georgia Inst. of Tech

15:00-15:20 — WeB1.1

Bird's Eye View: Cooperative Exploration by UGV and UAV, pp. 247-255

Hood, Shannon — Univ. of South Carolina
Benson, Kelly — Univ. of South Carolina
Hamod, Patrick — Univ. of South Carolina
Daniel, Madison — Univ. of South Carolina
O'Kane, Jason — Univ. of South Carolina
Rekleitis, Ioannis — Univ. of South Carolina

This paper proposes a solution to the problem of cooperative exploration using an Unmanned Ground Vehicle (UGV) and an Unmanned Aerial Vehicle (UAV). More specifically, the UGV navigates through the free space, and the UAV provides enhanced situational awareness via its higher vantage point. The motivating application is search and rescue in a damaged building. A camera atop the UGV is used to track a fiducial tag on the underside of the UAV, allowing the UAV to maintain a fixed pose relative to the UGV. Furthermore, the UAV uses its front facing camera to provide a birds-eye-view to the remote operator, allowing for observation beyond obstacles that obscure the UGV's sensors. The proposed approach has been tested using a TurtleBot 2 equipped with a Hokuyo laser ranger finder and a Parrot Bebop 2. Experimental results demonstrate the feasibility of this approach. This work is based on several open source packages and the generated code is available on-line.

15:20-15:40 — WeB1.2

Particle Filter for Closed-Loop Detection and Tracking from Occluded Airborne Images, pp. 256-263

Nakamura, Takuma — Georgia Inst. of Tech
Magree, Daniel — Georgia Inst. of Tech
Johnson, Eric N. — Georgia Inst. of Tech
Haviland, Stephen — Georgia Inst. of Tech
Bershadsky, Dmitry — Georgia Inst. of Tech. Atlanta

This paper describes a novel vision-based target tracking and landing method that uses aerial images from an on-board camera. The proposed method explicitly deals with occlusions that often occur during these maneuvers. Normalized cross correlation (NCC) is used to locate an image patch in a reference image with a measure of certainty. The key insight is that over the course of the vehicle approach, there is a transition between the target being contained in the camera images, and camera images being contained in the target image. When a vehicle is at high altitude, the NCC of the target over an entire camera image is computed. When at low altitude, the reverse operation is performed: the NCC of the camera images is computed over the target image. Additionally, at both high and low altitude, we find interesting region using contour trees, and the NCC of the template with the region is calculated. This way, we can recognize a target even when it is only partly in view. A particle filter is used to fuse highly multi-modal measurements from the three techniques. Each particle chooses its update measurement using a roulette wheel selection with the size of the slice being proportional to the measurement's NCC and, therefore, converges to a location that has a greater NCC and numerous positive hits. The particle filter allows estimation of target position and velocity states, which are used to determine criteria for safe landing. We evaluate our system with an image-in-the-loop simulation and closed-loop flight tests with a quadrotor.

15:40-16:00 — WeB1.3

Heterogeneous Multi-Vehicle Modular Control Framework with Payload Integration, pp. 264-270

Rogers, Cameron — Texas A&M Univ
Noren, Charles — Texas A&M Univ
Valasek, John — Texas A&M Univ

Small unmanned aircraft are being used in an increasing number of applications requiring cooperation between multiple heterogeneous vehicles. Multi-agent control algorithms can be implemented to control such systems but often require an underlying communications framework with integrated payloads. This paper presents a modular heterogeneous multi-agent control framework with payload integration. This framework, named Clark, provides a wireless network between agents without relying on pre-existing communications infrastructure and provides software interfaces for connecting to a variety of payloads. Underlying design requirements that highlight key features of the Clark framework are presented, and an overview of the framework and software architecture is given in the context of fulfilling key design requirements. The architecture is demonstrated with a flight test of three heterogeneous agents that includes communication performance metrics.

16:00-16:20 — WeB1.4

Self-Localization of a Tethered Quadcopter Using Inertial Sensors in a GPS-Denied Environment, pp. 271-277

Al-Radaideh, Amer — New Mexico State Univ
Sun, Liang — New Mexico State Univ

This paper presents a novel approach to estimate the relative position of an aerial vehicle that is connected to a fixed location on the ground through a taut tether of varying length. The onboard commercial-of-the-shelf (COTS) inertial sensors are the only source of sensory data used for the proposed approach. A three-dimensional (3D) dynamics model of the tethered quadcopter system is presented illustrating the use of the cable force in estimating the relative position of the aerial vehicle. We demonstrate the validity of the proposed approach in software simulations. The results show the effectiveness and accuracy of the proposed approach.

16:20-16:40 — WeB1.5

ChimneySpector: Autonomous MAV-Based Indoor Chimney Inspection Employing 3D Laser Localization and Textured Surface Reconstruction, pp. 278-285

Nieuwenhuisen, Matthias — Univ. of Bonn
Quenzel, Jan — Univ. of Bonn
Beul, Marius — Univ. of Bonn
Droeschel, David — Univ. of Bonn
Houben, Sebastian — Univ. of Bonn
Behnke, Sven — Univ. of Bonn

Inspection of industrial chimneys and smoke pipes induces high costs due to production downtimes and imposes risks to the health of human workers due to high temperatures and toxic gases. We aim at speeding up and automating this process with sensors mounted on multicopters. To acquire high quality sensor data, flying close to the walls of the chimney is inevitable, imposing high demands on good localization and fast and reliable control.

In this paper, we present an integrated chimney inspection robot based on a small lightweight flying platform, well-suited for maneuvering in narrow space. For navigation and obstacle avoidance, it is equipped with a multimodal sensor setup including a lightweight 3D laser

scanner, stereo cameras, and a high-resolution camera for surface inspection. We tested our system in a mock-up chimney modeling several surfaces found in real chimneys, and present results from autonomous flights and the reconstruction of the chimney surface.

WeB2	Salon AB
Path Planning - II	
Chair: Theilliol, Didier	Univ. of Lorraine
Co-Chair: Campoy, Pascual	Univ. Pol. Madrid

15:00-15:20 WeB2.1

Development and Testing of the Intercept Primitives for Planar UAV Engagement, pp. 286-293

Ghosh, Satadal	Naval Postgraduate School
Davis, Duane	Naval Postgraduate School
Chung, Timothy H.	Defense Advanced Res. Projects Agency
Yakimenko, Oleg A.	Naval Postgraduate School

With the advance in technologies and applications involving unmanned aerial systems cooperation among the autonomous agents within such an unmanned system as well as preparedness for responding to adversarial threat to such a system has become of pivotal importance. A multi-phase operational scenario of such cooperative and adversarial engagement, motivated by manned aerial engagement scenarios, is presented in this paper. A Proportional navigation-based integrated guidance methodology is proposed and investigated as a candidate strategy for intercept primitives in such realistic multi-phase UAV engagements. Numerical examples are presented to demonstrate the performance of the proposed guidance strategy for an UAV in such an engagement. Finally, implementation of these guidance laws in a waypoint-based manner, well suited for use in modern-day autopilots of UAVs, is demonstrated in software-in-the-loop simulations, further accelerating future live-fly capabilities for autonomous aerial engagements.

15:20-15:40 WeB2.2

Three-Dimensional Dubins Path Generation and Following for a UAS Glider, pp. 294-303

Di Donato, Pedro Fernando Almeida	National Civil Aviation Agency - ANAC/Brazil
Atkins, Ella	Univ. of Michigan

Small unmanned aircraft systems (UAS) typically do not offer the redundancy typical in commercial aviation due to budget and weight limitations. UAS, therefore, have a nontrivial probability of encountering a scenario in-flight that requires an emergency landing. For fixed-wing UAS, one of the most common in-flight emergencies is a total loss of engine or motor thrust, necessitating that the UAS glide to a safe landing site. This paper builds on the extensive previous work in Dubins path planning based on a point-mass model to provide a complete solution to the emergency glider landing problem applicable to a full six-degree-of-freedom fixed-wing aircraft model. Path planning and guidance algorithms are proposed to feed a standard autopilot low-level controller. While most previous work focused on maximizing the range or minimizing flight time, this work focus on providing a "safe solution" in the sense that the aircraft is maintained well inside its flight envelope. This provides margin to the controllers to deal with the different sources of environmental and vehicle performance uncertainties. The proposed solution can also be applied to an unmanned fixed-wing platform for which a detailed dynamics model is not available.

15:40-16:00 WeB2.3

Path Following Control of Unmanned Quadrotor Helicopter with Obstacle Avoidance Capability, pp. 304-309

Liu, Zhixiang	Concordia Univ
CIARLETTA, Laurent	Univ. De Lorraine, Loria
Yuan, Chi	Concordia Univ
Zhang, Youmin	Concordia Univ
Theilliol, Didier	Univ. of Lorraine

This paper proposes a new path following methodology combining with an obstacle avoidance scheme for unmanned quadrotor helicopter (UQH) capable of working in the cluttered and hazardous environments. A new cross-track error prediction based mechanism, where the cross-track error is estimated by utilizing the extend Kalman filter (EKF), is first developed for the path following scheme. Then, the UQH is equipped with obstacle avoidance capability employing a light-computational approach, the visibility graph algorithm. The priority of UQH is to switch to obstacles avoidance maneuvering in the presence of obstacles, and continue to execute the assigned mission after avoiding all hazardous objects blocking the desired path. The control system developed for attitude and position control of UQH is also introduced. Finally, extensive simulation studies on a nonlinear model of UQH with a series of dangerous scenarios are conducted to demonstrate the effectiveness of the proposed methodology.

16:00-16:20 WeB2.4

A Power Consumption Model for Multi-Rotor Small Unmanned Aircraft Systems, pp. 310-315

Liu, Zhilong	Univ. of Berkeley, Berkeley
Sengupta, Raja	Univ. of California at Berkeley
Kurzhanskiy, Alex	Univ. of California-Berkeley

We develop a theoretical power consumption model for multi-rotor Unmanned Aircraft Systems (UAS), estimate the model parameters, and validate it by flying an IRIS+ quadrotor UAS and measuring its energy consumption experimentally. The model is derived from the helicopter literature. Such models are required to create UAS flight planning systems.

16:20-16:40 WeB2.5

A Robust Real Time Path Planner for the Collision Free Navigation of Multirotor Aerial Robots in Dynamic Environments, pp. 316-325

Sanchez-Lopez, Jose Luis	CSIC - Univ. Pol. De Madrid, Centro De Automatica Y
Pestana Puerta, Jesus	Computer Vision Group, Centre for Automation and Robotics, CSIC
Campoy, Pascual	Univ. Pol. Madrid

The development of deliberative capabilities is required to achieve an intelligent fully autonomous behavior of unmanned aerial systems. An important deliberative capability is the generation of collision-free paths in complex environments.

This paper presents a robust real-time collision-free path planner used for the horizontal 2D navigation of multirotor aerial robots in dynamic environments. Its design, using geometric primitives to describe the environment combined with a launching time generation of a probabilistic roadmap graph, permits an efficient management of dynamic obstacles. The use of an A* discrete search algorithm, together with a potential field map as the cost function, allows to speed up the collision-free path computation ensuring that it never falls in local minima. Additionally, the velocity and acceleration along the collision-free planned path is calculated.

The performance of the proposed path planner is evaluated in this paper with two simulations with complex environments including a labyrinth and dead ends, and with a real flight experiment where three fully autonomous aerial robots executed an emulated search and rescue mission.

The proposed path planner has been released to the scientific community as an open-source software included in Aerostack (www.aerostack.org). In addition, it has extensively been used in multiple research projects with real flights, demonstrating its good performance.

WeB3	Salon CD
Control Architectures - II	
Chair: Lozano, Rogelio	Univ. of Tech. of Compiègne
Co-Chair: Quagliotti, Fulvia	Pol. Di Torino

15:00-15:20 WeB3.1

Dancing UAVs: Using Linear Programming to Model Movement Behavior with Safety Requirements, pp. 326-335

Dinh, Hoang Tung	Imec-Distrinet, KU Leuven
Cruz Torres, Mario Henrique	KU Leuven
Holvoet, Tom	KU Leuven

In this paper we present the use of linear programming to systematically create control software for choreographed UAVs. This application requires the control of multiple UAVs where each UAV follows a predefined trajectory while simultaneously maintaining safety properties, such as keeping a safe distance between each other and geofencing. Modeling and incorporating safety requirements into the movement behavior of UAVs is the main motivation of our research. First, we describe an approach where the movement behavior of each UAV is formulated as a linear program. Second, we compare and analyze two different modeling techniques to implement the safe distance and geofencing requirements. Our approach was validated by doing experiments with Parrot Bebop UAVs. Besides being tested in the laboratory, our approach was validated in real life conditions in more than 30 performances of a dance show where five UAVs perform choreographed movements as part of the show introduction.

15:20-15:40 WeB3.2

Nonlinear Control Based on H-Infinity Theory for Autonomous Aerial Vehicle, pp. 336-345

Garcia, Gonzalo	Univ. of Kansas
Keshmiri, Shawn	Univ. of Kansas
Shukla, Daksh	Univ. of Kansas

Existence of modeling errors, external disturbances, and inaccurate design assumptions make robustness a desired property for any control system in real-life applications. Linear robust controllers are widely seen as acceptable solutions when systems are controlled close to known equilibrium points and a known trajectory. Unfortunately, linear robust control designs become partially ineffective when these conditions are not met. The nonlinear and unsteady aerodynamics of aircraft in the presence of external disturbances and adverse conditions make application of linear robust controllers challenging. This paper presents a nonlinear version of robust H-infinity controller based on L2 gain and dissipativity concepts. The nonlinear H-infinity approach allows larger perturbations from the trim condition and delays any control degradation and risk of instability compared with the linear versions. The nonlinear H-infinity controller requires the solution of a Hamilton-Jacobi-Isaacs equation which is a limiting factor due to its complexity. This paper applies a state-feedback Taylor series expansion of the value function to iteratively solve the partial differential equations in incremental steps for an increasing degree of accuracy. A large UAS in trajectory tracking is used for performance comparison and robustness analysis in one hand with a linear robust controller, and on the other, with a robust nonlinear model predictive controller.

15:40-16:00 WeB3.3

Robust Trajectory Tracking for Unmanned Aircraft Systems Using High Order Sliding Mode Controllers-Observers, pp. 346-352

MUÑOZ PALACIOS, FILIBERTO	Univ. Pol. DE PACHUCA
Bonilla, Moises E.	CINVESTAV-IPN
Espinoza Quesada, Eduardo Steed	Univ. Pol. De Pachuca
Gonzalez-Hernandez, Ivan	Cinvestav - IPN
Salazar, Sergio	Umi Lafmia Cinvestav
Lozano, Rogelio	Univ. of Tech. of Compiègne

This article deals with the design of a novel algorithm that combines a Modified Super-Twisting Controller with a High Order Sliding Mode Observer to enable an aerial vehicle to track a trajectory under the assumption that i) its translational velocities are unavailable and ii) there are unmodeled dynamics and external disturbances. We present a mathematical justification that ensures the existence of a second-order sliding motion for the combination Controller- Observer. In order to demonstrate the effectiveness of the proposed solutions, a set of simulation results are presented.

16:00-16:20 WeB3.4

Mixed-Structure Control System for an Unconventional Coaxial-Ducted Fan Aircraft with Input Saturation, pp. 353-361

Fan, Wei	Beijing Inst. of Tech
Xiang, Changle	Beijing Inst. of Tech
Xu, Bin	Beijing Inst. of Tech
Peng, Yifan	Beijing Inst. of Tech

This paper presents a mixed-structure control system for a novel ducted fan aircraft in the presence of input constraint, system uncertainty and external disturbance. The control system includes mainly two parts: a robust nominal controller and a L1 adaptive augmentation. The robust nominal controller architecture consists of two loops. The inner-loop is designed as a static state feedback control matrix via H-infinity synthesis. This loop mainly provides state decoupling and external disturbance rejection. The outer-loop is defined as a series of PD controllers. This loop ensures the nominal tracking performance. Unlike tradition robust controller solution, the design constraints are expressed in terms of a series of closed-loop transfer functions. Both inner and outer loop controller elements are calculated by a non-smooth H-infinity optimizer at the same time. The L1 adaptive augmentation is mainly responsible for large uncertainty estimation and compensation. The simulation results prove that the L1 adaptive structure is able to provide a relative better performance for system with input saturation and large uncertainty.

16:20-16:40 WeB3.5

Partial State Robust Output Maneuvering Controller Applied to a Quadcopter Vehicle, pp. 362-368

Corona-Sanchez, José J.	ESIME Azcapotzalco
Mendoza Soto, José Luis	UNAM, Inst. De Ingenieria, Mexico
Rodriguez Cortes, Hugo	CINVESTAV-IPN

This article addresses the problem of quadrotors following a path geometry under the action of a constant external disturbance and with partial state measurement. To solve these issues, under the assumption of time scale separation between the translational dynamics and the closed-loop rotational dynamics, we propose an integral output robust maneuvering controller in combination with a translational velocity observer and an external disturbance estimator. Experimental results demonstrate the performance of the proposed control algorithm.

WeB4 Lummus Island

UAS Applications - II

Chair: Chen, YangQuan	Univ. of California, Merced
Co-Chair: Zhang, Youmin	Concordia Univ

15:00-15:20 WeB4.1

Fugitive Methane Leak Detection Using Suas and Miniature Laser Spectrometer Payload: System, Application and Groundtruthing Tests, pp. 369-374

Smith, Brendan	Univ. of California, Merced
John, Garrett	Univ. of California, Merced
Christensen, Lance	JPL
Chen, YangQuan	Univ. of California, Merced

A miniature emph{in-situ} CH$_4$ concentration measurement instrument based upon tunable laser spectroscopy (TLS) was developed and applied in numerous field campaigns. The instrument, a 3.4 $mu m$ laser spectrometer developed at NASA Jet Propulsion Lab (JPL), is lightweight (250 g), low power (<8 W), and high sensitivity (10 ppb s^{-1}). The payload was further developed and integrated onto a small UAV at UC Merced, rendering an overall payload weight of 400 g and real-time data acquisition. The remarkable characteristics of the instrument and prior investigative work regarding sensor placement yielded excellent trial and field results, which are presented in this work.

15:20-15:40 WeB4.2

System Simulation of a Fleet of Drones to Probe Cumulus Clouds, pp. 375-382

Bailon-Ruiz, Rafael	LAAS-CNRS
Reymann, Christophe	LAAS-CNRS
Lacroix, Simon	LAAS/CNRS
Hattenberger, Gautier	ENAC
Garcia de Marina, Hector	Univ. of Groningen
Lamraoui, Fayçal	CNRM-CNRS

Simulation plays an essential role in the development of complex systems. This paper reports on the development of a simulation infrastructure for a fleet of UAVs conceived to probe clouds, using an adaptive sampling scheme that calls for cloud mapping and trajectory planning. The mission is presented, the global approach to solve it and the ensemble of required processes are sketched. An overall simulation architecture is then depicted, and the details of its development using the Robot Operating System (ROS) are presented.

15:40-16:00 WeB4.3

Target Localization and Pursuit by Sensor-Equipped UAVs Using Distance Information, pp. 383-392

Lima, Rolif	Indian Inst. of Science, Bangalore
Ghose, Debasish	Indian Inst. of Science

This paper describes a problem in which a network consisting of a sensor-equipped UAV and multiple beacons, operating in a large geographical space, uses distance measurements to estimate the position of a target and pursue it. The positions of the beacon are also not known to the UAV and needs to be estimated by the UAV, again using distance measurements. Distance measurements are assumed to have been obtained from methods which are noisy in nature, due to which Kalman filter is used to get more accurate location estimates of the beacons and the target. The trajectory of the UAV is decomposed into a discovery phase and a pursuit phase. In discovery phase only beacon positions are estimated and in the pursuit phase a pursuit guidance law is used to guide the UAV to approach the target. Performance of the algorithm is demonstrated through simulations.

16:00-16:20 WeB4.4

Distributed Cooperative UAV Loss Detection and Auto-Replacement Protocol with Guaranteed Properties, pp. 393-401

Huang, Sunan	National Univ. of Singapore
Teo, Rodney	Temasek Lab. National Univ. of Singapore
Liu, Wenqi	National Univ. of Singapore
Dymkou, Siarhei Michailovich	National Univ. of Singapore

In this paper, we explore the UAV loss detection and auto-replacement scheme in a multi UAV system. The developed scheme is based on the concept of cooperative multi UAV control, where the cooperation is achieved by broadcasting heartbeats (HBs) and information fusion technology. We first propose the UAV loss detection method by checking the HB time. Subsequently, we present the UAV auto-replacement which is based on a contention protocol. Next, we propose the recovery algorithm for the lost UAV rejoining the UAV group. Finally, case studies are given to demonstrate the proposed scheme.

16:20-16:40 WeB4.5

Adaptive Robust Tracking Control of Quadrotor Helicopter with Parametric Uncertainty and External Disturbance, pp. 402-407

Wang, Ban	Concordia Univ
Mu, Lingxia	Northwestern Pol. Univ
Zhang, Youmin	Concordia Univ

This paper proposes an adaptive robust tracking control strategy for a quadrotor helicopter with parametric uncertainties and external disturbances based on sliding mode control. The inner loop of the control strategy is concerned about the attitude and altitude control of the quadrotor helicopter, while the outer loop is employed to track the desired horizontal positions. By assuming knowledge of the bounds on external disturbances, an integral sliding mode control is designed to maintain system performance and keep it insensitive to disturbances. For parametric uncertainties (e.g., total mass and moments of inertia) of the quadrotor helicopter, an on-line adaptive scheme is proposed and incorporated into the nominal sliding mode control to deal with it. With this adaptive scheme, there is no need to know the parametric uncertainty bounds. A guaranteed transient and steady-state tracking performance can be obtained with the adaptive robust sliding mode controller. The effectiveness of the proposed control strategy is validated through a simulation on a quadrotor helicopter subject to parametric uncertainties and external disturbances.

WeB5 San Marco Island

UAS Navigation - II

Chair: Sabatini, Roberto RMIT Univ

Co-Chair: Lozano, Rogelio Univ. of Tech. of Compiègne

15:00-15:20 WeB5.1

Fast Full State Trajectory Generation for Multirotors, pp. 408-416

Beul, Marius	Univ. of Bonn
Behnke, Sven	Univ. of Bonn

Micro aerial vehicles, such as multirotors, are developed for applications like autonomous monitoring, inspection, and surveillance. Most of the current application scenarios assume a stationary environment and thus, trajectory generation relies on static targets. In this paper, we address time-optimal trajectory generation in dynamic environments, e.g., for landing on a moving platform.

We extend our existing trajectory generation method by the ability to synchronize several axes of motion, following a master/slave approach for individual axes. We further explicitly treat moving targets, like moving landing platforms by planning in a target-centric frame. Our evaluation demonstrates the performance of the method under disturbances.

These results have application in dynamic multicopter flight, and also allow for fast and precise multicopter motion under challenging conditions.

15:20-15:40 WeB5.2

*An Analytical Framework for Evaluating Navigation System Integrity for Urban UAS**

Bijjahalli, Suraj	RMIT Univ
Ramasamy, Subramanian	RMIT Univ
Sabatini, Roberto	RMIT Univ

In recent years, Unmanned Aerial Systems (UAS) are increasingly employed for a variety of civil and military applications and the need to integrate these platforms in non-segregated airspace requires improved integrity and availability of the navigation system solution. In particular, with an introduction of UAS Traffic Management (UTM) supporting operation of multiple Unmanned Aerial Vehicles (UAVs) in dense urban environments, the evaluation of navigation system integrity is even more important. In this paper, a framework for integrating generic Signals-of-Opportunity (SoO) with existing multi-sensor navigation system architectures for urban UAS is presented. Required Navigation Performance (RNP) levels for UAS operating in urban environments are defined based on standards and guidelines for civil aviation, along with the concept of integrity risk and alert limits. Suitable test statistics based on measurement innovations are identified in order to support sensor fault detection. The use of protection levels to bound the positioning error is described and the means of evaluating protection levels that fulfill a given probability requirement for false alarms and missed detections is presented. A simulation case study is presented to assess the impact of SoO on protection levels in scenarios where Global Navigation Satellite System (GNSS) signals are not available or sparsely available. The simulations are performed using the AEROSONDETM dynamics model and an Extended Kalman Filter (EKF) to fuse the available sensor measurements. The presented framework supports the evaluation of navigation system integrity in line with assessment criteria defined in the civil aviation context.

15:40-16:00 WeB5.3

*Development of a Software Platform to Control Squads of Unmanned Vehicles in Real-Time** pp. 1858-1862

Santos, Nuno ISCTE-IUL
Raimundo, António ISCTE-IUL
Peres, Diogo ISCTE-IUL
Sebastião, Pedro ISCTE-IUL
Souto, Nuno ISCTE-IUL

16:00-16:20 WeB5.4

Haptic Feedback for Obstacle Avoidance Applied to Unmanned Aerial Vehicles, pp. 417-424

Courtois, Hugo Cranfield Univ
Aouf, Nabil Cranfield Univ

In the context of Unmanned Aerial Vehicle (UAV) teleoperation, the platform is remotely controlled by a human pilot. In order to provide a better situational awareness to the pilot, haptic feedback can be sent through the controller to indicate the presence of obstacles around the UAV. This feedback makes obstacle avoidance easier for the pilot and complements the visual cues obtained from a camera mounted on the UAV. To compute the feedback, an artificial force field is extended to 3D and modified to correct the situation caused by symmetric obstacles. This feedback is provided by the controller using a new algorithm involving virtual springs. An experimental evaluation of the method using a simulation is carried out including a statistical analysis of the results. This experiment shows that our method can reduce the number of collisions and decrease the operator's workload at a safety cost.

16:20-16:40 WeB5.5

On the Guidance for an UAV Formation Applying Multi-Layer Control Scheme, pp. 425-431

Brandao, Alexandre Santos Federal Univ. of Vicosa
Castillo, Pedro Unviersité De Tech. De Compiègne
Lozano, Rogelio Univ. of Tech. of Compiègne

In robotics, the navigation problem can be split in planning, execution, checking and correction. An approach to deal with these tasks is based on the Multi-Layer Control scheme (MLCS). In this technique, each layer is responsible for an individual step of the formation control problem, such as; to define and optimize the desired robot pose; to avoid or minimize collision risks; to control the robots for accomplishing the formation, and so on. In this work, a positioning task for a platoon of six aerial robots is guided by the MLCS methodology. The procedure is developed as follows: first, the off-line planning layer organizes the desired formation according to the current robot position; then, the robots are clustered in a set of triangular formations; and finally, each triangle is controlled for reaching its desired goal. Simulation results illustrate and validate the proposal.

WeC1 Salon E

Autonomy - III

Chair: Chen, YangQuan Univ. of California, Merced
Co-Chair: Sun, Liang New Mexico State Univ

16:40-17:00 WeC1.1

A Decentralized Game Theoretic Approach for Team Formation and Task Assignment by Autonomous Unmanned Aerial Vehicles, pp. 432-437

Bardhan, Rajarshi Nanyang Tech. Univ
BERA, TITAS Nanyang Tech. Univ
Sundaram, Suresh Nanyang Tech. Univ

A number of autonomous unmanned aerial vehicles (UAV) are tasked to search an unknown/uncertain environment, and neutralize targets whenever they come across such threats. Due to resource constraints of the UAVs, neutralizing some threats require simultaneous effort of a certain number of UAVs in minimum. When a UAV detects multiple such targets, it needs to communicate with its neighbor UAVs asking for their cooperation to form a team. Since the involved entities are dynamic in nature, a UAV may have to terminate information exchange with its neighbors within a few iterative steps so that the decision making process can be finished before any topological change takes place. Moreover, due to sensor range and communication bandwidth limitations, a UAV cannot know about other tasks available to its neighbors in an instantaneous manner. We formulate the problem that a UAV faces when it detects multiple such targets and needs to decide as to which target it should try to neutralize, given the uncertainty over the neighbor UAVs' actions, in a game theoretic framework. We propose a correlated equilibrium concept based decentralized game theoretic solution that requires local information of the UAVs.

17:00-17:20 WeC1.2

Opening the Aperture: Regulatory Changes for Safe Autonomous Flight in the U.S. National Airspace, pp. 438-446

Zoldi, Dawn United States Air Force Acad
Hyer, Timothy US Air Force Acad
Switzer, Jessica United States Air Force

Autonomous systems are a part of everyday life. Tesla recently introduced the Model S and Model X line of automobiles, which have self-drive capabilities including the ability to self-park.1 Other commonly accepted autonomous systems include automatic emergency braking for vehicles and even house cleaning robots, to name a few.2 Most manned and UAS today are semi-autonomous. Yet for many, the idea of fully autonomous UAS operations in the United States national airspace system (NAS) seems a bridge too far.

The purpose of this paper is to review current FAA regulations in light of anticipated technological advances and propose regulatory suggestions to enable autonomous UAS flights in the U.S. NAS. To do this, Part I summarizes relevant UAS regulations and the rationale behind them. Part II identifies different types of technological advances necessary to mitigate concerns associated with UAS flight safety in general and as applicable to autonomous flight. Part III explores potential regulatory improvements that will be required once sufficient technological mitigation measures exist. Part IV concludes by suggesting a new philosophical paradigm is required, in addition to regulatory and other changes, to truly open up the aperture in the NAS for safe autonomous unmanned flight.

17:20-17:40 WeC1.3

A Cloud-Based Framework for Risk-Aware Intelligent Navigation in Urban Environments, pp. 447-455

Primatesta, Stefano Pol. Di Torino
Capello, Elisa Pol. Di Torino
Antonini, Roberto Company
GASPARDONE, MARCO TIM
Guglieri, Giorgio Pol. Di Torino
Rizzo, Alessandro Pol. Di Torino

Remotely Piloted Aircraft Systems (RPAS) are being widely studied and developed due to their mission flexibility, reconfigurable architecture and low cost. In this paper, a novel Cloud-based framework for intelligent navigation of RPAS in urban environments is proposed, toward achieving fully-autonomous missions without compromising safety. The advantages of the proposed approach reside in the flexibility in designing and implementing complex systems and algorithms with partial independence of the specific flying and control hardware. Thanks to the real-time use of Cloud-based algorithms, advanced control ability and risk-aware navigation and planning can be implemented, without increasing the flying payload. The proposed framework is structured in stacked logical layers, distributed between the Cloud and the RPAS, implementing the tasks of autonomous flying, processing information and decision-making. The architecture comprises five layers, including map and risk-aware path planning generation, and control layers. Important novelty elements are: (i) the definition of a dynamical risk-map, and (ii) an On-board Control System able to perform emergency maneuvers, if communication with the Cloud is poor or missing.

17:40-18:00 WeC1.4

Vision-Based Object Path Following on a Quadcopter for GPS-Denied Environments, pp. 456-461

De Mel, Daniel Henry Sebastion	The Univ. of Auckland
Stol, Karl	Univ. of Auckland
Mills, Jay Alexander Davis	Univ. of Auckland
Eastwood, Blair Richard	Univ. of Auckland

This paper presents the development of an object path following algorithm for a quadcopter using on-board vision and localization. This development aims to increase capabilities of autonomous unmanned aerial vehicles (UAV), with the use of object path following. By following an object's path, reliance on obstacle avoidance strategies can be reduced, under the assumption that the object's path is free of static obstacles. Relative position of the target has been estimated using on-board processing and monocular vision. On-board localization has been achieved through dead-reckoning, where velocity estimates are calculated from optical flow. Horizontal positional estimates with a standard deviation of 6.5cm have been achieved experimentally with this method. The use of optical flow allows for localization in GPS-denied environments. Both the position and path following can successfully run in moderate winds and variable lighting. The UAV can station-keep to within 40 cm of desired position. The object's path can be followed with an rms error of 28 cm and maximum deviation of 78 cm.

18:00-18:20 WeC1.5

Design, Implementation and Verification of a Quadrotor Tail-Sitter VTOL UAV, pp. 462-471

Wang, Ya	HKUST
Lyu, Ximin	HKUST
Gu, Haowei	Hong Kong Univ. of Science and Tech
SHEN, Shaojie	Hong Kong Univ. of Science and Tech
Li, Zexiang	Hong Kong Univ. of Science & Tech
Zhang, Fu	Hong Kong University of Science and Tech

This paper presents the design and implementation of a cost-effective, lightweight, yet power efficient tail-sitter Vertical Take-off and Landing (VTOL) unmanned aerial vehicle (UAV). The UAV consists a pair of wings for efficient level flight and four rotors for attitude control. The aerodynamic and mechanical configurations of the UAV are designed and implemented from scratch to meet the required power efficiency, and subsequently optimized to enhance the stability and maneuverability. The developed VTOL UAV has a weight and cost comparable to a typical quadrotor, while consuming only half power, as shown by real flight tests. In addition, it can achieve all key VTOL maneuvers, including vertical take-off, landing, hovering, cruising and transition.

18:20-18:40 WeC1.6

An Event-Triggering-Based Approach for Three-Dimensional Local-Level Frame Formation Control of Leader-Follower UAVs, pp. 472-479

Sun, Liang	New Mexico State Univ
HU, Bin	Univ. of Notre Dame
Zhao, Shiyu	Univ. of Sheffield

The development of a three-dimensional (3D) formation controller for unmanned aerial vehicles (UAVs) associated with an event-triggered transmission protocol is presented in this paper. The formation controller is derived based on a 3D relative kinematic model established upon a local-level coordinate frame, which does not require any absolute global information. The proposed controller is developed using the Lyapunov theory and proved to be capable of driving the follower UAV to exponentially converge to a desired formation. An event-triggered transmission protocol is developed based on the derived 3D formation controller in order to efficiently schedule the transmission of the leader's state to the follower according to the dynamic change of the leader's state. The performance of the formation control law integrated with the event-triggered protocol is verified in simulation.

WeC2 Salon AB

Path Planning - III

Chair: Sharma, Rajnikant — Univ. of Cincinnati

Co-Chair: Ghose, Debasish — Indian Inst. of Science

16:40-17:00 WeC2.1

Path Planning for Multiple Heterogeneous Unmanned Vehicles with Uncertain Service Times, pp. 480-487

Sundar, Kaarthik	Texas A&M Univ
Venkatachalam, Saravanan	Wayne State Univ. Detroit, MI
Manyam, Satyanarayana Gupta	National Acad

This article presents a framework and develops a formulation to solve a path planning problem for multiple heterogeneous Unmanned Vehicles (UVs) with uncertain service times for each vehicle--target pair. The vehicles incur a penalty proportional to the duration of their total service time in excess of a preset constant. The vehicles differ in their motion constraints and are located at distinct depots at the start of the mission. The vehicles may also be equipped with disparate sensors. The objective is to find a tour for each vehicle that starts and ends at its respective depot such that every target is visited and serviced by some vehicle while minimizing the sum of the total travel distance and the expected penalty incurred by all the vehicles. We formulate the problem as a two-stage stochastic program with recourse, present the theoretical properties of the formulation and advantages of using such a formulation, as opposed to a deterministic expected value formulation, to solve the problem. Extensive numerical simulations also corroborate the effectiveness of the proposed approach.

17:00-17:20 WeC2.2

Dynamic Motion Planning for Aerial Surveillance on a Fixed-Wing UAV, pp. 488-497

DARBARI, VAIBHAV	Delhi Tech. Univ
Gupta, Saksham	Delhi Tech. Univ
Verma, Om Prakash	Delhi Tech. Univ

We present an efficient path planning algorithm for an Unmanned Aerial Vehicle surveying a cluttered urban landscape. A special emphasis is on maximizing area surveyed while adhering to constraints of the UAV and partially known and updating environment. A Voronoi bias is introduced in the probabilistic roadmap building phase to identify certain critical milestones for maximal surveillance of the search space. A kinematically feasible but coarse tour connecting these milestones is generated by the global path planner. A local path planner then generates smooth motion primitives between consecutive nodes of the global path based on UAV as a Dubins vehicle and taking into account any impending obstacles. A Markov Decision Process (MDP) models the control policy for the UAV and determines the optimal action to be undertaken for evading the obstacles in the vicinity with minimal deviation from current path. The efficacy of the proposed algorithm is evaluated in an updating simulation environment with dynamic and static obstacles.

17:20-17:40 WeC2.3

Comparison of 3D Path-Following Algorithms for Unmanned Aerial Vehicles, pp. 498-505

Pelizer, Guilherme	Univ. De São Paulo
Silva, Natassya B. F.	Univ. De São Paulo - USP
Branco, Kalinka Regina Lucas Jaquie Castelo	Univ. of São Paulo

Unmanned Aerial Vehicle (UAV) development is a field with rising interest in recent years. One of its essential part is the autopilot, responsible for keeping the aircraft in desired flight conditions and for executing navigation tasks. Among the navigation tasks, one that stands out is the path-following operation, which guarantees that the aircraft follows a predefined trajectory. The literature presents a variety of approaches with this function, based in geometric and control

techniques; however, compared only for the 2D scenario. Therefore, the main purpose of this paper is to perform a comparison in the 3D scenario of the path-following algorithms Look ahead, Non-Linear Guidance Law (NLGL), Pure Pursuit and Line-of-Sight (PLOS) and Vector Field, regarding accuracy and computational cost. The simulation results of straight lines trajectories show that PLOS and Look ahead present lower errors and lower computational cost than NLGL and Vector Field, thus being more adequate.

17:40-18:00 WeC2.4

Pursuing a Time Varying and Moving Source Signal Using a Sensor Equipped UAV, pp. 506-515

KASHYAP, ABHISHEK — INDIAN Inst. OF SCIENCE, BANGALORE
Ghose, Debasish — Indian Inst. of Science

A methodology to locate a target using measurements of its signal strength is discussed in this paper. One of the main challenges lie in locating the source when it is moving or has time varying signal strength. In this paper two different strategies to locate and intercept a time varying and moving source by an Unmanned Aerial Vehicle (UAV) is presented. In the first strategy the UAV traverses a complete circular path during the first phase, also called the discovery phase, and uses the measurements of the signal strength to estimate the direction of the source location. This is followed by the pursuit phase in which the UAV realigns itself towards the desired direction and then moves along it in order to intercept the source. In the second strategy the UAV moves along a semi-circular path during the discovery phase and then using the measurements of the signal strength realigns itself and moves towards the target in the pursuit phase. The performance of both these algorithms is demonstrated through simulations for different kinds of target motion and variations, including measurements affected by noise.

18:00-18:20 WeC2.5

A Grid-Based Path Planning Approach for a Team of Two Vehicles with Localization Constraints, pp. 516-523

Garber, Mark — Texas a & M Univ
Rathinam, Sivakumar — Texas a & M Univ
Sharma, Rajnikant — Univ. of Cincinnati

This paper proposes a path finding method for two unmanned aerial vehicles with localization constraints using a modified shortest path algorithm. A beacon vehicle has GPS or other absolute positioning information, and a target vehicle has only bearing information taken relative to the beacon vehicle or known stationary landmarks. By overlaying a grid on the map and discretizing the position uncertainty, the path planning problem for two vehicles can be formulated as a dynamic programming problem and solved using a modified form of the A* shortest path algorithm. Edge costs are found using a factored covariance method for an Extended Kalman filter based on results available in literature. In simulation, paths found from the dynamic programming method outperform a greedy algorithm.

WeC3 Salon CD

Control Architectures - III

Chair: Quagliotti, Fulvia — Pol. Di Torino
Co-Chair: Colorado, Julian — Pontificia Univ. Javeriana Bogota

16:40-17:00 WeC3.1

Modeling and Flight Control of a Commercial Nano Quadrotor, pp. 524-532

Garcia, Gonzalo — Univ. of Kansas
Kim, A Ram — Univ. of Kansas
Jackson, Ethan — Microsoft Res
Keshmiri, Shawn — Univ. of Kansas
Shukla, Daksh — Univ. of Kansas

This work presents the flight test validation of an autonomous nano quadrotor called Crazyflie 2.0 in arbitrary trajectory tracking. The complexity of the control tasks was due to the low rigidity and high flexibility of propellers and airframe components, high sensitivity of vehicle inertial dynamic model to the battery location, uncalibrated motors, and unsteady battery depletion rate. Keeping the Crazyflie embedded inner control loop system, different outer loop guidance logics were designed for trajectory following. The guidance logics were running on an external computer and communicated via a radio link with the quadrotor in real-time. Attitude estimations were done using OptiTrack position information. An accurate dynamic model of aircraft was developed using principal moments of inertia and motor performance parameters. The Crazyflie dynamic model was used for the 6-DOF simulations and LQR and MPC implementations. All three guidance techniques, PID, LQR, and MPC, were validated through actual flight tests and fulfilled tracking tasks with an acceptable performance.

17:00-17:20 WeC3.2

Trajectory Control of a Quadrotor Using a Control Allocation Approach, pp. 533-539

Zaki, Hammad — Sabanci Univ
Unel, Mustafa — Sabanci Univ
Yildiz, Yildiray — Bilkent Univ

A quadrotor is an underactuated unmanned aerial vehicle with four inputs to control the dynamics. Trajectory control of a quadrotor is a challenging task and usually tackled in a hierarchical framework where desired/reference attitude angles are analytically determined from the desired command signals, i.e. virtual controls, that control the positional dynamics of the quadrotor and the desired yaw angle is set to some constant value. Although this method is relatively straightforward, it may produce large and nonsmooth reference angles which must be saturated and low-pass filtered. In this work, we show that the determination of desired attitude angles from virtual controls can be viewed as a control allocation problem and it can be solved numerically using nonlinear optimization where certain magnitude and rate constraints can be imposed on the desired attitude angles and the yaw angle need not be constant. Simulation results for both analytical and numerical methods have been presented and compared. Results for constrained optimization show that the flight performance is quite satisfactory.

17:20-17:40 WeC3.3

Low-Altitude Autonomous Drone Navigation for Landmine Detection Purposes, pp. 540-546

Colorado, Julian — Pontificia Univ. Javeriana Bogota
Devia Pinzon, Carlos Andres — Pontificia Univ. Javeriana
Perez Cerquera, Manuel Ricardo — Pontificia Univ. Javeriana
Mondragón Bernal, Iván Fernando — Pontificia Univ. Javeriana
Mendez Chaves, Diego — Pontificia Univ. Javeriana
Parra, Carlos — Pontificia Univ. Javeriana

This paper proposes an integrated system architecture composed by a custom-designed lightweight Ground Penetrating Radar (GPR) and a novel method for low-altitude autonomous flight called Backstepping + DAF. Simulations and experimental results are carried out to evaluate how steady flight is achieved by means of the proposed flight controller that consequently enables the GPR detection of buried objects with similar materials and morphology of real explosive landmines.

17:40-18:00 WeC3.4

Adaptive Dynamic Control of a Quadrotor for Trajectory Tracking, pp. 547-553

Rosales, Claudio Dario — Univ
Soria, Carlos — Univ. Nacional De San Juan
Carelli, Ricardo — Univ. Nacional De San Juan
Rossomando, Francisco — Inst. De Automática - Univ. Nacional De San Juan

This work presents an adaptive trajectory tracking controller for an unmanned aerial vehicle (UAV) which combines a feedback linearization controller based on a nominal model of a quadrotor and a Neuro Adaptive Compensation (NAC). The NAC is introduced in order

to minimize the control errors caused by uncertainties in the nominal parameters. The uncertain parameters of the nominal model are balanced by a Neuro Adaptive Compensator. The proposed adaptive control scheme is robust and efficient to achieve a good trajectory following performance for outdoor and indoor applications. The analysis of the neural approximation error on the control errors is included. Finally, the effectiveness of the control system is proved through numerical simulation.

18:00-18:20 WeC3.5

Task Assignment/Trajectory Planning for Unmanned Vehicles Via HFLC and PSO, pp. 554-559

Hafez, Ahmed Taimour Kamaleldin	Military Tech. Coll
Kamel, Mohamed A.	Military Tech. Coll
Givigi, Sidney	Royal Military Coll. of Canada
Jardine, Peter Travis	Royal Military Coll. of Canada

This paper investigates the problems of task assignment and trajectory planning for teams of cooperative unmanned aerial vehicles (UAVs). A novel approach of hierarchical fuzzy logic controller (HFLC) and particle swarm optimization is proposed. Initially, teams of UAVs are moving in a pre-determined formation covering a specified area. When one or more targets are detected, the teams send a package of information to the ground station (GS) including the target's degree of threat, degree of importance, and the separating distance between each team and each detected target. First, the ground station assigns the teams to the targets based on the gathered information. HFLC is implemented in the GS to solve the assignment problem ensuring that each team is assigned to a unique target. Then, each team plans its own path by formulating the path planning problem as an optimization problem, while the objective is to minimize the time to reach their destination considering the UAVs dynamic constraints and the collision avoidance between teams. A hybrid approach of control parametrization and time discretization (CPTD) and PSO is proposed to solve the optimization problem. Finally, numerical simulations demonstrate the effectiveness of the proposed algorithm.

WeC4 Lummus Island

UAS Applications - III

Chair: Theilliol, Didier	Univ. of Lorraine
Co-Chair: Casbeer, David	Air Force Res. Lab

16:40-17:00 WeC4.1

Transition Control of Tilt Rotor Unmanned Aerial Vehicle Based on Multi-Model Adaptive Method, pp. 560-566

Liu, Zhong	Shenyang Inst. of Automation Chinese Acad. of Sciences
Theilliol, Didier	Univ. of Lorraine
Yang, Liying	Shenyang Inst. of Automation Chinese Acad. of Sciences
He, Yuqing	Shenyang Inst. of Automation, CAS, P.R.China
Han, Jianda	Shenyang Inst. of Automation

Tilt rotor unmanned aerial vehicle (TRUAV) with ability of hovering and high-speed cruise has attached much attention, but its transition control is still a difficult point because of varying dynamics. This paper proposes a multi-model adaptive control (MMAC) method for a quad-TRUAV, and the stability in the transition procedure could be ensured by considering corresponding dynamics. For safe transition, tilt corridor is considered firstly, and actual flight status should locate within it. Then, the MMAC controller is constructed according to mode probabilities, which are calculated by solving a quadratic programming problem based on a set of input-output plant models. Compared with typical gain scheduling control, this method could ensure transition stability more effectively.

17:00-17:20 WeC4.2

Fire Detection Using Infrared Images for UAV-Based Forest Fire Surveillance, pp. 567-572

Yuan, Chi	Concordia Univ
Liu, Zhixiang	Concordia Univ
Zhang, Youmin	Concordia Univ

Unmanned aerial vehicle (UAV) based computer vision system, as a more and more promising option for forest fires surveillance and detection, is now widely employed. In this paper, an image processing method for the application to UAV is presented for the automatic detection of forest fires in infrared (IR) images. The presented algorithm makes use of brightness and motion clues along with image processing techniques based on histogram-based segmentation and optical flow approach for fire pixels' detection. First, the histogram-based segmentation is used to extract the hot objects as fire candidate regions. Then, the optical flow method is adopted to calculate motion vectors of the candidate regions. The motion vectors are also further analyzed to distinguish fires from other fire analogues. Through performing morphological operations and blob counter method, a fire can be finally tracked in each IR image. Experimental results verified that the designed method can effectively extract and track fire pixels in IR video sequences.

17:20-17:40 WeC4.3

Multi-UAV Routing for Persistent Intelligence Surveillance and Reconnaissance Missions, pp. 573-580

Manyam, Satyanarayana Gupta	National Acad
Rasmussen, Steven	Miami Valley Aerospace LLC
Casbeer, David	Air Force Res. Lab
Kalyanam, Krishnamoorthy	AFRL
Suresh, M	Ade, Drdo

We consider a Persistent Intelligence, Surveillance and Reconnaissance (PISR) routing problem, which includes collecting data from a set of specified task locations and delivering that data to a control station. Each task is assigned a refresh rate based on its priority, where higher priority tasks require higher refresh rates. The UAV team's objective is to minimize the maximum of the delivery times of all the tasks' data to the control station, while simultaneously, satisfying each task's revisit period constraint. The centralized path planning problem for this PISR routing problem is formulated using mixed integer linear programming and solved using a branch-and-cut algorithm. Heuristics are presented to find sub-optimal feasible solutions that require much less computation time. The algorithms are tested on several instances and their performance is compared with respect to the optimal cost and computation time.

17:40-18:00 WeC4.4

A UAV Ice Tracking Framework for Autonomous Sea Ice Management, pp. 581-590

Stendahl Leira, Frederik	Norwegian Univ. of Science and Tech
Johansen, Tor Arne	Norweigian Univ. of Sci. & Tech
Fossen, Thor I.	Norwegian Univ. of Sci and Tech

This paper describes a unmanned aerial vehicle (UAV) ice tracking framework for use in sea ice management applications. The framework is intended to be used in an ice management scenario where the UAV should detect and track the movement of icebergs and ice floes in an Arctic environment, and seeks to enable the UAV to do so autonomously. This is achieved by using an occupancy grid map algorithm and a locations of interest generator coupled with a Model Predictive Control (MPC) UAV path planner. The main contribution of this paper is interfacing the occupancy grid map algorithm with a machine vision object detection module in order to enable the UAV to generate an occupancy grid map of a pre-defined search area in real-time using on-board processing of UAV sensor data. Further, the paper presents a locations of interest generator module which generates locations that the UAV should investigate based on the generated occupancy grid map. These locations of interest are then used by an MPC path planner in order to make the UAV autonomously investigate and track ice features at said locations. Furthermore, the paper verifies the use of the developed ice tracking framework for autonomously detecting and tracking ice features based on thermal images captured with a UAV, as well as verifying the usefulness and role of UAVs in ice management scenarios by conducting two flight experiments.

18:00-18:20 WeC4.5

*Application in Biological Prevention and Control Based on a Hex-Rotor UAV**

Bai, Yue	Changchun Inst. of Optics, Fine Mechanics and Physics
Wu, Helong	Changchun Inst. of Optics, Fine Mechanics and Physics
Peng, Cheng	Changchun Inst. of Optics, Fine Mechanics and Physics
Pei, Xinbiao	Changchun Inst. of Optics, Fine Mechanics and Physics
Li, Chuanzheng	Changchun Inst. of Optics, Fine Mechanics and Physics
Ma, Ping	Changchun Inst. of Optics, Fine Mechanics and Physics

WeC5 San Marco Island

Maritime and Coastal Applications of UASs

Chair: Johansen, Tor Arne	Norweigian Univ. of Sci. & Tech
Co-Chair: Ollero, Anibal	Univ. De Sevilla
Organizer: Johansen, Tor Arne	Norweigian Univ. of Sci. & Tech
Organizer: Ollero, Anibal	Univ. De Sevilla

16:40-17:00 WeC5.1

Cooperative Remote Sensing of Ice Using a Spatially Indexed Labeled Multi-Bernoulli Filter (I), pp. 591-600

Olofsson, Jonatan	NTNU
Brekke, Edmund	NTNU
Johansen, Tor Arne	Norweigian Univ. of Sci. & Tech

In polar region operations, drift ice positioning and tracking is useful for both scientific and safety reasons. Many sensors can be employed to generate detections of sea ice, such as satellite-carried Synthetic Aperture Radar (SAR) and, recently, imagery equipment carried by Unmanned Aerial Systems (UAS). Satellite-carried SAR has the advantage of being able to cover large areas and provide consistent imagery largely independent of weather, albeit at a relatively coarse resolution. Using UAS, the resolution and precision of the tracking can be locally improved. To track the large amount of individual objects present in an area as large as the Arctic, it is necessary to efficiently select and exclusively work with the objects in the relevant field-of-view. In this paper, a Spatially Indexed Labeled Multi-Bernoulli filter is presented and applied to a tracking problem representing a mission setup for field-tests due this year. In the setup, satellite and UAS imagery is combined to provide real- time Multi-Target Tracking of sea ice objects. A brief introduction is given to the implementation of the proposed Spatially Indexed Labeled Multi-Bernoulli filter, which is made available under an Open Source license.

17:00-17:20 WeC5.2

Mission Performance Trade-Offs of Battery-Powered Suas (I), pp. 601-608

Hovenburg, Anthony Reinier	Norges Teknisk-Naturvitenskapelige Univ
Johansen, Tor Arne	Norweigian Univ. of Sci. & Tech
Storvold, Rune	Norut Northern Res. Inst

A sensitivity analysis is presented on the influence of the weight, altitude and speed of battery-powered sUAS on the resulting stall speed, endurance and range. To aid in the determination of the aircraft performance prior to flight, a method is being brought forth that quantifies the impact of these mission parameters. As a case study the P31015 sUAS is used. The P31015 is a concept model of a battery-powered sUAS with a total battery capacity of 977Wh. Since the aerodynamic model of the aircraft was determined through simulations, and the specific propulsion set-up is yet to be determined, the case study remains to be a theoretical approach. The proposed methods and limitations of this study are applicable to other electric sUAS in similar set-up.

17:20-17:40 WeC5.3

The LSTS Software Toolchain for Persistent Maritime Operations Applied through Vehicular Ad-Hoc Networks (I), pp. 609-616

Ferreira, António Sérgio	Univ. of Porto
Pinto, José	Univ. Do Porto - Faculdade Engenharia
Dias, Paulo	Univ. Do Porto - Faculdade Engenharia
Sousa, Joao	Univ. Do Porto - Faculdade Engenharia

In order to further expand the sustainability of maritime operations the use of autonomous vehicles has been employed at an increasing scale. This natural increase comes not only in the form of the multiplication of the numbers of the same vehicle model, but also in diversifying the vehicle composition setup in order to allow the exploitation of different types of payloads. Moreover, this use of heterogeneous multi-vehicle teams allows overcoming individual limitations that one specific vehicle model might have. Nevertheless, this increase in scale and functionality also causes an increase in control, management, and spatial and operational complexity. This complexity is addressed in the framework of the LSTS Neptus-IMC-Dune software toolchain. The software toolchain is a framework for mixed-initiative control (humans in the planning and control loops) of unmanned ocean and air vehicles operating in communications challenged environments with support for Disruptive Tolerant Networking (DTN) protocols. The use of such a toolchain has allowed for repeated and successful deployments of heterogeneous multi-vehicle teams. The paper reports these deployments together with an in-depth description of the toolchain.

17:40-18:00 WeC5.4

Spiral-Like Coverage Path Planning for Multiple Heterogeneous UAS Operating in Coastal Regions (I), pp. 617-624

Balampanis, Fotios	Univ. De Sevilla
Maza, Ivan	Univ. De Sevilla CIF Q-4118001-I
Ollero, Anibal	Univ. De Sevilla

This paper addresses area coverage in complex non concave coastal regions for an arbitrary number of heterogeneous Unmanned Aircraft Systems (UAS). The space is discretized with the constrained Delaunay triangulation and the Lloyd optimization is applied to the computed mesh. The paper presents an algorithm to compute a waypoint list for each UAS such that each sub-area is covered with its sensor on-board following a pattern that goes from the borders of the sub-area to the inner regions. In addition, the resulting paths lead to a uniform coverage pattern that avoids visiting some regions more times than others. Different sensitivity parameters of the algorithm are compared based on the average angles between the waypoints and the total length of the paths. Results show that these parameters support the optimization of the computed waypoint lists and the proposed algorithm produces feasible coverage paths while increasing their smoothness.

18:00-18:20 WeC5.5

A Feedback Motion Strategy Applied to a UAV to Work As an Autonomous Relay Node for Maritime Operations (I), pp. 625-632

Braga, Juan	Univ. of Porto
Alessandretti, Andrea	Faculty of Engineering, Univ. of Porto (FEUP)
Aguiar, A. Pedro	Faculty of Engineering, Univ. of Porto (FEUP)
Sousa, Joao	Univ. Do Porto - Faculdade Engenharia

One important aspect that needs to be carefully considered in maritime operations using unmanned robotic vehicles is the communication restrictions between the vehicles and the mission controller that arises mainly due to long distances and/or low power transmissions. This paper addresses the problem of maintaining a communication link

between a command station and an Unmanned Aerial Vehicle (UAV) with limited communication range during maritime operations. The proposed scheme uses an additional UAV that acts as a relay for the communication between the command station and the UAV in mission and is actively driven to maintain a desired Quality-of-Service (QoS) level, defined in this paper. Exploiting this architecture, it is possible to plan a maritime operation for a robotic vehicle without the need of considering vehicle-to-command-station communication constraints that will be satisfied by the introduction of the extra autonomous relay-UAVs. To this end, we propose a feedback strategy that has the dual task of commanding and optimizing the execution of the relay UAV motion tasks and adapting the scheduler algorithm according to a desired QoS level. The performance of the proposed strategy is illustrated through computer simulations and preliminary experimental results.

18:20-18:40 WeC5.6

Autonomous UAV Surveillance of a Ship's Path with MPC for Maritime Situational Awareness (I), pp. 633-639

Andrade, Fabio — Norut, Northern Res. Inst
Johansen, Tor Arne — Norweigian Univ. of Sci. & Tech
Storvold, Rune — Norut Northern Res. Inst

Maritime Situational Awareness is crucial in maritime operations to identify threats and to deal with them as soon as possible. These threats can be pirates in shipping operations, icebergs when sailing in the northern sea routes, or even unknown vessels or objects that might be on the ship's path. A solution to identify these threats is the use of UAV's to overfly the ship's planned path. This solution is described in this paper, using an autonomous fixed wing UAV. Based on the provided ship's planned path, the UAV should autonomously map the area close to the ship track. To do that, an optimization problem is solved using Model Predictive Control, where the turn rate for the next time period is optimized. Based on the turn rate, the future path of the UAV is calculated and the waypoints are sent to the autopilot. This application is thoroughly tested using a Software In Loop environment, where an aircraft model is used with the autopilot's simulation. The results show that surveillance performance is improved if the UAV has information about the ship's velocity in addition to position.

ThA1 — Salon E
Micro and Mini UAS - I

Chair: Quagliotti, Fulvia — Pol. Di Torino
Co-Chair: Lozano, Rogelio — Univ. of Tech. of Compiègne

10:00-10:20 ThA1.1

Nonlinear Super Twisting Algorithm for UAV Attitude Stabilization, pp. 640-645

Ibarra-Jimenez, Efrain — Heudiasyc UMR 7253, Univ. De Tech. De Compiègne
Castillo, Pedro — Unviersité De Tech. De Compiègne

Keep at hover an aerial vehicle is one of the most important task to realize when working on UAVs. Once this task is solved, the user can easily give high-orders to move the vehicle. In this paper, a nonlinear super-twisting algorithm to stabilize the nonlinear attitude of a quadcopter is presented. The controller is based on the Singular Optimal Control (SOC) and the Lyapunov theory with the sliding mode technique. Its robustness with respect nonlinear and unknown uncertainties is demonstrated in the stability analysis. Simulations results are carried out to illustrate the well performance of the controllers in closed-loop system even in presence of this kind of disturbances. Main graphs corroborate this fact.

10:20-10:40 ThA1.2

In-Flight Data Acquisition and Flight Testing for System Identification of Flapping-Wing MAVs, pp. 646-655

Caetano, Joao Vieira — Portuguese Air Force Res. Center
Armanini, Sophie F. — Delft Univ. of Tech
Karasek, Matej — Delft Univ. of Tech

Although flapping-wing micro aerial vehicles have become a hot topic in academia, the knowledge we have of these systems, their force generation mechanisms and dynamics is still limited. Recent technological advances have allowed for the development of free flight test setups using on-board sensors and external tracking systems, for system identification purposes. Nevertheless, there is still little knowledge about the system requirements, as well as on how to perform free flight test experiments, and process the collected data. The present article presents the guidelines for flapping-wing micro aerial vehicle free flight testing. In particular, it gathers information produced by different studies and provides the best practices for the proper system dimensioning, system setup, on-board sensors, maneuver input design, error analyses and data post-processing, for the reconstruction of the forces and moments that act during free flight of a flapping-wing robot, for system identification and modeling purposes. Furthermore, this article compares the results obtained using external optical position tracking systems with on-board and external sensor fusion, and provides suitable solutions and methods for data fusion and force reconstruction.

10:40-11:00 ThA1.3

Energy Efficiency of Trajectory Generation Methods for Stop-And-Go Aerial Robot Navigation, pp. 656-662

Kreciglowa, Nadia — Univ. of Pennsylvania
Karydis, Konstantinos — Univ. of Pennsylvania
Kumar, Vijay — Univ. of Pennsylvania

The paper reports on the energy consumption of smooth trajectories for stop-and-go navigation of aerial robots. We consider a decimeter-scale quadrotor tasked to travel on straight line, constant height trajectories from an initial hover configuration to another hover configuration. We investigate three prominent types of smooth trajectories (minimum acceleration, minimum jerk and minimum snap), and evaluate their energetic efficiency through the total energy consumption. The energy consumed by each trajectory type is determined via aerodynamics-based expressions for power consumption of rotorcraft. We extensively test in simulation trajectories of varying length, and designed with varying desired maximum velocities and accelerations. Several representative cases are also tested and validated experimentally.

11:00-11:20 ThA1.4

Hexacopter Fault Tolerant Actuator Allocation Analysis for Optimal Thrust, pp. 663-671

Pose, Claudio Daniel — Facultad De Ingeniería - Univ. De Buenos Aires
Giribet, Juan Ignacio — Univ. of Buenos Aires
Ghersin, Alejandro — ITBA

Recently, it was shown that a hexagon shaped hexa-rotor vehicle with tilted rotors, is capable of fault tolerant attitude and altitude control. In this work, we propose a strategy to select the signals commanded to each rotor in order to achieve a desired torque and vertical force. The proposed strategy is optimal in the sense that minimizes the maximum force exerted by the rotors.

A comparison with the commonly used strategy based upon the Moore-Penrose pseudoinverse is carried out. It is shown that, with the optimal strategy proposed here, maneuverability is improved, because the new method takes into account the actuators constraints. Although the optimal strategy is computationally more demanding than the classical method, the additional computational burden is not significant when both strategies are compared in a real application. To show this, both algorithms were programmed in an autopilot based on an ARM Cortex M3 microcontroller, and the experimental results are presented.

11:20-11:40 ThA1.5

Modeling and Analysis of a Tricopter/Flying-Wing Convertible UAV with Tilt-Rotors, pp. 672-681

Bautista Medina, Jose Antonio — Centro De Investigación Y De Estudios Avanzados Del Inst. Po
Osorio-Cordero, Antonio — CINVESTAV
Lozano, Rogelio — Univ. of Tech. of Compiègne

The aim of this paper is to provide a mathematical model for a

convertible unmanned aerial vehicle that combines the capabilities of a flying wing and tricopter with tilt rotors. This article presents the mathematical model for airplane and tricopter modes as well as the way they are related during the transition phase. Also is presented a control strategy to hover flying. Finally, it is presented simulation results of tricopter mathematical model under controls developed.

ThA2 Salon AB

Path Planning - IV

Chair: Girard, Anouck — Univ. of Michigan at Ann Arbor
Co-Chair: Darrah, Marjorie — West Virginia Univ

10:00-10:20 ThA2.1

Towards Automatic Code Generation for UAV Mission Planning Using Decision Sensors, pp. 682-689

Martins, Ricardo Ferreira — Santa Catarina State Univ
Almeida, Gian Lucas Nunes de — Univ. Do Estado De Santa Catarina
Leal, André Bittencourt — Santa Catarina State Univ. – UDESC

The planning of an autonomous mission for UAVs requires more than the description of the points to be visited along the trajectory by which a certain task must be performed. However, the way in which such missions are planned does not provide conditions for the aircraft or the ground control system to find alternative ways of carrying out the mission, in the event of a risk or other situation different from what was initially planned. In this sense, this paper makes use of a complementary description of the trajectory of a UAV, specifying it through the Discrete Events Systems (DES) framework. Furthermore, it makes use of sensor information to identify situations of risk and, from this, to systematically carry out changes in the mission initially programmed in the aircraft in order to avoid undesired situations.

10:20-10:40 ThA2.2

Bi-Level Flight Path Optimization for UAV Formations, pp. 690-697

D'Amato, Egidio — Univ. of Campania
Mattei, Massimiliano — Seconda Univ. Di Napoli
Notaro, Imma — Seconda Univ. Di Napoli
Silvestre, Francesco — Univ. of Campania "L.Vanvitelli"

A two-stage optimization model for flight path planning of cooperative UAVs in formation flight in the presence of polygonal obstacles and no-fly zones is proposed. Adopting a Visibility Graph (VG) approach, the virtual formation leader plans its flight path composed of circular arcs and segments connecting obstacles vertices. Then groups of obstacles, being not permeable by the flight formation without UAVs separation or formation shape deformation, are clustered and the VG is revised with the addition of so called rendezvous waypoints, forcing the formation to be recomposed at a given location beyond groups of obstacles. Such rendezvous waypoints are optimized at a higher hierarchical level with respect to the flight path optimization leading to a Stackelberg game. The validity of the proposed approach and optimization model is shown by means of numerical simulations where flight paths are obtained calculating shortest path on the revised Visibility Graph and waypoints positions are optimized via a genetic algorithm. Finally, anti-collision among UAVs is achieved via a simple potential based method.

10:40-11:00 ThA2.3

A Cohesive and Well-Spaced Swarm with Application to Unmanned Aerial Vehicles, pp. 698-705

Devi, Amrita — Fiji National Univ
Vanualailai, Jito — Univ. of the South Pacific
Kumar, Sandeep Ameet — Fiji National Univ
sharma, Bibhya — Univ. of the South Pacific

In swarm robotics, the self-organization of multi-agent systems which consists of a number of comparatively simple agents is an approach inspired from natural swarms. In this paper, we solve the find path problem of $ninmathbb{N}$ agents using the principle of swarming. A Lagrangian swarm model which could navigate in a cluttered configuration space is developed. A Lyapunov like function is constructed from which the velocity controllers are derived. The Lyapunov-like function contains attractive and repulsive components. The swarm model is simulated for verification of its functionality and intuitive insight into the system behavior suggest that the solutions are bounded about the centroid. We show that indeed the solutions are bounded about the centroid by showing the wellspacedness and cohesiveness of the swarm. The velocity controllers are then applied to swarm of unmanned aerial vehicles.

11:00-11:20 ThA2.4

Path Planning for Information Collection in Contested Environments Using Marsupial Systems, pp. 706-715

Tian, Ran — Univ. of Michigan
Chen, Hao — Univ. of Michigan
Frey, Gregory — Univ. of Michigan
Zu, Bingqing — Univ. of Michigan
Girard, Anouck — Univ. of Michigan at Ann Arbor
Kolmanovsky, Ilya V. — Univ. of Michigan

This paper addresses a path planning problem where a marsupial system is assigned to collect a specified amount of information about a set of objects of interest while minimizing the likelihood of detection by an opponent's sensor. A marsupial system consists of aircraft (agents) with different capabilities. The agents are characterized by their velocities, information collection capabilities, and their effectiveness at remaining undetected. This work is motivated by surveillance missions that can be accomplished more effectively and safely by leveraging the distinct capabilities of agents in a marsupial system. The models for the agents and the environment are presented, the optimal control problem is formulated, and optimal trajectories for the marsupial system as well as characteristics of the trajectories under various mission time constraints are given.

11:20-11:40 ThA2.5

Optimized 3D Mapping of a Large Area with Structures Using Multiple Multirotors, pp. 716-722

Darrah, Marjorie — West Virginia Univ
Mera Trujillo, Marcela — West Virginia Univ
Speransky, Kirill — 4D Tech
Wathen, Mitchell — Army Res. Lab

This paper presents an optimized method to employ a team of multirotors for collecting images to generate a 3D map of an area with emphasis on special features (e.g. man-made structures) and areas of avoidance. When an area is too large to be mapped by one multirotor within its battery life, then either several flights or several multirotors need to be employed to complete the job. This paper introduces a method for equitably dividing the task of collecting images utilizing multiple vehicles to map a large area with man-made structures, which need to be mapped with high resolution. First, the number of vehicles or flights required must be determined and then the special features within the area that require more time must be considered. A parallel flood fill algorithm incorporating game theory is used to determine the best way to divide the tasking.

ThA3 Salon CD

Networked Swarms

Chair: Zhang, Youmin — Concordia Univ
Co-Chair: Ollero, Anibal — Univ. De Sevilla

10:00-10:20 ThA3.1

Formation Control for Multi-Domain Autonomous Vehicles Based on Dual Quaternions, pp. 723-730

Mas, Ignacio — ITBA
Moreno, Patricio — Univ. De Buenos Aires
Giribet, Juan Ignacio — Univ. of Buenos Aires
Valentino Barzi, Diego — Inst. Tecnologico De Buenos Aires

Unmanned networked multirobot systems have the potential to

accomplish complex field tasks with minimum human intervention. Motion coordination of vehicles that operate in different domains (land, sea, air) is one of the problems that need to be addressed to achieve such a goal. This article presents a representation method based on dual quaternions for leader-follower formation control architectures. This representation offers the most compact and computationally efficient screw transformation formalism and can be used to describe rigid body motions because they simultaneously describe positions and orientations with only eight parameters. A controller in dual quaternion formation space is proposed and analyzed. Computer simulation results and experimental tests applied to the task of escorting an UGV with UAVs are shown to verify the functionality of the proposed system.

10:20-10:40 ThA3.2

Semi-Global Leader-Follower Consensus for Networked Unmanned Multi-Aircraft Systems with Input Saturation, pp. 731-739

MUÑOZ PALACIOS, FILIBERTO	Univ. Pol. DE PACHUCA
Espinoza Quesada, Eduardo Steed	Univ. Pol. De Pachuca
GARCIA CARRILLO, Luis Rodolfo	Texas A&M Univ. - Corp. Christi
Márquez Vera, Marco Antonio	Pol. Univ. of Pachuca

This paper deals with the design of a consensus algorithm for a multi-aircraft (type Quadrotor) leader-follower system. This algorithm uses directed communication topologies, as well as input saturation for the follower agents. The convergence analysis of the proposed strategies is analyzed by using Lyapunov stability theory. Semi-global asymptotic consensus tracking is obtained for the case of leader with input zero, while semi-global practical consensus tracking is achieved for the case of leader with input non-zero. To demonstrate the effectiveness of the proposed solution, a set of simulation results is presented.

10:40-11:00 ThA3.3

A Fault Detection and Isolation Scheme for Formation Control of Fixed-Wing UAVs, pp. 740-746

Sequeira, Pedro Manuel Nunes	Faculty of Engineering, Univ. of Porto (FEUP)
Aguiar, A. Pedro	Faculty of Engineering, Univ. of Porto (FEUP)

This paper presents an approach to fault detection and isolation for a network composed by multiple Unmanned Aerial Vehicles (UAVs) flying in formation. The methodology consists on the use of a bank of unknown input observers (UIO) that runs in each UAV in order to generate a set of residual signals, that will be used to perform the detection. To this end, we consider an extended version of the unicycle model to describe the kinematics of the UAVs and apply a convenient coordinate transformation to make the resulting closed loop dynamics of the overall multi-UAVs so that be described by two almost identical decoupled affine systems. This allows us to use a linear procedure by considering the independent term as a constant known external input. Simulation results under non-linear faults in the UAVs are presented and discussed.

11:00-11:20 ThA3.4

Bluetooth Network for Micro-UAVs for Communication Network and Embedded Range Only Localization, pp. 747-752

Ramon Soria, Pablo	Univ. of Seville
Palomino Suescun, Andres Felipe	Univ. De Sevilla
Arrue, B.C.	Escuela Superior De Ingenieros, Univ. De Sevilla
Ollero, Anibal	Univ. De Sevilla

The use of the Bluetooth smart technology as a communication framework to interconnect the robots is presented in this paper. Moreover, signal metrics of this network are used to provide an embedded Range Only localization scheme (RO-SLAM). When working with teams of robots, the communication between them is very important as it allows them to cooperate for the performing of the tasks. Additionally, being able to localize each other can allow the robots to optimize tasks and work more efficiently. Having both communication and localization integrated on-board in an small device is advantageous for micro-aerial systems in which payload is highly limited.

11:20-11:40 ThA3.5

Distributed Fault-Tolerant Containment Control for Multi-UAVs with Actuator and Sensor Faults, pp. 753-758

Yu, Ziquan	Northwestern Pol. Univ
Zhang, Youmin	Concordia Univ
Qu, Yaohong	Northwestern Polytechnical Univ
Zhang, Yintao	Concordia Univ

This paper considers the disturbance observer-based distributed fault-tolerant containment control problem for longitudinal motion of multiple unmanned aerial vehicles (multi-UAVs) in the presence of actuator, sensor faults, and input saturation when only a subset of the multi-UAVs has access to the leaders. The communication network is an undirected, fixed topology and the distributed control scheme is proposed for each UAV with the information from neighboring UAVs. By using the disturbance observer (DO), the lumped uncertainties including actuator fault, sensor fault, and external disturbance are estimated. The computational complexity caused by the repeated derivatives of the virtual control item in traditional backstepping method is eliminated by using the command filter. The control input saturation is handled with an auxiliary dynamic system. By utilizing the command filter and disturbance observer technique, all follower UAVs can be driven into the convex hull spanned by the altitudes and velocities of leaders. Furthermore, by using graph theory and Lyapunov approach, it is shown that the proposed distributed control scheme can guarantee that the velocities and altitudes of follower UAVs can be driven to the convex hull formed by the altitudes and velocities of leaders and all signals of the resulting closed-loop system are ultimately uniform bound. Finally, numerical simulations are presented to verify the effectiveness of proposed distributed fault-tolerant containment control scheme.

11:40-12:00 ThA3.6

Distributed Cooperative Control for Joint Optimization of Sensor Coverage and Target Tracking, pp. 759-766

Moon, Sangwoo	Univ. of Colorado Boulder
Frew, Eric W.	Univ. of Colorado, Boulder

This paper presents two approaches considering a distributed framework for joint optimization of sensor coverage for target detection and target tracking for maximizing estimation performance for multi-agent systems. The first algorithm is based on the Lloyd algorithm, which uses a centroid of Voronoi partitions, one of the workarounds of sensor coverage problems. The other algorithm is based on the Voronoi partition, which is the result of assigning the target to the agent considering the control input that maximizes the information matrix corresponding to the state estimate of the target. Two presented algorithms are compared and analyzed in terms of target state estimation errors through a series of simulations. The simulation results show that the Voronoi partition-based target tracking approach performs better than Lloyd's algorithm-based approach in terms of sensor coverages and estimation error of targets.

ThA4 Lummus Island

UAS Applications - IV

Chair: Alexis, Kostas — Univ. of Nevada, Reno

Co-Chair: Shin, Hyo-Sang — Cranfield Univ

10:00-10:20 ThA4.1

Multirotor UAS for Bridge Inspection by Contact Using the Ceiling Effect, pp. 767-774

Sanchez-Cuevas, P. J.	Univ. De Sevilla
Heredia, Guillermo	Univ. of Seville
Ollero, Anibal	Univ. De Sevilla

The inspection of bridges and other infrastructure with UAVs when the sensors need to be in contact with the surface (i.e. ultrasound for crack inspection or reflector prism for beam deflection) is a great challenge

due to the coupling which occurs between the aerial and the inspection problems. This paper presents a new design of a multirotor UAV that can be used in some of these applications to eliminate the coupling and to be able to carry out the inspection by contact in a more effective way. The proposed solution uses the so-called ceiling effect to maintain in contact a specially designed aerial platform to the ceiling. So, the coupling disappears because the multirotor is still in contact with the ceiling in a fixed position while performing inspection. Moreover, the presented results show that making use of the ceiling effect also improved the maximum flight time of the platform. The solution is presented with experimental results in a test stand and flight tests representing a bridge inspection application (Fig. 1). A video of the experiments is also included.

10:20-10:40 ThA4.2

Autonomous Exploration of Visually-Degraded Environments Using Aerial Robots, pp. 775-780

Alexis, Kostas	Univ. of Nevada Reno
Khattak, Shehryar	Univ. of Nevada, Reno
Alexis, Kostas	Univ. of Nevada, Reno

This paper presents a combined perception systems and planning algorithms approach to the problem of autonomous aerial robotic navigation and exploration in degraded visual (dark) GPS-denied environments. A perception system that comprises of a synchronized near-infrared stereo camera system, flashing LEDs, inertial sensors and a 3D depth sensor is utilized in order to derive visual-inertial odometry and dense mapping in conditions of complete darkness. Exploiting this ability within the framework of a localizability-aware receding horizon exploration and mapping planner, the proposed approach ensures robotic autonomy in dark environments for which no prior knowledge exists. A set of experimental studies in a dark room of complex geometry, as well as a city tunnel at night were conducted to evaluate and verify the abilities of the system and the proposed solution.

10:40-11:00 ThA4.3

An Image Based Visual Servoing Approach for Multi-Target Tracking Using an Quad-Tilt Rotor UAV, pp. 781-790

Zarudzki, Mateusz	Cranfield Univ
Shin, Hyo-Sang	Cranfield Univ
Lee, Chang-Hun	Cranfield Univ

This paper proposes a guidance algorithm of a UAV for multiple targets tracking, considering physical constraints of the platform and its sensor. The on-board sensor used for target tracking is a camera. To relax the need of a gimbal system and provide flexibility in utilization of the vision sensor, a new rotorcraft type of UAV is developed. The main focus in designing tracking guidance is to develop an image based visual servoing approach, appropriate to the newly developed platform. This paper shows that the tracking guidance can be significantly simplified with the new type of UAV developed. A complementary to the guidance system a control system for the unconventional UAV is also presented. Both control and guidance algorithms are based on the PID control techniques. The performance of the proposed tracking guidance along with the controller designed is validated by numerical simulations and flight tests.

11:00-11:20 ThA4.4

Recursive Fast Orthogonal Search for Real-Time Adaptive Modelling of a Quadcopter, pp. 791-796

Jardine, Peter Travis	Royal Military Coll. of Canada
Givigi, Sidney	Royal Military Coll. of Canada
Yousefi, Shahram	Queen's Univ
Korenberg, Michael	Queen's Univ

This paper presents a novel application of Recursive Fast Orthogonal Search (R-FOS) to develop a time-varying, linear, state-space model approximating the dynamics of a quadcopter. The algorithm is successfully executed in real-time at a rate of 1000Hz using a simulated quadcopter testbed. The performance of the linear models is evaluated in terms of Accumulated Mean Squared error (AMSE) over finite prediction horizons. A significant decrease in AMSE is observed with more frequent model updates, particularly during aggressive maneuvers. This demonstrates the real-time adaption of the models to various flight regimes.

11:20-11:40 ThA4.5

Realization of Pursuit-Evasion Games with Unmanned Aerial Vehicles, pp. 797-805

Alexopoulos, Alexander	Heidelberg Univ
Kirsch, Benjamin	Heidelberg Univ
Badreddin, E.	Univ. of Heidelberg

Multi-agent pursuit-evasion games are a common way to describe problems in topics like police missions, surveillance, or warfare. Since many agents are involved in such problems, a game-theoretical solution seems reasonable. Game-theoretical solution approaches are generally very complex, especially in games with more than two agents, as it is the case in this paper. More and more unmanned aerial vehicles (UAV), in particular multi-rotors, are used in such applications because of their high maneuverability in all three dimensions. Especially in dangerous missions and applications UAVs excel, as they do not risk the life of the pilot. Tele-operated UAVs still require a pilot which has to be trained to do a task and a constant radio link between the pilot and the vehicle has to be maintained. An autonomous agent, able of performing the task of cooperative pursue and evasion can substitute the pilot. In this work, a realization of cooperative pursuit-evasion games with UAVs is presented. A real-time implementation is proposed, enabling a game-theoretical solution of the regarded problem. The applicability was proven during several real outdoors flight experiments with a hex-rotor UAV. Furthermore, the results obtained by the flight experiments were compared to simulations of the same games. Although, the most experimental results met the reference, disturbances like strong wind, wind gusts and sensor uncertainties affected the results significantly.

ThA5 San Marco Island

Sensor Fusion - I

Chair: Nahon, Meyer	McGill Univ
Co-Chair: Chao, Haiyang	Univ. of Kansas

10:00-10:20 ThA5.1

Descent 4D Trajectory Optimisation for Curved GNSS Approaches, pp. 806-815

Gardi, Alessandro Giacomo Maria	RMIT Univ
Sabatini, Roberto	RMIT Univ

This paper describes the 4-Dimensional Trajectory (4DT) optimization algorithm implemented to avoid a variety Global Navigation Satellite System (GNSS) signal degradations predicted by Avionics Based Integrity Augmentation system (ABIA). The paper focusses on descent and initial curved GNSS approach phases in a dense Terminal Maneuvering Area (TMA) scenario, with multiple aircraft converging on the same short and curved final GNSS approach leg. The reference platform for this study is the Javelin Remotely Piloted Aircraft System (RPAS). The 4DT optimization algorithm implements three degrees-of-freedom aircraft dynamics models as well as suitable GNSS satellite visibility models based on Global Positioning System (GPS) constellation ephemeris data. Direct transcription methods of the global orthogonal (pseudo spectral) collocation family are implemented, generating optimal high-integrity trajectories for curved GNSS approaches in real-time. The optimal trajectories calculated by the pseudo spectral method are subsequently processed by control input smoothing and maneuver identification algorithms to translate the mathematical optimum into a pilot- /autopilot-flyable and concisely described 4DT intent. The characteristics of the proposed 4DT optimization algorithm are evaluated in representative simulation case studies targeting short and curved GNSS approaches in dense TMA conditions, showing very satisfactory performance.

10:20-10:40 ThA5.2

State Estimation Using Inertial Optical Flows for a Fixed-Wing UAS, pp. 816-821

Ringkowski, Michael	Univ. of Kansas
Chao, Haiyang	Univ. of Kansas

Autonomous navigation and obstacle avoidance in complex terrains such as canyons or urban/indoor environments is one of the biggest challenges for the next generation of unmanned aircraft systems. Insects such as honeybees use optical flow for various navigation tasks. Similar strategies can be used by unmanned aircraft as well. More importantly, optical flow can be combined with inertial measurements to achieve state estimation such as ground velocity and terrain shape. In this paper, a new state estimation algorithm is proposed for the estimation of ground speed and simple terrain shape using inertial optical flows. Epipolar constraints are combined with optical flow motion of equation for robust state estimation. Simulation results show the effectiveness of the proposed algorithm.

10:40-11:00 ThA5.3

Control-Enabled Observability in Visual-Inertial Odometry, pp. 822-829

Bai, He	Oklahoma State Univ
Taylor, Clark	Air Force Res. Lab

Visual-inertial odometry (VIO) is a nonlinear estimation problem where control inputs, such as acceleration and angular velocity, play a significant role in the estimation performance. In this paper, we examine effects of controls on the VIO problem. We first analyze the effects of acceleration and angular velocity inputs on state observability of the VIO problem. Representing the vehicle dynamics and the measurement equation in the line of sight coordinates, we prove observability properties for several VIO scenarios, including constant acceleration with no rotation and biased acceleration measurements. We next consider how the acceleration magnitude impacts the estimation performance. Using a planar example and Monte-Carlo simulations, we demonstrate that the estimation accuracy improves as the acceleration magnitude increases. We also show an interesting fact that deceleration along the velocity direction yields better performance than acceleration with the same magnitude for the same amount of time.

11:00-11:20 ThA5.4

Observer Design for Visual Inertial SLAM Scale on a Quadrotor UAV, pp. 830-839

Fink, Geoff	Univ. of Alberta
Franke, Mirko	Inst. Für Regelungs Und Steuerungstheorie, Fakultät Elektrot
Lynch, Alan	U Alberta
Röbenack, Klaus	Tech. Univ. Dresden, Fakultä T Elektrotechnik Und
Godbolt, Bryan	Meggitt Training Systems Canada Inc.

Estimation an Unmanned Aerial Vehicle's (UAV) state, i.e., its pose and velocity, is fundamentally important to its operation. Computer vision provides an alternate or augmentation source for performing state estimation. This work uses an existing monocular Visual Simultaneous Localization and Mapping (VSLAM) system which estimates scaled vehicle position. Two observers are proposed for Visual Inertial Simultaneous Localization and Mapping (VISLAM) by combining measurements from an Inertial Measurement Unit (IMU) with the VSLAM system output to estimate vehicle position, linear velocity, and accelerometer bias. Attitude is assumed measured from an onboard Attitude Heading and Reference System (AHRS). We introduce a change of coordinates to transform the system into a Linear Time-Varying (LTV) form. Using these coordinates, we study the observability of the VISLAM problem and present two observer designs. The approach does not require an approximate linearization of the model equations. Simulations and experimental results onboard a quadrotor UAV validate the proposed designs.

11:20-11:40 ThA5.5

Attitude Estimation for Normal Flight and Collision Recovery of a Quadrotor UAV, pp. 840-849

Battiston, Adrian	McGill Univ
Sharf, Inna	McGill Univ
Nahon, Meyer	McGill Univ

A comparison of attitude estimation algorithms is performed to allow selection of an appropriate algorithm for a quadrotor collision recovery system. A Multiplicative Extended Kalman Filter (MEKF), an Unscented Kalman Filter (UKF), a complementary filter, an H Infinity Filter, and adaptive varieties of the selected filters are chosen for comparison. The adaptive modifications to the estimation algorithms are developed to better estimate the attitude during a collision. The algorithms are compared in simulated normal flight as well as during a simulated collision in order to show which estimation algorithm provides the best quadrotor attitude estimate in all conditions. An approach to modify simulated Inertial Measurement Unit (IMU) data to match experimental data during a quadrotor collision is developed. The results show that slight improvements can be found using the adaptive algorithms and that overall, the UKF algorithms are found to outperform other estimators during regular flight and after a collision.

11:40-12:00 ThA5.6

Collaborative Multi-Vehicle Localization with Respect to Static/dynamic Target from Range and Velocity Measurements, pp. 850-859

SARRAS, Ioannis	ONERA-The French Aerospace Lab
Marzat, Julien	ONERA - the French Aerospace Lab
Bertrand, Sylvain	ONERA
Piet-Lahanier, Hélène	ONERA

We treat the problem of collaborative multi-vehicle localization using time-varying range and relative velocity measurements. The proposed solution combines local nonlinear observers that estimate the relative positions between agents and their neighbors, and cooperative filters that fuse each agent's local estimates to globally localize them with respect to a target (and therefore to each other). Furthermore, we explicitly introduce an estimator that filters the noisy measured signals and feeds the aforementioned observers. Both scenarios of a static as well as a dynamic target are considered. The overall architecture is proved to provide a uniformly globally exponentially converging localization under the assumptions of persistently exciting motion and of a communication topology that contains a directed spanning tree. The efficiency of the results is illustrated through detailed numerical simulations.

ThB1 Salon E

Micro and Mini UAS - II

Chair: Lozano, Rogelio	Univ. of Tech. of Compiègne
Co-Chair: Lanteigne, Eric	Univ. of Ottawa

13:45-14:05 ThB1.1

Improving Quadrotor Trajectory Tracking by Compensating for Aerodynamic Effects, pp. 860-866

Svacha, James	Univ. of Pennsylvania
Mohta, Kartik	Univ. of Pennsylvania
Kumar, Vijay	Univ. of Pennsylvania

In this work, we demonstrate that the position tracking performance of a quadrotor may be significantly improved for forward and vertical flight by incorporating simple lumped parameter models for induced drag and thrust, respectively, into the quadrotor dynamics and modifying the controller to compensate for these terms. We further show that the parameters for these models may be easily and accurately identified offline from forward and vertical flight data. We demonstrate that the simple drag compensating controller can reduce the position error in the direction of forward flight in steady state by 75%, and that the controller using a more accurate thrust model, dubbed the “refined” thrust model, can improve the position error by 72% in the vertical direction.

14:05-14:25 ThB1.2

Attitude and Velocity High-Gain Control of a Tilt-Trirotor UAV, pp. 867-876

Canciello, Giacomo	Department of Industrial and Information Engineering, Univ

Cavallo, Alberto — Seconda Univ. Degli Studi Di Napoli
D'Amato, Egidio — Univ. of Campania
Mattei, Massimiliano — Seconda Univ. Di Napoli

The tilting trirotor presented in this paper is able to perform levelled flight at almost null attitude which is an important requirement for fixed wing tilt rotors in view of the lift control during transition from hovering to forward flight. The nonlinear dynamics, the large effect of wind due to the small scale, and the absence of aerodynamic data at low speed and Reynolds numbers, are crucial factors when designing controllers. A two nested loops, high-gain controller scheme is proposed to control attitude and both longitudinal and vertical speed. Controller design is based on the selection of high-gain PI control actions together with suitable sliding surfaces where the closed loop system state variables are forced to evolve. This approach guarantees robustness and fast tuning. To demonstrate the effectiveness of the proposed controller, also in the presence of actuator dynamics and saturations, numerical simulations have been conducted on a detailed simulator of the tri-rotor.

14:25-14:45 ThB1.3

*Experimental Investigation on Aerodynamics of Non-Planar Rotor Pairs in a Multi-Rotor UAV**

Bai, Yue — Changchun Inst. of Optics, Fine Mechanics and Physics
Li, Chuanzheng — Changchun Inst. of Optics, Fine Mechanics and Physics
Pei, Xinbiao — Changchun Inst. of Optics, Fine Mechanics and Physics
Wu, Helong — Changchun Inst. of Optics, Fine Mechanics and Physics
Ma, Ping — Changchun Inst. of Optics, Fine Mechanics and Physics

14:45-15:05 ThB1.4

Autonomous Take-Off and Landing on a Colored Platform, pp. 877-884

Orlando, García — UMI-CINVESTAV-IPN
Flores, Donovan — CINVESTAV-IPN
Santos, Omar — Univ. Autónoma Del Estado De Hidalgo
Romero, Hugo — Icbi - Uaeh
Salazar, Sergio — Umi Lafmia Cinvestav
Lozano, Rogelio — Univ. of Tech. of Compiègne

This paper presents a novel autonomous take-off and landing approach. Using a finite-horizon sub optimal of discrete-time nonlinear control to achieve a smooth landing on specific colored platform. By color-based tracking we can improve the performance of the position landing and correct the position given by the GPS. The signal of the GPS is not always reliable since the accuracy depends strongly on the environment situation and the correction by vision servoing is necessary. Experimental results show a better performance than only using GPS signal with take-off and landing test completely autonomous in presence of wind gusts.

15:05-15:25 ThB1.5

Optimal Control for the Trajectory Planning of Micro Airships, pp. 885-892

Blouin, Charles — RCbenchmark and Univ. of Ottawa
Lanteigne, Eric — Univ. of Ottawa
Gueaieb, Wail — Univ. of Ottawa

The objective of this paper is to demonstrate the application of optimal control for generating dynamically constrained minimal time trajectories in micro unmanned airships. By design, airships are generally underactuated and underpowered limiting their maneuvering capabilities. Using a simplified dynamic model derived with experimentally derived coefficients, two trajectory planning simulations are solved using optimal control. The generated trajectories are then evaluated experimentally on a micro airship to demonstrate that optimal control can be used in open loop over short distances.

ThB2 — Salon AB
See-And-Avoid Systems - I

Chair: Mejias Alvarez, Luis — Queensland Univ. of Tech
Co-Chair: Neubert, Jeremiah — Univ. of North Dakota

13:45-14:05 ThB2.1

Adaptive Detection Threshold Selection for Vision-Based Sense and Avoid, pp. 893-901

Molloy, Timothy L. — Queensland Univ. of Tech
Ford, Jason — Queensland Univ. of Tech
Mejias Alvarez, Luis — Queensland Univ. of Tech

Current state-of-the-art vision-based sense and avoid systems based on morphological and hidden Markov model filtering require the manual selection of static (time-invariant) detection thresholds. Manually selecting suitable static detection thresholds is challenging (and currently requires highly trained operators) because it involves balancing trade- offs between detection and false alarm performance in different image sensing conditions. In this paper, we exploit recent work on the characterization of vision-based aircraft detection problems in the sky-region to propose an adaptive threshold selection approach. Using data sets captured during flight experiments, we show that our proposed adaptive threshold approach can enable improved detection range performance compared to manually selected static thresholds.

14:05-14:25 ThB2.2

Determining Intruder Aircraft Position Using Series of Stereoscopic 2-D Images, pp. 902-911

Ramani, Aditya — The Univ. of Texas at Arlington
Sevil, Hakki Erhan — The Univ. of Texas at Arlington Res. Inst. (UTARI)
Dogan, Atilla — The Univ. of Texas at Arlington

The aim of this study is to investigate methods for computing the position of an intruder aircraft relative to an observer aircraft with onboard stereo cameras. To focus on relative position estimation rather than the intruder aircraft detection through image processing, the first phase is to generate camera images given the relative position information. This process uses a simple pinhole camera method where cameras are characterized by focal length, angle of view, and resolution. The second phase is to develop two methods to estimate the relative position based on the generated camera images. Both methods employ epipolar geometry of stereo vision based on two cameras placed on the aircraft with lateral separation. Various cases are run in a MatLab/Simulink simulation environment. Simulation cases are designed to evaluate the relative position estimation methods with different aircraft trajectories, different camera separations, and different camera resolutions. Simulation results show that relative position can be estimated while both aircraft are flying along any trajectories as long as the intruder aircraft is visible by both cameras. The estimation accuracy degrades as the relative distance between the aircraft increases. The larger lateral separation seems to improve the estimation accuracy. Image resolution seems to have little to no impact on estimation accuracy.

14:25-14:45 ThB2.3

Repeatability of Edge Detectors in Various Environmental Conditions, pp. 912-919

Allen, Nicholas — Univ. of North Dakota
Tabassum, Asma — Univ. of North Dakota
Semke, William — Univ. of North Dakota
Neubert, Jeremiah — Univ. of North Dakota

This paper explores the interactions between environmental conditions and edge detector performance for use as a critical function for detect and avoidance (DAA) operations in the unmanned aerial systems

(UAS) industry. The goal of this study was to establish the best edge detection scheme for sunny, low light, cloudy, and foggy conditions. A laboratory test chamber was developed to simulate these conditions. Canny, Laplacian of Gaussian (LoG), Roberts, and Prewitt edge detectors were evaluated. Images were taken in these conditions and Pratt's Figure of Merit was used to evaluate the repeatability of the edge detector. It was determined that Prewitt performs best in low light and cloudy conditions, while LoG performs well in foggy conditions. Prewitt was shown to be the best overall edge detector with the properly chosen threshold. These results were validated with a natural image to show laboratory produced images can be used in place of images taken outdoors for this study. This validation proved laboratory settings produce comparable results to real world conditions.

14:45-15:05 ThB2.4

A Unified Approach to Separation Assurance and Collision Avoidance for UAS Operations and Traffic Management, pp. 920-928

Ramasamy, Subramanian	RMIT Univ
Sabatini, Roberto	RMIT Univ
Gardi, Alessandro Giacomo Maria	RMIT Univ

A unified approach to cooperative and non-cooperative Separation Assurance and Collision Avoidance (SA&CA) is presented addressing the technical and regulatory challenges of Unmanned Aircraft Systems (UAS) integration into all classes of airspace. Additionally, the emerging UAS Traffic Management (UTM) system requirements are captured and addressed in this novel unified framework. Uncertainties in navigation and tracking error measurements associated to each manned/unmanned platform (as seen by all other conflicting platforms) are combined statistically to generate avoidance volumes in the airspace. The unified approach to SA&CA provides the required tools to generate uncertainty volumes at discrete time intervals as a function of traffic relative dynamics and thus supports the generation of dynamic geo-fences and multi UTM system implementation. Case studies are presented for evaluating the feasibility of the approach in an urban environment. In this approach, real-time and off-line determination of the UAS safe-to-fly envelope is performed based on the installed avionics sensors and on the own/intruder platform dynamics. Alternatively, the required sensors are identified for the UAS to safely fly a certain pre-defined envelope supporting the development of the SA&CA system certification case and thus providing a clear pathway to certification.

15:05-15:25 ThB2.5

Evaluation of Extant Computer Vision Techniques for Detecting Intruder Suas, pp. 929-938

Sevil, Hakki Erhan	The Univ. of Texas at Arlington Res. Inst. (UTARI)
Dogan, Atilla	The Univ. of Texas at Arlington
Subbarao, Kamesh	Univ. of Texas at Arlington
Huff, Brian	The Univ. of Texas at Arlington

In this study, we investigate the feasibility of detecting small intruder aircraft through camera images obtained onboard a small unmanned aircraft. The research group (Small Unmanned Aerial Vehicle Laboratory) from NASA Langley Research Center flew a set of missions with their small UAS (sUAS) where one of those vehicles is outfitted with three 4K resolution cameras located at the tips of the wings and one at the nose. We utilize the Math Works Computer Vision System Toolbox components to process the video data that are provided by NASA. We demonstrate the capabilities of COTS (Commercial Off-The-Shelf) state-of-art algorithms to detect the intruder aircraft in the video files. In the evaluation of these algorithms, various parameters of each algorithm are tuned to improve the detection performance in the case of the NASA flights, and the results are presented. The aim is to analyze performance of existing COTS state-of-art algorithms in detecting intruder aircraft from the camera images.

15:25-15:45 ThB2.6

KCF Based 3D Object Tracking Via RGB-D Camera of a Quadrotor, pp. 939-944

Ma, Yue	Beijing Inst. of Tech
Pei, Peng	Beijing Inst. of Tech
Xiang, Changle	Beijing Inst. of Tech
Yao, Shouwen	Beijing Inst. of Tech
Gao, Yang	Beijing Inst. of Tech

A real-time vision-based object tracking system embedded in a quadrotor is presented in this paper. The integrated system is expected to enable the quadrotor to track a target object and keep with a constant distance. A robust object tracking method via improving Kernelized Correlation Filters algorithm is proposed to achieve accurate visual tracking. In addition, a simple PID controller is applied to utilize the data from a RGB-D Camera. And the effectiveness of our proposed methods verified by experimental results.

ThB3 Salon CD
Reliability of UAS

Chair: Zhang, Youmin	Concordia Univ
Co-Chair: Johansen, Tor Arne	Norweigian Univ. of Sci. & Tech

13:45-14:05 ThB3.1

Fuzzy Adaptive Fault-Tolerant Control for Quadrotor Helicopter, pp. 945-950

Wang, Ban	Concordia Univ
Zhang, Youmin	Concordia Univ

This paper proposes a fuzzy adaptive sliding mode control for accommodating large actuator fault and maintaining system stability. Boundary layer is employed to smooth control discontinuity and eliminate control chattering. However, if the thickness of boundary layer is chosen too big, the tracking accuracy will be degraded. Whereas, if the boundary layer thickness is too small, control chattering will be stimulated and system stability will also be affected. With this consideration, a fuzzy logic based boundary layer is designed together with the proposed adaptive control scheme to maintain system stability. The on-line adaptive control scheme can seamlessly change control gains to make a compensation in the presence of actuator fault. When there is a trend to overestimate the control gain, the fuzzy boundary layer will be triggered to enlarge boundary layer thickness to ensure system stability. In such a way, larger actuator fault can be accommodated within the proposed control scheme. The effectiveness of the proposed control strategy is validated through a simulation based on a quadrotor helicopter under two different fault scenarios.

14:05-14:25 ThB3.2

A Simplified Situational Environment Risk and System Reliability Assessment for Behavior Assurance of Autonomous and Semi-Autonomous Aerial Systems: A Simulation Study, pp. 951-960

Hägele, Georg	Univ. of Duisburg-Essen
Söffker, Dirk	Univ. of Duisburg-Essen

Autonomous and semi-autonomous aerial systems (AES) as example of autonomous and semi-autonomous systems (AS) have to perform tasks in complex and dynamic environment, for example in logistics and transportation applications. In this context AS's behavior has to be verifiably safe. Traditionally, behavioral safety aspects are combined with mission-related tasks. The consequence of this combination may be unmanageable system's complexity as well as unpredictable effects during the interaction with the environment leading to inapplicability of traditional safety assurance methods. Furthermore, real-time system's hardware reliability assessment and management are often not considered.

This paper introduces a novel simplified real-time environmental situation risk assessment approach to be applied for determination of required situational AS's reliability. Furthermore, the novel real-time AS's hardware reliability assessment and situational hardware structure and behavior control for AS's safe behavior assurance is presented. The introduced approach can verify AS's safe situational behavior by real-time environmental risk assessment and AS's hardware structure and emergency behavior control to minimize the situational risk. A technical proof of concept is given demonstrating the

successful use of the introduced approach based on AES and its environment simulation using Virtual Robot Experimental Platform in combination of concept realization using real soft Programmable Logic Controller.

14:25-14:45 ThB3.3

An Airspace Capacity-Based Safety Assessment Model Considering UAS Integration, pp. 961-970

Pinto Neto, Euclides	Univ. of São Paulo
Moreira Baum, Derick	Univ. of São Paulo
Hernandez-Simoes, Carlos Enrique	Univ. of Sao Paulo
Almeida Jr, Jorge Rady	Univ. of Sao Paulo
Camargo Jr, João Batista	Univ. of Sao Paulo
Cugnasca, Paulo Sérgio	Univ. of Sao Paulo

Complexity is a measure of the difficulty that a particular air traffic situation represents to Air Traffic Controller (ATCo). This measure impacts on ATCo workload, which is an important factor for defining airspace capacity. This paper presents an evaluation of the impact of the insertion of Remotely Piloted Aircraft (RPA) on safety levels within a non-segregated airspace based on the calculation of airspace capacity. The experiments consider a sector of a complex Terminal Control Area (TMA) as well as failures of command and control (C2) link of RPA. This research considers different scenarios, varying the presence of RPA (0%, 10%, 20%, 30%, 40% and 50%) in the sample, applying contingency procedures in the case that the C2 link is lost. Finally, the proposed experiments showed that, considering the additional activities related to RPA operation, the contingency operation land at nearest appropriate designated landing site presents the most significant impact.

14:45-15:05 ThB3.4

Flight Test Results for Autonomous Icing Protection Solution for Small Unmanned Aircraft, pp. 971-980

Sorensen, Kim Lynge	The Norwegian Univ. of Science and Tech
Johansen, Tor Arne	Norweigian Univ. of Sci. & Tech

The primary focus of the work presented in this paper is a proof-of-concept study of a novel electro-thermal-based autonomous icing protection solution for small unmanned aircraft. The solution includes a central control unit, where several control algorithms, ensure temperature control of electrothermal sources, applied to exposed aircraft surfaces. The solution includes three different control procedures (icing detection, anti-icing, and de-icing) that are validated through test flights conducted in Ny-Aalesund, Svalbard, Norway.

15:05-15:25 ThB3.5

Safe Navigation Control for a Quadcopter Using User's Arm Commands, pp. 981-988

Sánchez, Luis Fernando	ITESM
Abaunza, Hernan	Univ. De Tech. De Compiègne
Castillo, Pedro	Unviersité De Tech. De Compiègne

The goal in this paper is to introduce an intuitive way to control a VTOL vehicle (Vertical Take-Off and Landing) using commands from a user, i.e., the idea is to provide a non-cumbersome easy-to-handle interface that will allow even inexpert users a safe command interface for this kind of vehicles. The aerial vehicle chosen for validating this safe-control- scheme is the quadcopter vehicle. The user will use a bracelet composed by inertial (gyroscopes, accelerometers and magnetometers) and electromyographic sensors that will measure the arm user movements and construe them in references for the drone. In order to achieve this, the data acquired from the bracelet has to undergo a signal treatment and safety algorithms were put in place. A method for gesture recognition was developed in order to fully exploit the capabilities of both, the user and the UAV 1. Data collection and analysis were performed to improve the algorithms. Experimental tests with real time flight were performed to validate the proposed safe-control-scheme. Main graphs illustrate the satisfactory results obtained when controlling the quadcopter vehicle in acrobatic maneuvers.

ThB4 Lummus Island

UAS Applications - V

Chair: Bhattacharya, Subhrajit — Lehigh Univ

Co-Chair: Vacek, Lukas — Univ. of Pennsylvania

13:45-14:05 ThB4.1

A Fully-Autonomous Aerial Robotic Solution for the 2016 International Micro Air Vehicle Competition, pp. 989-998

Sampedro, Carlos	Univ
Bavle, Hriday	PhD Student at Univ. Pol. De Madrid
Rodríguez-Ramos, Alejandro	PhD Student at Univ. Pol. De Madrid
Carrio, Adrian	Univ. Pol. De Madrid
Suárez Fernández, Ramón A.	Univ. Pol. De Madrid
Sanchez-Lopez, Jose Luis	CSIC - Univ. Pol. De Madrid, Centro De Automatica Y
Campoy, Pascual	Univ. Pol. Madrid

In this paper, a fully-autonomous quadrotor aerial robot for solving the different missions proposed in the 2016 International Micro Air Vehicle (IMAV) Indoor Competition is presented. The missions proposed in the IMAV 2016 competition involve the execution of high-level missions such as entering and exiting a building, exploring an unknown indoor environment, recognizing and interacting with objects, landing autonomously on a moving platform, etc. For solving the aforementioned missions, a fully-autonomous quadrotor aerial robot has been designed, based on a complete hardware configuration and a versatile software architecture, which allows the aerial robot to complete all the missions in a fully autonomous and consecutive manner. A thorough evaluation of the proposed system has been carried out in both simulated flights, using the Gazebo simulator in combination with PX4 Software-In-The-Loop, and real flights, demonstrating the appropriate capabilities of the proposed system for performing high-level missions and its flexibility for being adapted to a wide variety of applications.

14:05-14:25 ThB4.2

Relative-Pose Optimisation for Robust and Nonlinear Control of Unmanned Aerial Manipulators, pp. 999-1005

Rodríguez de Cos, Carlos	Univ. De Sevilla
Acosta, Jose Angel	Univ. De Sevilla
Ollero, Anibal	Univ. De Sevilla

Recently, the complexity of control systems for autonomous Aerial Manipulators (AMs), i.e. Unmanned Aerial Vehicle (UAV) + Robot Manipulator (RM), is growing faster as per our demand of being able to perform more and more complex tasks. In the present work, we go a step forward adding an optimizer to the actual (nonlinear) control strategy, in order to comply with high-level control demands related to safety, accuracy and efficiency of the operational task. The actual strategy combined robust controllers–for both aerial vehicle and robot manipulator–optimizing their shared priorities. Here, we demand the controller to meet an additional feed-forward action, so that the a priori free degree of freedom of the UAV relative-pose reference is optimized in real time according to the aforementioned requirements. In particular, the influence of the UAV relative-pose reference on the capabilities of the AM has been thoroughly analyzed, demonstrating among others the benefits of a correct configuration to meet such high level requirements, while reducing the End-Effector (EE) error, preventing instability of hazardous situations and increasing the energetic efficiency of the whole system. A complete analysis of realistic simulations on a benchmark AM is reported.

14:25-14:45 ThB4.3

UAV Assisted Smart Parking Solution, pp. 1006-1013

Chuah, Mooi	Lehigh Univ
Li, Xin	Lehigh Univ
Bhattacharya, Subhrajit	Lehigh Univ

Smart parking solutions for big cities are critically important for reducing traffic congestion and vehicle energy consumption in big

cities. Visual-based detection methods have been proposed since their maintenance costs are typically lower. However, visual based detection methods in existing systems are not robust due to varying light intensities, occlusions, and their deployment costs can still be expensive. In this paper, we present a collaborative UAV aided smart parking solution where a small team of low cost UAVs are used to collaboratively identify free parking spots of parking lots within campuses. We design a novel navigation control scheme to allow such UAVs to avoid obstacles and cover the parking lots sufficiently. In addition, we also present a visual detection scheme using the generative adversarial network (GAN) which allows us to predict parking availability without requiring pre-identification of parking spots. Simulation results indicate that our approach show promising results.

14:45-15:05 ThB4.4

Development and Field Test of Novel Two-Wheeled UAV for Bridge Inspections, pp. 1014-1021

Yamada, Moyuru	FUJITSU Lab. LTD
Nakao, Manabu	FUJITSU Lab. LTD
Hada, Yoshiro	FUJITSU Lab. LTD
Sawasaki, Naoyuki	FUJITSU Lab. LTD

This paper presents the development and field test of a novel unmanned aerial vehicle (UAV) for bridge inspections. The proposed UAV, which consists of a quadrotor, a cylindrical cage installed in it, and two spokeless wheels freely rotating around the cage, can climb and run on the bridge surface. Its structure improves durability and reduces air resistance compared with conventional UAVs with a cage or wheels. These advantages expand the uses of the UAV in various fields. This paper evaluates the effectiveness of the proposed UAV in real-world bridge inspection scenarios. We tested basic locomotion and measured air resistances. Experimental results on bridges demonstrated the ability to inspect various locations on bridges that are difficult for human inspectors to access.

15:05-15:25 ThB4.5

Suas for Deployment and Recovery of an Environmental Sensor Probe, pp. 1022-1029

Vacek, Lukas	Univ. of Pennsylvania
Atter, Edward	Univ. of Pennsylvania
Rizo, Pedro	Univ. of Pennsylvania
Nam, Brian	Univ. of Pennsylvania
Kortvelesy, Ryan	Univ. of Pennsylvania
Kaufman, Delaney	Univ. of Pennsylvania
Das, Jnaneshwar	Univ. of Pennsylvania
Kumar, Vijay	Univ. of Pennsylvania

Small Unmanned Aircraft Systems (sUAS) are already revolutionizing agricultural and environmental monitoring through the acquisition of high-resolution multi-spectral imagery on-demand. However, in order to accurately understand various complex environmental and agricultural processes, it is often necessary to collect physical samples of pests, pathogens, and insects from the field for ex-situ analysis. In this paper, we describe a sUAS for autonomous deployment and recovery of a novel environmental sensor probe. We present the UAS software and hardware stack, and a probe design that can be adapted to collect a variety of environmental samples and can be transported autonomously for off-site analysis. Our team participated in an NSF-sponsored student unmanned aerial vehicle (UAV) challenge, where we used our sUAS to deploy and recover a scale-model mosquito trap outdoors. Results from indoor and field trials are presented, and the challenges experienced in detecting and docking with the probe in outdoor conditions are discussed.

ThB5 San Marco Island

Sensor Fusion - II

Chair: Chen, YangQuan	Univ. of California, Merced
Co-Chair: Lozano, Rogelio	Univ. of Tech. of Compiègne

13:45-14:05 ThB5.1

Optical Aircraft Navigation with Multi-Sensor SLAM and Infinite Depth Features, pp. 1030-1036

Andert, Franz	German Aerospace Center (DLR)
Krause, Stefan	German Aerospace Center

In the context of optical-aided navigation and visual Simultaneous Localization and Mapping (SLAM) for satellite-denied aircraft navigation, this paper extends the monocular SLAM approach by the use of multiple sensors with different viewing directions. Downward optical sensors see other movements than forward-looking cameras, hence it is straightforward to combine the benefits of both.

This combination helps to estimate all the six motion components with increased robustness, yielding a more stable and accurate state estimation for optical-aided navigation solutions. The method is evaluated with aerial data from manned and unmanned flights. In the data analysis, a satellite navigation dropout is simulated, and the flight trajectory is then reconstructed just by the optical data. The method is tested in small-scale scenarios as well as in longer flights with several kilometers of flight range. The results show some increased performance of an additional forward camera in comparison to a setup with only downward sensors. It is proposed to use such multi-sensor configurations wherever motion estimation ambiguities with a single camera are probable, especially when larger distances have to be flown with optical navigation.

14:05-14:25 ThB5.2

Quaternion Kalman Filter for Inertial Measurement Units, pp. 1037-1043

Cariño Escobar, Jossué	CINVESTAV-IPN
Cabarbaye, Aurélien	Cinvestav
Bonilla, Moises E.	CINVESTAV-IPN
Lozano, Rogelio	Univ. of Tech. of Compiègne

This paper presents a theoretical and practical implementation of a Kalman Filter (KF) to obtain the attitude and angular velocity from a nine degrees of freedom (DoF) inertial measurement unit (IMU). These include three DoF from an accelerometer, three from a magnetometer and the last three from a gyroscope. It differs from other attitude filters in two main aspects, the model representation and how the information is acquired from the IMU. The quaternion model presented has an analogous linear representation that can be used, in conjunction with the algorithm that is presented in order to extract the attitude information from the IMU, leading to a considerable lower computational cost in order to avoid the calculation of Jacobians matrices or gradients.

14:25-14:45 ThB5.3

A Flight Altitude Estimator for Multirotor UAVs in Dynamic and Unstructured Indoor Environments, pp. 1044-1051

Bavle, Hriday	PhD Student at Univ. Pol. De Madrid
Sanchez-Lopez, Jose Luis	CSIC - Univ. Pol. De Madrid, Centro De Automatica Y
Rodríguez-Ramos, Alejandro	PhD Student at Univ. Pol. De Madrid
Sampedro, Carlos	Univ
Campoy, Pascual	Univ. Pol. Madrid

A reliable estimation of the flight altitude in dynamic and unstructured indoor environments is an unsolved problem. Standalone available sensors, such as distance sensors, barometers and accelerometers, have multiple limitations in presence of non-flat ground surfaces, or in cluttered areas. To overcome these sensor limitations, maximizing their individual performance, this paper presents a modular EKF-based multi-sensor fusion approach for accurate vertical localization of multirotor UAVs in dynamic and unstructured indoor environments.

The state estimator allows to combine the information provided by a variable number and type of sensors, including IMU, barometer and distance sensors, with the capabilities of sensor auto calibration and bias estimation, as well as a flexible configuration of the prediction and update stages. Several autonomous indoors real flights in unstructured environments have been conducted in order to validate our proposed state estimator, enabling the UAV to maintain the desired flight altitude when navigating over wide range of obstacles.

Furthermore, it has been successfully used in IMAV 2016 competition. The presented work has been made publicly available to the scientific community as an open source software within the Aerostack (www.aerostack.org) framework.

14:45-15:05 ThB5.4

SmartCaveDrone: 3D Cave Mapping Using UAVs As Robotic Co-Archaeologists, pp. 1052-1057

Zhang, Guoxiang	Univ. of California, Merced
Shang, Bo	Northeastern Univ. Shenyang
Chen, YangQuan	Univ. of California, Merced
Moyes, Holley	Univ. of California, Merced

This paper proposes the concept of drones capable of functioning as “Co-Archaeologists” that can map large caves and enter dangerous or hard-to-reach spaces. Using RGB-D data collected by drones, we will be able to produce accurate 3D models and semantic maps with proper lighting co-supervised by human archaeologists. This is going to be a major advance in archaeological practice, which can accelerate the speed of archaeological exploits by extending the archaeologists' sight and perception range. This will enable us to conduct 3D analyses so that we may answer new questions and create new insights into the archaeological record. The archaeologists will be able to visualize data collected by drones and instruct the drones' next step in real-time. These data will also be important in site management, data sharing and visualization. Human/drone interaction becomes important, not only for operating the equipment, but also for guiding drones to areas of interest to be mapped. Maps or real-time “fly-throughs” only make sense when they are organized by human interaction with the space. This human interaction is vital when visualizing and understanding a space and should be reflected in the imagery. We envision that this technology will be game changing in cave mapping and pertinent to anyone rendering interior spaces. It creates longer term impacts in archaeology and digital heritage and potentially creates a transformative way for further enhancing the performance of 3D mapping.

15:05-15:25 ThB5.5

Localization and Tracking of RF Emitting Targets with Multiple Unmanned Aerial Vehicles in Large Scale Environments with Uncertain Transmitter Power, pp. 1058-1065

Hasanzade, Mehmet	Aerospace Res. Center, Istanbul Tech. Univ
Herekoglu, Omer	Aerospace Res. Center, Istanbul Tech. Univ
ÜRE, Nazim Kemal	Massachusetts Inst. of Tech
Koyuncu, Emre	Aerospace Res. Center, Istanbul Tech. Univ
Yeniçeri, Ramazan	Aerospace Res. Center, Istanbul Tech. Univ
INALHAN, GOKHAN	ISTANBUL Tech. Univ

In this paper we study the localization and tracking of a radio frequency (RF) emitting target using multiple unmanned aerial vehicles (UAVs) over a large scale environment. Although localization of RF emitting targets using multiple measurements is a well-studied problem, the standard approaches become inefficient when the signal power is uncertain and there is significant noise in the received signal strength (RSS) when the search environment is large scale. We present a localization and tracking architecture, where a data driven neural network model is used for estimating the unknown signal strength and extended Kalman filters are utilized for eliminating the RSS noise and increase the precision of target tracking performance. We present simulation results in a $10 times 10 text{ km}^2$ search area, where 3 fixed wing UAVs localize and track a target with up to $28.3 text{ m}$ average error distance.

ThC1 Salon E

Micro and Mini UAS - III

Chair: Ollervides Vazquez, Edmundo Javier — Inst. Tecnologico De La Laguna; CIIIA-FIME-UANL

Co-Chair: Castaneda, Herman — Tecnologico De Monterrey

15:40-16:00 ThC1.1

Semi-Autonomous Teleoperation of UAVs in Search and Rescue Scenarios, pp. 1066-1074

Perez-Grau, Francisco Javier	Center for Advanced Aerospace Tech. (CATEC)
Ragel, Ricardo	Univ. De Sevilla
Caballero, Fernando	Univ. of Seville
Viguria, Antidio	FADA-CATEC
Ollero, Anibal	Univ. De Sevilla

Unmanned Aerial Vehicles (UAVs) exhibit great agility and usually require a trained pilot to operate them, while being restricted to line-of-sight range. This prevents their wide introduction in applications such as inspection for disaster scenarios. Our goal is to enable rescue teams untrained in piloting to teleoperate a UAV as an aid to their mission, while being able to focus on the task at hand. The assisted teleoperation of a small UAV is presented in this work, within a framework to perform localization and state estimation of the UAV without any external positioning system (e.g. GPS) and perform autonomous local obstacle avoidance. The computational efficiency of the whole processing pipeline allows for real-time operation. Field experiments have been conducted in a realistic mock-up using an indoor testbed with a very accurate tracking system in order to validate the algorithms.

16:00-16:20 ThC1.2

Future Mesh-Networked Pico Air Vehicles, pp. 1075-1082

Drew, Daniel S.	Univ. of California, Berkeley
Kilberg, Brian	Univ. of California-Berkeley
Pister, Kris	UC Berkeley

Taken together, recent advances in microelectromechanical systems, wireless mesh networks, digital circuits, and battery technology have made the notion of autonomous pico air vehicles viable. In this work we describe the core technologies enabling these future vehicles as well as propose two possible future platforms. We draw on recent research on high thrust density atmospheric ion thrusters, micro fabricated silicon control surfaces, and extremely low mass and power mesh networking nodes. Using the same open-source network implementation as we have already demonstrated in larger UAVs, these flying microrobots will open up a new application space where unobtrusiveness and high data granularity are vital.

16:20-16:40 ThC1.3

Spatial Modeling, Identification and Adaptive Second Order Sliding Mode Control of a Micro Air Vehicle, pp. 1083-1091

Castaneda, Herman	Tecnologico De Monterrey
Gordillo, José Luis	Tecnológico De Monterrey

This paper addresses the modeling, identification and adaptive sliding mode control for a quadrotor micro aerial vehicle. In order to obtain a compact kinematics and dynamics representation, the spatial vectors convention is used, making more efficiently the model computation by reducing the number of algebraic operations. Identification of parameters such as inertia moments, thrust and torque of the motor-propeller with motor features by means of estimation and experimental tests are also included. In addition, a flight control based on a recent adaptive second order sliding mode control is designed. This controller allows to mitigate external disturbances with unknown bounds. Simulation results shows the feasibility and attractiveness of the proposed set up.

16:40-17:00 ThC1.4

Experimental and Computational Analysis of Microscale Shrouded Coaxial Rotor in Hover, pp. 1092-1100

Han, Han	Beijing Inst. of Tech
Xiang, Changle	Beijing Inst. of Tech
Xu, Bin	Beijing Inst. of Tech
Yu, Yong	Beijing Inst. of Tech

Experimental and computational studies of the hovering performance

of micro coaxial shrouded rotors were carried out. The ATI Mini Multi-Axis Force/Torque Transducer system was used to measure all six components of the force and moment. Meanwhile, numerical simulation of flow field around rotor was carried out using sliding mesh method and multiple reference frame technique by ANASYS FLUENT. The computational results were well agreed with experimental data. Several important factors, such as blade pitch angle, rotor spacing and tip clearance, which influence the performance of shrouded coaxial rotor are studied in detail using CFD method in this paper. Results shows that, evaluated in terms of Figure of Merit, open coaxial rotor is suited for smaller pitch angle condition while shrouded coaxial rotor is suited for larger pitch angle condition. The negative pressure region around the shroud lip is the main source of the thrust generation. In order to have a better performance for shrouded coaxial rotor, the tip clearance must be smaller. The thrust sharing of upper- and lower-rotor is also discussed in this paper.

17:00-17:20 ThC1.5

Implementation of a Super Twisting Controller for Distributed Formation Flight of Multi-Agent Systems Based on Consensus Algorithms, pp. 1101-1107

Rojo Rodriguez, Erik Gilberto	Univ. Autonoma De Nuevo Leon
Ollervides Vazquez, Edmundo Javier	Inst. Tecnologico De La Laguna; CIIIA-FIME-UANL
Rodriguez Macias, Juan Gerardo	CIIIA-FIME-UANL
Espinoza Quesada, Eduardo Steed	Univ. Pol. De Pachuca
Zambrano-Robledo, Patricia	CIIIA-FIME-UANL
Garcia Salazar, Octavio	CIIIA-FIME-UANL

This paper presents the implementation of a Super Twisting (ST) controller for distributed formation flight based on a consensus algorithm for multi-agent systems (MAS). The equations of motion of each agent are based on the Newton-Euler approach and the navigation of each agent is distributed. For the navigation, two controllers namely, a PID algorithm and a Super Twisting algorithm, are tested in order to obtain the best performance for the formation flight. These algorithms control the orientation and position dynamics of each agent computing its own algorithm based on local information and information from its neighbors in the multi-agent systems. A consensus algorithm is proposed for formation flight in trajectory tracking of the MAS, and the real-time experiments of the formation flight are presented in order to illustrate the performance of the proposed algorithms.

ThC2 Salon AB

See-And-Avoid Systems - II

Chair: Bokor, Jozsef	Hungarian Acad. of Sciences
Co-Chair: Lee, Andrew	Massachusetts Inst. of Tech

15:40-16:00 ThC2.1

Monocular Image-Based Intruder Direction Estimation at Closest Point of Approach, pp. 1108-1117

Bauer, Peter	Inst. for Computer Science and Control, HungarianAcademyof S
Hiba, Antal	Hungarian Acad. of Sciences Inst. for Computer Science And
Bokor, Jozsef	Hungarian Acad. of Sciences

This paper deals with monocular image-based aircraft Sense and Avoid for small UAVs. After summarizing previous results of the authors it proposes a complete solution which calculates time to closest point of approach, relative closest point of approach (CPA) and the direction of intruder at CPA. These parameters are enough to make a collision decision and design the avoidance maneuver. The applicability of the proposed solution is demonstrated considering an omnidirectional multi-camera system in an extensive software -in-the-loop test campaign covering the whole possible size and velocity range of manned aircraft as intruder. Straight aircraft paths with constant velocity and camera pixelization errors were considered. Almost 100% decision success was achieved. After the simulations the solution is demonstrated on real flight test data and even in real flight giving 90% avoidance success (10% missed detection) in close and 60% decision success (40% false alarm) in far encounters.

16:00-16:20 ThC2.2

Real-Time Graph-Based SLAM in Unknown Environments Using a Small UAV, pp. 1118-1123

Annaiyan, Arun	Univ. of Luxembourg, Interdisciplinary Centre for Security
Olivares-Mendez, Miguel A.	SnT - Univ. of Luxembourg
Voos, Holger	Univ. of Luxembourg

Autonomous navigation of small Unmanned Aerial Vehicles (UAVs) in cluttered environments is still a challenging problem. In this work, we present an approach based on graph slam and loop closure detection for online mapping of unknown outdoor environments using a small UAV. Here, we used an onboard front facing stereo camera as the primary sensor. The data extracted by the cameras are used by the graph-based slam algorithm to estimate the position and create the graph-nodes and construct the map. To avoid multiple detections of one single object as different objects and to identify re-visited locations, a loop closure detection is applied with optimization algorithm using the g2o toolbox to minimize the error. Furthermore, 3D occupancy map is used to represent the environment. This technique is used to save memory and computational time for the online processing. Real experiments are conducted in outdoor cluttered and open field environments. The experiment results show that our presented approach works under real time constraints, with an average time to process the nodes of the 3D map is 17.79ms.

16:20-16:40 ThC2.3

Detection of Clouds in Sky/cloud and Aerial Images Using Moment Based Texture Segmentation, pp. 1124-1133

Tulpan, Dan	National Res. Council Canada
Bouchard, Cajetan	National Res. Council Canada
Ellis, Kristopher	National Res. Council Canada
Minwalla, Cyrus	National Res. Council Canada

Unmanned aircraft flying beyond line of sight in uncontrolled airspace need to maintain adequate separation from local inclement weather patterns for regulatory compliance and operational safety. Although commercial solutions for weather avoidance exist, they are tailored to manned aviation and as such either lack the accuracy or the size, weight, and power (SWaP) requirements of small Unmanned Aerial System (UAS). Detection and ranging to the cloud ceiling is a key component of weather avoidance. Proposed herein is a computer vision approach to cloud detection consisting of feature extraction and machine learning. Six image moments on local texture regions were extracted and fused within a classification algorithm for discrimination of cloud pixels. Three different popular classifiers were evaluated for efficacy. Two publicly available datasets of all-sky images were utilized for training and test datasets. The proposed approach was compared to five well-known thresholding techniques via quantitative analysis. Results indicate that our method consistently outperformed the popular thresholding methods across all tested images. Comparison between the classification techniques indicated random forests to possess the highest training accuracy, while multilayer perceptrons showed better prediction accuracy on the test dataset. Upon extending the method to realistic images including background clutter, the random forest classifier demonstrated the best training accuracy of 100% and the best prediction accuracy of 96%. Although computationally more expensive, the random forest classifier also produced the fewest number of false positives. Sensitivity analysis for window sizes is presented for robust validation of the chosen approach, which showed improved detection accuracy.

16:40-17:00 ThC2.4

A Vision Based Sense-And-Avoid System Tested on a ScanEagle UAV, pp. 1134-1142

Bratanov, Dmitry	Queensland Univ. of Tech
Mejias Alvarez, Luis	Queensland Univ. of Tech
Ford, Jason	Queensland Univ. of Tech

This paper presents a study of near collision course engagements

between a Cessna 172R aircraft and a ScanEagle UAV carrying a custom built vision-based sense-and-avoid system. Vision-based systems are an attractive solution for the sense-and-avoid problem because of size, weight and power considerations. We present post flight test analysis that shows our detection system successfully detecting an approaching Cessna aircraft in all 15 flight test encounters at ranges greater than 1500 m, with no false alarms events. Moreover, this paper characterizes the image inter-frame stabilization required to achieve acceptable detection performance, and compares a range of stabilization techniques for achieving this type of stabilization precision. Our analysis illustrates that the image inter-frame stabilization requirements are demanding, suggesting that images must be stabilized in real-time at 9Hz to within 2 pixels between consecutive frames. We present performance comparisons between stabilization using GPS/INS, IMU-only and image-based techniques.

17:00-17:20 ThC2.5

Integration of Suas-Enabled Sensing for Leak Identification with Oil and Gas Pipeline Maintenance Crews, pp. 1143-1152

Lee, Andrew — Massachusetts Inst. of Tech
Dahan, Mathieu — Massachusetts Inst. of Tech
Amin, Saurabh — Massachusetts Inst. of Tech

The U.S. Department of Energy and Transportation considers pipeline security and the timely containment of leaks as a top priority for the oil and natural gas industry. However, despite significant investment in network sensing and maintenance, utilities still incur significant delays (and associated losses) in managing failures. This article focuses on the use of small Unmanned Aerial Systems (sUASs) for the inspection of network components and to facilitate timely repair of failures. Our framework integrates sUAS-enabled sensing with fixed sensing systems and ground-based maintenance crews, and aims to minimize the time to repair multiple network failures. It also reduces human effort in network inspection (e.g. manned reconnaissance, ground patrols, and leak surveys). We consider inspection tasks on a set of failure regions (localization sets) that are generated from fixed sensors installed on the network (e.g. pressure sensors). We focus on the problem of routing a set of available maintenance vehicles at specified yard (base) locations carrying sUASs to optimally identify and repair the network failures. To address this problem, we propose two Mixed-Integer Programming (MIP) formulations: (a) the multi-trip sUAS exploration problem, and (b) maintenance vehicle routing problem. We show that these formulations can be integrated to optimally route the sUASs for identification of multiple network failures that may occur anywhere within the localization sets (MIP-a); and to optimally dispatch maintenance vehicles to repair the identified network failures (MIP-b). We illustrate this approach on a benchmark pipeline network, and demonstrate the inherent tradeoffs between sUAS exploration time and maintenance vehicle travel time in our solution.

ThC3 Salon CD
UAS Communications

Chair: Iannucci, Bob — Carnegie Mellon Univ
Co-Chair: Coopmans, Calvin — Utah State Univ

15:40-16:00 ThC3.1

Improving Communication Security of Open Source UAVs: Encrypting Radio Control Link, pp. 1153-1159

Podhradsky, Michal — Galois Inc.
Coopmans, Calvin — Utah State Univ
Hoffer, Nathan — AggieAir, Utah State Univ. (USU)

Safety and reliability (also referred to as airworthiness) are well-known factors of Unmanned Aerial Vehicle (UAV) operations, and significant effort has been put into maintaining and improving them for everyday UAV users. Cyber-security, on the other hand, gained attention only recently. Currently, a malicious user can relatively easily disturb operation or even seize control of the most popular open-source UAVs, as a result of their poor communications security (COMSEC). Even though solutions to improve UAV's COMSEC are known, they have not been fully implemented in a user-friendly way. The contribution of the paper is an implementation of an encrypted Radio Control (RC) link that can be used with a number of popular RC transmitters. We use Galois Embedded Crypto library, an ArduinoLibs Crypto library together with openLRSng open-source radio project. We provide some lessons learned during development, implementation, and testing so users wishing to use their own encrypted link can leverage our work.

16:00-16:20 ThC3.2

Measurements on C-Band Air-To-Air Channel for Coexistence among Multiple Unmanned Aircraft Systems, pp. 1160-1164

Ono, Fumie — National Inst. of Information and Communications Tech

The measurements of air-to-air channel at C-band for coexistence among multiple unmanned aircraft (UA) systems are presented. The measurement campaign was performed to clarify the channel characteristic of the air-to-air radio propagation between small UAs. This paper presents a measurement result of our campaign on radio channel characteristics in C-band held in Japan in March 2016. The received signal consisting of the LOS component and multi-path component formed predominately by the single ground reflected wave was observed. These results can be used to model the statistical channel characteristics in order to assist an efficient sharing of the airspace with multiple UAs.

16:20-16:40 ThC3.3

Holes-In-The-Sky: A Field Study on Cellular-Connected UAS, pp. 1165-1174

Teng, Ervin — Carnegie Mellon Univ
Falcao, Joao Diogo — Carnegie Mellon Univ
Iannucci, Bob — Carnegie Mellon Univ

Small unmanned aerial systems (UAS) require constant, safety-critical connectivity for telemetry, command-and-control, and collision avoidance. Today, dedicated, short-range pilot-to-aircraft links provide this connectivity for UAS operation. For UAS operating in fleets and beyond line-of-sight, a robust multi-transmitter network to provide connectivity over a wide area will be needed. However, networks that could serve this purpose, such as the ubiquitous broadband cellular networks, were planned and deployed for terminals on the ground. Hardening multi-transmitter networks for aerial use remains an open problem.

In this paper, we demonstrate through field measurement that a typical cellular deployment could result in low-coverage areas for UAS---what we call the ``hole-in-the-sky'' phenomenon. Furthermore, many of the propagation models and assumptions commonly used in terrestrial network planning fail to accurately predict aerial signal strength. From first principles, we identify and model the predominant contributors to path loss, and form a combined propagation model that more accurately reflects reality for the tested scenarios. Motivated by this study, we identify a new research direction towards avoiding holes-in-the-sky during flight.

16:40-17:00 ThC3.4

Channel Estimation for Wideband Doubly Selective UAS Channels, pp. 1175-1180

Vahidi, Vahid — Unlv
Saberinia, Ebrahim — Univ. of Nevada Las Vegas

Reliable high-speed wireless communication is essential for abundant new unmanned aircraft system's (UAS) applications. While orthogonal frequency division multiplexing (OFDM) has been widely used for wideband communications because of its efficiency and its robustness to multipath propagation, high Doppler shift of UAS channels makes the implementation of OFDM challenging for UAS applications. Doppler shift makes the communication channel to vary with time and therefore, destroys the orthogonality between the subcarriers in OFDM and results in inter carrier interference (ICI). To mitigate ICI, channel state information (CSI) is needed at the receiver. In numerous scenarios, UAS wideband wireless channel is sparse. Therefore, compressed sensing (CS) methods can be implemented for the channel estimation. In this paper, both the sparsity of the delay spread and Doppler shift of the UAS payload communication channel are considered for channel estimation and three major adjustments to a regular CS method are proposed in order to enhance the channel estimation performance for high Doppler shift scenarios of UAS. The proposed modifications take into account the precise frequency

domain channel model, the Doppler shift statistics of UAS wireless channels, and the ICI effect of the data on the channel estimation precision. Simulation results indicate that the proposed modifications enhance the channel estimation accuracy considerably for high Doppler shift scenarios.

17:00-17:20 ThC3.5

A Low-Computation Distributed Connectivity Control for Coordinated Multi-UAS, pp. 1181-1188

Fehr, Ric	Univ. of Nevada, Reno
Boles, Kevin	Univ. of Nevada, Reno
Jafari, Mohammad	Univ. of Nevada, Reno
Xu, Hao	Univ. of Nevada, Reno
GARCIA CARRILLO, Luis Rodolfo	Texas A&M Univ. - Corp. Christi

Multi-UAS (MAS) flocking requires multiple controllers with connected communication topologies. Real-time deployment of multi-agents is commonly associated with dynamic communication topologies, which has been considered as a challenging topic. This paper proposes a novel low-computation distributed connectivity control method to generate connected communication topologies and maintain the connectivity for coordinated multi-UAS. Considering the real-time communication imperfections, the communication links among multi-UAS have been priced. In addition, a multi-UAS communication price matrix has been generated. The proposed method cannot only maintain the connectivity of multi-UAS and also minimize the communication price in a distributed manner. Furthermore, proposed method is also very flexible and can be applied to multi-UAS with varying number of agents. Both numerical simulation and experiment results demonstrate the effectiveness of the proposed low computation distributed connectivity control. It is very promising for a wide range of applications where multi-UAS will greatly aid missions such as those expected to be performed by team of cooperative UAS, e.g. search and rescue, surveillance, vehicle tracking, and MAS-based load delivery.

ThC4 — Lummus Island

UAS Applications - VI

Chair: Farhood, Mazen	Virginia Tech
Co-Chair: Lu, Han-Hsun	Texas A&M

15:40-16:00 ThC4.1

A Framework for Detection of Sensor Attacks on Small Unmanned Aircraft Systems, pp. 1189-1198

Muniraj, Devaprakash	Virginia Pol. Inst. and State Univ
Farhood, Mazen	Virginia Tech

The work presented in this paper is part of an overall effort to design a secure autopilot, resilient against malicious attacks on both the cyber and physical layers, for a small unmanned aircraft system (UAS). This paper specifically deals with identification of malicious attacks on the sensors of a small UAS. A framework is presented wherein techniques from statistical analysis are used in a probabilistic setting to detect sensor attacks. The paper describes in detail the design of anomaly detectors and the Bayesian network. A case study involving detection of a spoofing attack on the GPS is used throughout the paper to illustrate the proposed approach. The anomaly detectors are designed based on a simulation dataset, and are re-tuned based on flight tests conducted on a small fixed-wing UAS platform. The performances of the detectors are studied under different external disturbances and conclusions are drawn.

16:00-16:20 ThC4.2

Detecting Nests of Lapwing Birds with the Aid of a Small Unmanned Aerial Vehicle with Thermal Camera, pp. 1199-1207

Israel, Martin	German Aerospace Center
Reinhard, Aline	NABU-Naturschutzstation Münsterland

Due to increasingly dense agricultural land use, many ground breeding birds are threatened with extinction or near threatened. We present a new method, to detect lapwing and other ground breeding bird nests. A small UAV with a thermal camera is suitable to detect a lapwing nest from a flight altitude of 40 m. With the aid of a special thermal camera image preprocessing algorithm the contrast could be enhanced by 10 to 50% which improves the detectability of nests. We successfully demonstrated, that we detected 93% of the known nests. This paper describes and analyzes the necessary conditions for optimal lapwing nest detection with a UAV borne thermal camera.

16:20-16:40 ThC4.3

Development and Testing of a Customized Low-Cost Unmanned Aircraft System Based on Multispectral and Thermal Sensing for Precision Agriculture Applications, pp. 1208-1216

Valasek, John	Texas A&M Univ
Lu, Han-Hsun	Texas A&M
Shi, Yeyin	Univ. of Nebraska-Lincoln

The ability to conduct useful science under the framework of precision agriculture is not only dependent upon the collection of high quality usable data of plants, soil, and water, but also dependent upon the type of vehicle the sensors are flown on, properly tuned sensors, and the way in which the vehicle is flown. To achieve this capability requires the proper matching and integration of air vehicle, sensors, mission design, and image processing techniques. Although commercial Unmanned Air Systems are starting to be equipped with autopilots, sensors, and simple data processing software, they are often limited to only one sensor, and often lack cross platform integration expandability. This paper develops methodologies and procedures for a highly integrated fixed-wing Unmanned Air System that is customized for precision agriculture science. It addresses sensor selection, vehicle platform selection, flight planning, and data processing procedures. The approach is validated by assessment of collected imagery and data from flights conducted on actual plots. Results presented in the paper show that by comparison to data collected during earlier flights with a non-integrated system, the approach presented here which matches vehicle characteristics to sensor characteristics and employs proper flight planning, mission design, and auto-triggering of the sensor produces better data quality, and improved mosaicking. The approach is judged to be a promising candidate for improved data collection for precision agriculture.

16:40-17:00 ThC4.4

Aerial Manipulator with a Compliant Arm for Bridge Inspection, pp. 1217-1222

Jimenez Cano, Antonio Enrique	Univ. De Sevilla
Heredia, Guillermo	Univ. of Seville
Ollero, Anibal	Univ. De Sevilla

This paper presents the design, development and testing of a 4-DoF aerial manipulator for bridge inspection, where the arm is placed at the upper part of the multirotor body. The manipulator joints are equipped with a compliant mechanism that allows the contact with the environment reducing the influence over the platform stability. The transmission mechanism consists of two pairs of springs and a potentiometer for measuring the angular deflection between the servo and the joint angular position, which allows the estimation of the contact forces. Experimental tests have been done with the aerial manipulator placing the end effector at different points in the lower part of a bridge girder, which is needed by bridge inspectors to measure girder's deflections over time.

17:00-17:20 ThC4.5

Real Time Degradation Identification of UAV Using Machine Learning Techniques, pp. 1223-1230

Manukyan, Anush	Univ. of Luxembourg
Olivares-Mendez, Miguel A.	SnT - Univ. of Luxembourg
Voos, Holger	Univ. of Luxembourg
Geist, Matthieu	CentraleSupelec

The usages and functionalities of Unmanned Aerial Vehicles (UAV) have grown rapidly during the last years. They are being engaged in many types of missions, ranging from military to agriculture passing by entertainment and rescue or even delivery. Nonetheless, for being able to perform such tasks, UAVs have to navigate safely in an often

dynamic and partly unknown environment. This brings many challenges to overcome, some of which can lead to damages or degradations of different body parts. Thus, new tools and methods are required to allow the successful analysis and identification of the different threats that UAVs have to manage during their missions or flights. Various approaches, addressing this domain, have been proposed. However, most of them typically identify the changes in the UAVs behavior rather than the issue. This work presents an approach, which focuses not only on identifying degradations of UAVs during flights, but estimate the source of the failure as well.

ThC5	San Marco Island
Intelligent and Autonomous UASs	
Chair: Johansen, Tor Arne	Norweigian Univ. of Sci. & Tech
Co-Chair: Ollero, Anibal	Univ. De Sevilla
Organizer: Johansen, Tor Arne	Norweigian Univ. of Sci. & Tech
Organizer: Ollero, Anibal	Univ. De Sevilla

15:40-16:00 ThC5.1

Self-Triggered Cooperative Path Following Control of Fixed Wing Unmanned Aerial Vehicles (I), pp. 1231-1240

Jain, R Praveen Kumar	Univ. of Porto
Aguiar, A. Pedro	Faculty of Engineering, Univ. of Porto (FEUP)
Sousa, Joao	Univ. Do Porto - Faculdade Engenharia

Formation control of multi-robot system may involve extensive inter-robot information exchange. This paper proposes a methodology to reduce the frequency of information exchange in a formation control problem through the use of a self-triggered control strategy for cooperative path following (CPF) problems. In particular, a decentralized, self-triggered CPF controller is developed for fixed-wing Unmanned Aerial Vehicles, where the vehicles are tasked to follow desired geometric paths and keeping a desired formation pattern. Using the Input-to-State Stability framework, we provide guarantees of stability and convergence in the presence of event-based communication. Simulation results are provided to illustrate the efficacy of the developed strategy. It is shown that the self-triggered approach results in significant reduction of information exchange when compared to the conventional time-triggered (periodic) implementation.

16:00-16:20 ThC5.2

Smooth Trajectory Generation for Wind Field Exploitation with a Small UAS (I), pp. 1241-1249

Rodriguez Salazar, Leopoldo	Univ. De Sevilla
Cobano, Jose Antonio	Univ. of Seville
Ollero, Anibal	Univ. De Sevilla

This paper proposes a solution to generate energy-efficient trajectories for small fixed-wing Unmanned Aerial Systems (UAS) to harvest energy available from the surrounding wind mass. The process of generating such trajectories consists of the identification of the wind field and the different wind features such as gusts and/or wind shear in order to generate on a waypoint-to-waypoint basis trajectory that increase the efficiency. The paper presents a method to generate smooth trajectories that prioritize the wind energy harvesting for different cases of wind fields. The algorithm for curve generation is a tridiagonal system of linear equations with slope unitary vector, tension and velocity function parameters in order to determine the spline direction at each node. The unitary direction is adjusted for each node to harvest wind energy and also the tension parameters can be determined to adjust the curvature and its rate of change, so that they can be aligned with the dynamic specification of the UAS. Simulations and results are presented in order to demonstrate the performance of the proposed methods showing dramatic airspeed gains for cases in which the wind vector is considered as an input of the curve parametrization.

16:20-16:40 ThC5.3

Dead Reckoning of a Fixed-Wing UAV with Inertial Navigation Aided by Optical Flow (I), pp. 1250-1259

Fusini, Lorenzo	Norwegian Univ. of Science and Tech
Johansen, Tor Arne	Norweigian Univ. of Sci. & Tech
Fossen, Thor I.	Norwegian Univ. of Sci and Tech

This paper provides experimental results for dead reckoning of a fixed-wing UAV using a non-linear observer (NLO) and a more recent tool called eXogenous Kalman Filter (XKF), which uses the NLO itself as a first-stage filter. The sensors used are an IMU (accelerometers, inclinometers, and rate gyros), a camera, and an altimeter; the observed states are position, velocity, and attitude. A machine vision system provides the body-fixed velocity of the UAV. Although the calculated velocity results affected by a bias, it is necessary both for estimating the attitude and for bounding the rate of divergence of the position during dead reckoning. Gyro, accelerometer, and optical flow (OF) velocity biases are estimated, but only as long as GNSS is available. When dead reckoning begins, they are frozen at their last calculated value. The experimental results show that the position error grows at a bounded rate with the proposed estimators.

16:40-17:00 ThC5.4

Mass Estimation of a Quadcopter Using IMU Data (I), pp. 1260-1266

Du, Ho	Linköping Univ
Linder, Jonas	Linköping Univ
Hendeby, Gustaf	Linköping Univ
Enqvist, Martin	Linköping Univ

In this paper, an approach to estimate the mass of a quadcopter using only inertial measurements and pilot commands is presented. For this purpose, a lateral dynamic model describing the relation between the roll rate and the lateral acceleration is formulated. Due to the quadcopter's inherent instability, a controller is used to stabilize the system and the data is collected in closed loop. Under the effect of feedback and disturbances, the inertial measurements used as input and output are correlated with the disturbances, which complicates the parameter estimation. The parameters of the model are estimated using several methods. The simulation and experimental results show that the instrumental-variable method has the best potential to estimate the mass of the quadcopter in this setup.

17:00-17:20 ThC5.5

Estimation of Wind Velocities and Aerodynamic Coefficients for UAVs Using Standard Autopilot Sensors and a Moving Horizon Estimator (I), pp. 1267-1276

Wenz, Andreas Wolfgang	Norwegian Univ. of Science and Tech
Johansen, Tor Arne	Norweigian Univ. of Sci. & Tech

While operating any aircraft it is vital to know its current flight state. Some of the most important variables to assess the flight state are the airspeed, the angle of attack and the sideslip angle. Larger aircraft are equipped with sensors specifically designed to measure these variables. How- ever on small unmanned aerial vehicles (UAVs) much stricter restrictions on size, weight and cost prohibit the use of such sensors. Therefore, we propose a method to estimate the airflow variables utilizing only sensors that are part of a standard UAV autopilot. This includes an inertial measurement unit (IMU), a global navigation satellite system (GNSS) receiver and a pitot-static tube. These measurements together with kinematic and aerodynamic models will be fused within an estimator to estimate steady and turbulent wind velocities as well as aerodynamic coefficients. With these estimates it is possible to calculate the angle of attack, the sideslip angle and the airspeed. A main challenge is to distinguish between changes in the aerodynamic coefficients and changes in wind velocity, since pitot-static tube measurements of the relative airspeed are only available in one direction at a time and hence the system is not always observable. Therefore, attitude changes have to be undertaken to achieve persistence of excitation. In this paper a Moving Horizon Estimator (MHE) is used for estimation. Simulation results show overall good estimation results and significant improvements compared to a previous Extended Kalman Filter approach. Root mean square errors (RMSE) are 0.25 degrees for the angle of attack, 0.08m/s for the airspeed and 1.06 degrees for the side slip estimates.

17:00-17:20 ThC5.6

Analysis of Data Structures and Exploration Techniques Applied to Large 3D Marine Structures Using UAS (I), pp. 1277-1284

Costa, Faria, Margarida	FADA-CATEC
Maza, Ivan	Univ. De Sevilla CIF Q-4118001-I
Viguria, Antidio	FADA-CATEC

This paper is focused on the analysis and comparison of different data structures for 3D space representation in autonomous exploration of large marine structures with UAS. The classical and widely used frontier exploration approach is applied: the frontier cells, which are the locations in the world representation map that are explored and unoccupied but has unexplored space in its vicinity, are of particular interest as they yield the highest information gain. Thus, the data structures have been compared from the point of view of their performance to be applied in the frontier exploration approach. The same algorithm has been run for the different data structures under different scenarios, both with synthetic and real datasets gathered with an UAS. The results are analyzed in detail taking into account the amount of iterations required and the number of computed frontier cells.

FrA1 — Salon E

Micro and Mini UAS - IV

Chair: Fasano, Giancarmine	Univ. of Naples
Co-Chair: Castaneda, Herman	Tecnologico De Monterrey

10:00-10:20 FrA1.1

Embedded Control Using Monocular Vision: Face Tracking, pp. 1285-1291

Flores-Delgado, José Isaac	UMI-LAFMIA
Martínez-Santos, Laura Guadalupe	UMI-LAFMIA
Lozano, Rogelio	Univ. of Tech. of Compiègne
Gonzalez-Hernandez, Ivan	Cinvestav - IPN
Mercado Ravell, Diego Alberto	Univ. De Tech. Compiegne

This paper presents a quadcopter capable of tracking a human face using an embedded system which consists of an autopilot for controlling the vehicle and an Odroid computer for image processing. Image acquisition is performed by a fisheye monocular camera. A digital treatment consisting of a Gaussian filter and a histogram equalization is applied, reducing false positives in the detection algorithm. The detection algorithm used is a cascade classifier (Haar algorithm), which is trained to detect a human face in an image. Depending on the displacement of the detected face, a Kalman filter is implemented to estimate the position and velocity which are used to follow the person.

10:20-10:40 FrA1.2

Experimental Study on the Wing-Wake Interaction of a Flapping Wing Micro Aerial Vehicle, pp. 1292-1301

Jadhav, Siddharth	National Univ. of Singapore
Lua, Kim Boon	National Univ. of Singapore

This work presents an experimental study of the aerodynamics of different types of wings during the clap-and-peel mechanism on a hovering flapping wing Micro Aerial Vehicle (MAV) platform. A comprehensive analysis of the phenomenon through force measurement, motion capture and flow measurement using Particle Image Velocimetry in a fixed position was performed. The flow field around the two types of wings with identical dimensions but different deformation characteristics is compared to understand the role of their flexibility in enhancing the benefits of clap-and-peel effect. The two wings have different configurations of carbon fiber rod stiffeners. Varying degrees of flexibility along the camber were observed in the two wings. Insights were obtained on the correlation between the chord wise camber of wings and their influence on force generation and energy efficiency of the flapping wing MAV. The relative strength and location of the leading edge vortices were compared. One of the wings exhibited higher average lift force by 32% and higher average power efficiency by 18% than the other. For Particle Image Velocimetry, Rhodamine-B fluorescent particles were used to seed the flow, over the conventional fog and oil droplets. This mitigated the optical obstruction due to reflection of the wing through the use of optical filters on camera lens.

10:40-11:00 FrA1.3

Guidelines for Propulsion System Design and Implementation in a Quadrotor MAV, pp. 1302-1308

Castaneda, Herman	Tecnologico De Monterrey
Cantu, Luis Alfredo	Tecnologico De Monterrey
Isla, Alejandro	Tecnologico De Monterrey
Gordillo, José Luis	Tecnológico De Monterrey

This paper addresses practical guidelines for propulsion system design and implementation in a quadrotor micro air vehicle. Due to tiny scale of the motor and propellers required by MAVs, information about features of these devices is frequently unavailable. Therefore, the proposal includes selection of devices, parameter identification and electronic power interface in order to control a motor propeller system. From characterization of the system, thrust and torque coefficients as well as the inertia moment of the motor propeller are obtained, allowing to choose a proper propulsion set according to lift requirements. Furthermore, some aspects for implementing a low level control are presented, including a power interface circuit design based on high efficient consumption of energy criteria, where pulse width modulation is used for implementing some control strategy. The proposed practical guidelines are supported by means of the theoretical and experimental test benches.

11:00-11:20 FrA1.4

Numerical Optimization Techniques for Nonlinear Quadrotor Control, pp. 1309-1315

Matus-Vargas, Antonio	Inst. Nacional De Astrofísica, Óptica Y Electrónica
Rodriguez-Gomez, Gustavo	INAOE
Martinez-Carranza, Jose	Inst. Nacional De Astrofisica Optica Y Electronica
Muñoz Silva, Arturo	INAOE

Currently, quadrotors have become very popular and have different applications in entertainment, transportation, rescue and military areas, among others. A key activity in the design of quadrotors is the flight control. A well-known flight controller is the PD, which is sufficient to make the quadcopter to hover in the air. One crucial problem with this type of controllers is the coefficient tuning. Typically, linear models are supposed for the latter, however, in this work we study the use of two optimization techniques for coefficient tuning when the dynamic model is nonlinear. These techniques refer to parametric control tuning based on numerical strategies using Conjugate Gradient (CG) optimization. We also analyze the optimal control law for the same nonlinear model by applying the Pontryagin's Maximum Principle, which yields the conditions to numerically find the optimal flight control to transfer the quadrotor between hovering states. We carried out a comparison of the behavior of the quadcopter dynamics regarding the tuned parametric controls obtained with the two CG strategies and with the achieved optimal control. In addition, we analyzed, from the point of view of the user, which one of these strategies is the easiest to implement.

11:20-11:40 FrA1.5

Proof of Concept of Micro-UAV-Based Radar Imaging, pp. 1316-1323

Fasano, Giancarmine	Univ. of Naples "Federico II"
Renga, Alfredo	Univ. of Naples "Federico II"
Vetrella, Amedeo Rodi	Univ. of Naples "Federico II"
LUDENO, GIOVANNI	IREA--CNR
Catapano, Ilaria	Inst. for Electromagnetic Sensing of the Environment (IREA)
Soldovieri, Francesco	CNR-IREA

The potential of micro-UAV-based radar imaging is far from being exploited, though radar sensors having budgets compatible with micro-UAV are increasingly available. As a contribution to this topic, this paper discusses the relation between UAV dynamics and navigation, and radar processing, and presents a proof-of-concept ground imaging

experiment in which a commercial hexacopter has been equipped with an ultralight radar. Flight results are presented in terms of both raw data and images obtained by means of an ad-hoc data processing approach. Results suggest that, in spite of its accuracy limitations, standalone GNSS information can be effectively integrated within radar processing algorithms, thus improving ground target detection and localization performance.

FrA2	Salon AB
Aviation and Risk Analysis	
Chair: Aranda-Bricaire, Eduardo	CINVESTAV
Co-Chair: Dong, Yingfei	Univ. of Hawaii

10:00-10:20 FrA2.1

Observer-Based Time-Varying Backstepping Control for a Quadrotor Multi-Agent System, pp. 1324-1332

Rosaldo-Serrano, Marcos Alberto — CIE6010281U2
Santiaguillo-Salinas, Jesús — CINVESTAV
Aranda-Bricaire, Eduardo — CINVESTAV

This paper studies the formation tracking problem for a multi-agent system composed by a set of quadrotor UAVs. Parrot AR. Drone 2.0 quadrotors are used as the agents of the system. The proposed control strategy is designed using a time-varying version of the backstepping technique for each agent. For the implementation of the control law, it is assumed that each agent only measures the leader and its own positions, while the leader also knows the desired trajectory the system must follow. Linear and angular velocities of the agents are estimated using suitable Luenberger observers. The proposed control strategy allows the leader agent to converge asymptotically to a predetermined flight trajectory while the follower agents converge asymptotically to their own trajectories defined by the leader position and a constant formation vector. The theoretical results are validated through real-time experiments.

10:20-10:40 FrA2.2

Quaternion-Based Robust Fault-Tolerant Control of a Quadrotor UAV, pp. 1333-1342

Nguyen, Duc-Tien — Ec. Pol. De Montreal
Saussie, David — Ec. Pol. De Montreal
Saydy, Lahcen — Ec. Pol. of Montreal

This paper deals with the active fault-tolerant control (FTC) of a quadrotor in the presence of actuator faults. Generally, it is assumed that the fault has been detected, isolated or identified, and then, one proceeds with a reconfigurable controller. This paper presents a complete active fault-tolerant control system with both fault detection and diagnosis (FDD), and FTC. The proposed FTC design is based on gain-scheduling control in the framework of structured H-inf synthesis. The scheduled gains are parameterized as polynomial functions of the loss of control effectiveness of the quadrotor actuators, estimated by a two-stage Kalman filter. Then, the MATLAB-based function systune tunes the polynomial coefficients to meet the robustness and performance requirement. In comparison with other FTC systems that use switching mechanisms, this smooth self-scheduled controller allows one to avoid undesirable transient phenomena during the controller reconfiguration process. Numerical simulations performed on an underactuated six degrees of freedom quadrotor nonlinear model show the effectiveness of the proposed FTC in accommodating different levels of actuator faults. To avoid singularities associated with Euler angles, unit quaternion representations are used to describe the rotational motion of the quadrotor.

10:40-11:00 FrA2.3

Ground Risk Assessment for Long-Range Inspection Missions of Railways by UAVs, pp. 1343-1351

Bertrand, Sylvain — ONERA
Nicolas, Raballand — ONERA
Flavien, Viguier — SNCF Réseau
Florent, Muller — ONERA

This paper investigates the feasibility of a long-range inspection mission of railways by UAVs from a risk point of view. Ground risk for population of inhabited areas is assessed for such a mission and compared to the ones of shorter “elementary” flights for which flight authorizations have already been obtained or would be easy to obtain. By this comparative approach, the feasibility of the full inspection mission can be investigated without too much sensitivity to input data and model parameters. Use of an emergency parachute is also investigated as a potential risk mitigation procedure. Risk evaluation models as well as developed metrics for risk analysis are presented in the paper. Results of risk numerical assessment and comparison are presented for the cases with and without an emergency parachute.

11:00-11:20 FrA2.4

Quantifying Risk of Ground Impact Fatalities of Power Line Inspection BVLOS Flight with Small Unmanned Aircraft, pp. 1352-1360

Cour-Harbo, Anders — Aalborg Univ

One of the major challenges of conducting operation of unmanned aircraft, especially operations beyond visual line-of-sight (BVLOS), is to make a realistic and effective risk assessment. An important part of such an assessment is to identify the risk of fatalities, preferably in a quantitative way since this allows for comparison with manned aviation to determine whether an equivalent level of safety is achievable. This works presents a method for quantifying the probability of fatalities resulting from an uncontrolled descent of an unmanned aircraft conducting a BVLOS flight. The method is based on a standard stochastic model, and employs a parameterized high fidelity ground impact distribution model that accounts for both aircraft specifications, parameter uncertainties, and wind. The method also samples the flight path to create an almost continuous quantification of the risk as a function of mission flight time. The probability of fatality is determined for a Talon model aircraft on a power line inspection mission.

11:20-11:40 FrA2.5

Dynamic Output Feedback Image-Based Visual Servoing of Rotorcraft UAVs, pp. 1361-1367

Xie, Hui — Nanyang Tech. Univ
Li, Jianan — Nanyang Tech. Univ. Tech. Univ. of Munich
Low, Kin Huat — Nanyang Tech. Univ

This paper presents an improved dynamic output feedback image-based visual servoing (IBVS) law for a quadrotor in comparison with our previous work (“Dynamic Visual Servoing of a Rotary-wing Unmanned Aerial Vehicle Without Velocity Measurement,” in AIAA Guidance, Navigation, and Control Conference, Grapevine, Texas, January, 2017). The controller enables the quadrotor to regulate its position and yaw relative to a planar target consisting of multiple points. This new IBVS controller removes the integral term used to counter external disturbance, in which way the controller's structure is further simplified. Same as in our previous work, the controller requires a minimum set of sensors, i.e., an inertial measurement unit and a single downward facing camera. Also, this approach is adaptive to various unknown system parameters, such as thrust coefficient, mass of the vehicle, and bias errors in Euler angle measurement. The asymptotic stability of error dynamics is proven. Both simulation and experimental results are presented to demonstrate the performance of the proposed controller.

FrA3	Salon CD
UAS Swarms	
Chair: Quagliotti, Fulvia	Pol. Di Torino
Co-Chair: Lozano, Rogelio	Univ. of Tech. of Compiègne

10:00-10:20 FrA3.1

Evaluation of Cryptography Applied to Broadcast Storm Mitigation Algorithms in FANETs, pp. 1368-1377

Arnosti, Sergio Zumpano — Univ. Estadual De Campinas, Inst. of Computing
Pires, Rayner M. — Univ. De São Paulo - USP
Branco, Kalinka Regina Lucas — Univ. of São Paulo

Jaquie Castelo

The use of networks of small autonomous aircraft shall become a trend in the coming years in order to increase the scalability of missions like monitoring and surveillance, for example. The network composed exclusively by these aircraft is known as Flying Ad hoc Network (FANET), a new ad hoc fashion network with new challenges to be faced. Applications running on a FANET eventually require the use of security mechanisms. To verify which one is the most appropriate for embedded systems like those used in such autonomous aircraft, it is necessary to carry out a study about the cryptographic methods in these platforms. In this paper, we have added the symmetric-key algorithm AES (Advanced Encryption Standard) to three broadcast mitigation algorithms experimented in our previous work. The purpose is to guarantee confidentiality when exchanging messages and avoid an attacker to ruin the broadcast control strategies, what would let the network susceptible to the broadcast storm problem. We have performed outdoor experiments using an embedded platform and the results are analyzed in this paper and compared with the ones of the previous work, in which cryptography was not employed. Results show that a strong symmetric-key encryption did not significantly influenced the performance of the mitigation algorithms and can be applied to these systems without performance penalty.

10:20-10:40 FrA3.2

Towards the Development of an Autonomous Interdiction Capability for Unmanned Aerial Systems, pp. 1378-1384

See, Hongze Alex — Naval Postgraduate School
Ghosh, Satadal — Naval Postgraduate School
Yakimenko, Oleg A. — Naval Postgraduate School

As well-known, interdiction operations in adversarial environments can be quite challenging. With the advancement in technologies and applications involving unmanned aerial systems, an efficient autonomous aerial interdiction mission has been identified in literature as one of the pivotal elements. Effective interdiction usually requires a group of pursuers (as opposed to a single one), which enables achieving a certain formation around the target restricting its further maneuver. This paper presents a coordinated trajectory-shaping guidance strategy for a group of two autonomous pursuers, which can easily be generalized for a multi-pursuer case. Specific challenges in the group maneuvering include coordinated control of the arrival time and final relative attitude. The paper develops the corresponding algorithms and demonstrates their effectiveness in a set of computer simulations featuring different engagement geometries. It also addresses feasibility of obtained solutions from the standpoint of their applicability on board of a small unmanned aerial vehicle with a limited computational capability.

10:40-11:00 FrA3.3

Cooperative Control for Load Transportation Using Two PVTOL Vehicles with a Passivity Approach, pp. 1385-1391

Cariño Escobar, Jossué — CINVESTAV-IPN
Bonilla, Moises E. — CINVESTAV-IPN
Lozano, Rogelio — Univ. of Tech. of Compiègne

This paper presents a control strategy for two planar vertical take-off and landing (PVTOL) vehicles cooperating to transport a rigid body load without any explicit exchange of state information between them. This means that the vehicles have only access to their own state variables. The solution and stability analysis is based on a passivity approach.

11:00-11:20 FrA3.4

Area Exploration with a Swarm of UAVs Combining Deterministic Chaotic Ant Colony Mobility with Position MPC, pp. 1392-1397

Rosalie, Martin — Univ. of Luxembourg
Dentler, Jan — Univ. of Luxembourg
Danoy, Grégoire — Univ. of Luxembourg
Bouvry, Pascal — Univ. of Luxembourg
Kannan, Somasundar — Univ. of Luxembourg
Olivares-Mendez, Miguel A. — SnT - Univ. of Luxembourg
Voos, Holger — Univ. of Luxembourg

The recent advances in Unmanned Aerial Vehicles (UAVs) technology permit to develop new usages for them. One of the current challenges is to operate UAVs as an autonomous swarm. In this domain we already proposed a new mobility model using Ant Colony Algorithms combined with chaotic dynamics (CACOC) to enhance the coverage of an area by a swarm of UAVs. In this paper we propose to consider this mobility model as waypoints for real UAVs. A control model of the UAVs is deployed to test the efficiency of the coverage of an area by the swarm. We have tested our approach in a realistic robotics simulator (V-Rep) which is connected with ROS. We compare the performance in terms of coverage using several metrics to ensure that this mobility model is efficient for real UAVs.

11:20-11:40 FrA3.5

Skywriting Unmanned Aerial Vehicle Proof-Of-Concept Design, pp. 1398-1403

Kim, Dongbin — Univ. of Nevada, Las Vegas
Oh, Paul — Univ. of Nevada Las Vegas

With the goal of a skywriting unmanned aerial vehicle, a proof-of-concept design is presented. Drone swarms act as illuminated pixels for night-time aerial imagery. By contrast, this proof-of-concept employs a single quadcopter for day-time skywriting with smoke. This paper describes hardware and software selection and mounting configuration. A Snellen Chart approach is used to calculate appropriate sizing of letters written in the sky. Testing-and-evaluation reveal higher letter-shape fidelity when flight path factors in wind speed and direction. The proof-of-concept's efficacy present a platform for future work with multiple UAV coordination to acts as a dot-matrix or ink-jet printer for the sky.

FrA4 — Lummus Island

UAS Applications - VII

Chair: Tsourdos, Antonios — Cranfield Univ
Co-Chair: Zhang, Youmin — Concordia Univ

10:00-10:20 FrA4.1

Multiple UAVs in Forest Fire Fighting Mission Using Particle Swarm Optimization, pp. 1404-1409

Ghamry, Khaled A. — Concordia Univ
Kamel, Mohamed A. — Military Tech. Coll
Zhang, Youmin — Concordia Univ

This paper investigates forest fires fighting application using team(s) of unmanned aerial vehicles (UAVs), in view of UAVs having great advantages in performing such tasks. However, important challenges in firefighting missions in general are to perform the task with high performance in minimum time. In this paper, it is assumed that the fire spots are already detected and their coordinates will be sent to the firefighting UAVs teams. Once the firefighting team(s) receive relevant information, the team begins to solve the task assignment problem using the auction-based algorithm. The objective of the algorithm is to assign each UAV to each fire spot according to their relative distances, to minimize the distance traveled between each UAV's initial position and its assigned fire spot. Then, each UAV will optimally plan its path to its assigned fire spot by using particle swarm optimization (PSO) algorithm. The proposed algorithm calculates the optimal control inputs while taking into consideration the control inputs constraints while avoiding potential UAVs collisions during motion.

10:20-10:40 FrA4.2

Soil / Crop Segmentation from Remotely Sensed Data Acquired by Unmanned Aerial System, pp. 1410-1417

Mancini, Adriano — Univ. Pol. Delle Marche
Dyson, Jack — Univ. Pol. Delle Marche
Frontoni, Emanuele — Univ. Pol. Delle Marche
Zingaretti, Primo — Univ. Pol. Delle Marche

Today Unmanned Aerial Systems (UAS) are widely used for many applications that involve advanced payload as is found to be the case

for mounted remote sensing apparatus. Remote sensing from UAS platforms is now common and the use of light and smart multi/hyper-spectral cameras has opened the field to novel applications. These sensors can operate in cloudy conditions ensuring ultra-high resolution images while at the same time overcoming the limitations of satellite photography. In this paper we focus on just one such advanced payload application, namely, the segmentation of tree-cover / canopies over soil terrain. This task is mandatory in order to mask-out areas that are not of direct interest. The approaches studied are based on both supervised and unsupervised algorithms which take into account multi-spectral as well as synthetic features derived from the Digital Surface Model (DSM). We process the DSM by testing 2D convolution kernels together with a pseudo-random image slicing that tries to derive/model the ground/soil profile. Global thresholding is not able the segment tree / canopy area over the soil because the terrain slope is subject to significant change over small areas as is often seen to be the case with vineyards. The proposed approach takes into account such local variability to ensure a correct segmentation analysis in presence of slopes or other undulatory terrain variations. The results obtained show that the proposed method enables the segmentation of tree / canopy vs soil with an overall accuracy greater than 95%.

10:40-11:00 FrA4.3

Real-Time Wind Vector Estimation for a Micro UAV, pp. 1716-1721

Qu, Yaohong — Northwestern Polytechnical Univ
Xing, Zhewen — Northwestern Pol. Univ
Zhang, Youmin — Concordia Univ
Yu, Ziquan — Northwestern Pol. Univ

This paper presents an approach to estimate wind vector for a micro UAV by using only its inertial measurement unit in real-time. This method does not need additional sensors and dedicated anemometer, while just relying on the onboard inertial measurement unit to reserve the valuable payload for other onboard sensors. A smoothing filter is also designed based on the minimum summation of distance vector in order to reduce the effect of sensor noise. Simulation results prove the feasibility of the proposed real-time wind vector estimation approach.

11:00-11:20 FrA4.4

Exhaustive Mobile Target Search and Non-Intrusive Reconnaissance Using Cooperative Unmanned Aerial Vehicles, pp. 1425-1431

Brown, Douglas — New Mexico State Univ
Sun, Liang — New Mexico State Univ

This paper presents a novel pattern for the trajectories that a team of cooperative unmanned aerial vehicles (UAVs) adopt to perform an exhaustive search of mobile targets in a specified area. The proposed moving pattern also creates a safe area into which no target is able to intrude. The Progressively Spiral Out (PSO) path is developed to describe the proposed moving pattern, which can be applied to any number of UAVs. It also shows that the radius of the resulting non-intrusive defensible border grows proportionally to the number of UAVs. The performance of the proposed PSO path is tested against a baseline raster path in simulation. The simulation results show that the PSO path outperforms the baseline path on both time to detection and successful rate of defending attacks toward the non-intrusive region.

11:20-11:40 FrA4.5

Fault Detection of an Unmanned Quadrotor Helicopter Based on Particle Filter, pp. 1432-1437

Yi, Yingmin — Xi'an Univ. of Tech
Zhang, Youmin — Concordia Univ

To address the problem of fault detection and diagnosis of an unmanned quadrotor helicopter (Qball-X4) in the presence of actuator faults, this paper presents a fault diagnosis method based on a particle filter. The obtained state estimation and fault detection decision based on the particle filter is used to control the altitude of the Qball-X4 UAV with integration of a Linear Quadratic (LQ) technique. The developed fault detection scheme is implemented and experimentally tested in the Qball-X4 UAV. The faults are modelled as losses in control effectiveness of motors (actuators). Three faults cases are investigated: loss of control effectiveness in one signal actuator, loss of control effectiveness in two actuators, and loss of control effectiveness in three actuators. Experiments show the effectiveness of the proposed method.

FrA5 San Marco Island
UAS Control - I

Chair: Bhattacharya, Subhrajit — Lehigh Univ
Co-Chair: Lozano, Rogelio — Univ. of Tech. of Compiègne

10:00-10:20 FrA5.1

Flight Trajectory Tracking and Recovery in Presence of Large Disturbances, pp. 1438-1446

Guerrero-Bonilla, Luis — Univ. of Pennsylvania
Mohta, Kartik — Univ. of Pennsylvania
Bhattacharya, Subhrajit — Lehigh Univ
Kumar, Vijay — Univ. of Pennsylvania

We present a modified trajectory tracking controller based on a novel re-parameterization of the reference trajectory with respect to an independent variable whose dynamics can be controlled. A hybrid controller is designed so that the dynamics of both the robot and the reference parameter can respond to disturbances. The proposed hybrid controller is more robust to large disturbances, and hence is less prone to cause the robot to collide with obstacles and avoids skipping large segments of the trajectory. We demonstrate our controller through simulations and real-world experiments on a quadrotor.

10:20-10:40 FrA5.2

*Unmanned Quadrotor Path Following Nonlinear Control Tuning Using Particle Swarm Optimization**

Rendón, Manuel A. — Federal Univ. of Juiz de Fora
Ferraz, Felipe — Federal Univ. of Juiz de Fora

10:40-11:00 FrA5.3

Altitude and Attitude Cascade Controller for a Smartphone-Based Quadcopter, pp. 1447-1454

Astudillo, Alejandro — Univ. Del Valle
Muñoz Murillo, Pedro Luis — Univ. Del Valle
Alvarez, Fredy — Univ. Del Valle
Rosero, Esteban — Hambug Univ. of Tech

This paper presents the design and implementation of Android-based cascade PID controller structures to control the altitude and attitude of a quadcopter, and the sensor fusion algorithms implemented to estimate its flight dynamics. The main goal of this research is to stabilize the attitude of an unmanned aerial vehicle (UAV), such as a quadcopter, and control its altitude using exclusively the sensors and processor of a smartphone on-board. As the sensors embedded in the smartphones are not accurate enough to measure the altitude of the quadcopter, a linear Kalman filter for relative altitude estimation was designed and implemented. Here, it is described precisely the hardware that was used to build the test platform, the non-linear an linearized quadcopter model, the software structure to execute the controllers in the smartphone, the sensor fusion algorithms implemented to obtain reliable data from the smartphone sensors, and the cascade PID controllers design. Finally, the success of the proposed system is evidenced in the results of a set of experimental tests. In these tests, the quadcopter attitude was regulated after some disturbances were applied to the system and its altitude was controlled after the reference was changed.

11:00-11:20 FrA5.4

Robust Hovering Control of a Quadrotor Using Acceleration Feedback, pp. 1455-1462

Alcan, Gokhan — Sabanci Univ
Unel, Mustafa — Sabanci Univ

This paper presents a novel acceleration feedback control method for robust hovering of a quadrotor subject to aerodynamic disturbances.

An acceleration based disturbance observer (ABDOB) is designed to reject disturbances acting on the positional dynamics of the quadrotor. In order to provide high stiffness against disturbances acting on the attitude dynamics, a nested position, velocity and inner acceleration feedback control structure that utilizes PID and PI type controllers is developed. To obtain reliable angular acceleration information, a cascaded estimation technique based on an extended Kalman filter (EKF) and a classical Kalman filter (KF) is proposed. EKF estimates the Euler angles and gyro biases by fusing the data from gyroscope, accelerometer and magnetometer. Compensated gyro data are then fed into a Kalman filter whose process model is derived from Taylor series expansion of angular velocities and accelerations where angular jerks are considered as stochastic inputs. The well-known kinematic relation between Euler angular rates and angular velocities is employed to estimate reliable Euler accelerations. Estimated Euler angles, rates and accelerations are then used as feedback signals in the nested attitude control structure. Performance of the proposed method is assessed by a high fidelity simulation model where uncertainties in the sensor measurements, e.g. sensor bias and noise, are also considered. Developed controllers that utilize estimated acceleration feedback provide extremely robust hovering results when the quadrotor is subject to wind gusts generated by Dryden wind model. Simulation results show that utilization of acceleration feedback in hovering control significantly reduces the deviations in the x-y position of the quadrotor.

11:20-11:40 FrA5.5

Fast Adaptive Control of a 3-DOF Inertial Stabilised Platforms Based on Quaternions, pp. 1463-1469

Cabarbaye, Aurélien	Cinvestav
Bonilla, Moises E.	CINVESTAV-IPN
Lozano, Rogelio	Univ. of Tech. of Compiègne
Cariño Escobar, Jossué	CINVESTAV-IPN

Inertial Stabilised Platform, better known as gimbal are becoming increasingly popular, with a large range of products now available in mainstream shops. Most of these items are nonetheless controlled using very basic algorithms that do not offer best achievable performances. First, each axis is controlled independently of one another. Then, they make use of trigonometry for their calculation. Lastly, their behavior depends on the type of payload or on the orientation of this latter. Present paper proposes an advanced control which aims at solving these classic control issues without requiring as much computational power. It is based on quaternion representation and self-adapts to the characteristics of the payload it stabilizes. Although only simulation could be performed to check the performances of such control, results look very promising and may help to construct more polyvalent and efficient gimbals which would further facilitate their expansion.

FrB1 Salon E

Biologically Inspired UASs, Autonomy, and Training

Chair: Chakravarthy, Animesh	Wichita State Univ
Co-Chair: Caballero, Fernando	Univ. of Seville

13:45-14:05 FrB1.1

Brain Emotional Learning-Based Intelligent Tracking Control for Unmanned Aircraft Systems with Uncertain System Dynamics and Disturbance, pp. 1470-1475

Jafari, Mohammad	Univ. of Nevada, Reno
Fehr, Ric	Univ. of Nevada, Reno
GARCIA CARRILLO, Luis Rodolfo	Texas A&M Univ. - Corp. Christi
Xu, Hao	Univ. of Nevada, Reno

In this paper, a novel neurobiologically inspired intelligent tracking controller is developed and implemented for Unmanned Aircraft Systems (UAS) in presence of uncertain system dynamics and disturbance. The methodology adopted, known as Brain Emotional Learning Based Intelligent Controller (BELBIC), is based on a novel computational model of emotional learning in mammals' brain limbic system. Compared with conventional stable control, BELBIC is more suitable for practical UAS since it can maintain the real-time UAS performance without known system dynamic and disturbance. Furthermore, the learning capability and low computational complexity of BELBIC make it very promising for implementation in complex real-time applications. To evaluate the practical performance of proposed design, BELBIC has been implemented into a benchmark UAS. Numerical and experimental results demonstrated the applicability and satisfactory performance of the proposed BELBIC-inspired design.

14:05-14:25 FrB1.2

Bioinspired Vision-Only UAV Attitude Rate Estimation Using Machine Learning, pp. 1476-1482

Mérida Floriano, Macarena	Univ. Pablo De Olavide
Caballero, Fernando	Univ. of Seville
García Morales, Diana	Consejo Superior De Investigaciones Científicas (CSIC) - Univ
Casares, Fernando	Consejo Superior De Investigaciones Científicas (CSIC) - Univ
Merino, Luis	Univ. Pablo De Olavide

This paper presents a bioinspired system for attitude rate estimation using visual sensors for aerial vehicles. The sensorial system consists of three small low-resolution cameras (10x8 pixels), and is based on insect ocelli, a set of three simple eyes related to flight stabilization. Most previous approaches inspired by the ocellar system use model-based techniques and consider different assumptions, like known light source direction. Here, a learning approach is employed, using Artificial Neural Networks, in which the system is trained to recover the angular rates in different illumination scenarios with unknown light source direction. We present an study using real data in an indoor setting, in which we evaluate different network architectures and inputs.

14:25-14:45 FrB1.3

Avoidance Maps: A New Concept in UAV Collision Avoidance, pp. 1483-1492

Tony, Lima Agnel	Indian Inst. of Science
Ghose, Debasish	Indian Inst. of Science
Chakravarthy, Animesh	Wichita State Univ

A new concept of avoidance map is introduced which can effectively execute collision avoidance among UAVs. It is based upon representation of the effect of control effort by pairs of UAVs on achievement of avoidance, thus partitioning the control effort space into avoidance and collision regions. To do this, it is demonstrated that collision avoidance can be carried out by applying constant acceleration control inputs to UAVs. Also, the duration for which a UAV needs to execute avoidance maneuver can be determined by monitoring the location of the origin coordinates of the control effort space on the partitioned region. The idea is developed in an intuitive way and is extended to multiple UAVs. Several examples are given to demonstrate the simplicity and effectiveness of the concept.

14:45-15:05 FrB1.4

Non Linear Controller and Path Planner Algorithm for an Autonomous Variable Shape Formation Flight, pp. 1493-1502

Cordeiro, Thiago	Univ. of Brasilia
Ferreira, Henrique Cezar	Univ. of Brasilia
Ishihara, João Yoshiyuki	Univ. of Brasília

A formation flight controller can be used in a UAS fleet to avoid collision, reduce fuel consumption, or to execute interactions between the UASs, such as autonomous aerial refueling. In this paper, an autonomous formation flight (AFF) controller based on nonlinear dynamic inversion (NLDI) and a non-colliding path planner are proposed. The proposed NLDI AFF extends a NLDI controller found in literature to account a maneuvering leader and time-varying shape formations. The proposed path planner generates a time-varying shape formation in which a set of followers flies from their initial relative position to their desired final one, via non-colliding paths. Simulation results show that the proposed controller tracks the trajectories generated by the path planner and achieves lower formation errors than the NLDI AFF controller found in literature.

15:05-15:25 FrB1.5

ROSplane: Fixed-Wing Autopilot for Education and Research, pp. 1503-1507

Ellingson, Gary — Brigham Young Univ
McLain, Timothy W. — Brigham Young Univ

This paper presents a fixed-wing autopilot code base called ROSplane. ROSplane utilizes the ROSflight board, firmware, and driver, which was developed to make autopilot development faster, easier and cheaper. By leveraging a textbook and university course content, the autopilot facilitates education and accelerates research and development. The textbook provides high-level documentation for the code. The code is structured to facilitate learning by providing a framework for student assignments. The addition of ROSplane software and documentation make ROSflight closer to a plug-and-play solution while maintaining simplicity and usability for researchers and students. ROSplane has been used in a graduate level flight dynamics class, demonstrated through test flights, and modified for research purposes.

FrB2 — Salon AB
Simulation

Chair: Rollo, Milan — Czech Tech. Univ. in Prague
Co-Chair: Branco, Kalinka Regina Lucas Jaquie Castelo — Univ. of São Paulo

13:45-14:05 FrB2.1

VirtualArena: An Object-Oriented MATLAB Toolkit for Control System Design and Simulation, pp. 1508-1515

Alessandretti, Andrea — Faculty of Engineering, Univ. of Porto (FEUP)
Aguiar, A. Pedro — Faculty of Engineering, Univ. of Porto (FEUP)
Jones, Colin N — EPFL, Lausanne

This paper presents an open-source object-oriented MATLAB toolkit for control system design and system simulation. The objective of the toolkit is to reduce the time required for the design and validation of a control architecture while at the same time increasing the reliability, modularity, and reusability of each of its components and fostering collaborative design and sharing of the developed components. To reduce the development time, a set of ready-to-use functions that are commonly required by control design processes is provided, such as automatic generation of Extended Kalman Filters, discretization, and many others. Moreover, we define a set of common interfaces to integrate the different standard components. The toolkit is introduced by means of a practical example, starting from the modeling of a planar Unmanned Aerial Vehicle, implementation of a two state-feedback controllers (one simple but nonlinear and another more complex using a Model Predictive Control approach), automatic generation of a state estimator, simulation, and remote network control over a Local Area Network.

14:05-14:25 FrB2.2

*Solar Powered UAV: Terrain Follow Aircraft Attitude Impacts on Conceptual Design**

Ribeiro, Matheus — Inst. Tecnologico de Aeronautica
Adabo, Geraldo José — Inst. Tecnológico de Aeronáutica - ITA
Soares Lira da Silva, Antonio Lamounier — Inst. Tecnológico de Aeronáutica

14:25-14:45 FrB2.3

Robust and Adaptive Control of a Novel Ducted Fan Vehicle in the Presence of Actuator Uncertainties and Saturation, pp. 1516-1521

WANG, XIAOLIANG — Beijing Inst. of Tech
Xiang, Changle — Beijing Inst. of Tech
Xu, Bin — Beijing Inst. of Tech
Najjaran, Homayoun — The Univ. of British Columbia

This paper provides rigorous steps for controller design of a novel ducted fan vehicle under actuator uncertainties and saturation. Considering uncertain actuator dynamics, a control-oriented model is proposed to provide convenience for practical control applications. A structured robust controller that stabilizes the vehicle in the presence of actuator uncertainties and external disturbances is designed using parametric robust control tuning algorithm. Subject to input saturation, adaptive control is applied as an augmentation of the structured robust controller. Simulation results reveal that our method is able to keep fast reference tracking speed and strong ability to reject disturbance even with large uncertainties, and system performance is further improved by the adopted adaptive control law when actuator saturation is active.

14:45-15:05 FrB2.4

Cooperative UAV Formation Control Simulated in X-Plane, pp. 1522-1529

Ito, Fernando Soares Carnevale — Univ. of São Paulo
Querino Filho, Luiz Carlos — Univ. of São Paulo (USP)
Inoue, Roberto Santos — Federal Univ. of São Carlos
Branco, Kalinka Regina Lucas Jaquie Castelo — Univ. of São Paulo

Unmanned Aerial Vehicles (UAVs) have been used in a wide range of applications, due to high availability and low cost of their core components. One subject of research in the UAV field is the formation flying of a group of aircraft. In this paper, it is described the problem formulation for a formation of UAVs and the control law used to keep the aircraft in position. Following the theoretic model definition, additional information about its implementation and testing are provided: the algorithms were first tested in MATLAB and then implemented as a plugin for the X-Plane Flight Simulator. The results obtained by the simulation are then presented in this paper, showing the effectiveness of the formation representation and control law used to keep it in a predefined state.

15:05-15:25 FrB2.5

Mixed Reality Simulation for Incremental Development of Multi-UAV Systems, pp. 1530-1538

Selecký, Martin — Czech Tech. Univ. in Prague
Faigl, Jan — Czech Tech. Univ. in Prague
Rollo, Milan — Czech Tech. Univ. in Prague

Development of complex multi-robot systems requires time consuming and expensive testing and, especially in case of unmanned aerial systems, it aggregates risk of hardware failures and legal issues when operating more than one unmanned aircraft simultaneously. It is highly favorable to deal with most of eventual design flaws and system bugs before the final field tests in a simulation where the risks are significantly lower. On the other hand, the fidelity of the simulation needs to rise as the system development approaches the final stages and since some phenomena are difficult to be modelled precisely a partial embodiment of the simulation in physical world is necessary. In this paper, we present our results in utilization of mixed reality simulation for incremental development of multi-UAV systems. We present three use cases where this method was used for development of various systems to show its versatility: (i) an unmanned system consisting of heterogeneous team of autonomous unmanned aircraft; (ii) a system for verification of collision avoidance methods among fixed wing UAVs; and (iii) a system for planning collision-free paths for light-sport aircraft.

FrB3 — Salon CD
Path Planning - V

Chair: Imsland, Lars — Norwegian Univ. of Science and Tech
Co-Chair: Coombes, Matthew — Loughborough Univ

13:45-14:05 FrB3.1

Performance Bounds for Tracking Multiple Objects Using a Single UAV, pp. 1539-1546

Albert, Anders — Norwegian Univ. of Science and Tech
Imsland, Lars — Norwegian Univ. of Science and Tech

In this paper we calculate probabilistic estimates for the size of an area a single unmanned aerial vehicle (UAV) can expect to monitor when tracking multiple objects. The objects are assumed to move according to a linear velocity model with Gaussian process noise. We use a Kalman filter to estimate the position of the objects. By using the covariance matrix of the Kalman filter, we can derive the necessary visitation period for a UAV to have a probability within a given confidence interval of redetecting the object at the estimated position. Then, we use this visitation period to calculate the probabilistic estimate for the area a single UAV can monitor. We demonstrate the results in Monte Carlo simulations.

14:05-14:25 FrB3.2

Super-Twisting Control Scheme for a Miniature Quadrotor Aircraft: Application to Trajectory-Tracking Problem, pp. 1547-1554

Gonzalez-Hernandez, Ivan — Cinvestav - IPN
Salazar, Sergio — Umi Lafmia Cinvestav
MUÑOZ PALACIOS, FILIBERTO — Univ. Pol. DE PACHUCA
Lozano, Rogelio — Univ. of Tech. of Compiègne

This article addresses the trajectory-tracking problem for a Quadrotor aircraft system using a super-twisting technique in real-time application. This strategy ensures the convergence in finite time to a desired programmed trajectory under bounded external perturbations such as wind gusts. The proposed solution consists of implementing a real-time strategy based on super-twisting control using GPS measurements in order to obtain the horizontal position to accomplish the desired trajectory. A Lyapunov theory is used in order to demonstrate the stability of the system in finite time. Simulation results and experimental autonomous trajectory-tracking flight are presented to evaluate the corresponding efficiency of the proposed control algorithm under external disturbances affecting the aerial vehicle.

14:25-14:45 FrB3.3

Dubins Orienteering Problem with Neighborhoods, pp. 1555-1562

Penicka, Robert — Czech Tech. Univ. in Prague, Faculty of Electrical Engi
Faigl, Jan — Czech Tech. Univ. in Prague
Váňa, Petr — Czech Tech. Univ. in Prague
Saska, Martin — Czech Tech. Univ. in Prague

In this paper, we address the Dubins Orienteering Problem with Neighborhoods (DOPN) a novel problem derived from the regular Orienteering Problem (OP). In the OP, one tries to find a maximal reward collecting path through a subset of given target locations, each with associated reward, such that the resulting path length does not exceed the specified travel budget. The Dubins Orienteering Problem (DOP) requires the reward collecting path to satisfy the curvature-constrained model of the Dubins vehicle while reaching precise positions of the target locations. In the newly introduced DOPN, the resulting path also respects the curvature constrained Dubins vehicle as in the DOP; however, the reward can be collected within a close distant neighborhood of the target locations. The studied problem is inspired by data collection scenarios for an Unmanned Aerial Vehicle (UAV), that can be modeled as the Dubins vehicle. Furthermore, the DOPN is a useful problem formulation of data collection scenarios for a UAV with the limited travel budget due to battery discharge and in scenarios where the sensory data can be collected from a proximity of each target location. The proposed solution of the DOPN is based on the Variable Neighborhood Search method, and the presented computational results in the OP benchmarks support feasibility of the proposed approach.

14:45-15:05 FrB3.4

Boustrophedon Coverage Path Planning for UAV Aerial Surveys in Wind, pp. 1563-1571

Coombes, Matthew — Loughborough Univ
Chen, Wen-Hua — Loughborough Univ
Liu, Cunjia — Loughborough Univ

In the quickly developing world of precision agriculture UAV remote sensing, there is a need for a greater understanding of winds effect on fixed wing aerial surveying, as this is missing from current literature. This paper presents a method to define and calculate flight times in a Boustrophedon aerial survey coverage path in wind, for a given convex polygon, at a given sweep angle. It is shown that there exists no easy way to define a sweep angle relative to the wind that minimizes flight time. This method is validated by comparing the numerical simulated path and times with a number of surveys run in the high fidelity X-Plane simulator.

15:05-15:25 FrB3.5

Optimizing Multiple UAV Cooperative Ground Attack Missions, pp. 1572-1578

Manyam, Satyanarayana Gupta — National Acad
Casbeer, David — Air Force Res. Lab
Suresh, M — Ade, Drdo

This paper presents an optimization based approach for cooperative multiple UAV attack missions. The objective is to determine the minimum resources required to coordinately attack a target at a given set of directions. We restrict the paths of the munitions to direct Dubins paths to satisfy field of view constraints and to avoid certain undesirable paths. The proposed algorithm derives the feasible positions and headings for each attack angle, and determines intersection regions corresponding to any two attack angles. We pose a set cover problem, the solution of which gives the minimum number of UAVs required to accomplish the mission.

FrB4 Lummus Island
GNC-UAS

Chair: Azimov, Dilmurat — Univ. of Hawaii at Manoa
Co-Chair: Andersen, Tom Stian — The Arctic Univ. of Norway
Organizer: Azimov, Dilmurat — Univ. of Hawaii at Manoa

13:45-14:05 FrB4.1

Analytical Model and Control Solutions for Unmanned Aerial Vehicle Maneuvers in a Vertical Plane (I), pp. 1579-1587

Azimov, Dilmurat — Univ. of Hawaii at Manoa
Allen, John S. — Univ. of Hawaii at Manoa

In this study, we present a class of nonlinear analytical solutions for the dynamics of a fixed wing unmanned aircraft vehicle (UAV). These solutions are needed for the integration and fusion of sensor data for input to guidance and control algorithms. Derivation and integration of the 3-rd order vector differential equation of motion, and its applications to various dynamical models are presented. It is assumed that (a) acceleration due to aerodynamic lift, and the difference between the propulsive thrust and aerodynamic drag accelerations are not changed; (b) the bank angle is zero; (c) the sideslip angle is zero. The general integral and the corresponding analytical solutions for a class of flight trajectories consist of six independent integrals for heading angle, magnitude of velocity vector, time, altitude, and two components of the position vector. This explicit expression with respect to the governing parameters facilitates its direct incorporation into the development and design of trajectories, targeting, guidance and control schemes. It is shown that the first integrals which have been shown valid for a variety of aircraft platforms, re-entry vehicles and missiles, can specifically be applied to UAVs in which such control solutions are needed for sense and avoid situations. An illustrative example highlights the applicability of the general integral for range of trajectories and conditions pertinent to UAV flight patterns.

14:05-14:25 FrB4.2

Specification and Evaluation of Geofence Boundary Violation Detection Algorithms, pp. 1588-1596

Stevens, Mia — Univ. of Michigan

Rastgoftar, Hossein — Univ. of Michigan Ann Arbor
Atkins, Ella — Univ. of Michigan

In this paper, we study two methods of geofence boundary violation detection. The first method is Ray Casting, which iterates over each geofence boundary edge to determine if a given position of interest is inside the geofence. The second method, called Triangle Weight Characterization (TWC), subdivides the geofence domain into a finite number of triangles, then iterates over each triangle to determine if the given position of interest is inside the geofence. We apply the TWC and Ray Casting methods to case studies that include both keep-in and keep-out geofence boundaries.

14:25-14:45 FrB4.3

Quaternion Guidance and Control of Quadrotor, pp. 1597-1601

Andersen, Tom Stian — The Arctic Univ. of Norway
Kristiansen, Raymond — The Arctic Univ. of Norway

This paper addresses the problem of trajectory tracking for underactuated quadrotors. A quaternion based guidance law is proposed which feeds into an attitude control system based on a PD+ control law. The desired attitude from the guidance law is defined such that the attitude control system tries to align the position error along the axis of the translational actuator. Simulation results are provided and discussed to demonstrate the proposed method.

14:45-15:05 FrB4.4

Advanced PID Attitude Control of a Quadcopter Using Asynchronous Android Flight Data, pp. 1602-1607

Alsharif, Mohammad — Univ. of Bremen
Arslantas, Yunus Emre — Univ. of Bremen
Holzel, Matthew — Univ. of Bremen

In this paper, we implement an advanced model-free PID controller for a DJI F450 quadcopter which is controlled and stabilized by a non-rooted onboard Android smartphone, without the aid of an external IMU. Furthermore, since Android is not a real time system, the control commands and sensor measurements are subject to significant latencies, and hence the PID controller is modified to account for non-trivial measurement asynchronicities. While baseline PID control is widely used with no further modifications, we show that some features can be added to obtain better performance in the presence of latencies and noise.

15:05-15:25 FrB4.5

False Data Injection on EKF-Based Navigation Control (I), pp. 1608-1617

Chen, Wenxin — Univ. of Hawaii
Duan, Zhenhai — Florida State Univ
Dong, Yingfei — Univ. of Hawaii

Small consumer unmanned aircraft systems (sUASs) have been involved in many security incidents recently. Current defense methods have serious limitations because they mostly try to physically capture an sUAS or jam its communications and its GPS signals to trigger its fail-safe features. While physical methods are usually unscalable and often slow in response, the default fail-safe features can be easily changed to other options such as continuing its pre-configured mission, regardless of jamming. Therefore, new defense solutions must be developed to address these issues. To our best knowledge, very little research has been published in this area.

In this paper, we propose a false data injection attack to exploit the limitation of sensoring and processing capabilities on an sUAS and manipulate its on-board sensors, in order to deviate it from its (pre-configured) flight plan. We have analyzed the popular ArduPilot flight control system, identified potential vulnerabilities in its sensor data fusion process, and developed a method to manipulate on-board magnetometer readings while avoiding being detected by its bad-data detection schemes. Our initial results show that the proposed method is able to misguide the navigation system and deviate an sUAS from its target destination far away. While we present our main ideas in this paper, we are further investigating related theoretical issues and improving the proposed method with practical experimental tests.

FrB5 — San Marco Island

UAS Control - II

Chair: Chen, YangQuan — Univ. of California, Merced
Co-Chair: Quagliotti, Fulvia — Pol. Di Torino

13:45-14:05 FrB5.1

A Concept of a Non-Tilting Multirotor-UAV Based on Moving Mass Control, pp. 1618-1624

Haus, Tomislav — Univ. of Zagreb
Orsag, Matko — Univ. of Zagreb
Bogdan, Stjepan — Univ. of Zagreb

In this paper we present a concept of a multirotor unmanned aerial vehicle (UAV) capable of horizontally moving without tilting the vehicle body. The concept is based on the moving mass control, which we have recently proposed for roll and pitch control of a large multirotor UAV with internal combustion engines (ICEs). The vehicle is comprised of four ICEs with rotors tilted towards the body center and four moving masses, each placed in a motor arm. We give a complete 6 degrees of freedom (DOF) mathematical model in the form of nonlinear differential equations, which we linearize to obtain transfer functions. The models are used to design a control system comprised of state space controllers for roll/pitch stabilization and PID controllers for height, yaw and velocity control. The concept is verified in the Gazebo simulator and experimentally on a 2DOF laboratory gimbal.

14:05-14:25 FrB5.2

Nonlinear Flight Control with an Extended State Observer for a Fixed-Wing UAV, pp. 1625-1630

Kikkawa, Hirotaka — Nihon Univ
Uchiyama, Kenji — Nihon Univ

The present paper describes the design of a nonlinear flight control method for a fixed-wing UAV using an extended state observer (ESO). The dynamics of a UAV contains uncertainties such as modeling error and actuator dynamics that deteriorate control performance. Moreover, wind disturbance seriously affects stability with respect to the dynamics of a small UAV. The ESO can estimate not only the state variables of a UAV but also disturbances, uncertainties, nonlinear dynamics, and observation error; i.e., it is possible to simultaneously cancel the effect of disturbances on the dynamic behavior of a UAV by adjusting the observer and controller gains. However, the ESO has been applied, in principle, to a single-input single-output system. We design the nonlinear flight control system using the ESO and active disturbance reject control, which is used to obtain a state equation without approximation. Actuator dynamics, which may deteriorate control performance, is also taken into account in the design of the control system.

14:25-14:45 FrB5.3

A Feasibility Study of an Harmless Tiltrotor for Smart Farming Applications, pp. 1631-1639

Novaro Mascarello, Laura — Pol. Di Torino
Quagliotti, Fulvia — Pol. Di Torino
Ristorto, Gianluca — Free Univ. Bozen

In the last decades, Remotely Piloted Aircraft Systems (RPAS) have been developed for many civil applications, such as surveillance and terrain monitoring, Search and Rescue (S&R), topography, photogrammetry and law enforcement missions, and widely media and entertainment applications. Moreover, the use of the unmanned configuration is becoming very promising for smart farming or precision agriculture. The paper deals with a feasibility study of an harmless tiltrotor for specific smart faming applications. In order to define the final layout of the vehicle, the main RPAS configurations are analyzed in terms of performances and kinds of applications. Indeed, a trade-off between endurance and payload capacity is more than anything else required during the design of an RPAS for the smart farming application, where sensors are often heavy and several hectares must be scanned. For these reasons, the hybrid configuration, with features both of the fixed wing configuration and of the rotary wing one, has been identified. Moreover, the final configuration should be defined harmless, that is in case of impact with the human body, there are no

injuries for the involved people. As a matter of fact, people safety must not be compromised in each situation, also when RPAS are applied over wide fields.

14:45-15:05 FrB5.4

Experimental Pitch Control of an Unmanned Airship with Sliding Ballast, pp. 1640-1646

Alsayed, Ahmad — Univ. of Ottawa
Lanteigne, Eric — Univ. of Ottawa

In this paper, the pitch control of a miniature unmanned airship using a sliding ballast is presented. The sliding ballast design has been developed to address the limited altitude maneuverability of lighter-than-air vehicles by allowing for large changes in vehicle pitch and, when combined with forward facing thrusters, rapid changes in altitude. Using the longitudinal position of the ballast as the control input, the vehicle behavior is simulated under various reference trajectories and wind disturbances. Preliminary experimental flight tests are then performed to evaluate the pitch controller performance.

15:05-15:25 FrB5.5

Fixed-Wing MAV Adaptive PD Control Based on a Modified MIT Rule with Sliding-Mode Control, pp. 1647-1656

Espinoza Fraire, Arturo Tadeo — Univ. Juárez Del Estado De Durango
Chen, YangQuan — Univ. of California, Merced
Dzul, Alejandro — TECNM/Inst. Tecnológico De La Laguna
Lozano, Rogelio — Univ. of Tech. of Compiègne

This paper presents an adaptive PD control law by using a modified MIT rule. The adjustment mechanism of the MIT rule has been implemented with three types of sliding-mode control, i.e., classical sliding-mode control, second order sliding-mode (2-SM), and high order sliding-mode control (HOSM). The proposed controllers have been designed for the directional and lateral dynamics of a fixed-wing mini aerial autonomous vehicle (MAV). Several simulations have been carried out in order to analyze the modified MIT rule.

FrC1 Salon E

Airspace Management and Control

Chair: Tsourdos, Antonios — Cranfield Univ
Co-Chair: Tolman, Skyler — Brigham Young Univ

15:40-16:00 FrC1.1

Parametric Study on Efficient Formation Flying for a Blended-Wing UAV, pp. 1657-1664

Shin, Hyo-Sang — Cranfield Univ
Antoniadis, Antonis — Cranfield Univ
Tsourdos, Antonios — Cranfield Univ

This paper investigates aerodynamic performance improvements of formation flight at transonic speeds for a medium size Unmanned Aerial Vehicle (UAV). The metric for assessing the aerodynamic improvement of formation flight is the computed drag. The total drag for each formation configuration is compared with a single UAV, where a final drag reduction percentage is estimated. The evaluation of the aerodynamic performance is conducted by employing an in-house Computational Fluid Dynamics (CFD) solver, grid generation and post processing tools. For critical understanding of the tendency of the formation efficiency depending on main parameters, broad formation configurations are analyzed. The parameterization includes number of aircraft, proximity and formation shape. Full realization of the benefit predicted would need to be proven in the real world, but there is sufficient confidence to suggest that it exists: the empirical parametric analysis suggests that formation flight can improves aerodynamic performance and formation configuration greatly influence the degree of improvement.

16:00-16:20 FrC1.2

Counter UAS Using a Formation Controlled Dragnet, pp. 1665-1672

Tolman, Skyler — Brigham Young Univ
Beard, Randal W. — Brigham Young Univ

Rapidly developing UAS technology calls for innovative ways to achieve reliable counter UAS systems. This paper proposes a formation controlled dragnet as a possible solution and compares potential intercept algorithms that can be used in this scenario. Proportional navigation and target-predictive path planning, both existing algorithms, are explored and an original approach, Adaptive Radius Optimal Defense (AROD), is introduced. Simulation results are given and the strengths and weaknesses of each approach are discussed. Based on the results received, some advantages that AROD offers over other existing algorithms are listed. Possible improvements and future research directions are also suggested.

16:20-16:40 FrC1.3

Cooperative and Non-Cooperative UAS Traffic Volumes, pp. 1673-1681

Bulusu, Vishwanath — UC, Berkeley
Sengupta, Raja — Univ. of California at Berkeley
Polishchuk, Valentin — Linkoping Univ
Sedov, Leonid — Linkoping Univ

We describe an analytical process to determine how much UAS traffic is feasible. The process is a simulator and data processing tools. The two are applied to the US San Francisco Bay Area and Norrkoping, Sweden. The amount of UAS traffic is measured in flights per day and simulated up to 200,000 flights. A UAS traffic volume is feasible if specified metrics meet operational requirements with high probability and are stable, in the sense of being below thresholds observed for monotone properties in random geometric graphs. We focus on conflict cluster size and argue for it as a fundamental safety metric worthy of extraordinary consideration.

16:40-17:00 FrC1.4

Implications of Cyber Threats for the Design of Unmanned Air Traffic Management System, pp. 1682-1689

Sidorov, Vasily — Nanyang Tech. Univ
Ng, Wee Keong — Nanyang Tech. Univ
Lam, Kwok Yan — Nanyang Tech. Univ
Bin Mohamed Salleh, Mohamed Faisal — Air Traffic Management Res. Inst

Unmanned aircraft are quickly gaining credibility as an efficient tool for a wide range of tasks. With the increase in the amount of UAVs in the sky, the need for the UAV traffic management arises. Unmanned air traffic management system (UTMS), especially in the urban airspace, could be considered as a critical infrastructure, which—if disrupted—can lead to severe monetary losses and even casualties. As a computerized system, UTMS is susceptible to cyber-attacks ranging from cyber vandalism to cyber warfare. This work considers cyber threats to the UTMS, and how it should be designed in order to be resilient to these threats. The work was performed as a part of the early design of an urban UTMS in Singapore; however, the findings are applicable to designing UTMS for any urban environment.

17:00-17:20 FrC1.5

Aerial-Underwater Systems, a New Paradigm in Unmanned Vehicles, pp. 1690-1695

Mercado Ravell, Diego Alberto — Univ. De Tech. Compiegne
Maia, Marco Moreno — Rutgers, the State Univ. of New Jersey
Diez, F.J. — Rutgers Univ

Singularity-free modeling and control of Unmanned Aerial-Underwater Vehicles (UAUVs) are covered in this work. UAUVs are a special kind of unmanned vehicles capable of performing equally well in different mediums, and seamlessly transitioning between them. In particular, this work covers the modeling and attitude control of a special class of air-underwater vehicles with full torque actuation and a single thrust force directed upwards. A quaternion based representation is used to avoid singularities. A nonlinear quaternion feedback and a Proportional-Integral-Derivative (PID) with compensation of the

restoring forces are used to control the quaternion and altitude errors, respectively, while a gain scheduling handles the abrupt change in the medium density. The use of quaternions allows for the vehicle to follow any desired angular reference, which is critical underwater in order to efficiently overcome the vehicle's buoyancy and drag. Numerical simulations are presented to validate the proposed control scheme.

FrC2 Salon AB
UAS Payloads

Chair: Johansen, Tor Arne — Norweigian Univ. of Sci. & Tech
Co-Chair: Tsourdos, Antonios — Cranfield Univ

15:40-16:00 FrC2.1

Flight Test Instrumentation System for Small UAS System Identification, pp. 1696-1705

Lu, Han-Hsun — Texas A&M
Harris, Joshua — Texas A&M Univ
Guimaraes Goecks, Vinicius — Texas A&M Univ
Bowden, Ezekiel — Texas A&M Univ
Valasek, John — Texas A&M Univ

Common open-source flight controllers have the ability to log state data, but they often are unable to log at the rates required to obtain good identification of model characteristics. They are also often unable to log important flow parameters such as angle-of-attack and sideslip angle. This paper presents a custom flight test instrumentation system that is capable of providing accurate full-state and control surface deflection measurements for Small Unmanned Air Systems. The system consists of an embedded single-board computer integrated with a collection of sensors including commercial off-the-shelf air data and inertial navigation systems, in addition to direct measurement of control deflections. Developmental Flight Test Instrumentation data logging software runs onboard the computer. This software is released as open-source. Performance of the system is verified by flight test on a quarter scale Piper PA-18 Super Cub airframe. The Observer/Kalman Identification algorithm is used in post-processing to generate linear state-space models, which are then simulated with other input sets and compared to flight data. Results presented in the paper demonstrate that the integrated flight test instrumentation system is able to provide sufficiently accurate data at a high enough sample rate for the generation of quality linear state-space models.

16:00-16:20 FrC2.2

SyncBoard - a High Accuracy Sensor Timing Board for UAV Payloads, pp. 1706-1715

Albrektsen, Sigurd M — Norwegian Univ. of Science and Tech
Johansen, Tor Arne — Norweigian Univ. of Sci. & Tech

The SyncBoard is a reconfigurable sensor timing board that accurately records the Time of Validity (TOV) from sensors, while acting as a protocol conversion tool. It is intended to be usable by people without expertise in hardware development. To allow accurate timing, the SyncBoard has a high-performance microcontroller with a 32-bit timer clock running at a maximum of 100 MHz. By capturing the TOV signal using the Input/Interrupt Capture function of the microcontroller, sensor triggers can be captured with an accuracy of 10 ns, which is sufficient for most UAV applications.

The SyncBoard supports sensor input from several commonly used protocols, in addition to simple digital and analog input. Sensors of different rates and data sizes are supported, and TOV detection can be configured to comply with the specifications of the sensor. For usage with very high-bandwidth sensors, such as cameras, the SyncBoard can output an external signal to be used as a trigger for the sensor. To be compatible with most on-board computers on UAVs, the SyncBoard primarily uses a USB interface for configuration and sensor output, but output can also be transmitted by any of the available protocols if needed. The SyncBoard also has functionality to switch on and off power to individual sensors as needed.

This paper presents the SyncBoard system and experimental results in unmanned aerial vehicle payload systems for data acquisition.

16:20-16:40 FrC2.3

Target Detection Using Gaussian Mixture Models and Fourier Transforms for UAV Maritime Search and Rescue, pp. 1418-1424

Martinez Dinnbier, Nuria — Cranfield Univ
THUEUX, Yoann — Airbus
Savvaris, Al — Cranfield Univ
Tsourdos, Antonios — Cranfield Univ

In the event of a maritime disaster, casualties need to be found and rescued promptly. Image processing methods could help to perform automated detection from a UAV. The main current approaches are divided between the use of multispectral and thermal cameras, which can deal with lightning difficulties but are expensive and present high noise problems; or the use of EO vision cameras. This paper presents a method combining both color analysis and frequency patterns identification using an inexpensive vision camera, and implements it through an adaptive algorithm to deal with a dynamically changing background. The method is tested successfully in different environments.

16:40-17:00 FrC2.4

Challenges in Bridge Inspection Using Small Unmanned Aerial Systems: Results and Lessons Learned, pp. 1722-1730

Dorafshan, Sattar — USU
Maguire, Marc — USU
Hoffer, Nathan — AggieAir, Utah State Univ. (USU)
Coopmans, Calvin — Utah State Univ

Unmanned Aerial Systems (UAS) have gained considerable private and commercial interest for a variety of jobs and entertainment in the past 10 years. This paper presents the applications of UAS in transportation and structural engineering with emphasis on bridge inspection. A brief but thorough review of UAS applications for State Department of Transportation in the United States is provided. Potential advantages of UAS are acknowledged and the major challenges of using them for bridge inspections are determined. The feasibility of UAS in crack detection, real-time and post-processing, is studied through a case study in controlled conditions. In addition, fatigue crack detection in steel bridges is investigated using three platforms with different mounted cameras. The results of these case studies showed the possibility of using UAS for damage detection in concrete and steel bridges with comparable results with human inspections in real-time. At its best, current technology limits UAS use to an assistive tool for the inspector to perform a bridge inspection faster, cheaper, and without traffic closure. The major challenges for UAS are satisfying restrictive FAA regulations, control issues in a GPS denied environment, pilot expenses and availability, time and cost allocated to tuning, maintenance, post-processing time and acceptance of the collected data by bridge owners. Using UAS, with self-navigation abilities and improving image-processing algorithms to provide results near real-time could provide bridge inspectors with a useful tool to reduce costs and improve inspection quality.

17:00-17:20 FrC2.5

Dynamic Landing Gear for Balancing a Multirotor Helicopter, pp. 1731-1736

Molina, Javier — Ritsumeikan Univ
Hirai, Shinichi — Ritsumeikan Univ

This paper presents the procedure to experimentally determine the capacity of a multirotor helicopter to move payload placed in front of it. We propose a solution to maintain the stability of it during flying using one half of a landing gear acting as a tail to create counterbalance. The main aim of the proposed system is to use only the mechanical systems available in a multirotor, this due to the limited payload capacity a helicopter can handle. In addition, the battery, which provide energy to the whole system, has been attached to the tail to increase the effect of counterbalance when the center of mass of the helicopter is been affected by the payload.

FrC3 Salon CD

UAS Testbeds

Chair: Morrison, James R. KAIST

Co-Chair: Bierig, Andreas Deutsches Zentrum Für Luft Und Raumfahrt

15:40-16:00 FrC3.1

UAV Flight Test Characterization Using Minimal Test Equipment, pp. 1737-1741

Michalowski, Brent Aeroprobe Corp

Varano, Nathaniel Aeroprobe Corp

The aerodynamic performance characteristics of a small UAV were determined using minimal test equipment. Using air data and accelerometer measurement devices it is possible to characterize a UAV airframe using flight test data without the need for any laboratory or wind tunnel support.

16:00-16:20 FrC3.2

Multi-UAV Control Testbed for Persistent UAV Presence: ROS GPS Waypoint Tracking Package and Centralized Task Allocation Capability, pp. 1742-1750

Lee, Brad Hyeong-Yun KAIST

Morrison, James R. KAIST

Sharma, Rajnikant Univ. of Cincinnati

A system of unmanned aerial vehicles (UAVs) can be used to provide uninterrupted service to customers by handing the mission from a weary UAV to a fresh one in an automated manner. Toward such a system, we discuss the development of two components: ROS GPS waypoint tracking package and centralized task allocation network system (CTANS). The ROS GPS waypoint tracking package is the first open source software developed for the AR Drone 2.0 UAV that enables integration with a larger system. CTANS connects the UAV host computers to a central computer, receives the UAV status information and distributes GPS flight directives. CTANS is responsible for distributing the commands to the UAVs to ensure mission handoffs are conducted as required. This multi-UAV control software testbed was used to implement a small scale, outdoor, persistent, GPS based patrol mission with two UAVs.

16:20-16:40 FrC3.3

A Flexible Hardware-In-The-Loop Architecture for UAVs, pp. 1751-1756

Peter, Lepej Univ. of Maribor

Santamaria-Navarro, Angel Inst. De Robòtica I Informàtica Industrial (CSIC-UPC)

Solà, Joan Inst. De Robòtica I Informàtica Industrial, CSIC-UPC

As robotic technology matures, fully autonomous robots become a realistic possibility, but demand very complex solutions to be rapidly engineered. In order to be able to quickly set up a working autonomous system, and to reduce the gap between simulated and real experiments, we propose a modular, upgradeable and flexible hardware-in-the-loop (HIL) architecture, which hybridizes the simulated and real settings. We take as use case the autonomous exploration of dense forests with UAVs, with the aim of creating useful maps for forest inspection, cataloging, or to compute other metrics such as total wood volume. As the first step in the development of the full system, in this paper we implement a fraction of this architecture, comprising assisted localization, and automatic methods for mapping, planning and motion execution. Specifically, we are able to simulate the use of a 3D LIDAR endowed below an actual UAV autonomously navigating among simulated obstacles, thus the platform safety is not compromised. The full system is modular and takes profit of pieces either publicly available or easily programmed. We highlight the flexibility of the proposed HIL architecture to rapidly configure different experimental setups with a UAV in challenging terrain. Moreover, it can be extended to other robotic fields without further design. The HIL system uses the multi-platform ROS capabilities and only needs a motion capture system as external extra hardware, which is becoming standard equipment in all research labs dealing with mobile robots.

16:40-17:00 FrC3.4

Cyber-Physical Thermal Modeling for a Small UAS, pp. 1757-1766

Holper, James Univ. of Michigan

Henry, Kathryn Univ. of Michigan

Atkins, Ella Univ. of Michigan

Unmanned aircraft systems (UAS) can face nontrivial overheating challenges in environments with high ambient temperatures and solar insolation levels. Heat generated by propulsion, battery, and computer systems can be difficult to manage in such conditions. This paper presents results from a series of experiments designed to characterize heating and cooling profiles for an electric-powered small UAS. A single fuselage houses the electric propulsion system, an NVIDIA Jetson TK1 with multiple central processing units (CPUs) and graphics processing units (GPUs) along with a lithium-polymer battery pack powering the computer, propulsion, actuation, and communication systems. Temperature sensors were placed at multiple stations inside the fuselage, and temperature data was collected over a variety of motor thrust, CPU/GPU load, and ambient temperature conditions. Wind tunnel tests were performed to characterize heating and cooling as a function of free stream airspeed; stationary outdoor tests were conducted to examine the impact of direct sunlight on fuselage heating. Heating and cooling curves were fit to acquired data. These experimentally-derived thermal models can be used in future cyber-physical UAS models to enable tradeoffs over computational, power, and propulsion system use due to expected thermal load during mission planning and real-time flight.

17:00-17:20 FrC3.5

Design of the General Systems for the SAGITTA Demonstrator UAV, pp. 1767-1777

Bierig, Andreas Deutsches Zentrum Für Luft Und Raumfahrt

Nikodem, Florian Deutsches Zentrum Für Luft Und Raumfahrt

Gallun, Patrick Deutsches Zentrum Für Luft Und Raumfahrt

Greiner-Perth, Christian Deutsches Zentrum Für Luft Und Raumfahrt

Unmanned Aerial Vehicles (UAV) with a Maximum takeoff weight of up to 150 Kg are enjoying increasing popularity, especially as scaled-down demonstrator aircraft for future civil and military applications. This paper gives an overview about the development of the general systems for the SAGITTA demonstrator aircraft. General systems is an Airbus Defence and Space term and covers all flight safety critical Systems except the engine and flight control computers. The SAGITTA demonstrator aircraft is a scaled-down UAV for the purpose of demonstrating capabilities of future Unmanned Combat Aerial Vehicle (UCAV). On system level, the realization of the electrical power supply system, the electromechanical actuation system, the fuel system and the design of a retractable landing gear for the demonstrator aircraft is described. Since there is still no significant market for systems of a relevant size for aircraft of the dimension of SAGITTA, most of the components are essentially new developments. This paper gives an overview about the main design considerations of these systems.

FrC4 Lummus Island

UAS Applications - VIII

Chair: Morrison, James R. KAIST

Co-Chair: Chen, YangQuan Univ. of California, Merced

15:40-16:00 FrC4.1

Lightweight and Human-Size Dual Arm Aerial Manipulator, pp. 1778-1784

Suarez, Alejandro Univ. of Seville

Jimenez Cano, Antonio Enrique Univ. De Sevilla

VEGA GARCIA, VICTOR Univ. of Seville

Heredia, Guillermo Univ. of Seville

Castaño, Ángel Rodríguez — Univ. of Seville
Ollero, Anibal — Univ. De Sevilla

This paper presents the design of a dual-arm aerial manipulator consisting of a multi-rotor platform with an ultra-lightweight (1.8 Kg) human-size dual arm prototype and its control system. Each arm provides three degrees of freedom (DOF) for positioning the end-effector, and two DOF for orientation. As most model-based controllers assume that joint torque feedback is available, a torque estimator for the arms is developed. Note that low cost servos used for building low weight manipulators do not provide any torque feedback or control capability. The redundant DOFs in the dual arm prototype are exploited for generating coordinated motions during contact-less phases in such a way that reaction torques can be partially canceled. Preliminary flight tests have been conducted in outdoors, evaluating the torque compensation capability in test-bench. The influence of the reaction torques exerted by the arms over the UAV controller is also analyzed in simulation.

16:00-16:20 FrC4.2

Towards a Holistic Performance Evaluation Framework for Drone-Based Object Detection, pp. 1785-1793

Petrides, Petros — Univ. of Cyprus
Kyrkou, Christos — Univ. of Cyprus
Kolios, Panayiotis — Univ. of Cyprus
Theocharides, Theocharis — Univ. of Cyprus
Panayiotou, Christos — Univ. of Cyprus

Recent advances in drone visual sensors and integration of complex vision algorithms, facilitate further potential, entirely disrupting in a positive way their applications and capabilities. In particular, real-time object detection, usually the initial necessary step in multiple computer vision and image processing applications, has been gaining momentum in drone- based applications. Whilst heavily researched in conventional systems, drone-based vision algorithms have to consider extrinsic parameters to measure their efficiency, as their performance is heavily impacted by various flying parameters such as altitude. Further, the parameters that directly impact the performance of the vision algorithms, also impact the duration of the flight (i.e. battery life), as the vision algorithmic performance is affected by the flying route and altitude as well. This paper therefore, presents a holistic performance evaluation framework for multi-rotor drone-based object detection applications, that considers various trade-offs such as flight duration, camera resolution, computational platform performance, drone battery performance, etc., in providing a thorough analysis of the various factors affecting the operation of object detection. The framework showcases indeed that the flying altitude, in combination with the camera resolution, vastly impacts the flight duration as well as the performance of the object detection algorithm, when targeting coverage of a specific area. The framework has been experimentally verified using a commercial grade state-of-the-art drone and high-resolution camera, as well as a high-end embedded processing platform that performs the detection algorithm.

16:20-16:40 FrC4.3

A New Framework for UAV-Based Remote Sensing Data Processing and Its Application in Almond Water Stress Quantification, pp. 1794-1799

Zhao, Tiebiao — MESA LAB at UC Merced
Doll, David — Univ. of California, Div. of ANR
Wang, Dong — USDA ARS Parlier
Chen, YangQuan — Univ. of California, Merced

With the rapid development of small imaging sensors and unmanned aerial vehicles (UAVs), remote sensing is undergoing a revolution with greatly increased spatial and temporal resolutions. While more relevant detail becomes available, it is a challenge to analyze the large number of images to extract useful information. This research introduces a new general framework to process high-resolution multispectral images based on Principle Component Analysis (PCA) for crop stress quantification. As a case study, this framework is applied in almond water stress quantification using UAV-based remote sensing images. First, crop distributions of pixel value of sample trees are obtained as histograms consisted of 255 bins, assuming the stress information lies in the overall canopy pixels and ignoring the spatial relations among pixels. Second, PCA is applied to extract principle components out of histograms of 255 dimensions. This approach is advantageous in that it makes no assumption about the underlying canopy distribution of pixel values. It is shown that the first principle component has a significant correlation with stem water potential. This method is also compared with the traditional method of using the mean values of canopy Normalized Difference Vegetation Index (NDVI) as a baseline, and it shows improved performance in predicting the water stress.

16:40-17:00 FrC4.4

Persistent UAV Security Presence Service: Architecture and Prototype Implementation, pp. 1800-1807

Park, Hyorin — KAIST, Department of Industrial and Systems Engineering
Lee, Brad Hyeong-Yun — KAIST
Morrison, James R. — KAIST

While unmanned aerial vehicles (UAVs) are a promising technology, they suffer from fundamental fuel and payload restrictions. A system of UAVs can be used to address these limitations. In this paper, we consider an automated system of UAVs seeking to provide an uninterrupted, or persistent, security presence to customers in an outdoor environment. We define the goals of such a system and provide architecture to achieve them. Various components such as the central director, mission planner and UAV service stations are introduced and analyzed. Following the architecture, we constructed prototypes of each component and implemented a small scale outdoor experiment. The experiment included receiving customers' orders, algorithmic implementation of UAV tasks and UAV control.

17:00-17:20 FrC4.5

Adaptive Model-Based Event-Triggered Consensus Control for Multi-Agent Systems with Unknown System Dynamics, pp. 1808-1815

Xu, Hao — Univ. of Nevada, Reno
Espinoza Quesada, Eduardo Steed — Univ. Pol. De Pachuca
GARCIA CARRILLO, Luis Rodolfo — Texas A&M Univ. - Corp. Christi
Frey, Andreas — Tech. Univ. of Ingolstadt
MUÑOZ PALACIOS, FILIBERTO — Univ. Pol. DE PACHUCA

The model-based event-triggered strategies have been developed as an alternate for Zero-Order-Hold (ZOH) based event triggered scheme in continuous-time for multi-agent systems (MAS). However, traditional event-triggered schemes need the knowledge of system dynamics whereas model-based schemes are sensitive to model uncertainties. Therefore, in this paper, a novel distributed event-triggered consensus control schemes are proposed for MAS with uncertain system dynamics. In the proposed approach, the system is considered completely unknown and the MAS model or state estimator is updated online. The update law for tuning the unknown parameters of the MAS model, and distributed event triggering condition are derived. Lyapunov theory is used to demonstrate that all the closed-loop signals and estimated MAS model parameters are asymptotically stable and consensus. Computer-aid simulation results are included to demonstrate the effectiveness of the proposed approach. Additionally preliminary work towards the implementation of the proposed strategies on a real-time MAS platform is described in order to emphasize the implications and the complexity of developing practical solutions for real applications.

FrC5 — San Marco Island
UAS Control - III

Chair: Lozano, Rogelio — Univ. of Tech. of Compiègne
Co-Chair: Campoy, Pascual — Univ. Pol. Madrid

15:40-16:00 FrC5.1

Neuro-Fuzzy Controller for Attitude-Tracking Stabilization of a Multi-Rotor Unmanned Aerial System, pp. 1816-1823

Cervantes Rojas, Jorge Said — Umi-Lafmia 3175 Cnrs

MUÑOZ PALACIOS, FILIBERTO — Univ. Pol. DE PACHUCA
Gonzalez-Hernandez, Ivan — Cinvestav - IPN
Salazar, Sergio — Umi Lafmia Cinvestav
Chairez, Isaac — Upibi - Ipn
Lozano, Rogelio — Univ. of Tech. of Compiègne

This paper deals with developing an automatic controller that solves the attitude stabilization for a Quadrotor unmanned aerial system (UAS). The controller used a simultaneous strategy of estimation and compensation of uncertainties as well as disturbances. The approach consisted of integrating a neuro-fuzzy system that implemented a set of differential neural networks (DNNs) as consequence section of Takagi-Sugeno (T-S) fuzzy inference. The combination of these two strategies applied on a Quadrotor UAS has the main purpose of forcing a hover flight while the tracking desired angular positions are attained. The control method identified the unknown nonlinearities and bounded external disturbances firstly. This information served to compensate the uncertain section of the Quadrotor dynamics. An additional section in the controller design enforces the stabilization of the tracking error with respect to a given reference trajectory. The control design methodology supported on the Lyapunov stability theory and guaranteed ultimate boundedness of the identification and tracking errors. Academic simulation tests confirmed the superior performance of the proposed algorithm based on the combination of DNNs and T-S techniques.

16:00-16:20 FrC5.2

Toward Vision Based Landing of a Fixed-Wing UAV on an Unknown Runway under Some Fov Constraints, pp. 1824-1832

Burlion, Laurent — ONERA France
de Plinval, Henry — ONERA - the French Aerospace Lab

In this article, a vision based landing framework is proposed for fixed-wing UAVs. Being able to automatically land a UAV without on-ground instrumentation or in the case of e.g. GPS loss, is a challenge of strong practical relevance. In this study, the Avion Jaune UAV, was considered to apply such a framework enabling it with vision-only landing capability. The proposed approach considers the synthesis of vision based flight control laws under some field of view (fov) constraints. Such constraints can however destabilize the UAV in the case of a very poor knowledge about the runway. This problem is addressed by using a vision based-observer in combination with an anti-windup strategy. Some simulation results show the effectiveness and potential of the method.

16:20-16:40 FrC5.3

GPI Controller for Quadrotor UAV Stabilization, pp. 1833-1839

Trejo Escamilla, Edgar G. — IPN
Romero, Hugo — Icbi - Uaeh
Santos, Omar — Univ. Autónoma Del Estado De Hidalgo
Salazar, Sergio — Umi Lafmia Cinvestav
Lozano, Rogelio — Univ. of Tech. of Compiègne

In this paper a Generalized Proportional Integral controller is synthesized in order to stabilize both attitude and position a four rotor mini helicopter. The main idea to use this kind of controller is to avoid the use of derivative terms and asymptotic observers in the design of the control law and consequently their respective numeric algorithms for the real-time implementation. So, these asymptotic observers and derivative terms are replaced by integral state reconstructor. The synthesized GPI control law is tested by numerical simulation considering a quadrotor dynamical model obtained by Euler-Lagrange formalism and obtained results are satisfactory and they suggest that the synthesized GPI control law can be tested in real-time flights.

16:40-17:00 FrC5.4

L1 Adaptive Control for Wind Gust Rejection in Quad-Rotor UAV Wind Turbine Inspection, pp. 1840-1849

Suárez Fernández, Ramón A. — Univ. Pol. De Madrid
Dominguez, Sergio — Univ. Pol. De Madrid
Campoy, Pascual — Univ. Pol. Madrid

This work presents preliminary results of the control method developed for autonomous inspection of wind turbines. High wind gusts are a major deterrent of outdoor Unmanned Aerial Vehicle (UAV) operations, in which, common classical control methods such as Proportional-Integral-Derivative (PID) control do not perform well. Therefore, more robust adaptive control methods must be employed. We propose the use of an L1 adaptive velocity controller that is capable of fast adaptation and guaranteed robustness while withstanding any disturbances encountered during flights. Considerable increase in performance of the L1 adaptive controller is demonstrated by comparing the proposed approach to a Linear Quadratic Regulator (LQR) method in simulation and a benchmark PID controller in several real flight experiments with added wind gusts.

17:00-17:20 FrC5.5

Leader-Follower Robust Formation Control for Quad-Rotors Via Continuous Sliding-Modes, pp. 1850-1857

González-Sierra, Jaime — CONACyT-TECNM/Inst. Tecnológico De La Laguna
Ríos, Héctor — CONACYT - TECNM/Inst. Tecnológico De La Laguna
Dzul, Alejandro — TECNM/Inst. Tecnológico De La Laguna

This paper deals with the problem of robust output regulation for a set of Quad-Rotors forming a geometric pattern. The proposed control strategy is based on sliding-modes techniques, and it is able to robustly regulate the corresponding Quad-Rotors positions and angles in the presence of some class of disturbances acting on the Quad-Rotors. The proposed regulation is composed by cascaded continuous sliding-modes controllers providing uniform finite-time stability and uniform exponential stability for the corresponding Quad-Rotors positions. Simulation results illustrate the feasibility of the proposed strategy.