

Institute of Navigation International Technical Meeting (ITM 2025)

Long Beach, California, USA
27 - 30 January 2025

Volume 1 of 2

ISBN: 979-8-3313-1577-1

Printed from e-media with permission by:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571



Some format issues inherent in the e-media version may also appear in this print version.

Copyright© (2025) by Institute of Navigation
All rights reserved.

Printed with permission by Curran Associates, Inc. (2025)

For permission requests, please contact Institute of Navigation
at the address below.

Institute of Navigation
8551 Rixlew Lane
Suite 360
Manassas, VA 20109
USA

Phone: (703) 366-2723
Fax: (703) 366-2724

membership@ion.org

Additional copies of this publication are available from:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: 845-758-0400
Fax: 845-758-2633
Email: curran@proceedings.com
Web: www.proceedings.com

TABLE OF CONTENTS

VOLUME 1

About ION

Acknowledgements

PLENARY SESSION

Global Geodetic Observation Systems - Global Challenges to a Shared Resource

J.N. Markiel

Precision Timing and the Quest to Capture Images of a Black Hole

Michael Johnson

ADVANCEMENTS IN NAVIGATION ALGORITHMS

Set-Based Position Ambiguity Reduction Method for Zonotope Shadow Matching in Urban Areas

Using Estimated Multipath Errors 1

Sanghyun Kim, Jiwon Seo

Utilization of 3DMAP to Enhance RTK-GNSS in Challenging Environments 11

Kaito Kobayashi, Ellarizza Fredeluces, Nobuaki Kubo

Visual Segmentation for Autonomous Aircraft Landing on Austere Runways 23

Alissa Owens, Clark Taylor, Scott Nykl

A High-Efficiency Doppler Frequency Parallel Acquisition Method Based on A-GPS 37

Qiongqiong Jia, Yuchen Zhao

Ambiguity-Resolved Positioning Performance in Interferometric Systems: Can Constraining Phase

Biases Play a Decisive Role? 47

Amir Khodabandeh, Songfeng Yang, Peter J.G. Teunissen

Research on Bluetooth/MIMU Integrated Navigation Algorithm Based on Factor Graph

Optimization 60

Meng gang Sheng, Jiajia Lu, Xiaowen Cai, Yangzhuo Chen, Zhiqiang Yao, Daifeng Zhang,

Deyi Peng, Xiaona Guo, Kang Chen, Wenwen Zhang

ALTERNATIVES, BACKUPS, COMPLEMENTS TO GNSS

Event-Based Vision and Factor Graph-Based Approach for Sensor Geolocation from Observations

of an Orbiting Satellite 69

Kaleb Nelson, Clark Taylor, Rachel Oliver

Reducing Computational Complexity of Rigidity-Based UAV Trajectory Optimization for Real-

Time Cooperative Target Localization 80

Halim Lee, Jiwon Seo

Time Transfer Performance of the Broadcast Positioning System™ (BPST™) 88

Tariq I. Mondal, Jeffrey A. Sherman, David A. Howe

On the Feasibility of a Carrier Phase-Based Velocity Solution from LEO Satellites	98
<i>Zhen Zhu, Sanjeev Gunawardena, Eric Vinande, Jason Pontious</i>	
Accuracy Analysis and Simulation of Angle of Arrival Estimation in 5G Positioning	107
<i>Zihao Li, Yanhong Kou, Chao Sun, Honglei Qin, Tian Jin</i>	
Integrating LEO Satellite Signal Doppler Measurements and DME/VOR for enhanced GNSS-Free Positioning and Fault Detection	122
<i>Jiyu Liu, Kun Fang, Xiaowei Lan, Kelin Zhong</i>	
Leveraging 5G-NR and DVB-S2X for Positioning in LEO-NTN.....	139
<i>Harshal More, Francesco Menzione, Ottavio M. Picchi, Mauro De Sanctis, Ernestina Cianca</i>	

ATMOSPHERIC EFFECTS, GNSS REMOTE SENSING, AND SCIENTIFIC APPLICATIONS

A Method of Estimating Residual Bending Error in GNSS-RO Absolute TEC	151
<i>Jaehee Chang, Andrew K. Sun, Jihyeok Park, Jiyun Lee, Jade Morton</i>	
Machine Learning Classification of Ionosphere and RFI Disturbances in Spaceborne GNSS Radio Occultation Measurements	161
<i>Tim Dittmann, Yu Jade Morton, Hyecheon Chang</i>	
Isolation of Ionospheric Events in GNSS Phase Scintillation Observations in the Arctic.....	177
<i>Sarah S. Beeck, Daniel H. Olesen, Cathryn N. Mitchell</i>	
The G4 Solar Storm of May 2024: Impact on the GNSS Carrier-Phase Measurements	189
<i>Giovanni Cappello, Ciro Gioia, Antonio Angrisano, Gabriele Portelli, Salvatore Gaglione</i>	
Effects of Unknown Radio Frequency Interferences on Ionospheric Scintillation Monitoring in Urban Environments.....	200
<i>Weilin Gong, Kai Guo, Zhipeng Wang, Yiming Wang</i>	
Impact of Ionospheric Disturbances on NIC and NACp Degradation in ADS-B Messages	211
<i>Toru Takahashi, Anurak Pongpeaw, Susumu Saito, Tadashi Koga, Pornchai Supnithi, Jirapoom Budtho</i>	
Preliminary Results of Nearshore Ice and Water Level Monitoring in Arctic Using Single Antenna Ground-Based Reflectometry	216
<i>Althaf Azeez, Jihye Park, Andrew Mahoney</i>	
Time-Domain Modeling And Prediction of Global Ionospheric Total Electron Content: Applications of Attention Mechanisms	229
<i>Xingyu Liu, Yufei Wang, Kunlin Yang, Yang Liu</i>	

AUTONOMOUS NAVIGATION AND SAFETY-CRITICAL APPLICATIONS

Gaussian Bounding for Multivariate Distributions with an Application to GNSS Integrity.....	243
<i>Juan Blanch, Rebecca Wang, Todd Walter</i>	
Terrestrial Navigation Alternatives to Support PBN for Current and Future Aviation	253
<i>Okuary Osechas, Gary McGraw</i>	
Offline Covariance Prediction for Lidar-Based Map-Matching in Autonomous Systems.....	268
<i>Hadi S. Wassaf, Jonathon Poage, Jason H. Rife</i>	

Investigation on New Fuzzing Techniques to Address Navigation System Testing	290
<i>Nina Haag, Christophe Ouzeau, Lotfi Fejri, Patrick Bartolone, Antoin Blais, Daniel Prun</i>	

GNSS INTEGRITY AND AUGMENTATION

From Ground to Air: The Paradigm Shift in GBAS Monitoring and Its Benefits	305
<i>Michael Felux, Michael Nietlispach</i>	
Initial Considerations About Alternative Approaches for Sigma Ground Processing in GAST E.....	318
<i>Michael Nietlispach, Michael Felux</i>	
Enhancing Availability of SS-RAIM Based CDGNSS Using Integer Aperture Bootstrapping.....	331
<i>Dongchan Min, Jiyun Lee</i>	
Protecting Against Receiver Faults to a PPP Ground-Based Integrity Monitor System.....	343
<i>Yu-Fang Lai, Juan Blanch, Todd Walter</i>	
Time-Differenced Carrier Phase Based Integrity Monitoring in Urban Environment.....	359
<i>Hojoon Jeong, Chandon Kee, Junesol Song</i>	
Approach to Utilizing SFMC SBAS Message for Dual-frequency Users to Enable Universally Applicable SBAS	370
<i>Jina Lee, Yongrae Jo, Byungwoon Park, Donguk Kim</i>	
Development and Evaluation of a Multi-constellation Multi-frequency GBAS Prototype for Air Navigation	378
<i>Felipe Tintino Linhares de Souza, Weverton da Costa Silva, Crislaine Menezes da Silva, Italo Tsuchiya, João Francisco Galera Monico</i>	

GNSS SECURITY: INTERFERENCE, JAMMING, AND SPOOFING 1

Evaluation of NovAtel's Jamming and Spoofing Detection and Mitigation Capabilities During Jammertest2024.....	401
<i>Ali Broumandan, Ali Pirsiavash, Isabelle Tremblay, Sandy Kennedy</i>	
Real-World Spoofing Detection and Characterization Using Low-Cost Receivers.....	414
<i>Argyris Kriezis, Yu-Hsuan Chen, Dennis Akos, Sherman Lo, Todd Walter</i>	
Observations of GNSS Spoofing in Russia in 2023-2024	425
<i>Sherman Lo, Zixi Liu, Lyla Ibrahim, Yu Hsuan Chen, Todd Walter</i>	
Navigating Interference - Examining In-Flight GNSS Spoofing Patterns and Signal Disruptions	443
<i>Michael Felux, Valentin Fischer, Sophie Jochems, Benoit Figuet, Raphael Monstein</i>	
Combining ADS-B, LCM and DPA to Detect and Locate the Interference in a Massive GNSS Jammer Test.....	453
<i>Yu-Hsuan Chen, Zixi Liu, Argyris Kriezis, Sherman Lo, Todd Walter</i>	
Real-Time Multi-Constellation Navigation Message Authentication for Enhanced GNSS Security	464
<i>Xifeng Wen, Tor Melgård, Roel de Vries, Erik Vigen, Armine Panosyan</i>	

VOLUME 2

Authentication of GPS Modernized Signals Using TESLA Chimera.....	479
<i>Michael H. Cole, James T. Gillis, Rachel I. Allen, Albert H. Hayden</i>	
Towards a Trustworthy Position Solution; OSNMA Authentication and the use of Multi-Constellations	494
<i>Annemarie van Zwol, Heiko Engwerda, Kjeld van der Linden</i>	
A Low Complexity Implementation of the MLE-Based GNSS Anti-Spoofing Method	502
<i>Xiaoxuan Xu, Hong Li, Mingquan Lu</i>	
A New Method for AOA Estimation and TDOA/AOA Joint Localization of GNSS Spoofer.....	521
<i>Mingxiu Chen, Yanhong Kou, Yiwei Wang, Chun Wang</i>	
Co-Frequency Interference and Suppression of GBAS VDB and VOR/ILS Based on the Fast Independent Component Analysis	542
<i>Ziqi He, Hongxia Wang, Kun Fang, Xiao Li</i>	

GNSS SECURITY: INTERFERENCE, JAMMING, AND SPOOFING 2

Detection and Identification of Inauthentic Signals Based on the Frequency Drift of the GNSS Receiver Clock	554
<i>Zhen Zhu, Sanjeev Gunawardena, Mark Carroll, Nathan Pax, Eric Vinande, Jason Pontious</i>	
Consumer INS Coupled with Carrier Phase Measurements for GNSS Spoofing Detection	562
<i>Tore Johansson, Marco Spanghero, Panos Papadimitratos</i>	
Performance of Optimal INS Monitor Against Live Spoofing	579
<i>Birendra Kujur, Samer Khanafseh, Boris Pervan</i>	
Evaluation for BDSBAS Single-Frequency Service Assisted by Data Authentication	590
<i>Xiaoshuang Li, Kun Fang, Hongwen Wang, Shujing Wang, Zhipeng Wang</i>	

NEXT-GENERATION SATELLITE NAVIGATION TECHNOLOGY

An Analysis of Inter-Satellite Link Topologies in Future GNSS Constellations: Operational Constraints and Figures of Merit.....	604
<i>Giulia Schievano, Gabriele Giorgi, Grzegorz Michalak</i>	
Modernizing C/A Code.....	615
<i>Philip A. Dafesh, Gourav K. Khadge, Jason W. Zheng</i>	
Development of a Robust Positioning Method for Unknown Radio Sources Using Satellite Constellations	632
<i>Hirofumi Fukushima, Toshihiro Ito, Yuki Takabayashi</i>	
Accuracy Degradation Rate of LEO Satellite Predicted Orbits Using Different POD Methods	646
<i>Jiawei Liu, Kan Wang, Beixi Chen, Ahmed El-Mowafy, Amir Allahvirdi-Zadeh, Xuhai Yang</i>	
Research on Trusted Positioning, Navigation, and Timing: Concept, Framework and Perspective	658
<i>Shuren Guo, Lei Chen, Xiao Chen, Weiguang Gao, Hongliang Cai, Hong Yuan, Xiang Tian</i>	

PNT SOLUTIONS FOR SPACE APPLICATIONS

GNSS-Based Spaceborne Inverse VLBI for Cislunar Autonomous Navigation	674
<i>Chun Yang, Andrey Soloviev, Khanh Pham</i>	
Localization of Ad-Hoc Lunar Constellations in Communication Failure Modes for Distributed Spacecraft Autonomy	697
<i>Yeji Kim, Brian Kempa, Caleb Adams, Richard Levinson, Jeremy Frank</i>	
The Design of a Flexible, Interoperable Navigation Signal for Future Lunar Missions.....	712
<i>Philip A. Dafesh, Nathan Wong, Gourav K. Khadge, Goran Djuknic, Juan Crenshaw, Brian C. Peters, Cheryl Gramling, Floor Melman, Cosimo Stallo, Richard Swinden, Masaya Murata</i>	
Design of Navigation Satellite Constellation for Global Lunar PNT	732
<i>Minjae Kang, Hojoon Jeong, Jaewuk Park, Changdon Kee</i>	
High Precision Spacecraft Landing on the Moon Through Lunar Satellite Navigation Systems and Local Ultra-Wideband Positioning Network	742
<i>Danim Jung, Euiho Kim</i>	
Robust Precise on Board Orbit Determination Exploiting T-RAIM for LEO-PNT.....	757
<i>F. Menzione, C. Gioia, A. Piccolo, S. Casotto, M. Bardella</i>	
Clock Transfer and Positioning Method in Cislunar Space by Innovative Hybrid Device.....	770
<i>Shingo Nishimoto, Junichiro Kawaguchi</i>	
Predicted Orbit Determination Performance of a Lunar Navigation System: Utilizing Inter-Satellite Measurements with Batch and EKF Estimation	784
<i>Sungik Kim, Jisung Oh, Byungwoon Park</i>	

PRECISE GNSS POSITIONING APPLICATIONS

IONO4HAS, a Real-Time Ionospheric Model for Galileo High Accuracy Service, SL2. Results and Validation	805
<i>José M. Juan, Cristhian C. Timote, Jaume Sanz, Adria Rovira-Garcia, Guillermo González- Casado, Angela Aragon-Angel, Yu Yin, Jorge García-Mateos, Raúl Orús-Pérez, Ignacio Fernández-Hernández</i>	
Recent Updates of Multi-GNSS Advanced Demonstration Tool for Orbit and Clock Analysis (MADOCA).....	819
<i>Kento Ichinomiya, Yo Kawashima, Musashi Kato, Nobuhiro Kajiwaru, Kuniharu Endo, Kyohei Akiyama, Kaori Kawate, Yuki Igarashi, Toshitaka Sasaki</i>	
MADOCA-PPP/INS Tightly Coupled Integration Based on RTKLIB for Moving Vehicles	829
<i>Hideki Yamada, Saya Matsushita, Keito Yoshida, Fuya Ezuka, Tatsuya Nagano, Satoshi Kogure</i>	
Evaluating the Performance of Low-Cost PPPRTK Using Fugro's NextG4 Service	840
<i>Dennis Odijk, Xianglin Liu, Yahya Memarzadeh, Artur Oruba</i>	
An Architecture for Seamless Handover of PPP-RTK Corrections Across Redundant Networks.....	854
<i>Cheolmin Lee, Sulgee Park, Sanghyun Park</i>	
Design Strategies for RTK Systems for Universal Application in Various Fields	863
<i>Yongrae Jo, Byungwoon Park</i>	

RECEIVER DESIGN, SIGNAL PROCESSING, AND ANTENNAS

Optimizing High-Rate Scintillation Data Downlinks in Radio Occultations	872
<i>Tibor Durgonics, Paul Strauss, Margaret Chen, Endawoke Yizengaw, Jun Wang, Dominic Fuller-Rowell, Tzu-Wei Fang</i>	
Novel Shortened Polar Codes for GNSS L1C Subframes 2 and 3	885
<i>Nuwan J. G. Kankanamge, Nghi H. Tran, Khanh Pham, Dan Shen, Genshe Chen</i>	
The Synthetic Meta-Signal Observations: A Multipath Resistance Assessment	896
<i>Giovanni Cappello, Ciro Gioia, Antonio Angrisano, Salvatore Gaglione</i>	
Detection and Mitigation of NLOS and Multipath Effects Using Multi-Task Learning	906
<i>Ellarizza Fredeluces, Nobuaki Kubo</i>	
Analysis of Doppler Frequency and Doppler Frequency Rate Characteristics for Vehicular GNSS Receivers in Urban Environments	914
<i>Zhihang Qu, Yong Li, Wenhui Yang, Daifang Huang</i>	
Design of Dual-Mode DPE Receiver Based on GPS L1/BDS B1C Signals	928
<i>Qiongqiong Jia, Qiqi Guo</i>	
Preliminary Assessment of BDS-3 B1 and B2 Wideband Multiplexed Signal in Enhancing Ranging and Positioning Performance.....	937
<i>Jiahe Chen, Yunhan Qi, Caoming Fan, Zheng Yao, Mingquan Lu</i>	

SENSOR-FUSION FOR GNSS-CHALLENGED NAVIGATION

Increasing Positioning Accuracy in Urban Environments Using Radar-Based Point Clouds	950
<i>Zheng Yu Lang, Emma Dawson, Paulo Ricardo Marques de Araujo, Aboelmagd Noureldin</i>	
Improving GNSS Performance with Fish-eye Camera Integration and Robust Kalman Filter	961
<i>Arunima Das, Patrick Henkel</i>	
A High Availability Inertial-Vision Data Fusion Using an ES-KF for a Civil Aircraft During a Precision Approach in a GNSS-Challenged Environment.....	976
<i>Gabriel Thys, Christophe Macabiau, Julien Lesouple, Jérémy Vezinet, Anaïs Martineau, Raphaël Jarraud</i>	
Aircraft Taxi Guidance and Positioning Method Based on Onboard Forward View Cameras	992
<i>Shuguang Zhang, Hongwu Liu, Hongxia Wang, Kun Fang, Kelin Zhong</i>	
PF-LIO: Tightly-Coupled Lidar-Inertial Odometry Based on Plane Fusion	1008
<i>Daifang Huang, Yong Li, Wenhui Yang, Zhihang Qu</i>	

Author Index