



**ION®**  
INSTITUTE OF NAVIGATION

# GNSS+

# 2023

The 36th International Technical Meeting of the Satellite Division of the Institute of Navigation



## September 11 - 15, 2023

Exhibit Hall: September 13 - 14

Hyatt Regency Denver

(adjacent to the Colorado Convention Center)

Denver, Colorado

## ADVANCE PROGRAM

[ion.org](http://ion.org)



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# Pre-Conference Short Courses: Monday, September 11

Included with all paid full-conference registrations

Monday's short courses are provided on a complimentary basis to all paid ION GNSS+ attendees, with the compliments of the Satellite Division and the ION Master Instructors. ION Master Instructors are internationally recognized GNSS experts and educators. All of the ION Masters have generously donated their time and talents to this effort, as a service to the GNSS community, with the ION's gratitude.

Short courses are presented lecture-style. Course notes are the intellectual property of the ION Master Instructor, and are provided to registered attendees via the meeting website, at the discretion of the instructor.

**1:30 p.m. - 3:00 p.m.**

## Masters Course

### GPS/GNSS 101

**Dr. John Raquet, IS4S**

This course presents the fundamentals of the GPS, and other GNSS, and is intended for people with a technical background who do not have significant GPS experience. Topics covered include time-of-arrival positioning, overall system design of GPS, signal structure, error characterization, dilution of precision (DOP), differential GPS, GPS modernization, and other GNSS systems.



Dr. John Raquet is currently the director of IS4S-Dayton. Previously, he was the founding director of the Autonomy and Navigation Technology (ANT) Center at AFIT. He has published over 170 navigation-related conference and journal papers and taught 60 navigation-related short courses to over 3600 students in many organizations. He is an ION Fellow and past president. Dr Raquet holds a BS in Astronautical Engineering from the USAFA, an MS in Aero/Astro Engineering from MIT, and a PhD in Geomatics Engineering from the University of Calgary.

## Masters Course

### Space Applications of GNSS

**Dr. Penina Axelrad, University of Colorado Boulder**

GNSS receivers have become standard equipment for near-earth satellites, providing the onboard position, velocity, and timing information required to support real-time operations. Furthermore, precise GNSS observations from both direct and indirect paths collected onboard these platforms are used to support scientific and commercial purposes including characterization of Earth's atmosphere, measurement of ocean surface heights, and extraction of time varying features of Earth's gravity field. New advances in receiver technology and detailed modeling of the environmental influences on GNSS satellites and signals continue to expand the utility of GNSS to ever finer orbit resolution, and higher altitude missions – even to the point of being planned to support lunar exploration missions. This short course will present an

overview of the many applications of GNSS in space, and describe the unique challenges and requirements for its use in the space environment.



Dr. Penina Axelrad is Joseph T. Negler Professor of Aerospace Engineering Sciences at the University of Colorado Boulder. Her research interests include technology and algorithms for position, navigation, timing, and remote sensing – especially in spaceborne applications. She is a past ION president, a Fellow of ION and AIAA, and a member of the National Academy of Engineering.

**3:30 p.m. - 5:00 p.m.**

## Masters Course

### GNSS Jamming and Spoofing – LEO as Fallback

**Dr. Todd Humphreys, The University of Texas at Austin**

Intentional jamming and spoofing of GNSS signals is by now a widespread phenomenon. Especially common near conflict regions, but not limited to these, such interference erodes trust in GNSS and compromises safety in air and marine travel and shipping.

This tutorial will examine: 1) patterns of GNSS interference across the globe; 2) its effects on GNSS receivers; and 3) techniques for its detection and mitigation. The tutorial will highlight cooperative and non-cooperative use of signals from low-Earth-orbit (LEO) mega-constellations as an especially promising mitigation strategy. Compared to traditional GNSS, LEO constellations offer higher power, wider bandwidth, more rapid multipath decorrelation, and the possibility of stronger authentication and zero-age-of-ephemeris, all of which will enable greater accuracy and greater resilience against jamming and spoofing.



Dr. Todd E. Humphreys holds the Ashley H. Priddy Centennial Professorship in Engineering in the department of Aerospace Engineering and Engineering Mechanics at the University of Texas at Austin. He is director of the Wireless Networking and Communications Group and of the UT Radionavigation Laboratory, where he specializes in the application of optimal detection and estimation techniques to positioning, navigation, and timing. His awards include the UT Regents' Outstanding Teaching Award, the NSF CAREER Award, the ION Thurlow Award, and the PECASE. He is Fellow of the ION and of the RIN. He holds a BS and MS from USU and PhD from Cornell.

## New and Now

### LEO PNT – Architectures and Performance Trades

**Dr. Tyler Reid, Xona Space Systems**

Several emerging providers are targeting low Earth orbit (LEO) to deliver complementary and alternative position, navigation, and time (PNT) to meet the stringent requirements of certain applications. Here, we examine the system architectural elements, similarities and differences to medium Earth orbit (MEO) global navigation satellite systems (GNSS), and performance trades that result. The result is a system that takes a different form than the now familiar arrangement of around thirty satellites in MEO each with an atomic frequency standard as is the case with GNSS, as it is often driven by fundamentally different requirements. LEO-based satellite navigation has the potential to introduce new signals to complement existing GNSS in MEO to provide resilience, security, and high precision to navigation users.



Dr. Tyler Reid is a co-founder and CTO of Xona Space Systems. Previously, Tyler worked as a research engineer at the Ford Motor Company in the localization and mapping group for self-driving cars. He has also worked as a software engineer at Google and as a lecturer at Stanford University, where he co-taught the GPS course. He is a recipient of the RTCA's Jackson Award. Dr. Reid received his MSc and PhD in Aeronautics and Astronautics from Stanford University, where he worked in the GPS Research Lab.

# Pre-Conference Tutorials: Tuesday, September 12

(Additional registration/fee required; tutorials will not be live-streamed)

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## Multi-constellation GNSS Signals and Systems

**Date:** Tuesday, September 12, 2023

**Time:** 9:00 a.m. - 12:30 p.m.

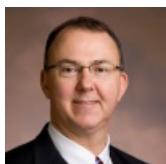
### Course Registration Fee:

\$450 if paid on or before August 11

\$500 if paid after August 11

This course emphasizes the fundamentals of multi-constellation GNSS. The course begins with an overview of GNSS followed by presentations on each of the GNSSs in operation and/or development today. The course will highlight common features of the various GNSSs and point out key differences between them. Topics to be covered include:

- GNSS segments; space, ground, user segments
- GNSS link budget
- Fundamental concept of GNSS position and time determination
- GNSS coordinate frames, datums and time
- GNSS signal structure formats: carrier, code, data
  - Direct sequence spread spectrum; auto and cross correlation
- GNSS antenna & receiver technologies - overview
- GPS Legacy: C/A, P(Y) code and NAV formats
- GPS Modernized: L2C, L5, L1C, CNAV and CNAV-2 formats
- GLONASS
  - GLONASS SV versions
  - Legacy C/A, P codes and FDMA signals
  - Modernized CDMA codes and frequencies
- Galileo, E1, E6/E6P, E5a, E5b, AltBOC, SAR Codes, frequencies and data formats
- BeiDou, BDS I, BDS II, BDS III, B1, B2, B3 signals and formats
- SBAS used throughout the globe
- QZSS, L1, L2, L5, L6 signals, codes and services
- NAVIC: L5, S band signals, message types
- GNSS corrections for clock, code, atmospheric, transit time, etc.
- GNSS user solutions



**Dr. Chris G. Bartone, P.E.**, is a professor at Ohio University with over 35 years of professional experience and is an ION Fellow. He received his Ph.D.EE from Ohio University, a M.S.EE from the Naval Postgraduate School, and B.S.EE from Penn State. Dr. Bartone has developed and teaches a number of GPS, radar, wave propagation and antenna classes. His research concentrates on all aspects of navigation.

# Pre-Conference Tutorials: Tuesday, September 12

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## GNSS Integrity

**Date:** Tuesday, September 12, 2023

**Time:** 9:00 a.m. - 12:30 p.m.

### Course Registration Fee:

\$450 if paid on or before August 11

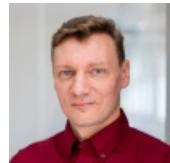
\$500 if paid after August 11

This course will describe (Part 1) fundamental concepts in GNSS integrity, (Part 2) successful implementations in aviation applications, and (Part 3) major challenges in future autonomous navigation for air, ground, and sea transportation. This year's version of the course will emphasize Receiver Autonomous Integrity Monitoring (RAIM); it will include a handout on RAIM theory and a set of problems with solutions and MATLAB codes.

In Part 1, we will define navigation safety metrics and requirement parameters including integrity and continuity risks, alert limit, time to alert, and exposure period. We will identify the three major over-bounding methods used to derive high-integrity signal-in-space error models. We will show the impact a GNSS fault such as, for example, an excessive satellite clock drift. We will outline how integrity-monitoring responsibilities can be allocated between reference and user receivers and how prior probabilities of satellite faults are evaluated.

In Part 2, we will briefly describe the major implementations used in aviation applications: the Ground-Based Augmentation Systems (GBAS), the Space-Based Augmentation Systems (SBAS) and the Aircraft-Based Augmentation System (ABAS). We will focus on RAIM and Advanced RAIM; we will use graphical tools of failure mode curves and parity space representations to identify differences between solution separation and chi-squared approaches. We will show recent developments in ARAIM intended to optimize ARAIM integrity and continuity monitoring performance while limiting computational load.

In Part 3, we will review recent efforts in standard developments and performance evaluations to achieve safe navigation in aviation, maritime, railway, and automotive applications. We will discuss recent research on robust modeling of measurement error time correlation that enables high-integrity Kalman filtering of combined GNSS and inertial data. We will identify major challenges in implementing precise point positioning (PPP) and real time kinematic (RTK) to simultaneously achieve high accuracy and high integrity.



**Dr. Mathieu Joerger** is an assistant professor at Virginia Tech, recipient of ION's Parkinson Award (2009) and Early Achievement Award (2014). He is the senior editor on Navigation for IEEE TAES and a member of EU/US ARAIM Working-Group-C and of RTCM's Integrity Monitoring for High Precision Applications (SC-134). He received his PhD from Illinois Institute of Technology.

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## Factor Graphs

**Date:** Tuesday, September 12, 2023

**Time:** 9:00 a.m. - 12:30 p.m.

### Course Registration Fee:

\$450 if paid on or before August 11

\$500 if paid after August 11

While the Kalman Filter (KF) family (linear KF, EKF, UKF, etc.) has been the workhorse of navigation systems for several decades, the factor graph is a generalization of the Kalman Filter that offers improved performance for non-linear systems and is more easily applied to complex systems. The goal of this tutorial is to take a practitioner who is familiar with the Extended Kalman filter and introduce them to factor graphs. By the end of the tutorial, the attendants should be able to create a simple factor graph system and will have been exposed to some of the more advanced concepts that make factor graphs an exceptional choice for navigation problems.

More specifically, this tutorial will introduce the factor graph representation of dynamic systems and how this representation is equivalent to a weighted least squares problem that can be solved with sparse matrix computational tools. We will demonstrate the (surprisingly low) computational costs of factor graphs and methods used to keep those costs low. We will also introduce popular software packages that can be used to solve factor graph problems, including GTSAM. Complex estimation problems that can be difficult to handle with other estimation frameworks will be introduced in the factor graph framework and example solutions to these problems will be demonstrated.



**Dr. Ryan Watson** currently works at Xona Space Systems enabling integrity for their LEO satellite navigation constellation. He previously worked at the NASA Jet Propulsion Laboratory and the Johns Hopkins University Applied Physics Laboratory on problems related to state estimation/data fusion for robotic and space missions. He holds a PhD from West Virginia University.



**Dr. Clark Taylor** is an assistant professor in the ANT Center at the Air Force Institute of Technology. He received his PhD from University of California, San Diego, and previously worked as a senior research engineer with the Air Force Research Laboratory and an assistant professor in electrical engineering at Brigham Young University.

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## GNSS for Remote Sensing of Ionosphere, Troposphere, and Earth Surface

**Date:** Tuesday, September 12, 2023

**Time:** 9:00 a.m. - 12:30 p.m.

### Course Registration Fee:

\$450 if paid on or before August 11

\$500 if paid after August 11

GPS/GNSS has impacted nearly every aspect of our modern society. Yet, it relies on extremely low power signals traversing a vast space to reach receivers on the Earth surface. Numerous factors interfere with the signals along their propagation path, including ionosphere plasma, moisture in the lower troposphere, and multipath reflections from the Earth's surface. Understanding these effects on navigation signals is the pre-requisite for developing robust navigation technologies. Moreover, these effects enable satellite navigation signals to function as signals-of-opportunity for low cost, distributed, passive sensing of the signal propagation environments.

This tutorial will discuss the effects of the space and local environments on GNSS signals, followed by the latest technology development to utilize GNSS signals for space weather monitoring, atmospheric profiling, ocean wind and soil moisture retrieval, and precision altimetry measurements over ocean, sea ice, inland water bodies, and land cover. Ground-based and LEO satellite-based systems will be discussed.



**Dr. Jade Morton** is Helen and Hubert Croft professor and director of the Colorado Center for Astrodynamics Research at the University of Colorado Boulder. Her research expertise lies at the intersection of satellite navigation technologies and remote sensing of the ionosphere, troposphere, and the Earth's surface. She received her PhD in EE from Penn State and was an Electrical Engineering Professor at Colorado State University and Miami University before she joined University of Colorado. Dr. Morton is a recipient of the IEEE Richard Kershner award; and Institute of Navigation's Burka, Kepler, Thurlow, and Distinguished Service awards. She is a fellow of the IEEE, the Institute of Navigation, and the Royal Institute of Navigation.

# Pre-Conference Tutorials: Tuesday, September 12

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## Indoor Navigation and Positioning

**Date:** Tuesday, September 12, 2023

**Time:** 1:30 p.m. - 5:00 p.m.

### Course Registration Fee:

\$450 if paid on or before August 11

\$500 if paid after August 11

This course will provide an overview of the Indoor Positioning and Indoor Navigation (IPIN) system. Starting from the markets and applications using IPIN, we will introduce the popular technologies and sensors related. Then, an IPIN framework will be introduced that consists of the source space, algorithm space, and integration. After introducing the single point positioning (SPP), we will discuss dead reckoning (DR).

Regarding the data sources of SPP, we separate the sources into homogeneous (geometry based) ones and heterogeneous (scene matching/analysis based) ones. The former ones contain the measurements model of RSS-ranging, AOA, TOA and TDOA while the latter ones contain the fingerprint and other transformed data sources that used to match with pre-surveyed databases. The error and limitation of the SPP will be discussed. The popular DR, using inertial, LIDAR, and visual sensors, namely PDR, LO, and VO, is also introduced before the sensor integration. Finally, the integration based on EKF and FGO is briefly introduced.

The course is suitable for the entry-level R&D students, researchers and engineers who will be working on the projects of IPIN. This course will also appeal to the managers and executives who wish to start a new project and application based on IPIN. The course will conclude with a discussion on the future direction of the indoor positioning system with the coming IoT and 5G era.



**Dr. Li-Ta Hsu**, born in Taiwan, is an associate professor in The Hong Kong Polytechnic University where he directs the Intelligent Positioning and Navigation Lab focused on the navigation for pedestrian and autonomous driving in urban canyons. His research interest is positioning in GNSS challenged environments.

# Pre-Conference Tutorials: Tuesday, September 12

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## GNSS in the National Airspace

**Date:** Tuesday, September 12, 2023

**Time:** 1:30 p.m. - 5:00 p.m.

### Course Registration Fee:

\$450 if paid on or before August 11

\$500 if paid after August 11

This course will describe the use of the Global Navigation Satellite System (GNSS) to support air navigation. Particular attention will be paid to challenges that can affect the availability and safety of GNSS based navigation. The currently operating systems that augment the Global Positioning System (GPS) will be described. These are Aircraft Based Augmentation Systems (ABAS), Ground Based Augmentation Systems (GBAS), and Satellite Based Augmentation Systems (SBAS). They support differing flight operations and different levels of operations. Each method is described in detail and how it overcomes the challenges to provide suitable guidance.

The main challenges that must be overcome are satellite faults, ionospheric effects, tropospheric effects, local reflections of the signals at the aircraft, and radio frequency interference. This course will describe each effect in detail and how they are addressed. Aircraft navigation is judged by four criteria: accuracy, integrity, continuity, and availability. How well each system performs on these metrics will be described. The course will also describe how these systems have been and are being integrated into the national airspace. The course will conclude with a discussion on the future direction of these augmentation systems utilizing new signals and new GNSS constellations.

*This course is suitable for all interested parties who have at least an introductory knowledge of satellite navigation. A brief review of the elements of GNSS most relevant to augmentation systems will be provided. No previous knowledge of differential GNSS, augmentation systems, or integrity algorithms is needed.*



**Dr. Todd Walter** received his Ph.D. in Applied Physics from Stanford University. He is a research professor in the Department of Aeronautics and Astronautics at Stanford University. His research focuses on implementing high-integrity air navigation systems. He has received the ION's Thurlow and Kepler awards. He is an ION Fellow and past president.

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## PNT for sUAVs

**Date:** Tuesday, September 12, 2023

**Time:** 1:30 p.m. - 5:00 p.m.

### Course Registration Fee:

\$450 if paid on or before August 11

\$500 if paid after August 11

Small Unmanned Aerial Vehicles (sUAVs) are becoming increasingly ubiquitous. While their utilization may not have quite hit projections offered by venture capitalists over the last decade, these vehicles have found utility and have been incorporated into products in a wide variety of ways, for example: remote-control flying, photography and videography, infrastructure/agriculture/construction site inspection, product/medical delivery, racing, mapping, intelligence, surveillance and reconnaissance (ISR), and defense.

sUAVs have been and will continue to be fantastic platforms for enabling research in GNC, PNT, and many other disciplines. A key reason is that sUAVs offer the unique constraint of coupling low size, weight, and power (SWAP) with a critical need for urgency and timeliness of PNT and control information. This class will review the consequences of this unique constraint and the influences on both sensors and algorithms.

This course is a hands-on introduction and review of PNT for sUAVs and will provide in-depth information on current sensors, autopilots, software architectures, and algorithms for PNT. One key algorithm for navigation for sUAVs has been visual-inertial odometry (VIO). This modality, often enabled by machine learning approaches, has been optimized to strike the unique balanced required for the SWAP-timeliness constraint mentioned. This class will provide a hands-on, deeper dive into VIO methods and provide python examples to promote further understanding.

This course is applicable for those wanting to utilize UAVs for research, as well as those desiring to better understand the current state of the art in PNT for sUAVs. Pre-requisites and equipment: a basic understanding of PNT topics, including estimation and sensor fusion and object-oriented programming and Python programming language familiarity for the VIO software projects. Attendees will need their own charged laptops if they want to work on the projects in-class. Relevant course materials/notes and software examples are provided to registered attendees in advance.



**Dr. Rob Leishman** is currently the PNT area lead with Draper. Formerly, he was director of the Autonomy and Navigation Technology (ANT) Center at the Air Force Institute of Technology. There Dr. Leishman led a team of researchers and students in developing cutting-edge, defense-focused autonomy and navigation technologies, primarily for sUAVs.

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## Introduction to Cryptography with Navigation

**Date:** Tuesday, September 12, 2023

**Time:** 1:30 p.m. - 5:00 p.m.

### Course Registration Fee:

\$450 if paid on or before August 11

\$500 if paid after August 11

This tutorial offers a brief, broad, and benign overview of cryptography. We will begin with the three main cryptographic methods: symmetric ciphers, hashes, and public key cryptography. These methods will be illustrated using a variety of non-navigation examples, along with a discussion of how to implement them in practice, such as using OpenSSL. We will describe the necessary enablers of cryptography, such as key management. Finally, we will show the various places cryptography is used in navigation applications, including current implementations.



**Dr. Joe J. Rushanan** is a principal mathematician in the Communications, SIGINT, & PNT department of The MITRE Corporation. He was part of the M-code signal design and the L1C signal design teams and was the 2019 recipient of ION's Capt. P.V.H. Weems award for his sustained contributions to the design on GPS. Additionally, he currently teaches cryptography for Northeastern University's Khoury College Cybersecurity graduate program. He received his BS/MS and PhD in mathematics respectively from The Ohio State University and the California Institute of Technology.

# ION GNSS+ Technical Sessions

## Smartphone Decimeter Challenge (Co-sponsored by Google)

**Date:** Tuesday, September 12, 2023

**Time:** 1:30 p.m. - 3:30 p.m.

### Session Chairs



**Dr. Michael Fu**  
Google Inc.



**Justyna Redelkiewicz**  
EUSPA

### Track Chair



**Dr. LI-TA HSU**  
*The Hong Kong Polytechnic University*

## Smartphone Decimeter Challenge Workshop, Sponsored by Google

The new year's competition will be announced and described. A summary of innovative ideas collected over the last two years of the competition will be reviewed. The following will be addressed:

- Details about the data sets
- How the data collection is made will be addressed
- How the ground truth is computed
- How the time synchronization is made between sensors
- The meaning of the different fields in the datasets
- The effort made by Google to ensure the quality of the ground truth
- Questions from the audience related to data, Kaggle platform, etc.

This session will only be available to in-person attendees. This session is included in the cost of a full ION GNSS+ conference registration. Separate registration is not required to attend, but your conference badge will be required.

# ION GNSS+ Plenary Session

Tuesday, September 12, 2023 • 6:30 p.m.–8:30 p.m.

The plenary session will be recorded and made available to registered attendees on the conference's virtual portal.



## Welcome, Meeting Highlights and Introduction of Technical Committee

Satellite Division Chair  
Sandy Kennedy  
*Hexagon*



## Opening of the Plenary Session

Plenary Chair  
Dr. Dorota Grejner-Brzezinska  
*The Ohio State University*

## Keynote Addresses

### Where Pokémon GO: Building a Dynamic 3D AR Map of the World

Brian "Bam" McClendon

*DSVP Engineering and Board Member, Niantic*

Controlling a fleet of uncrewed robotic ships from remote locations with Autonomous Underwater Vehicles (AUVs) that gather information from the shallowest and deepest waters with speed, scale, and precision present unique navigational challenges. Locating and analyzing seabed assets and completing detailed mapping and survey tasks covering vast areas of the seabed require continuous precise locations for both above water and underwater vehicles. This plenary address will present the challenges faced under normal and off-nominal operations and the pioneering navigational technologies used to overcome these challenges.



Dr. Brian "Bam" McClendon leads ARGeo at Niantic, which includes AR, mapping, research and webAR (8th Wall). He was part of the founding team at Keyhole, which would become Google Earth. Dr. McClendon led the Geo team at Google that built Google Maps, Google Earth and Street View, before leading engineering work at Uber.

### New North Stars: The Dawn of Commercial Space Stations and their Impact on Navigation Technologies and Applications

David Marsh

*Space Station Strategy Lead, Nanoracks*



David Marsh is the Space Station Strategy Lead for Nanoracks, where he is responsible for charting the development and implementation of next-generation space technologies. Based in Washington D.C., Mr. Marsh has been on the Nanoracks team since 2020, previously working as a strategy consultant for the United States Department of Defense on uncrewed technology development. He studied international relations at the University of California, Los Angeles, where his research focused on Russian foreign policy.

# ION GNSS+ Technical Sessions

## A1: Navigation and Positioning

Date: Wednesday, September 13, 2023

Time: 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Brian Schipper**  
Honeywell



**Dr. Terry Moore**  
University of Nottingham

### Track Chair



**Deborah Lawrence**  
Federal Aviation Administration

**8:35. A Comparison of Ambiguity Resolution Methods for RTK and PPP-IAR Under Challenging Environments**, Viet Duong, Hemisphere GNSS (USA) Inc.

**8:57. A New Ionospheric Model for Galileo Open Service with Good Performance and Less Computation**, M Mainul Hoque, German Aerospace Center (DLR); Matteo Sgammini, Francesco Menzio, Joint Research Center (JRC/EC); Raul Orus Perez, European Space Agency (ESA); Juan Andrés Cahuasquí, German Aerospace Center (DLR); Eric Chatre, European Commission (EC)

**9:20. AoA-based Coarse Positioning for Snapshot GNSS Receivers**, Noori BniLam, Paolo Crosta, European Space Agency

**9:43. DFMC SBAS Prototype in Africa**, J-L. Demonfort, T. Authié, S. Trilles, P. Giorgis, R. Lembachar, Thales Alenia Space; F. Dufour, C. Boulanger, Centre National d'Etudes Spatiales; J. Lapie, L. Bakienon, Agency for Air Navigation Safety in Africa and Madagascar

10:05-10:35, Break. Refreshments in Exhibit Hall

**10:40. Model Parameter Optimization for GNSS Point Positioning in a Kinematic Ocean Buoy Application**, Maria Gonzalez and Jason Gross, West Virginia University

**11:03. Passive Localization Using Multipath Propagation of Low-Cost Ultra-Wideband Devices**, Christian Gentner, Martin Schmidhammer, Benjamin Siebler, German Aerospace Center (DLR)

**11:26. Performance Improvement of Wearable GNSS Navigation with Smart Sensor Aiding**, Guang-Je Tsai, Song-Ying Li, You-Liang Chen, Tzu-Yin Chen, Shi-Xian Yang, AIROHA Technology (Company of MediaTek Group)

**11:48. Tolles-Lawson Coefficient Dependence Using F-16 Data Set**, Jonnathan Bonifaz and Aaron Nielsen, Air Force Institute of Technology/ANT Center

### Alternate Presentations

1. **Sequential RF-SLAM for Rapid Construction of RF Map in Underground Parking Lots Using Smartphone Only**, Beomju Shin, Taehun Kim, KIST; Donghyun Shin, Changsoo Yoo, TJLABS; Hangyul Kyung, KIST; Taikjin Lee, KIST & TJLABS
2. **A Method for Estimating the Approximate Position of a Receiver Using Visible Satellites**, Junfeng Zhang, Peng Wu, Rundong Li, Zhipeng Ren, Chen Yang, Jiahui Gan, Lu Feng, Haibo Tong, Xuemei Xiao, Yuying Chen, ChangSha University
3. **Multi-Layer PNT Development Framework for Opportunistic Navigation**, Javier Miguez, Tommaso Panicciari, Floor Melman, European Space Agency
4. **Tutorial on Inverse Mechanization**, David Woodburn, ANT Center at the Air Force Institute of Technology

### Virtual Presentations

1. **Human Pose Recognition Based on Multi-View RGB-D Images**, Jiahe Liu, Hongyang Yu, UESTC
2. **Improving GNSS Positioning Correction Using Deep Reinforcement Learning with Adaptive Reward Augmentation Method**, Jianhao Tang, Zhenni Li, Haoli Zhao, School of Automation, Guangdong University of Technology; Xie Kan, Guangdong Key Laboratory of IoT Information Technology; Lujia Wang, Department of Electronic and Computer Engineering, Hong Kong University of Science and Technology; Shengli Xie, Guangdong Key Laboratory of IoT Information Technology; Banage T.G.S. Kumara, Department of Computing and Information Systems, Faculty of Applied Sciences, Sabaragamuwa University of Sri Lanka
3. **Real-Time Wide-Area Scene Reconstruction Based on Volume Fusion**, Linhang Zhu, Hongyang Yu, University of Electronic Science and Technology

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m., • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.

# ION GNSS+ Technical Sessions

## B1: Augmentation Services, Integrity, and Authentication

Date: Wednesday, September 13, 2023

Time: 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Jianming She**

The MITRE Corporation



**Dr. Allison Kealy**

Environment, Land Water & Planning

### Track Chair



**Dr. Andrew Neish**

Xona Space Systems

**8:35. Practical Considerations in PSD Upper Bounding of Experimental Data**, Mathieu Joerger and Sandeep Jada, Virginia Tech; Steve Langel, The MITRE Corporation; Omar Garcia Crespillo, German Aerospace Center (DLR); Elisa Gallon, and Boris Pervan, Illinois Institute of Technology

**8:57. Mid-latitude Ionospheric Scintillation Impact on Availability of Dual-Frequency GNSS Augmentation Systems**, Andrew K. Sun, Jaehee Chang, Jiyun Lee, Korea Advanced Institute of Science and Technology (KAIST); Brian Breitsch, Y. Jade Morton, University of Colorado Boulder

**9:20. The Galileo High Accuracy Service (HAS): A Pioneer Free-of-Charge Precise Positioning Service**, F. Javier de Blas (EU Agency for the Space Programme - EUSPA) I. Fernández-Hernández (European Commission) D. Blonski (European Space Agency) Juan Vázquez (EUSPA) Carmelo Hernández (EUSPA) Stefano Lagrasta (EUSPA) Javier Ostolaza (EUSPA)

**9:43. The First Satellite-Based Open PPP-RTK Service: Operational Experiences and Improvements**, Rui Hirokawa, Seigo Fujita, Natsuko Hayase, Mitsubishi Electric Corporation

10:05-10:35, Break. Refreshments in Exhibit Hall

**10:40. Spatio-temporal Kriging based Ionospheric Correction and Threat Models for BDSBAS**, Hongwen Wang, Kun Fang, Zhiqiang Dan, Zhipeng Wang, Beihang University; Yanbo Zhu, Aviation Data Communication Corporation

**11:03. OSNMA User Performance Assessment at ESA/ESTEC – System Qualifications Tools and Methodologies**, L. Musumeci, D. Ibañez, X. Otero, N. Batzilis, P. Crosta, M.-S. Circiu, G. Caparra , A. Melara, N. Sirikan, European Space Agency, ESTEC

**11:26. Analysis of Combinatorial Watermarking for Signal Authentication**, Jason Anderson Sherman Lo Todd Walter, Stanford University

**11:48. SBAS Time-Correlated Error Characterization for Sequential Position Error Overbounding**, Leslie Montloin, Fabrice Legrand, Airbus Defence and Space; Frédéric Bauer, Guillaume Buscarlet, Mickael Dall'Orso, Carlos Lopez de Echararreta, European Space Agency

### Alternate Presentations

1. **Effective Carrier Phase Anomaly Detection Using Short Baseline Double Difference and Machine Learning**, Yebin Lee, Dong-Kyeong Lee, Junesol Song, Byungwoon Park, Sejong University
2. **Inter-Satellite and Inter-Receiver Aiding in the Verification of OSNMA**, Jyh-Ching Juang, Ying-Tong Chen, and Chung-Kee Chua, Department of Electrical Engineering, National Cheng Kung University
3. **Increasing OSNMA Performance with I/NAV Improvements in Degraded Reception Conditions**, Sophie Damy, Luca Cucchi, Beatrice Motella, Matteo Paonni, Joint Research Centre, European Commission
4. **Performance Assessment of Galileo High Accuracy Service (HAS) with Low-Cost GNSS/IMU Sensors in Urban Driving Environments**, Ding Yi, Nacer Naciri, Sunil Bisnath, Department of Earth and Space Science and Engineering, York University
5. **Seasonality of Nominal Ionospheric Gradient Using Time-Step Method Based on GNSS CORS Observations in Hong Kong**, Wang Li and Yiping Jiang; Department of Aeronautical Aviation Engineering, The Hong Kong Polytechnic University

### Virtual Presentations

1. **Fault Exclusion without Additional Conservative Manipulation for Advanced RAIM**, Hangtian Qi, Xiaowei Cui, Mingquan Lu. Tsinghua University
2. **First Signal-in-Space for KASS Augmentation System**, Jean-Rémi De Boer, Nicolas Bourry, Cyril Sarramiac, Guillaume Comelli, Thales Alenia Space; ByungSeok Lee, Eunsung Lee, Minhyuk Son, Korea Aerospace Research Institute; Cheon Sig Sin, Electronics and Telecommunication Research Institute
3. **Protection Level of PPP-RTK Based on Regional Slant Ionospheric Integrity Error Bounds**, Tiantian Tang, Yan Xiang, Sijie Lyu, Wenxian Yu, Shanghai Jiaotong University

# ION GNSS+ Technical Sessions

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m., • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.

# ION GNSS+ Technical Sessions

## C1: PANEL: Status of GPS, GLONASS, Galileo, BDS, QZSS, and UK GNSS

**Date:** Wednesday, September 13, 2023

**Time:** 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Chris Hegarty**

*The MITRE Corporation*



**Miguel Manteiga**

*European Space Agency*

### Track Chair



**Dr. Ilaria Martini**

*U-blox*

This panel session provides an update on the world's satellite-based navigation systems. A representative for each system will provide a system overview, summarize current or planned characteristics and performance, report recent programmatic events, update schedule and plans, and summarize ongoing interactions with other service providers. Questions from the audience are encouraged.

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m., • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.

# ION GNSS+ Technical Sessions

## D1: Alternative Technologies for GNSS-Denied Environments

Date: Wednesday, September 13, 2023

Time: 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Paolo Crosta**  
European Space Agency



**Dr. Christina Selle**

### Track Chair



**Dr. Simona Circiu**  
ESA

### 8:35. OneWeb Timing Technology and PNT Service Status and Plan, Rui Zuo, OneWeb

**8:57. Multi-layer PNT Solutions for Harsh User Conditions,** J.A. Garcia-Molina, Miguel Cordero, Rui Sarnadas, Eleftherios Plakidis, Ivan Lapin, Alexandru Budianu, Javier Miguez, Floor Melman, Michael Karpf, European Space Agency

**9:20. First Field Trial Results of Hybrid Positioning with Dedicated 5G Terrestrial and UAV-Based Non-Terrestrial Networks,** José A. del Peral-Rosado, Ali Yildirim, Susanne Schlötzer, Patric Nolle, Airbus Defence and Space; Sara M. Razavi, Ericsson; Sagar Parsawar, Rakesh Mundlamuri, Florian Kaltenberger, Eurecom; Niilo Sirola, Exafore; Stefano Garlaschi, Luca Canzian, Qascom; Jukka Talvitie, Tampere University; Detlef Flachs, Airbus Defence and Space

**9:43. Neural Radiance Maps for Extraterrestrial Navigation and Path Planning,** Adam Dai, Shubh Gupta, Grace Gao, Stanford University

10:05-10:35, Break. Refreshments in Exhibit Hall

**10:40. Pseudorange-based IR-UWB localization,** Vaclav Navratil; Josef Krska - Czech Technical University in Prague, Faculty of Electrical Engineering

**11:03. Integrated Remote Sensing and Map Registration System for High-Precision Positioning in Covered Parking Garages,** Emma Dawson, Queen's University

**11:26. WiFi-RTT Indoor Positioning Using Particle, Genetic and Grid Filters with RSSI-Based Outlier Detection,** Khalil Jibran Raja and Paul D. Groves, University College London

**11:48. RIDR: Radar/Inertial Dead Reckoning System for Land Vehicle Positioning in Challenging Environments,** Paulo Ricardo Marques de Araujo, Queen's University; Eslam Mounier, Queen's University, Kingston, and Ain Shams University; Mohamed Elhabiby, Micro Engineering Tech Inc.; Sidney Givigi, Queen's University; Aboelmagd Noureldin, Royal Military College, Kingston, and Queen's University

### Alternate Presentations

1. **Emerging Wireless Technologies for Reliable Indoor Navigation in Industrial Environments,** Mahmoud Elsanhoury, Akpo Siemuri, Petri Valisuo, Janne Koljonen, University of Vaasa; Heidi Kuusniemi, University of Vaasa & Finnish Geospatial Research Institute; Mohammed Elmusrati, University of Vaasa
2. **LIWO-SLAM: A LiDAR, IMU, and Wheel Odometry Simultaneous Localization and Mapping System for GNSS-Denied Environments Based on Factor Graph Optimization,** Eva Reitbauer, Christoph Schmied, Fabian Theurl, Manfred Wieser, Institute of Geodesy, Graz University of Technology
3. **An Enhanced WIFI Indoor Positioning Method Based on SNGAN,** Cui Shuyu, Dong Jiabin, Hwang Jun Gyu, Lila Rana, Li JinLong, Park Joon Goo, Kyungpook National University
4. **Path Planning for UAV-Aided Wireless Positioning System Calibration,** Zhen Wu, Zheng Yao, Mingquan Lu, Department of Electronic Engineering, Tsinghua University
5. **Performance Analysis of INS Dead Reckoning Aided by LIDAR, Visual SLAM or Wheel Odometry Under Challenging Autonomous Applications,** Pierre Bénet, Lynda Zaid, Franck Houssen, Mourad Saidani, Alexis Guinamard, SBG Systems

### Virtual Presentations

1. **Evaluation of Zero Velocity Detectors Using Motion Capture System,** Ashwani Kumar, Indian Institute of Technology, & University of Melbourne; Kourosh Khoshelham, University of Melbourne; Salil Goel, Indian Institute of Technology
2. **Localization Accuracy Analysis for Roadside Sensing System,** Zheng Gong, Zhen Liao, Xuyan Bao, Bingyan Yu, Yuming Ge, China Academy of Information and Communications Technology

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m., • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.

# ION GNSS+ Technical Sessions

## E1: Advanced Processing of Terrestrial Signals of Opportunity

**Date:** Wednesday, September 13, 2023

**Time:** 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Christian Gentner**



**Dr. Yiran Luo**

German Aerospace Center (DLR) University of Calgary The Hong Kong Polytechnic University

### Track Chair



**Dr. Li-Ta Hsu**

**8:35. Grid-Based Hybrid 3DMA GNSS and Terrestrial Positioning**, Paul Schwarzbach, Albrecht Michler, Oliver Michler, Technische Universität Dresden

**8:57. 5G and Beyond: An EKF-Based Reconfigurable Intelligent Surface (RIS)-Aided Navigation Approach**, Ali A. Abdallah and A. Lee Swindlehurst, University of California, Irvine

**9:20. Multipath Characterization and Mitigation for GNSS/5G/INS Integrated Navigation Using Gauss Markov Process Model**, Ali Kaiss, Mu Jia, and Zak (Zaher) M. Kassas; The Ohio State University

**9:43. Cognitive Array Processing-Based Acquisition and Tracking of Unknown Terrestrial and Space Signals**, Shaghayegh Shahcheraghi, Mohammad Neinavaie, Zak (Zaher) M. Kassas; The Ohio State University

10:05-10:35, Break. Refreshments in Exhibit Hall

**10:40. Passive Single Satellite Geolocation of Ground-Based EMI Sources**, Dan Shen, Genshe Chen, Intelligent Fusion Technology, Inc.; Khanh Pham, Air Force Research Lab., Space Force

**11:03. Methods for Signals of Opportunity Mapping using Probabilistic Data Association Filter and Cooperative Motion Planning**, Andrew Brevick Kirsten Strandjord, University of Colorado Boulder

**11:26. Experimental Performance of a Cellular LTE and GPS L1 C/A Vector Tracking Receiver**, Samuel Morgan and Scott Martin, Auburn University

**11:48. A Step Closer Towards 5G mmWave-based Multipath Positioning in Dense Urban Environments**, Qamar Bader, Sharief Saleh, Queen's University; Mohamed Elhabiby, Micro Engineering Tech Inc.; Aboelmagd Noureldin, Queen's University; Royal Military College of Canada

### Alternate Presentations

1. **Commercial Radio Phase Difference of Arrival (PDOA) for GNSS-Independent PNT**, David W.A. Taylor, Setter Research, Inc.
2. **Centimeter-level Carrier Phase Positioning with Asynchronous Ground-based Positioning Systems**, Xincheng Zhang, Tengfei Wang, Zheng Yao, Department of Electronic Engineering, Tsinghua University; Yi Wang, Cheng Li, Huawei Technologies Co., Ltd.; Mingquan Lu, Department of Electronic Engineering, Tsinghua University
3. **Power Absorbing Structure for Multipath Suppression in DME Applications**, Veenu Tripathi and Stefano Caizzone, Institute of Communications and Navigation, German Aerospace Center (DLR)
4. **Performance Analysis of GNSS Signal Based on SFBOC Modulation**, Sangjae Cho, Hong-Woo Seok, Seung-Hyun Kong, Korea Advanced Institute of Science and Technology

### Virtual Presentations

1. **Multiple-Epoch Jointly Localization and Synchronization in a 5G System**, Lu Bai, Chao Sun, Beihang University; Andrew G. Dempster, University of New South Wales; Wenquan Feng, Beihang University
2. **Precise LTE Transmitter Localization Using CRS Carrier Phase Tracking with an On-Board Atomic Clock and LTE Double-Difference Observations**, Muhammad Subhan Hameed, Markel Arizabaleta-Diez, Mathias Philips-Blum, Thomas Pany, Universität der Bundeswehr München

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m., • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.

# ION GNSS+ Technical Sessions

## F1: Remote Sensing, Timing, Space and Scientific Applications

Date: Wednesday, September 13, 2023

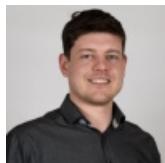
Time: 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Rebecca Bishop**

The Aerospace Corporation



**Dr. Sebastian Mrak**

University of Colorado Boulder

### Track Chair



**Dr. Seebany Datta-Barua**

Illinois Institute of Technology

**8:35. Pulsar Timing for Clock Stability – Exploring an Autonomous and Resilient Approach to Timing Using Radio Pulsars**, Joshua Critchley-Marrows, The University of Sydney; Charleston Ambatali, The University of Tokyo; Xiaofeng Wu, The University of Sydney; Shinichi Nakasuka, The University of Tokyo

**8:57. Doppler Compensation Algorithm for Highly Accurate Inter-Satellite and Satellite-to-Ground Frequency Transfer**, Manuele Dassié, Gabriele Giorgi, Pablo Nahuel Dominguez, Ludwig Blümel, German Aerospace Center (DLR); Christoph Gohle, OHB System AG

**9:20. Addressing Inaccurate Phase Center Offsets in Precise Orbit Determination for Agile Satellite Missions**, Kevin Gutsche, Thomas Hobiger, Institute of Navigation, University of Stuttgart; Stefan Winkler, Airbus Defence and Space

**9:43. Sensing Thermospheric Density Using COSMIC-2 Satellite GNSS Data**, Jian Yao, Jan-Peter Weiss, University Corporation for Atmospheric Research (UCAR); Tzu-Wei Fang, Eric Sutton, and Tim Fuller-Rowell, NOAA Space Weather Prediction Center

10:05-10:35, Break. Refreshments in Exhibit Hall

**10:40. Grazing-angle GNSS-R for the Determination of Tropospheric Delay and Water Vapor Content**, Yang Wang, Smead Department of Aerospace Engineering Sciences, University of Colorado Boulder

**11:03. Improving GNSS-Based Tropospheric Delay Estimation for Airborne Quantum Gravimetry: First Results Using NWM Forecasting**, Francesco Darugna, Temmo Wübbena, Gerhard Wübbena, and Jannes B. Wübbena, Geo++ GmbH

**11:26. A Stochastic Approach for Near Real-Time Tide Estimation Using GNSS-Reflectometry**, Kasidet Srisutha and Jihye Park, Oregon State University

**11:48. GNSS Reflectometry Correlation with Camera Images for Surface Type Determination**, Seebany Datta-Barua, Roohollah Parvizi, Illinois Institute of Technology; Alison F. Banwell, University of Colorado Boulder; and Shahrukh Khan, Illinois Institute of Technology

### Alternate Presentations

1. **Snapshot Tracking of GNSS Signals in Space: A Case Study at Lunar Distances**, Andrea Nardin, Alex Minetto, Department of Electronics and Telecommunications (DET) Politecnico di Torino; Salvatore Guzzi, Qascom s.r.l.; Fabio Dovis, DET, Politecnico di Torino; Lauren Konitzer, Joel J.K. Parker, Goddard Space Flight Center (GSFC) National Aeronautics and Space Administration (NASA)
2. **Integrating Spaceborne GNSS-R Measurements in 3D Ionospheric Imaging: A Simulation Study**, Brenna Royersmith, Brian Breitsch, Y. Jade Morton, University of Colorado Boulder
3. **The Effect of the Ballistic Coefficient on Satellite Orbit Prediction**, Madeline McDougal, Scott Martin, Kip Underwood, Auburn University
4. **A GNSS-Based Technique to Investigate the Black-Out During Space Vehicles' Re-Entry**, Giovanni B. Palmerini, Prakriti Kapilavai, Scuola di Ingegneria Aerospaziale, Sapienza Università di Roma
5. **Validation Methods to Study the Consistency and Quality of Radio Occultation Electron Density Profiles: Application to COSMIC**, Gabriel O. Jerez, Sao Paulo State University (UNESP), & Universitat Politècnica de Catalunya (UPC); Manuel Hernández-Pajares, Universitat Politècnica de Catalunya (UPC); Daniele B. M. Alves, and João F. G. Monico, Sao Paulo State University (UNESP)

### Virtual Presentations

1. **A Calibration Algorithm of Ultra-rapid Orbit Boundary Discontinuity Based on Adaptive Orbital Arc Length**, Zhao Lin, Xitie Lu, Hui Li, Renlong Wang, and Ziheng Gao, College of Intelligent Systems Science and Engineering, Harbin Engineering University
2. **Water Vapor Retrieved From Ground-Based GNSS and its Applications to Lightning Weather in Hong Kong**, Ting Ni, Hang Guo, School of Information Engineering, Nanchang University; Min Yu, College of Computer Software, Jiangxi Normal University; Jian Xiong, School of Advanced Manufacturing, Nanchang University

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m., • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.

# ION GNSS+ Technical Sessions

## A2: Applications of GNSS Measurements from Smartphones

Date: Wednesday, September 13, 2023

Time: 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Dr. Mohammed Khider**  
Google Inc.



**Ivan Ng**  
Hong Kong Polytechnic University

### Track Chair



**Deborah Lawrence**  
Federal Aviation Administration

**1:50. Elevating Android GNSS Raw Measurement Processing: A Universal RINEX Converter for Precise Post-Processing Solutions**, Jeonghyeon Yun, Byungwoon Park, Sejong University; Dong-Kyeong Lee, Dennis M. Akos, University of Colorado Boulder

**2:12. The Supercorrelation™ API for Smartphones and Smartwatches**, Ramsey Faragher, Paulo Esteves, Maria Evans, Chris Higgins, Steve Mole, Mark Crockett, Focal Point Positioning Ltd.

**2:35. A-GNSS Improvements with Galileo Secondary Synchronization Patterns**, P. Crosta, L. Musumeci, X. Otero, S. Puglia, European Space Agency, ESTEC, The Netherlands

**2:58. Detecting Single-Antenna Spoofing Attacks by Correlation in Time Series of Raw Measurements**, Alex Minetto, Akmal Rustamov, Fabio Dovis, Department of Electronics and Telecommunications, Politecnico di Torino

3:25 - 3:55, Break. Refreshments in Exhibit Hall

**4:00. RTK-GNSS with Smartphone in Moving Vehicles using GNSS Repeater**, Nobuaki Kubo, Tomohiro Ozeki, Kaito Kobayashi, Tokyo University if Marine Science and Technology

**4:23. Real-Time GNSS+IMU Smartphone Positioning with Trimble RTX Corrections**, Carlos Rodriguez-Solano, Felix Eisenlohr, Stefan Junker, David Rüegg, Trimble Inc., Germany

**4:46. Fusion of Augmented GNSS with SLAM on Smartphones**, Francesco Darugna, Jannes Wübbena, Gerhard Wübbena, and Temmo Wübbena Geo++

**5:08. MediaTek GNSS Solution with 3DMA**, DeMarco Chou, Chia Yen Chong, Darren Yang, Pei-Hung Jau, MediaTek Inc.

### Alternate Presentations

1. **Preliminary Assessment of Improved Smartphone GNSS Quality Control Methods Based on Range Errors**, Jiahuan Hu and Sunil Bisnath, York University
2. **IP3-Mobile: A GNSS Real-Time Precise Point Positioning APP for Android Smartphones**, Fei Liu, Mohamed Elsheikh, Yang Jiang, Zhitao Lyu, Farzaneh Zangeneh Nejad, Yang Gao, Naser Elsheimy Profound Positioning Inc.
3. **Performance Analyses of the Stonex S70 Android Tablet Using Different Tri-Constellation GNSS Solutions**, Jenan Rajavarathan, Faculty of Geomatics, Sabaragamuwa University of Sri Lanka (SUSL); Guenther Retscher, Department of Geodesy and Geoinformation, TU Wien – Vienna University of Technology; Thilantha Lakmal Dammalage, University of New England; Vipula Abeyratne, Faculty of Geomatics, Sabaragamuwa University of Sri Lanka (SUSL)
4. **A Method for Adaptive GNSS/PDR Integrated Navigation**, Ryoya Shiraiwa, Fumiya Odai and Yukihiro Kubo, Ritsumeikan University

Free Time in Exhibit Hall • 5:30 p.m. - 7:00 p.m.

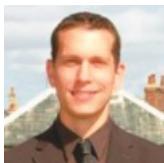
# ION GNSS+ Technical Sessions

## B2: Marine Applications, and Search and Rescue

**Date:** Wednesday, September 13, 2023

**Time:** 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Dr. Alan Grant**  
General Lighthouse Authorities



**Dr. Gregory Johnson**  
Serco, Inc.

### Track Chair



**Dr. Andrew Neish**  
Xona Space Systems

**1:50. Potential LEO Satellite Augmentation for Rescue-21 in Alaska**, Richard J. Hartnett, U.S. Coast Guard Academy; Peter F. Swaszek, University of Rhode Island; Dahnyoung McGarry, U.S. Coast Guard Academy

**2:12. VDE-Terrestrial Channel Performance Assessment**, Gregory Johnson, Kenneth Dykstra Serco, Inc.; John Forster, James Spilsbury USCG Research and Development Center

**2:35. VDES - R-Mode Advanced User Technologies for Alternative PNT**, Martin Bransby, Tim Whitworth, Louise Mercy, Telespazio UK

**2:58. R-Mode – Terrestrial Navigation for Maritime Users**, Stefan Gewies, Filippo Giacomo Rizzi, Lars Grundhöfer, Niklas Hehenkamp, German Aerospace Center (DLR); Michael Hoppe, German Federal Waterways and Shipping Administration

3:25 - 3:55, Break. Refreshments in Exhibit Hall

**4:00. Resilient PNT for the Black Sea and Danube Region**, Florin Mistrapau, Roxana Mihaela Clopot, Ciprian-Vladut Circu, Vlad Gabriel Olteanu, GMV; Irina Beatrice Stefanescu, Mirela Bivolaru, ROSA RC; Lucian Dumitache, Petrica Popov, MHD

**4:23. Study on the Benefits and Uses of OSNMA in Maritime Navigation**, H. Llorca, M. López, E. Domínguez, GMV; T. Tisell, SAAB; P. Scheidemann, EUSPA

**4:46. The PASSport Solution: A GNSS Approach Towards the Improvement of Safety and Security in Ports with Drone Surveillance**, A. R. Martín, I. Armengol, M. López, GMV; M. Nisi, SISTEMATICA S.p.A; M. Lopez, EUSPA

**5:08. Comparison on the Network Expansion Strategy of Maritime PPP-RTK Correction From Multiple Local Networks in Korea**, Gimin Kim, TaeHyeong Jeon, Jaeyoung Song, Sul Gee Park, Sang Hyun Park, Maritime PNT Research Office

### Alternate Presentations

1. **Enhancing Global PPP Service Reliability with Hemisphere Atlas® and Galileo HAS: A Dual Redundant Approach**, Jianping Chen, Viet Duong, Alim Kanji, Hemisphere GNSS
2. **GNSS and PNT Related Work Within IALA**, Jaime Alvarez, Minsu Jeon, IALA

Free Time in Exhibit Hall • 5:30 p.m. - 7:00 p.m.

# ION GNSS+ Technical Sessions

## C2: Trends in GNSS Augmentation Systems

Date: Wednesday, September 13, 2023

Time: 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Deborah Lawrence**  
Federal Aviation Administration



**Dr. Todd Walter**  
Stanford University

### Track Chair



**Dr. Ilaria Martini**  
U-blox

**1:50. Brief History of GPS Backward Compatibility (BC) Requirements for Psat & Pconst**, Karl Kovach, The Aerospace Corporation; Calvin Miles, U.S. Federal Aviation Administration; Karen Van Dyke, U.S. Department of Transportation

**2:12. Update on Galileo Performance Characterization and Integrity Support Message Definition for H-ARAIM**, S. Wallner, S. Perea, A. Lemke, European Space Agency; M. Schoenfeldt, K. Binder, R. Cirillo, M. Odriozola, Airbus Defense and Space GmbH; G. Centelles, Deimos Space; A. Donatelli, E. Foucault, C. Stallo, D. Lauria, Thales Alenia Space; M. Sgammini, I. Martini, J.P. Boyero, European Commission; M. Mabilieu, E. Canestri, N. Castrillo, European GNSS Agency

**2:35. Implementation of the Baseline Advanced RAIM User Algorithm**, Jianming She, Kathy Misovec, The MITRE Corporation; Juan Blanch, Stanford University; Natali Cacciopoli, David Duchet, EUROCONTROL; Enrique Domínguez Tijero, GMV; Fan Liu, FAA; Danielle Racelis, Mathieu Joerger, Virginia Tech; Matteo Sgammini, European Commission, Joint Research Centre (JRC)

**2:58. GNSS Signal Anomaly Detection Using DCB Estimates and Machine Learning Algorithms**, Steffen Thoelert, German Aerospace Center - DLR and RWTH Aachen University; Gerardo Allende-Alba, Peter Steigenberger, DLR

3:25 - 3:55, Break. Refreshments in Exhibit Hall

**4:00. DFMC GBAS Processing of Flight Trial Data – a First Comparison of Options**, Natali Cacciopoli, David Duchet, Andreas Lipp, EUROCONTROL

**4:23. Evaluating Performance of Ionospheric Anomaly Monitor for DFMC GBAS with Flight Data in Ionospheric Disturbed Conditions**, Susumu Saito, Takayuki Yoshihara, ENRI; Tim Murphy, Matt Harris, Glaucia Balvedi, Boeing; Joel Wichgers, Collins Aerospace; Linda Lavik, Morten Topland, Mutaz Tuffaha, Indra Navia

**4:46. Prototyping Message Authentication on L1 SBAS**, Takeyasu Sakai, Mitsunori Kitamura, and Atsushi Kezuka, National Institute of Maritime, Port and Aviation Technology

**5:08. Integrity Bounds Computation for SBAS Multi-Domain Users**, Alejandro Rodriguez-Veiga and Leslie Montloin, Airbus Defence and Space SAS

### Alternate Presentations

- Extensibility of the GBAS VHF Datalink to the Needs of DFMC GBAS**, Andreas Lipp, David Duchet, EUROCONTROL; Natali Cacciopoli, CNworks
- Wide Area Network (WAN) Connectivity Validation on Installed Sites of Korea Augmentation Satellite System (KASS)**, Chulhee Choi, Eunsung Lee, Daehee Won, Korea Aerospace Research Institute
- Evaluation for BDSBAS Ionospheric Grid Augmented by LEO Constellations**, Xiaowei Lan, Hongwen Wang, Kun Fang, Beihang University; Yanbo Zhu, Aviation Data Communication Corporation; Zhipeng Wang, Beihang University
- Advanced RAIM for Rail, Maritime and UAS Sectors**, Javier Fidalgo, Enrique Domínguez, Ana Cezón, Ginés Moreno, Fulgencio Buendía, Javier de Toro, GMV; Florin Mistrapau, Roxana Clopot, GMV-RO; Merle Snijders, Heiko Engwerda, Juliette Casals, NLR; Armando Luciano, Karel Callewaert, Marco Bolchi, VVA; Sophie Damy, Ilaria Martini, Matteo Sgammini, Juan Pablo Boyero, EC
- An Approach to Eliminating the Space Discontinuities of Network RTK Corrections**, Xiyang He and Ziyuan Huang, Shanghai Huace Navigation Technology Ltd.

### Virtual Presentations

- Integrity for future SBAS users: concept and experimentations**, Odile Maliet, Julie Antic, Sébastien Trilles, Marie Abbal, Hélène Delfour-Cormier, Thales Alenia Space; Mickael Dall'orso, Nicolas Giron, Guillaume Buscaret, Frédéric Bauert, Carlos Lopez de Echazarreta, European Space Agency

Free Time in Exhibit Hall • 5:30 p.m. - 7:00 p.m.

# ION GNSS+ Technical Sessions

## D2: PANEL: Autonomous Navigation for Ground, Seaborne, and Airborne Vehicles

**Date:** Wednesday, September 13, 2023

**Time:** 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Dr. Dorota Grejner-Brzezinska**

*The Ohio State University*



**Dr. Zak Kassas**

*The Ohio State University*

### Track Chair



**Dr. Simona Circiu**

*ESA*

How will automated vehicles transform our lives in the future? What are the remaining challenges that hold back autonomous vehicles, from self-driving cars to unmanned aerial vehicles to autonomous transit, from the mass market? How much can we trust the autonomous navigation and guidance of these cyber-physical systems? What sensors/signals should we use that provide continuous, trustworthy, and secure flow of information needed for autonomous navigation? How is the robustness and integrity addressed by different stakeholders and industries? Seek answers to these questions, and ask more, in this panel on ground, seaborne, and airborne vehicles.

Free Time in Exhibit Hall • 5:30 p.m. - 7:00 p.m.

# ION GNSS+ Technical Sessions

## E2: High Precision and High Integrity Navigation

Date: Wednesday, September 13, 2023

Time: 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Dr. Sriramya Bhamidipati**  
Stanford University



**Dr. Jianghui Geng**  
Wuhan University

### Track Chair



**Dr. Li-Ta Hsu**  
The Hong Kong Polytechnic University

**1:50. PPP Performance Assessment Setup for Galileo High Accuracy Service**, Javier Miguez, Filipe De Oliveira Salgueiro, Paolo Zoccarato, Dimitrios Psychas, Elena Galletti, Daniel Blonski, European Space Agency

**2:12. Galileo High Accuracy Service SDR Implementation**, Carles Quilis Alfonso, Fred Taylor, Dennis M. Akos, University of Colorado Boulder, The RF & SatNav Laboratory

**2:35. Accelerated SF-PPP Convergence of BDS-3 B1 Band by Wideband Signal Observations**, Yunhan Qi, Zheng Yao, Mingquan Lu. (All authors are from 1: Department of Electronic Engineering, Tsinghua University, Beijing, China; 2: Beijing National Research Center for Information Science and Technologu, Beijing, China)

**2:58. Real-Time Precise Orbit and Clock Errors Bounding for High Integrity PPP**, Yingchao Xiao, Xingqun Zhan, Yawei Zhai, School of Aeronautics and Astronautics, Shanghai Jiao Tong University

3:25 - 3:55, Break. Refreshments in Exhibit Hall

**4:00. Python Toolkit for Open PPP/PPP-RTK Services**, Rui Hirokawa, Mitsubishi Electric Corporation; André Hauschild, German Aerospace Center (DLR); Tim Everett, RTK Consultants LLC

**4:23. Mitigation of Receiver Biases to Derive Ionospheric SSR Corrections for Multi-GNSS PPP-RTK Under High Ionospheric Activity**, Paulo Sergio de Oliveira Jr., UPPR - Federal University of Paraná, and João F. Galera Monico, Unesp - São Paulo State University

**4:46. Homogeneous Network RTK Correction Residual Error Modeling Techniques for Improving the Position Accuracy of Network Internal and External Users**, Yunho Cha, Cheolsoon Lim, Yebin Lee, Yongrae Jo, Byungwoon Park, Sejong University; Junesol Song, Suwon University;

**5:08. SS-RAIM based Integrity Architecture for CDGNSS Systems against Satellite Measurement Faults**, Dongchan Min, Noah Minchan Kim, Junsoo Kim, Jiyun Lee, Korea Advanced Institute of Science and Technology, Sam Pullen, Stanford University

### Alternate Presentations

1. **Receiver bias Estimation Strategy in the Uncombined Triple-Frequency PPP-AR Model**, Liu Yichen, Technical University of Munich, Robert Bosch GmbH; Hugentobler Urs, Technical University of Munich; Mikhaylov Nikolay, Robert Bosch GmbH; Duan Bingbing, Technical University of Munich; Simon Jeffrey, Robert Bosch GmbH
2. **Characterization of Galileo High Accuracy Service (HAS) Corrections and Positioning Performance in Initial Phase**, J. Capolicchio, I. Milani, M. Carosi, M. Fortunato, C. Cristodaro, L. Marchionne, S. La Barbera, Thales Alenia Space Italia; C. Speranza, Randstad Italia
3. **The Galileo High Accuracy Service: Assessment of the quality of Corrections and Preliminary PPP Performance**, Camille Parra, Technical University of Munich; Andreas Schütz, University of the Bundeswehr Munich; Urs Hugentobler, Technical University of Munich; Thomas Pany, University of the Bundeswehr Munich; Stefan Baumann, Industrieanlagen-Betriebsgesellschaft mbh (IABG)
4. **Prototyping Integrity Monitors for PPP Corrections**, Yu-Fang Lai, Juan Blanch, Todd Walter, Stanford University

### Virtual Presentations

1. **A Height Constrained Piecewise Fitting tropospheric Delay Interpolation Method Based on CORS**, Ziyang Chen, University of Electronic Science Technology of China

Free Time in Exhibit Hall • 5:30 p.m. - 7:00 p.m.

# ION GNSS+ Technical Sessions

## F2: Advanced Software and Hardware Technologies for GNSS Receivers

Date: Wednesday, September 13, 2023

Time: 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Dr. Yu (Joy) Jiao**  
Trimble



**Dr. Roohollah Parvizi**  
Hemisphere GNSS

### Track Chair



**Dr. Seebany Datta-Barua**  
Illinois Institute of Technology

**1:50. Future GNSS Acquisition Strategies and Algorithms**, Nicholas Spens, Anna Cismaru, Dennis Akos, University of Colorado Boulder

**2:12. Bicomplex Kalman Filter Tracking for GNSS Meta-Signals**, Daniele Borio, European Commission, Joint Research Centre, Melania Susi, Topcon Positioning Systems Inc.

**2:35. Weiss-Weinstein Bound of Frequency Error Considering von Mises Distribution as Prior for Very Weak GNSS Signals**, Xin Zhang, Xingqun Zhan, School of Aeronautics and Astronautics, Shanghai Jiao Tong University

**2:58. A New GNSS Ambiguity Resolution Method Through Mixed Integer Non-Linear Programming**, Hongmin Zhang, Weisong Wen and Li-Ta Hsu, The Hong Kong Polytechnic University

3:25 - 3:55, Break. Refreshments in Exhibit Hall

**4:00. Blind Estimation of Starlink LEO Satellites Downlink Signal Structure**, Haitham Kanj, Sharbel Kozhaya, and Zak (Zaher) M. Kassas; The Ohio State University

**4:23. Configurable Multi-band GNSS Receiver and Antenna for Robust Handheld Devices**, Santiago Urquijo, Fabio Garzia, Alexander Popugaev, Alexander Rügamer, Wolfgang Felber, Fraunhofer Institute for Integrated Circuits IIS

**4:46. Fully Reconfigurable Lab-scale Testbed for Assistance of New Satellite Navigation System Developments**, Young-Jin Song, ByungHyun Choi, Subin Lee, Jong-Hoon Won, Autonomous Navigation Lab., Dept. of Electrical and Computer Engineering, Inha University

**5:08. In-Situ Calibration of Antenna Arrays for Improved Spatial Signal Processing using In-Space GNSS Signals**, Tobias Bamberg, German Aerospace Center (DLR) & Chair of Navigation, RWTH Aachen University; L. Kurz, A. Konovaltsev, DLR; M. Meurer, DLR & Chair of Navigation, RWTH Aachen University

### Alternate Presentations

1. **Galileo-SDR-SIM: An Open-Source Tool for Generating Galileo Satellite Signals**, Harshad Sathaye, Maryam Motallebighomi, Aanjan Ranganathan, Northeastern University
2. **Development of Kalman Filter-Based Software Receiver for QZSS L6 and Galileo E6-B Signals**, Cheng-Wei Wang, Shau-Shiun Jan, Department of Aeronautics and Astronautics, National Cheng Kung University
3. **Evaluation of Actual Performance of PPP Positioning in Urban Areas Using Pocket-SDR**, Tomohiro Ozeki, Nobuaki Kubo, Tomoji Takasu, Tokyo University of Marine Science and Technology; Taro Suzuki, Chiba Institute of Technology; Takuji Ebinuma, Chubu University
4. **Digital Twin Platform for BDS-3 Satellite Navigation Using Digital Twin Intelligent Visualization Technology**, Rundong Li, Peng Wu, Junfeng Zhang, Zhipeng Ren, Chen Yang, Jiahui Gan, Lu Feng, Haibo Tong, Xuemei Xiao, Yuying Chen, College of Electronic Communication and Electrical Engineering, Changsha University

### Virtual Presentations

1. **Analysis of Correlation Loss for MBOC Signals**, Divyang Arora, ISRO Telemetry Tracking and Command Network, ISRO, Bengaluru, India, divyang@isstrac.gov.in Pravin Patidar, Space Applications Center, ISRO, Ahmedabad, India
2. **Dynamic Carrier Tap Selection (DyCaTS): A Novel Approach for GPS M-Code Pull-in**, Ryan S. Cassel, Lawrence Elentukh, Shawn D. Miller, The MITRE Corporation
3. **High Order DPLL for High Order Doppler Dynamics Tracking**, Sébastien ROCHE, Thales Alenia Space France

Free Time in Exhibit Hall • 5:30 p.m. - 7:00 p.m.

# ION GNSS+ Technical Sessions

## A3: PANEL: Extended Reality and PNT

**Date:** Thursday, September 14, 2023

**Time:** 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Andrew Hansen**  
DOT/Volpe-Center



**Dr. Sherman Lo**  
Stanford University

### Track Chair



**Deborah Lawrence**  
Federal Aviation Administration

The next mainstream computing platform will likely be a headset that offers its wearer an immersive extended reality (XR) visual and auditory experience. Applications range from recreation to education to defense. Various 6-degree-of-freedom headset tracking techniques, including lighthouse-based tracking, inside-out systems based on visual SLAM, and GNSS-IMUbased tracking, are being developed to estimate the position and orientation of the headset accurately and with low latency. Accurate time determination and a common reference frame are required to support collaborative XR. This panel will explore the opportunities and challenges of XR as it relates to PNT.

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m. • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.,

# ION GNSS+ Technical Sessions

## B3: Autonomous Applications

Date: Thursday, September 14, 2023

Time: 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Boubeker Belabbas**  
Bosch



**Mitch Narins**  
Strategic Synergies LLC

### Track Chair



**Dr. Andrew Neish**  
Xona Space Systems

**8:35. Supercorrelation™ for Autonomous Platforms, Providing Increased Accuracy, Sensitivity and Integrity**, Ramsey Faragher, Paulo Esteves, Javier Garcia, J. Rossouw van der Merwe, Dana Jamal, Samir Benmendil, Chris Higgins, Rose Grey, Mark Crockett, Focal Point Positioning Ltd.

**8:57. A Joint Vision of Infrastructure Strategy for Resilient Navigation in the Airspace**, Okuary Osechas, German Aerospace Center (DLR); Sherman Lo, Stanford University; Gerhard Berz, EUROCONTROL

**9:20. Sensor Fusion of Precise GNSS/INS with Lidar Map-Based Localization**, David Rüegg, Keith Leung, Damir Gumerov, Lorenz Görcke, Trimble Inc.

**9:43. Extended Results of Single Epoch Position Bound (SEPБ) for High Integrity Automotive Applications**, Olivier Julien, Hayden Dorahy, Chris Hide, u-blox; Ian Sheret, Polymath Insight Ltd

10:05-10:35, Break. Refreshments in Exhibit Hall

**10:40. High-altitude Aircraft Navigation via Radio Simultaneous Localization and Mapping**, Zak (Zaher) M. Kassas, The Ohio State University; Nadim Khairallah, SpaceX; Joe Khalife, University of California, Irvine; Chiawei Lee, Juan Jurado, Steven Wachtel, Jacob Duede, Zachary Hoeffner, Thomas Hulsey, and Rachel Quirarte, US Air Force; and RunXuan Tay, Republic of Singapore Air Force

**11:03. Obscuration Modelling for Autonomous Vehicle Operation Using GNSS**, Matthew Pottle, Paul Hansen, Esther Anyaegbu, Jeremy Bennington, Positioning, Navigation & Timing, Spirent Communications PLC

**11:26. Bounding GPS-Based Positioning and Navigation Uncertainty for Autonomous Drifting via Reachability**, Asta Wu, Adyasha Mohanty, Anonto Zaman, Grace Gao, Stanford University

**11:48. Estimation Method of a Probability Rate of Hazardous Misleading Information based on Limited Samples and using the Extreme Value Theory**, Thomas Ulrich, Noha El Gemayel and Boubeker Belabbas, BOSCH GmbH

### Alternate Presentations

1. **Baro-aided LDACS Architecture Studies and Service Area Analysis**, Gianluca Zampieri, German Aerospace Center (DLR) & RWTH; Gary McGraw, Consultant; Filip-Dhaubhadel Alexandra, Brandon Weaver, Okuary Osechas, DLR; Sai Kalyanaraman, Collins Aerospace; Michael Meurer, DLR & RWTH
2. **SOTIF Considerations for a GNSS Based Positioning System**, Marco Limberger, Juan Carlos Venegas Rincon, Mehran Khaghani, Kepa Garcia Campo, u-blox
3. **A Novel Data-Driven Adaptive Robust Filter Based on TCN-ACKF Method for Autonomous Train Localization System**, Weishu Wang, Jiang Liu, Wei Shangguan, Beijing Jiaotong University
4. **GMV GSharp® Safe Solution for High Accuracy**, A. González, E. Carbonell, L. Martínez, J.L. Carretero, G. Tobías, D. Calle, P.F. Navarro, I. Rodríguez, GMV
5. **Multi-Sensor Fusion and Real-Time FDE for UGVs Based on Factor Graph Optimization**, Jiahao Xu, Hongxia Wang, Zhiqiang Dan, Zhipeng Wang, Yanbo Zhu, Beihang University

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m. • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.,

# ION GNSS+ Technical Sessions

## C3: Spectrum: Protection and Optimization

Date: Thursday, September 14, 2023

Time: 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Emanuela Falletti**  
Leonardo S.p.A.



**Dr. Christophe Macabiau**  
ENAC

### Track Chair



**Dr. Ilaria Martini**  
U-blox

**8:35. Detecting Space-Based Interference on GNSS Signals Using FFT Observations**, Akshata Patil, R. Eric Phelts, Sherman Lo, Todd Walter, Stanford University

**8:57. Interference Effects on a Multi-GNSS Receiver on Board of a CubeSat in LEO**, Austin McKibben, Ryan McKnight, Brian C. Peters, Zachary Arnett and Sabrina Ugazio, Ohio University

**9:20. A Test Set for Evaluating GNSS Radio Frequency Interference Monitors**, Sherman Lo, Yu Hsuan Chen, Nicolas Roberto San Miguel, Hagop Chinchinian, Todd Walter, Stanford University; Dennis Akos, University of Colorado, Boulder

**9:43. U.S. DOT IDM Real World Concepts & Case Comparison**, James S. Aviles Karen L. Van Dyke, US Department of Transportation

10:05-10:35, Break. Refreshments in Exhibit Hall

**10:40. A Study on the Effects of Radio Location Service on KPS in the L6-band**, Subin Lee and Jong-Hoon Won, Autonomous Navigation lab., Electrical and Computer Engineering, Inha University

**11:03. SDR Receivers Robust to Jamming and Spoofing: From Single Antenna to Multi-Antenna Processing**, Guillaume Carrié, Cyrille Gernot, Joel Korsakissok, Syntony GNSS

**11:26. Staggered Examination of Non-Trusted Receiver Information (SENTRI) Algorithm for Spoof Detection and Integrity Monitoring in GNSS Receivers**, Bernard Schnaufer, Angelo Joseph, Huan Phan, Collins Aerospace

**11:48. No GPS No Problem: Exploiting Cellular OFDM-Based Signals for Accurate Navigation in a GPS-Jammed Environment**, Zak (Zaher) M. Kassas, The Ohio State University; Ali Abdallah, University of California, Irvine; and Chiawei Lee, US Air Force

### Alternate Presentations

1. **Galileo-Powered Signal Authentication: Implementing a Commercial Software Solution for Enhanced Security**, M. A. Ramírez, A. Chamorro, S. Cancela, D. Calle, GMV
2. **Data Signals: Enabling Fast-TTFF and Flexibility with the GeoFocus and GNSE Schemes**, J.A. Garcia-Molina, S. Wallner, and G. Lopez-Risueno, European Space Agency
3. **GPS Spreading Code Design for Families of Long Memory Codes Using the Cross Entropy Method**, Tara Mina, Alan Yang, and Grace Gao, Stanford University
4. **Spreading Code Sequence Design is a Convex Optimization Problem with Binary Constraints**, Alan Yang, Tara Mina, Grace Gao, Stanford University

### Virtual Presentations

1. **An Interference Detection Algorithm for GNSS Frequency-Hopping Signals Based on Optimized Energy and Multi-Segment Spectral Clustering**, Chengjun Guo, Qing Zhao, University of Electronic Science and Technology of China (UESTC)

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m. • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.,

# ION GNSS+ Technical Sessions

## D3: GNSS Integrity Augmentation

Date: Thursday, September 14, 2023

Time: 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Michael Felux**

Zurich University of Applied Science (ZHAW)



**Dr. María Caamano Albuerne**

German Aerospace Center (DLR)

### Track Chair



**Dr. Simona Circiu**

ESA

### 8:35. Adaptive Airborne Ionospheric Gradient Monitoring for Dual-Frequency GBAS, D. Gerbeth, M. Caamano, German Aerospace Center (DLR)

**8:57. Investigating the Influence of Smoothing Time Constant for GBAS in Low Latitude Regions with Occurrence of Ionospheric Scintillation**, Weverton da Costa Silva, Crislaine Menezes da Silva, Felipe Tintino Linhares de Souza, João Francisco Galera Monico, São Paulo State University - UNESP, School of Technology and Sciences; Natali Caccioppoli, EUROCONTROL

**9:20. Enabling LPV for GLS Equipped Aircraft Using a SBAS to GBAS Converter**, Thomas Ludwig, Thomas Dautermann, German Aerospace Center (DLR)

**9:43. Performance Analysis of Orbit and Clock Correction of Wide Area Differential Regional Navigation Satellite System**, Jaeuk Park, Bu-Gyeom Kim, Changdon Kee, Department of Aerospace Engineering and SNU-IAMD, Seoul National University; Donguk Kim, Agency for Defense Development

10:05-10:35, Break. Refreshments in Exhibit Hall

**10:40. Approaches to Improve Advanced RAIM Protection Levels**, Juan Blanch and Todd Walter, Stanford University

**11:03. Detection and Exclusion of Multiple Faults using Euclidean Distance Matrices**, Derek Knowles and Grace Gao, Stanford University

**11:26. Research on the Impact of DME on the Integrity of BDS B2a Signal**, Yuan Liu, Kun Fang, Zhiqiang Dan, Yanbo Zhu, Beihang University

**11:48. Mitigating the Impact of Inaccurate State Variance-Covariance Matrix in Kalman filtering for Real-Time PPP with Low-Cost GNSS Devices**, Yan Zhang, Yang Jiang, Yang Gao, Department of Geomatics Engineering, University of Calgary

### Alternate Presentations

1. **GBAS for UAV operations – The Positioning Service, Vertical Integrity and Operational Lessons Learned**, Valentin Fischer, Sophie Jochems, Michael Jäger, Luciano Sarperi, Michael Felux, Zurich University of Applied Sciences
2. **A Breakthrough Positioning System for Autonomous Operations with Large Vessels in Ports: The Grimaldi Satellite Assisted Berthing System**, Giovanni Bocchetti, Dario Bocchetti, Cosimo Cervicato, Andrea D'Ambra, Grimaldi Euromed; Alessandro Neri, Radiolabs - Università degli Studi Roma Tre Federica Pascucci, Radiolabs - Università degli Studi Roma Tre; Francesco Rispoli, Agostino Ruggeri, Radiolabs; Stig Erik Christiansen, Henrik Foss, Ketil Olaf Paulsen, Kongsberg; Alessandra Fiumara, Felix Toran, ESA
3. **A Robust Navigation Solution to Enable Safe Autonomous Aerospace Operations**, Moshe Kaplan, infiniDome
4. **POMELO: A 4G Prototype Testbed to Demonstrate Scalable and Bandwidth Efficient Broadcast of GNSS Corrections**, Lisa Guerriero, Elisa Benedetti, GMV; Florin-Catalin Grec, European Space Agency (ESA)
5. **Occurrence of Critical Satellites in GAST-D+ Processing**, Michael Nietlispach, Michael Felux, Zurich University of Applied Sciences

### Virtual Presentations

1. **Assessing the Performance of Dual-Frequency Multi-Constellation GBAS Architectures during Periods of Ionospheric Scintillation in Brazil**, Crislaine Menezes da Silva, Weverton da Costa Silva, Felipe Tintino Linhares de Souza, João Francisco Galera Monico, Daniele Barroca Marra Alves, São Paulo State University (UNESP); Gláucia Balvedi, Tim Murphy, BOEING; Susumu Saito, ENRI; Joel Wichgers, COLLINS
2. **Availability Assessment of ARAIM FDE With Time-Correlated Error**, Jingtian Du, Hongxia Wang, Kun Fang, Yanbo Zhu, Beihang University

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m. • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.,

# ION GNSS+ Technical Sessions

## E3a: All-Source Intelligent PNT Methods

Date: Thursday, September 14, 2023

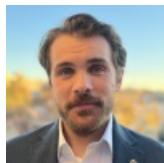
Time: 8:30 a.m. - 10:05 a.m.

### Session Chairs



**Dr. Weisong Wen**

The Hong Kong Polytechnic University   The Johns Hopkins University APL   The Hong Kong Polytechnic University



**Dr. Ryan Watson**

### Track Chair



**Dr. Li-Ta Hsu**

**8:35. Improvements to GNSS Positioning in Challenging Environments by 3DMA Lidar Informed Selective Satellites Usage**, Russell Gilabert, Julian Gutierrez, Evan Dill, NASA Langley Research Center

**8:57. Seamless Navigation for Indoor-Outdoor Positioning Using GNSS-Aided UWB/WiFi/IMU System**, Akpojoto Siemuri, Mahmoud Elsanhoury, Kannan Selvan, Petri Välijöö, Heidi Kuusniemi, Mohammed S. Elmusrati, University of Vaasa

**9:20. GRU/LSTM-CNN/Bayesian-LSTM based Fusion Architecture for Multi-Sensor GNSS/INS/Monocular Deployment in Urban Canyons with Integrity**, Patrick Geraghty, School of Aerospace, Transport and Manufacturing (SATM), Cranfield University; Ivan Petrunin, Weisi Guo, Centre for Autonomous and Cyberphysical Systems, Cranfield University; Raphael Grech, Technical Strategist in Emerging Technologies, Spirent Communications PLC

**9:43. Defining an Integrity Metric for Diverse, Multi-Sensor PNT Devices**, John Fischer, Safran Navigation and Timing

10:05-10:35, Break. Refreshments in Exhibit Hall

### Alternate Presentations

1. **Android GNSS/INS Using Complementary Filter**, Dong-Kyeong Lee, Jeonghyeon Yun, Evan Gattis, Dennis Akos, Byungwoon Park, University of Colorado
2. **Exploring the Benefits of Deep Learning-Based Sensors Error Estimation for Improved Attitude and Position Accuracy**, Eslam Mounier, Queen's University, and Ain Shams University; Paulo Ricardo Marques de Araujo, Queen's University; Mohamed Elhabiby, Micro Engineering Tech Inc.; Michael Korenberg, Queen's University; Aboelmagd Noureldin, Royal Military College, and Queen's University

# ION GNSS+ Technical Sessions

## E3b: High Precision GNSS Positioning in Challenging Environments

Date: Thursday, September 14, 2023

Time: 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Dr. YuXiang (Phillip) Peng**  
Qualcomm Technologies Inc.



**Dr. Michael Fu**  
Google

### Track Chair



**Dr. Li-Ta Hsu**  
The Hong Kong Polytechnic University

**8:35. Riemannian Optimization for GNSS-Based Attitude Models: Beyond MC-LAMBDA**, Oliviero Vouch, Department of Electronics and Telecommunications (DET), Politecnico di Torino; Andrea Bellés, Daniel Medina, Institute of Communications and Navigation, German Aerospace Center (DLR); Fabio Dovis, DET, Politecnico di Torino

**8:57. All-Frequency GNSS PPP-RTK Using Observable-Specific Signal Biases for Urban Environments**, Feng Wang, Kunlun Zhang, GNSS Research Center, Wuhan University

**9:20. Towards GNSS Ambiguity Resolution for Smartphones in Realistic Environments: Characterization of Smartphone Ambiguities with RTK, PPP, and PPP-RTK**, Jiahuan Hu and Sunil Bisnath, York University

**9:43. Testing the Galileo High Accuracy Service in Different Operational Scenarios**, Luca Cucchi, Sophie Damy, Ciro Gioia, Beatrice Motella, Matteo Paonni, European Commission Joint Research Centre

10:05-10:35, Break. Refreshments in Exhibit Hall

**10:40. Generalized Integer Aperture Bootstrapping for Constrained Baselines and Attitude**, Nathan Green, Coherent Technical Services, Inc.

**11:03. Validation of RTK and PPK Solutions Assisted with Random Sample Consensus**, Zhen Zhu, Cole Dickerson, and Alqasem Hindi, East Carolina University Eric Vinande and Jason Pontious, Air Force Research Lab

**11:26. Precise Positioning of Smartphones Using a Robust Adaptive Kalman Filter**, Anurag Raghuvanshi, Sudha Vana, Sunil Bisnath, York University

**11:48. Differential Factor Graph Optimization with Intelligent Covariance Adaptation for Accurate Smartphone Positioning**, Hoi-Fung Ng, Penghui Xu, Yihan Zhong, Guohao Zhang, Weisong Wen, Li-Ta Hsu, Department of Aeronautical and Aviation Engineering, The Hong Kong Polytechnic University

### Alternate Presentations

1. **Resilient High Precision Positioning using RTK and Distributed GNSS Antenna Subarrays**, Can Özmaden, Marius Brachvogel, Chair of Navigation, RWTH Aachen University; Tobias Bamberg, Chair of Navigation, RWTH Aachen University & German Aerospace Center (DLR); Michael Niestroj, Chair of Navigation, RWTH Aachen University; Michael Meurer, Chair of Navigation, RWTH Aachen University & DRL
2. **Analysis of Smartphone Based Dynamic User RTK Performance Using Portable RF Shielded Box**, Bu-Gyeom Kim, Changdon Kee, Department of Aerospace Engineering and SNU-IAMD, Seoul National University
3. **Map-Aided Particle Filter for Improved Multi-hypothesis Ambiguity Resolution**, Rene Manzano-Islas, Kyle O'Keefe, Department of Geomatics Engineering, University of Calgary

### Virtual Presentations

1. **Robust Regional Ionospheric Augmentation Based on IRIM for PPP-RTK**, Sijie Lyu, Yan Xiang and Wenxian Yu, Shanghai Jiao Tong University

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m. • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.,

# ION GNSS+ Technical Sessions

## E3c: LEO for Positioning, Navigation, and Timing

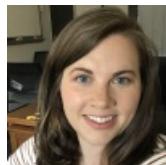
Date: Thursday, September 14, 2023

Time: 10:35 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Kazuma Gunning**  
Xona Space Systems



**Dr. Kirsten Strandjord**  
University of Colorado Boulder

### Track Chair



**Dr. Li-Ta Hsu**  
The Hong Kong Polytechnic University

**10:40. Assessment of Measurement Errors in Differential Navigation with LEO Satellites**, Joe Saroufim, Samer Hayek, and Zak (Zaher) M. Kassas; The Ohio State University

**11:03. Tracking GPS-like Signals Transmitted from LEO Satellites and Propagated Through Ionospheric Plasma Structures**, Jiawei Xu, Y. Jade Morton, University of Colorado Boulder; Dongyang Xu, NovAtel; Yu Jiao, Trimble Navigation; Joanna Hinks, Air Force Research Laboratory

**11:26. Analysis of LEO-Doppler Alternative Navigation System Performance in High-Altitude Environments**, Jennifer Sanderson, Daniel Bowman, Lauren Wheeler, Andrew Glen, Erika Roesler, Andres Sanchez, Philip Miller, Ben Bishop, Justin LaPierre, Jake Zenker, Sandia National Laboratories

**11:48. An Agile, Portable, Antenna System for LEO Megaconstellation-Based PNT**, Wenkai Qin, Zacharias M. Komodromos, Todd E. Humphreys, University of Texas at Austin

### Alternate Presentations

1. **Time Delay of Arrival Based Orbit (TDOA) Determination of Geosynchronous Signals of Opportunity (SoOp)**, Siddharth S. Subramanyam, James L. Garrison, Purdue University; Patrick Smith, Yu Zhang, C. K. Shum, The Ohio State University
2. **Signal Simulator for Starlink Ku-Band Downlink**, Zacharias M. Komodromos, Wenkai Qin, Todd E. Humphreys, Department of Aerospace Engineering and Engineering Mechanics, The University of Texas at Austin
3. **Performance Analysis of LEO Multi-Constellation Aided GNSS Positioning under Weak Signals Environments**, Ya-Xun Yang, Shau-Shiun Jan, National Cheng Kung University

### Virtual Presentations

1. **Custom GNSS Signal Simulator for LEO GNSS Augmentation System**, Mohamed Abduljawad, United Arab Emirates University, Al Ain, UAE Alina M. Hasbi, National Space Science and Technology Center, Al Ain, UAE Jean-luc Issler, Centre national d'études spatiales (CNES)

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m. • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.,

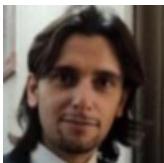
# ION GNSS+ Technical Sessions

## F3: Lunar Positioning, Navigation, and Timing 1

Date: Thursday, September 14, 2023

Time: 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Cosimo Stallo**

Thales Alenia Space



**Dr. Angela Stickle**

Johns Hopkins University APL Civil Space

### Track Chair



**Dr. Seebany Datta-Barua**

Illinois Institute of Technology

**8:35. NavCube3-mini Lunar GNSS Receiver**, Munther A. Hassouneh, Darren Midkiff, Luke M.B. Winternitz, Samuel R. Price, Luke Thomas, David Hatke, NASA; Tyler Lee, William Bamford, Emergent Space Technologies; Jason W. Mitchell, NASA

**8:57. Multi-Sensor Fusion for Improved Navigation in Lunar Landing Missions**, Giuseppe Tomasicchio, Luca Andolfi, Marco Brancati, Arsenio Maria Di Donna, Telespazio S.p.A; Roberto Del Prete, Alfredo Renga, Michele Grassi, Department of Industrial Engineering, University of Naples Federico II; Michele Ceresoli, Michelle Lavagna, Aerospace Science and Technology Department, Politecnico di Milano

**9:20. LunaNet Navigation Services and Signal, Enabling the Future of Lunar Exploration**, Pietro Giordano, Richard Swinden, ESA; Cheryl Gramling, Juan Crenshaw, NASA; Javier Ventura-Traveset, ESA

**9:43. Lunar South Pole Region Navigation Using Lunar Navigation Satellite System**, Masaya Murata, Kyohei Akiyama, and Naoki Satoh, Japan Aerospace Exploration Agency

10:05-10:35, Break. Refreshments in Exhibit Hall

**10:40. Early Artemis Surface Navigation: Challenges, Approaches, and Opportunities**, Evan Anzalone, NASA/MSFC; Lemuel Carpenter, NASA/LARC; Cheryl Gramling, Laurie Mann, NASA/GSFC; Thomas Moody, NASA/JSC

**11:03. Development of a Lunar Surface Navigation Pseudolite Testbed**, Brodie Wallace, Scott Palo, Penina Axelrad, John Marino, Nicholas Rainville, Ryan Kingsbury, and Julia Ditomas, University of Colorado Boulder; Dennis Ogbe and Mazen Shihabi, Jet Propulsion Laboratory

**11:26. Cooperative DGNSS Positioning in Space: Application Based on NaviMoon Receiver Measurements**, Anaïs Delépaut, Alex Minetto, Fabio Dovis, Politecnico di Torino; Pietro Giordano, European Space Agency

**11:48. Satellite Ephemeris Approximation Methods to Support Lunar Positioning, Navigation, and Timing Services**, Marta Cortinovis, Keidai Iiyama, Grace Gao, Stanford University

### Alternate Presentations

1. **Future SSV for the Moon and beyond**, S. Corvo, F. Paggi, E. E. Zini, C. Cristodaro, Thales Alenia Space Italy
2. **Positioning Performance of a Lunar Lander Using LCNS and a Lunar Surface Beacon with Realistic ODTs**, Floor Thomas Melman, Yoann Audet, European Space Agency; Serena Molli, Sapienza University of Rome; Paolo Zoccarato, Richard Swinden, Pietro Giordano, and Javier Ventura-Traveset, European Space Agency
3. **Performance Analysis of an Extended Lunar Radio Navigation System**, Cosimo Stallo, Mattia Carosi, Laura De Leo, Daniele Musacchio, Enrico Edoardo Zini, Martina Cappa, TAS-I; Henno Boomkamp, TPZ-G
4. **Towards cm-level Accuracy Lunar Reference Frames: A roadmap for future Lunar Navigation Service Providers**, Marco Laurenti, Thales Alenia Space France; Cosimo Stallo, Mattia Carosi, Laura De Leo, Thales Alenia Space Italy; Jean-Charles Marty, CNES, Centre National d'études Spatiales
5. **Moon Navigation: Development of a Moon RFCS and Preliminary Concept of a Moon Station**, Matteo Nardini, Stefano Garlaschi, Marco Rotoloni, Luca Canzian, Andrea Dalla Chiara Qascom
6. **Using HEO Spacecraft Data to Investigate Navigating Cis Lunar Space**, Faith Cornish Kirsten Strandjord, University of Colorado Boulder
7. **Lunar Navigation - Where do we go From Here?**, John Ware and Nate Bickus, Lockheed Martin Space
8. **Identifying the Technical and Economic Challenges of Position, Navigation, and Timing in a Lunar Environment**, Danielle Mortensen, Sarah Withee, Johns Hopkins University Applied Physics Lab

### Virtual Presentations

1. **Analysis of PNT Algorithms and Related Performance for Lunar Navigation Service Users**, Filippo Rodriguez, Alessio Martinelli, Luca Spazzacampagna, Carlo Albanese, Telespazio SpA; Giovanni B. Palmerini, Marco Sabatini, Scuola di Ingegneria Aerospaziale, Sapienza Università

# ION GNSS+ Technical Sessions

di Roma

Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m. • Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.,

# ION GNSS+ Technical Sessions

## A4: Positioning Technologies and Machine Learning

Date: Thursday, September 14, 2023

Time: 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Dr. Diana Fontanella**  
Airbus Defence and Space



**Dr. Naser El-Sheimy**  
University of Calgary

### Track Chair



**Deborah Lawrence**  
Federal Aviation Administration

**1:50. Effectiveness of Neural Network Approaches for the Acquisition of Non-Periodic Spreading Codes**, Marco Trombini, Davide Leone, Angelo Bruno, Marco D'Addezio, Gianluca Falco, Emanuela Falletti, Leonardo S.p.A.

**2:12. Evaluation of (Un-)Supervised Machine-Learning-Based Detection, Classification, and Localization Methods of GNSS Interference in the Real World**, Tobias Feigl, Fraunhofer Institute for Integrated Circuits (IIS), & Friedrich-Alexander-Universität (FAU); Tobias Brieger, Felix Ott, Fraunhofer IIS, & Ludwig-Maximilians-Universität (LMU); Jonathan Hansen, David Contreras Franco, Alexander Rügamer, Wolfgang Felber, Fraunhofer IIS

**2:35. Ionosphere VTEC Map Forecasting Based on Graph Neural Network with Transformers**, Ruirui Liu, Yiping Jiang, Department of Aeronautical and Aviation Engineering, The Hong Kong Polytechnic University

**2:58. A Deep Learning Approach for a Real-Time Ionospheric Delay Forecasting Map System**, Andre L.A. Silva - Instituto Tecnológico de Aeronáutica; Moises S. Freitas - Instituto Tecnológico de Aeronáutica; Clodoaldo Faria Jr - Universidade Estadual Paulista; Paulo R.P. Silva - Instituto Tecnológico de Aeronáutica; Alison O. Moraes - Instituto de Aeronáutica e Espaço; Bruno C. Vani - Instituto Federal de Educação, Ciência e Tecnologia de São Paulo; Jonas Sousasantos - The University of Texas at Dallas; João F.G. Monico - Universidade Estadual Paulista;

3:25 - 3:55, Break. Refreshments in Exhibit Hall

**4:00. Transformer Deep Learning for Real-Time Precise Orbit Corrections**, Wahyudin P. Syam, Shishir Priyadarshi, Andrés Abelardo García Roqué, Alejandro Pérez Conesa, GMV; Guillaume Buscarlet, Mickael Dall'Orso, European Space Agency (ESA)

**4:23. Deep Learning in GNSS Orbit and Clock Extended Predictions to Improve the Accuracy and Robustness of Positioning**, Li-Hsiang Chu, Yin-Lien Lo, Yao-cheng Lin, Shi-Xian Yang, AIROHA Technology (Company of MediaTek Group)

**4:46. Tightly Coupled Graph Neural Network and Kalman Filter for Improving Smartphone GNSS Positioning**, Adyasha Mohanty and Grace Gao, Stanford University

**5:08. First Real-World Results of a Deep Neural Network Assisted GNSS/INS Kalman-Filter with MEMS Inertial Sensors for Autonomous Vehicle**, Shuo Li, Robert Bosch GmbH and Bundeswehr University Munich; Maxim Mikhaylov, ITMO University; Nikolay Mikhaylov, Robert Bosch GmbH; Thomas Pany, Mohamed Bochkati, Bundeswehr University Munich

### Alternate Presentations

1. **High-Solar Activity Ionospheric Modelling Using Machine Learning: A Comparison Against Classical Models**, Shishir Priyadarshi, Wahyudin P. Syam, Andrés Abelardo García Roqué, Alejandro Pérez Conesa, GMV; Guillaume Buscarlet, Raül Orús Pérez, Mickael Dall'Orso, European Space Agency (ESA)
2. **Assessing Machine Learning Approach for GNSS Satellite Orbit Prediction**, Kannan Selvan, Akpojoto Siemuri, Fabricio S. Prol, Petri Välijuso, Heidi Kuusniemi, University of Vaasa
3. **Inter-System Bias Estimation Using the MAFA Method**, Dawid Kwasniak, Sławomir Cellmer, The University of Warmia And Mazury in Olsztyn
4. **GSSC Now: Data-Centric Digital Platform to Boost Exploitation of GNSS Science Opportunities**, Vicente Navarro, ESA; Sara del Rio, Luis Mendes, Jordi Prados, Emilio Fraile, RHEA for ESA; Maria del Mar Millán, Alain Messina, Miguel Barragán, Marcos Castro, GMV; Javier Ventura-Traveset, ESA

### Virtual Presentations

1. **A Machine Learning-based Approach for Correcting Cooperative DGNSS Differential Corrections**, Guoqiang Zeng, Hongbo Zhao, Chen Zhuang, Shan Hu, Beihang University
2. **A Robust RF Fingerprint Extraction Scheme for GNSS Spoofing Detection**, Chengjun Guo, University of Electronic Science and Technology of China (UESTC), China; Zhongpei Yang, University of Electronic Science and Technology of China (UESTC)
3. **Efficient Graph Neural Network driven Reinforcement Learning for GNSS Position Correction**, Zhenni Li, Zhuoyu Wu, Haoli Zhao, School of Automation, Guangdong University of Technology; Shengli Xie, Guangdong Key Laboratory of IoT Information Technology; Qianming Wang,

# ION GNSS+ Technical Sessions

Techtop Microelectronics Technology Co. Ltd.

4. **Incremental Learning for LOS/NLOS Classification of Global Navigation Satellite System**, Yuan Sun, Shang Li, Zhongliang Deng, School of Electronics Engineering, Beijing University of Posts and Telecommunications

# ION GNSS+ Technical Sessions

## B4: PANEL: Emerging Autonomous Application – Challenges and Prospects

**Date:** Thursday, September 14, 2023

**Time:** 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Dr. Tyler Reid**  
Xona Space Systems



**Marcus Graf von Wilamowitz**  
*u-blox*

### Track Chair



**Dr. Andrew Neish**  
Xona Space Systems

Experts from academia, government, and industry will discuss the technical challenges associated with emerging autonomous applications. These systems span a wide spectrum of applications from robot lawnmowers or Level 2 driver assistance, to technology under development such as SAE Level 4-5 autonomous driving. This panel discussion will look at emerging applications, their tradeoffs including cost, complexity, maturity, reliability and long-term viability, and their promise for the future.

### Panel Members:

1. Ms. Irma Rodríguez Pérez, *GMV*
2. Dr. Toni Huovinen, *u-blox*
3. Dr. Nikolay Mikhaylov, *Robert Bosch GmbH*
4. Dr. Ramsey Faragher, *Focal Point Positioning*

# ION GNSS+ Technical Sessions

## C4: Trends in Future Satellite Navigation Technology, System Design and Development

Date: Thursday, September 14, 2023

Time: 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Dr. Takeyasu Sakai**

National Institute of Maritime, Port and Aviation Technology European Commission JRC



**Dr. Sophie Damy**

### Track Chair



**Dr. Ilaria Martini**

U-blox

1:50. Galileo System Performance Trends and Evolution Towards Full Operational Capability, a Time and Geodetic Validation Facility (TGVF) Perspective, G. Galluzzo, S. Circiu, D. Ibañez, G. Lopez, S. Wallner, J. Hahn, ESA-ESTEC; C. García, L. Domínguez, F. J. Sobrero, A. García, GMV

2:12. Galileo Quasi-Pilot Signals: Assessment and Design Options for Acquisition and Time Dissemination, J.A. Garcia-Molina, S. Wallner, J. Hahn, G. Lopez-Risueno, European Space Agency; Matteo Paonni, EC/JRC; Marco Caparrini, EUSPA

2:35. Preliminary Evaluation of Galileo ACAS Using Existing E1-E6 Open Signals and a Low-Cost SDR Platform, Rafael Terris-Gallego, José A. López-Salcedo, Gonzalo Seco-Granados, Univ. Autonoma de Barcelona/IEEC; Ignacio Fernandez-Hernandez, DG DEFIS, European Commission

2:58. Internet-based GNSS Signal Authentication, Dinesh Manandhar Center for Spatial Information Science, The University of Tokyo

3:25 - 3:55, Break. Refreshments in Exhibit Hall

4:00. Ensuring PNT Resilience: A Global Review of Navigation Policies and Roadmaps, Joshua Critchley-Marrows, The University of Sydney; Quentin Verspieren, The University of Tokyo

4:23. Design Considerations for a European LEO-PNT, Christoph Günther, German Aerospace Center, DLR and Technical University Munich; Michael Günther, Technical University Munich, TUM

4:46. A GNSS-Synchronized Satellite Navigation Payload for LEO PNT, Florian Kunzi, Benjamin Braun, Markus Markgraf, Oliver Montenbruck, German Aerospace Center (DLR) / German Space Operations Center (GSOC)

5:08. GNSS Augmentation by Low-Earth-Orbit (LEO) Satellites: Integrity Performance Under Non-Ideal Conditions, Sam Pullen, Sherman Lo, Sukrut Oak, Isaiah Colobong, Juan Blanch, and Todd Walter, Stanford University; Mark Crews and Robert Jackson, Lockheed Martin

## Alternate Presentations

1. Increasing the Resilience of Multi-Constellation Multi-Frequency Mass Market Receiver by Taking Advantage of Galileo OSNMA, Jesus Zamora, Magdalini Rouseti, Christoph Schmid, u-blox AG
2. Assessment of Galileo High Accuracy Service (HAS) using the Galileo High Accuracy Reference Algorithm and User Terminal (HAUT), Emilio González, Pedro Pintor, Ana Senado, Narayan Dhital, Spaceopal GmbH; Stefano Lagrasta, Javier de Blas, EUSPA
3. EGNOS V3 Single Frequency and Dual Frequency Multi Constellation – Preliminary Performances, Roland Braun, Airbus Defence & Space GmbH; Marc Boyer, Airbus Defence & Space SAS; Mickael Dall'Orso(3), Nicolas Giron, Carlos López de Echarre, EGNOS Project Office - European Space Agency (ESA)

## Virtual Presentations

1. Considerations in SSR Corrections Format Design, Sudha Vana, Vijaykumar Bellad, Rx Networks Inc.; Guangyu Zhou, TruePoint Technology Inc.

# ION GNSS+ Technical Sessions

## D4: Indoor and Urban Navigation and Mapping

Date: Thursday, September 14, 2023

Time: 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Dr. Jason Gross**  
West Virginia University



**Irma Rodríguez Pérez**  
GMV

### Track Chair



**Dr. Simona Cinciu**  
ESA

1:50. Asymmetric Positioning for NLOS Mitigation, Qiming Zhong, University College London

2:12. Attitude Determination in Urban Canyons: A Synergy Between GNSS and 5G/6G Observations, Pinjun Zheng, Xing Liu, Tarig Ballal, and Tareq Y. Al-Naffouri, King Abdullah University of Science and Technology (KAUST)

2:35. An Integrated RTK/INS/Solid-State LiDAR Method for Large-Scale Vehicle Navigation in High-Mobility Scenarios, Jiahui Liu, Cheng Chi, Xingqun Zhan, and Xin Zhang, School of Aeronautics and Astronautics, Shanghai Jiao Tong University

2:58. Neural City Maps: A Case for 3D Urban Environment Representations Based on Radiance Fields, Mira Partha, Shubh Gupta, Grace Gao, Stanford University

3:25 - 3:55, Break. Refreshments in Exhibit Hall

4:00. GNSS/INS Positioning in Dense Urban Environment with Adaptive Choice of Process Noise Covariance Based on Satellite Geometry, Yoji Takayama, Furuno Electric Co., Ltd.; Takateru Urakubo, Hisashi Tamaki, Kobe University

4:23. Factor Graph Optimization-based Activity-SLAM for Pedestrian Trajectory Estimation Using Smartphones, Shiyu Bai, Weisong Wen and Li-Ta Hsu Department of Aeronautical and Aviation Engineering, The Hong Kong Polytechnic University

4:46. RSS Signal Modeling-based Rapid and Accurate Fingerprinting Database Construction of Indoor Localization Technology, Jung Ho Lee, City & Geospatial ICT Research Section, Electronics and Telecommunications Research Institute; Taehun Kim, Augmented Safety System with Intelligence Sensing & Tracking, Korea Institute of Science and Technology; Yongsu Cho, Juil Jeon, Kyeongsoo Han, City & Geospatial ICT Research Section, Electronics and Telecommunications Research Institute; Taikjin Lee, Augmented Safety System with Intelligence Sensing & Tracking, Korea Institute of Science and Technology

5:08. Neural Network-Based Multipath Mitigation Method for Precise Indoor Positioning, Min-Ji Kim, Ki-Hyun Kim, O-Jong Kim, Department of Aerospace Engineering, Sejong University

## Alternate Presentations

1. Positioning in the GNSS Signal Disconnection Area Based on Multiple Pseudolites, Sihwa Song, Jiyoung Moon, Jongsin Lee, Daehyun Kim, NGII
2. Indoor Mapping Structure based on Cloud Platform for Seamlessness and Effectiveness of Indoor Localization, Taehun Kim, KIST & Korea University; Beomju Shin, KIST; Chung G. Kang, Korea University; Donghyun Shin, Changsoo Yu, TJ LABS corp.; Hankyeol Kyung, KIST; Taikjin Lee, KIST & TJ LABS corp.
3. Building Update Monitoring with Sky Pointing Images and GNSS Measurements, HaoSheng Xu, Guohao Zhang, Li-Ta Hsu, Department of Aeronautical and Aviation Engineering, The Hong Kong Polytechnic University
4. The Description of a Prototype MC-CDMA Indoor Geolocation System, Ilir F. Progri, Giftet Inc.

## Virtual Presentations

1. Enhanced Positioning Through Hybrid 5G-NR/GNSS, Amir M. Osman, Charles K Toth, Marco Araújo, Bosch
2. Tightly Coupled GNSS/INS Integration Accurate Location Algorithm Under Urban Canyons Based On Factor Graph Optimization, Yuan Sun, Qikai Li, Zhongliang Deng, School of Electronics Engineering, Beijing University of Posts and Telecommunications

# ION GNSS+ Technical Sessions

# ION GNSS+ Technical Sessions

## E4: GNSS Navigation in Challenging Environments

Date: Thursday, September 14, 2023

Time: 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Dr. Nesreen Ziedan**



**Dr. Paul Groves**

Zagazig University

University College London

The Hong Kong Polytechnic University

### Track Chair



**Dr. Li-Ta Hsu**

**1:50. Extending 3DMA GNSS with Diffraction Features in Urban Areas: Feasibility Analysis and Preliminary Results**, Guohao Zhang, Di Hai, Hoi-Fung Ng, and Li-Ta Hsu, Department of Aeronautical and Aviation Engineering, The Hong Kong Polytechnic University

**2:12. 3D Mapping Aided GNSS Positioning Using Doppler Frequency for Urban Areas**, Liyuan Zhang, Hoi-Fung Ng, Guohao Zhang, and Li-Ta Hsu, Department of Aeronautical and Aviation Engineering, The Hong Kong Polytechnic University

**2:35. Experimental Investigation of GNSS Direct Position Estimation in Densely Urban Area**, Sergio Vicenzo, Bing Xu, Li-Ta Hsu, Department of Aeronautical and Aviation Engineering, The Hong Kong Polytechnic University; Abhijit Dey, Department of Electrical and Electronics Engineering, Birla Institute of Technology and Science

**2:58. GNSS Multi-Frequency Combined Direct Position Estimation in the Urban Canyon Environment**, Jihong Huang, Rong Yang, Xingqun Zhan, School of Aeronautics and Astronautics, Shanghai Jiao Tong University

3:25 - 3:55, Break. Refreshments in Exhibit Hall

**4:00. Jamming Robust Interference Mitigation in GNSS Snapshot Receivers**, Helena Calatrava, Electrical and Computer Engineering Dept., Northeastern University; Adrià Gusi-Amigó, Albora Technologies, London, UK; Floor Melman, European Space Agency (ESA/ESTEC), Noordwijk, Netherlands; Pau Closas, Electrical and Computer Engineering Dept., Northeastern University

**4:23. 3D LiDAR-Aided GNSS NLOS Correction by Reflecting Path Restoration Using Reflection Map**, Xikun Liu, Weisong Wen, Li-Ta Hsu, Department of Aeronautical and Aviation Engineering, the Hong Kong Polytechnic University

**4:46. Improving Tracking Robustness Through Interference Using Pilot Signals with a Deeply Coupled Estimator**, Logan Bednarz, Samer Khanafseh, Boris Pervan, Illinois Institute of Technology

**5:08. Time-Differenced Carrier Phase Based Integrity Monitoring for Urban Air Mobility Using 3D City Model**, Hojoon Jeong, Changdon Kee, Department of Aerospace Engineering and SNU-IAMD, Seoul National University; Junesol Song, Department of Mechanical Engineering, University of Suwon; Jungbeom Kim, Samsung Electronics System LSI

## Alternate Presentations

1. Normalized Bandwidth Control Algorithm for Robust GNSS Adaptive Tracking, Inigo Cortés, Natalia Conde, Fabio Garzia, Fraunhofer IIS; Elena Simona Lohan, Jari Nurmi, Tampere University; and Wolfgang Felber, Fraunhofer IIS
2. Hopular-Based GNSS Signal Reception Classification Algorithm with Optimal Feature Selection and Environmental Pattern Recognition, Zelin Zhou, Hongzhou Yang, Department of Geomatics Engineering, University of Calgary
3. Towards Accurate GNSS Receiver Clock Calibration: Robust Wavelet Variance-Based Stochastic Analysis of Instantaneous Code Phase-Based Oscillator Instability, Chrysostomos Minaretzis, Yiran Luo, University of Calgary; Stéphane Guerrier, University of Geneva; Naser El-Sheimy, Michael Sideris, University of Calgary
4. Evaluating GNSS Ray Tracing Performance in Urban Canyons, Peng Xie, OpenLoopNav Inc.
5. Data Interpolation Method for 3D City Modeling to aid Satellite Navigation, Erne Mc Cabe, Kirsten Strandjord, Clare Graney-Dolan, University of Minnesota

## Virtual Presentations

1. A Solution Separation Algorithm for Velocity Estimation in Rail and Road Applications, Michele Brizzi, Roma Tre University; Alessandro Neri, Roma Tre University & RADIOLABS; Francesco Rispoli, RADIOLABS

## ION GNSS+ Technical Sessions

2. **Features Effectiveness Verification Using Machine-Learning-Based GNSS NLOS Signal Detection in Urban Canyon Environment**, Naishu Yin, Di He, Yan Xiang, Shanghai Key Laboratory of Navigation and Location-based Services, Shanghai Jiao Tong University; Fusheng Zhu, Guangdong Communications & Networks Institute; Wenxian Yu, Shanghai Key Laboratory of Intelligent Sensing and Recognition, Shanghai Jiao Tong University
3. **GNSS Positioning using Cost Function Regulated Triangulation and Graph Neural Networks**, Amir Jalalirad, Davide Belli, Bence Major, Qualcomm AI Research; Songwon Jee, Himanshu Shah, Will Morrison, Qualcomm Technologies, Inc.

# ION GNSS+ Technical Sessions

## F4a: GNSS Robustness to Vulnerabilities 1

Date: Thursday, September 14, 2023

Time: 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Dr. Anna B. O. Jensen**  
Swedish Maritime Administration



**Jason Anderson**  
Stanford University

### Track Chair



**Dr. Seebany Datta-Barua**  
Illinois Institute of Technology

1:50. Multi-Circular Ring CRPA with Robust GNSS Performance for Civil Applications, Chris Bartone, Ohio University; Bradford W Parkinson, Stanford University; Tom Stansell, Stansell Consulting

2:12. Enhancements Enabled by Multi-Element Antennas for GPS Anti-jamming Capabilities in Civil Applications, Bradford Parkinson, Stanford University, and Chris Bartone, Ohio University

2:35. Hybrid Autoencoder for Interference Detection in Raw GNSS Observations, Karin Mascher, Stefan Laller, Philipp Berglez, Institute of Geodesy, Graz University of Technology

2:58. A Satellite-Based Two-Way Ranging Protocol for GNSS Positioning Authentication and Time Transfer, Federica Rozzi, Luca Canzian, Oscar Pozzobon, Qascom

3:25 - 3:55, Break. Refreshments in Exhibit Hall

4:00. FGI-OSNMA: An Open Source Implementation of Galileo's Open Service Navigation Message Authentication, Toni Hammarberg, Jose M. Vallet Garcia, Jarno Alanko, M. Zahidul H. Bhuiyan, Finnish Geospatial Research Institute

4:23. GNSS Spoofing Detection and Recovery by Decomposition of the Complex CAF and INS Aiding, Sahil Ahmed, Samer Khanafseh, Boris Pervan, Illinois Institute of Technology

4:46. Blind Spoofers Detection and Mitigation using an Array of Spatially Distributed Subarrays, Marius Brachvogel, Michael Niestroj, Chair of Navigation, RWTH Aachen University; Tobias Bamberg, Michael Meurer, Chair of Navigation, RWTH Aachen University, & Institute of Communications and Navigation, German Aerospace Center (DLR)

5:08. Fault-Robust GPS Spoofing Mitigation with Expectation-Maximization, Ashwin Vivek Kanhere and Grace Gao, Stanford University

## Alternate Presentations

1. Testing a Coherent Software Defined Radio Platform for Detection of Angle of Arrival of RF Signals, Lucca Trapani, Benon Gattis, Nathaniel Lee, University of Colorado Boulder; Yh Chen, Sherman Lo, Todd Walter, Stanford University; Dennis Akos, University of Colorado Boulder & Stanford University
2. Advantages of a Robust Multi-Antenna GNSS Receiver in UAV Flight Jamming Scenarios, Philipp Rudnik, German Aerospace Center (DLR)
3. Multi-Frequency, Multi-Constellation INS-assisted GNSS for Improved Navigation Under Jamming Conditions, Abdelsatar Elmezayen, Royal Military College of Canada (RMCC), and Tanta University; Haidy Elghamrawy, Malek Karaim, RMCC; Aboelmagd Noureldin, RMCC, and Queen's University
4. On the Parameterization of Single Pole Adaptive Notch Filter Against a Wide Range of Linear Chirp Interference, Syed Ali Kazim, Juliette Marais, Nourdine Aït Tmazirte, COSYS-LEOST, Univ Gustave Eiffel, Univ Lille
5. A Navigation Signals Monitoring, Analysis and Recording Tool: Application to Real-Time Interference Detection and Classification, Iman Ebrahimi Mehr, Alex Minetto, and Fabio Dovis, Politecnico di Torino, Department of Electronics and Telecommunications

## Virtual Presentations

1. A Modified Sparse Bayesian Learning Method for High-Accuracy DOA Estimation with TCN under Array Imperfection, Yi Jin, Di He, Shanghai Jiao Tong University; Shuang Wei, Shanghai Normal University; Longwei Tian, Shanghai Jiao Tong University; Fusheng Zhu, Communications & Networks Institute; Wenxian Yu, Shanghai Jiao Tong University
2. Novel Replay Attacks Against Galileo Open Service Navigation Message Authentication, Haiyang Wang, School of Computer Science and

# ION GNSS+ Technical Sessions

Technology, Xidian University; Yuanyu Zhang, School of Computer Science and Technology, Xidian University; Jinxiao Zhu, Toyo University; Yin Chen, Reitaku University; Yulong Shen, School of Computer Science and Technology, Xidian University; Xiaohong Jiang, Future University Hakodate

## F4b: Atmospheric Effects on GNSS

Date: Thursday, September 14, 2023

Time: 1:45 p.m. - 5:30 p.m.

### Session Chairs



**Dr. Susan Skone**  
University of Calgary



**Dr. Endawoke Yizengaw**  
The Aerospace Corporation

### Track Chair



**Dr. Seebany Datta-Barua**  
Illinois Institute of Technology

**1:50. Residual Error Model to Bound Unmodeled Tropospheric Delays for Terrestrial Navigation Systems for Very Low Elevation Angles, Shrivathsan Narayanan, Technical University of Berlin**

**2:12. Connection between Stratospheric Gravity Waves, Mesospheric Winds and Traveling Ionospheric Disturbances, Sevag Derghazarian, Larisa P. Goncharenko, Shun-Rong Zhang, Anthea J. Coster, MIT Haystack Observatory; V. Lynn Harvey, Cora Randall, University of Colorado Boulder, LASP**

**2:35. Ionospheric Irregularities Signature Correlation on ROT Variation for Earthquake Detection and Epicenter Estimation: A Case Study of the Türkiye-Syria Earthquake, Minhyoung Cho, Jeonghyeon Yun, Byungwoon Park, Sejong University**

**2:58. Ionosphere TEC Observation over Ocean Using Single-frequency Wideband GNSS Signal Reflectometry, Yang Wang, Smead Department of Aerospace Engineering Sciences, University of Colorado Boulder**

**3:25 - 3:55, Break. Refreshments in Exhibit Hall**

**4:00. Near-Real-Time Anomaly Detection in Total Electron Content for the GUARDIAN Ionospheric Monitor, Siddharth Krishnamoorthy, Léo Martire, Jet Propulsion Laboratory, California Institute of Technology; Fiona Luhrmann, Jihye Park, School of Civil and Construction Engineering, Oregon State University; Attila Komjathy, Béla Szilágyi, Larry Romans, Panagiotis Vergados, Jet Propulsion Laboratory, California Institute of Technology**

**4:23. Comparative Study of the Equatorial Plasma Bubble Using VHF Radar and ROTI Spatial Map From Low-Latitude Region, Napat Tongkasem, Lin M.M. Myint, Pornchai Supnithi, School of Engineering, King Mongkut's Institute of Technology Ladkrabang, Thailand and Kornyanat Hozumi, National Institute of Information and Communications Technology, Japan.**

**4:46. Effects of Equatorial Plasma Bubbles over Real-Time Kinematic Positioning in Low-Latitude Region, Phyoe C Thu, Pornchai Supnithi, Lin Min Min Myint, Jirapoom Budtho, School of Engineering, King Mongkut's Institute of Technology Ladkrabang**

**5:08. Modeling the Interference of Ionospheric Irregularities on GNSS Signals Using Discrete Markov Chains, Paulo R. P. Silva, Instituto Tecnológico de Aeronáutica; Alison O. Moraes, Instituto de Aeronáutica e Espaço; and Marcelo G. S. Bruno, Instituto Tecnológico de Aeronáutica**

## Alternate Presentations

1. Transient Intermediate-Scale Irregularities and GPS Scintillation Associated With Mid-Latitude Trough, Sebastijan Mrak, University of Colorado Boulder
2. Analysis of an Ionospheric Free Dual Frequency Vector Tracking GPS L1/L5 Software Defined Radio, C. Anderson Givhan, Scott Martin, Auburn University
3. Reporting Abnormally High Amplitude Scintillation with GLONASS L1 during Low Solar Activity, Muhammad Mubasshir Shaikh, Abdollah Masoud Darya, Ilias Fernini, Space Weather and Ionosphere Laboratory, Sharjah academy for Astronomy, Space Sciences and Technology, University of Sharjah

## Virtual Presentations

1. Comparison of Global TEC Prediction Performance with Two Deep Learning Frameworks, Kunlin Yang, School of Instrumentation and Opto-Electronic Engineering, Beihang University; Yang Liu, School of Instrumentation and Opto-Electronic Engineering, Beihang University, Marconi Lab, Science, Technology and Innovation Section, Abdus Salam International Centre for Theoretical Physics

## ION GNSS+ Technical Sessions

2. Comparison of Ionospheric Responses in America Induced by Two Different Geomagnetic Storms in 2015, Yang Liu, School of Instrumentation and Opto-Engineering, Beihang University, Marconi Lab, Science, Technology and Innovation Section, Abdus Salam International Centre for Theoretical Physics; Kunlin Yang, School of Instrumentation and Opto-Engineering, Beihang University
3. Non-Isotropic Definition And Characterization Of GNSS Tropospheric Delay Based On IGGIII, Hongzhan Zhou, Ying Xu, Zaozao Yang, Shandong University of Science and Technology

# ION GNSS+ Technical Sessions

**A5a: BeiDou - The Next Generation**

**Date: Friday, September 15, 2023**

**Time: 8:30 a.m. - 10:05 a.m.**

**Session Chairs**



**Dr. Xiaochun Lu**

*CSNO/National Time Service Center, Chinese Academy of Sciences  
(NTSC, CAS)*



**Dr. Jun Lu**

*China Satellite Navigation Project Center  
(CSNPC)*

**Track Chair**



**Dr. Seebany Datta-Barua**

*Illinois Institute of Technology*

**8:35. A More Accurate, Credible and Convenient GNSS Architecture, Shuren Guo, China Satellite Navigation Project Center**

**8:57. Communication and Navigation Integration, Fujian Ma, Chinese Academy of Space Technology**

**9:20. BeiDou Augmentations and Applications, Qile Zhao, Wuhan University**

**9:43. Time and Frequency System, Shougang Zhang, National Time Service Center, Chinese Academy of Sciences**

**10:05-10:35, Break. Refreshments served outside of session rooms**

**Awards Luncheon • 12:15 p.m. - 1:30 p.m. (Lunch served until 12:30 p.m.; late arrivals will not be served)**

# ION GNSS+ Technical Sessions

## A5b: Harsh Urban and Indoor GNSS

Date: Friday, September 15, 2023

Time: 10:35 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Thomas Powell**  
The Aerospace Corporation



**Nacer Naciri**  
York University

### Track Chair



**Deborah Lawrence**  
Federal Aviation Administration

**10:40. A Feasibility Study on 3DMA GNSS in GNSS Accessible Indoor Areas**, Hoi-Fung Ng, Guohao Zhang, Department of Aeronautical and Aviation Engineering, The Hong Kong Polytechnic University; John-Ross Rizzo, Grossman School of Medicine, New York University; Li-Ta Hsu, Department of Aeronautical and Aviation Engineering, The Hong Kong Polytechnic University

**11:03. Pure L5 Long Coherent Based High Sensitivity Snapshot Positioning in Weak Signal Environments**, Chin Lok Tsang, Yiran Luo, Bing Xu, Li-Ta Hsu, The Hong Kong Polytechnic University

**11:26. Towards Integrity Monitoring of GNSS Velocity Estimates in Urban Environment**, Dennis Kulemann, Steffen Schön, Institute for Geodesy, Leibniz University Hannover

**11:48. Fast Time to Fine Time Method To Improve First Fix Accuracy with Modernized Signals In Urban Canyons**, Paul McBurney, oneNav

## Alternate Presentations

1. Synergistic Fusion of GNSS Multipath Map and CMC-based Multipath Estimation for Enhanced GNSS Positioning in Urban Canyon, Yongjun Lee, Byungwoon Park, Sejong university
2. On the Impact of Co-Op Tracking on Multi-Frequency GNSS Synthetic Aperture Processing, Jürgen Dampf, Mohamed Bochkati, Thomas Pany, Institute of Space Technology and Space Applications (ISTA), Space Systems Research Center (FZ-Space), University of the Bundeswehr Munich (Unibw M)
3. Benefits of CNN-Based Multipath Detection for Robust GNSS Positioning, Anthony Guillard, 3D Aerospace/ENAC; Paul Thevenon, Carl Milner, ENAC

## Virtual Presentations

1. Crowdsourcing Radar Maps with AUTO's Integration of Multiple Imaging Radars and INS/GNSS for Autonomous Applications, Abdelrahman Ali, Dylan Krupity, Noah Giustini, Hallet Duan, Jacques Georgy, and Christopher Goodall, TDK Trusted Positioning Inc.
2. Improving Prediction of GNSS Satellite Visibility in Urban Canyon Based on Graph Transformer, Shaolong Zheng, Zhenni Li, Guangdong University of Technology; Kungan Zeng, Sun Yat-sen University; Xie Kan, Guangdong University of Technology; Lujia Wang, Hong Kong University of Science and Technology; Shengli Xie, Guangdong University of Technology; Qianming Wang, Techtop Microelectronics Technology Co. Ltd.

Awards Luncheon • 12:15 p.m. - 1:30 p.m. (Lunch served until 12:30 p.m.; late arrivals will not be served)

# ION GNSS+ Technical Sessions

## B5: Land-Based Applications

Date: Friday, September 15, 2023

Time: 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Ed Olson**  
John Deere



**Tara Mina**  
Stanford University

### Track Chair



**Dr. Andrew Neish**  
Xona Space Systems

**8:35. Achieving Sub-Decimetre Accuracy with the Galileo High Accuracy Service: Results from GMV's HAS Positioning Engine, A. Chamorro, J. Rocamora, S. Cancela, D. Calle, A. García, GMV**

**8:57. Galileo Synthetic Meta-Signal Observations: Performance and Limitations, Ciro Gioia, Independent Researcher; Daniele Borio, European Commission, Joint Research Centre**

**9:20. Commercial Satellite Navigation Architecture, Trades, & Roadmap, Tyler G. R. Reid, Simon Banville, Bryan Chan, Kazuma Gunning, Brian Manning, Thyagaraja Marathe, Andrew Neish, Adrien Perkins, Aurore Sibois, Xona Space Systems**

**9:43. An ASIC-Based Receiver of PULSAR Low-Earth Orbit PNT Demonstration Signals, Wim De Wilde, Jean-Marie Sleewaegen, Sibren De Bast, Frank Boon, Bruno Bougard, Septentrio NV**

**10:05-10:35, Break. Refreshments served outside of session rooms**

**10:40. ITHACA: A Feasibility Study of a Potential Integrity Service Complementing European GNSS (EGNSS) High Accuracy, A. González Sainz, H.S. Martínez Radl, J. D. Calle Calle, C. García Serrano, GMV; S. T. H. Jansen, TNO; M. Bolchi, A. Wion, A. Luciano, VVA; S. Porfili, J. Ostolaza, G. De Pasquale, EUSPA**

**11:03. High Integrity Navigation for Intelligent Vehicles, Philippe Xu, Maxime Noizet, Université de Technologie de Compiègne, CNRS, Heudiasyc; Laia Vilalta, Idneo; Javier Ibañez-Guzmán, Renault; Emmanuel Stawiarski, Renault; Pierre Nemry, Septentrio; Su Yin Voon, Artisense; Wesley Fox, Karel Callewaert, VVA**

**11:26. Cloud Centric Architecture for Precise Positioning in Automotive Industry, Tony Höijer, HERE Technologies; Laurent Mussot, Orange Innovation; Muriel Desaeger, Toyota Motor Europe NV/SA; Pavel Ivanov, HERE Technologies**

**11:48. Multipath Estimation of Dynamic Users in Urban Environment Using Time Differential Code-Minus-Carrier, Yonghwan Bae, Changdon Kee, Department of Aerospace Engineering and SNU-IAMD, Seoul National University**

## Alternate Presentations

1. Real Time Sensor Based Spoofing Detection and Mitigation for Mass Market Automotive GNSS Receivers, Enric Moncasi and Dr. Alexander Somieski, u-blox AG
2. PPP-RTK Supporting Low-Cost Inertial Navigation System for Land Vehicle Navigation, Matteo Cutugno, University of Benevento Giustino Fortunato; Umberto Robustelli, University of Naples Parthenope; Giovanni Pugliano, University of Naples Federico II
3. AIPLAN (Artificial Intelligence for Land Planning), Simon Roberts, Paul Bhatia, Chris Hill, Geospatial Ventures Ltd.; Craig Hancock, University of Loughborough
4. Galileo OSNMA-Enabled MediaTek GNSS Solution, WenChun Shih, Hung-Wei Chen, Albert Chou and Pei-Hung Jau, MediaTek Inc.
5. SBTides – A Modular Tool for Modeling Viscoelastic Solid Body Tides in Python, W. Joseph Durkin, Clayton Davis, The MITRE Corporation

## Virtual Presentations

1. A Real-Time Clock Offset Datum Maintenance Method Based on Short-Term Clock Offset Prediction, Jianhua Cheng, Xue Liu, Hui Li, Nan Li, and Wenzhen Peng, College of Intelligent Systems Science and Engineering, Harbin Engineering University
2. Improving the Railway Through a European GNSS Based Safety Service, Jonathan Vuillaume, Zineb El Aissaoui, Eric Lakour, François Piednoir, Philip Church, Jan-Bjorn Schomann, Sebastian Placzek, Egis; Michael Hutchinson, Gines Moreno Lopez, GMV; Hélène Delfour-Cormier, Céline Rénaze, TAS; Javier Ostolaza, Silvia Porfili, Ettore Canestri, Gerarda Depasquale, Daniel Lopour, EUSPA

# ION GNSS+ Technical Sessions

**Awards Luncheon • 12:15 p.m. - 1:30 p.m. (Lunch served until 12:30 p.m.; late arrivals will not be served)**

# ION GNSS+ Technical Sessions

## C5: GNSS Applications in Space

Date: Friday, September 15, 2023

Time: 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Joel Parker**  
NASA



**Dr. Oliver Montenbruck**  
German Aerospace Center (DLR)

### Track Chair



**Dr. Ilaria Martini**  
U-blox

**8:35. Characterization of Multi-GNSS Receiver Biases and Their Temperature-Induced Variations in LEO**, Zachary Arnett, Brian C. Peters, Ryan McKnight and Sabrina Ugazio, Ohio University

**8:57. Single Frequency RTK Relative Navigation for Autonomous Formation Flying Mission of SNUGLITE-III CubeSat**, Hanjoon Shim, Yonghwan Bae, Jae Woong Hwang, Changdon Kee, Department of Aerospace Engineering and the Institute of Advanced Machines and Design, Seoul National University

**9:20. Plasmaspheric Correction with Global Core Plasma Model (GCPM) for GPS-Based GEO Precise Orbit Determination**, Takehiro Matsumoto, Takushi Sakamoto, Ayano Nakajima, Kiyoshi Hamada, and Shinichi Nakamura, Japan Aerospace Exploration Agency

**9:43. NAVIMOON: Performance and Characteristics of GNSS Spaceborne Receiver in Representative Lunar Orbit**, Pietro Giordano, ESA; Michele Scotti, SpacePNT; Ben Kieniewicz, EECL; Anais Deleaut, Politecnico di Torino; Richard Swinden, ESA; Cyril Botteron, SpacePNT; Javier Ventura-Traveset, ESA

**10:05-10:35, Break. Refreshments served outside of session rooms**

**10:40. Science Objectives and Investigations for the Lunar GNSS Receiver Experiment (LuGRE)**, Lauren Konitzer, Joel J.K. Parker, Benjamin Ashman, Nathan Esantsi, NASA GSFC; Frank Bauer, FBauer Aerospace Consulting Service; Claudia Facchinetti, Luigi Ansalone, Gabriele Impresario, ASI; Fabio Dovis, Alex Minetto, Andrea Nardin, Politecnico di Torino

**11:03. Positioning and Timing of Distributed Lunar Satellites via Terrestrial GPS Differential Carrier Phase Measurements**, Keidai Iiyama and Grace Gao, Stanford University

**11:26. Exploring the Use of GNSS Beyond the Moon**, Brian C. Peters, Ryan McKnight, Zachary Arnett, Sabrina Ugazio, Michael Braasch, Ohio University

**11:48. Martian User Positioning via a Semi-Autonomous Smallsat Constellation**, Serena Molli, Pasquale Tartaglia, Andrea Sesta, Daniele Durante, Luciano Iess, Department of Mechanical and Aerospace Engineering, Sapienza University of Rome; Yoann Audet, Floor Melman, Richard Swinden, Pietro Giordano, Paolo Zoccarato, European Space Research and Technology Centre (ESTEC), European Space Agency; Javier Ventura-Traveset, ESA Toulouse, Centre Spatial de Toulouse, European Space Agency

## Alternate Presentations

1. Update on the Interoperable GNSS Space Service Volume: International PNT Activities of the ICG Space Use Subgroup, Xinuo Chang, China Academy of Space Technology; Juan-Pablo Boyero, European Commission; Werner Enderle, European Space Agency; P.S. Sura, Vishwanath Tirlapur, Indian Space Research Organization; Satoshi Kogure, Masaya Murata, Japan Aerospace Exploration Agency; Ivan Revnivykh, Roscosmos; Frank H. Bauer, FBauer Aerospace Consulting Services; James J. Miller, Joel J. K. Parker, National Aeronautics and Space Administration
2. LuPNT: Open-Source Simulator for Lunar Positioning, Navigation, and Timing, Keidai Iiyama, Guillem Casadesus Vila, and Grace Gao, Stanford University
3. The ESA-JAXA Collaboration to Foster the GNSS POD. An Overview of the Joint Effort to Improve the Accuracy of the QZSS Constellation, F. Gini, Navigation Support Office at ESA/ESOC; K. Akiyama, Satellite Navigation Unit at JAXA; E. Schönenmann, Navigation Support Office at ESA/ESOC; K. Kawate, Satellite Navigation Unit at JAXA; F. Dilssner, Navigation Support Office at ESA/ESOC; Y. Igarashi, Satellite Navigation Unit at JAXA; T. Springer, Navigation Support Office at ESA/ESOC; S. Ikari, University of Tokyo; M. v. Kints, Navigation Support Office at ESA/ESOC; T. Sasaki, Satellite Navigation Unit at JAXA; V. Mayer, Navigation Support Office at ESA/ESOC; S. Matsushita, H. Narita, H. Takiguchi, S. Kogure, Satellite Navigation Unit at JAXA; W. Enderle, Navigation Support Office at ESA/ESOC
4. Improving GNSS Navigation Messages Performance using Inter Satellite Links Technology, Marco Laurenti, Pedro Roldan, Julie Anton, Pierre Guerin, Sébastien Trilles, Thales Alenia Space France

## Virtual Presentations

# ION GNSS+ Technical Sessions

1. A Pre- and Post-Correlation Comparative Analysis to Assess Resilience Against Jamming for GNSS Space Receivers, Sahana Bandagadde Umehsa, Clovis Maia, Mohamed Bochkati, Jürgen Dampf, Thomas Pany, University of the Bundeswehr Munich - Institute of Space Technology and Space Applications

Awards Luncheon • 12:15 p.m. - 1:30 p.m. (Lunch served until 12:30 p.m.; late arrivals will not be served)

# ION GNSS+ Technical Sessions

## D5: Navigation Using Environmental Features

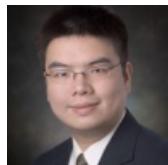
Date: Friday, September 15, 2023

Time: 8:30 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Clark Taylor**



**Dr. Zhen Zhu**

Air Force Institute of Technology    East Carolina University

### Track Chair



**Dr. Simona Circiu**

ESA

**8:35. ME4VIO: Manifold Encapsulation for Visual Inertial Odometry with Application to Vehicle Navigation in Urban Environments, Shaza I. Kaoud Abdelaziz, Sidney Givigi, Queen's University; Mohamed Elhabiby, Micro Engineering Tech Inc.; Aboelmagd Noureldin, Royal Military College & Queen's University, Kingston**

**8:57. Observability Analysis and Performance Evaluation for a Graph-Based GNSS-Visual-Inertial Odometry on Matrix Lie Groups, Shu-Hua Tsao, National Cheng Kung University**

**9:20. Performance Evaluation of Image-Aided Navigation in GNSS-Challenged Environments with Deep-Learning Local Features, Luca Morelli, 3D Optical Metrology (3DOM) & University of Trento; Fabio Menna, 3D Optical Metrology (3DOM); Alfonso Vitti, Dept. of Civil, Environmental and Mechanical Engineering (DICAM), University of Trento; Fabio Remondino, 3D Optical Metrology (3DOM); Charles Toth, Dept. of Civil, Environmental and Geodetic Engineering, The Ohio State University**

**9:43. Tightly Integrated Smartphone GNSS and Visual SLAM for Enhanced Urban Pedestrian Positioning, Yang Jiang, Yan Zhang, Zhitao Lyu, Shuai Guo, Yang Gao, Department of Geomatics Engineering, University of Calgary**

**10:05-10:35, Break. Refreshments served outside of session rooms**

**10:40. Neural City Maps for GNSS NLOS Prediction, Daniel Neamati, Shubh Gupta, Adyasha Mohanty, and Grace Gao, Stanford University**

**11:03. Trusted Inertial Terrain-Aided Navigation (TITAN), Tucker Haydon, Sandia National Labs**

**11:26. Georeferenced LiDAR-Based Terrain Relative Surface Navigation in GNSS-Denied Environments, Kyle Miller, Michael Zanetti, Paul Bremner, NASA Marshall Spaceflight Center**

**11:48. Ephemeris Error Modeling in Simultaneous Tracking and Navigation with LEO Satellites, Samer Hayek, Joe Saroufim, Zak (Zaher) M. Kassas; The Ohio State University**

## Alternate Presentations

1. **Tightly Integrated Map Based Train Localization, Andreas Wenz, Sebastian Ohrendorf-Weiss, Swiss Federal Railways**
2. **LiDAR Odometry with Pre-filtering of Plane Feature Points, Hanyeo Lee, Jae Hyung Jung, Chan Gook Park, Department of Aerospace Engineering, Seoul National University**
3. **A Localization Solution for an Unmanned Ground Vehicle in Unstructured Outdoor GNSS-Denied Environments, W. Jacob Wagner, Isaac Blankenau, Maribel De La Torre, Amartya Purushottam, Matthew Richards, Kenneth Niles, Ahmet Soylemezoglu, Engineer Research and Development Center**
4. **GNSS Measurement-Based Context Recognition for Vehicle Navigation Using Gated Recurrent Unit, Sheng Liu, School of Mathematics and Computing Science, Xiangtan University; Zhiqiang Yao, Xuemeng Cao, Xiaowen Cai, School of Automation and Electronic Information, Xiangtan University**

## Virtual Presentations

1. **Multi-Level Altitude Map Learning for Crowdsourcing 3D Positioning Data, Henri Nurminen and Pavel Ivanov, HERE Technologies**

**Awards Luncheon • 12:15 p.m. - 1:30 p.m. (Lunch served until 12:30 p.m.; late arrivals will not be served)**

# ION GNSS+ Technical Sessions

## E5: PANEL: Algorithms and Methods for GNSS Cyber Physical Security

Date: Friday, September 15, 2023

Time: 8:30 a.m. - 10:05 a.m.

### Session Chairs



**Dr. Ramsey Faragher**

Focal Point Positioning



**Dr. Pau Closas**

Northeastern University

### Track Chair



**Dr. Li-Ta Hsu**

The Hong Kong Polytechnic University

**Networked or cooperative applications of GNSS have become pervasive in low-cost devices such as smartphones, wearables, and geolocated Internet of Things (IoT) devices, and similar needs are rapidly growing in aerial and automotive settings. The potential vulnerability of PNT networked connectivity may be inherent in centralized large-network processing; in the use of heterogeneous and potentially untrustworthy sources of data for inference; and in the development of cyber-physical institutions for sensor certification, fraud prevention, and cooperative use of network resources. What new security challenges will arise in networked deployments of PNT technology for IoT, aerial, and vehicular applications? And what are the right coping strategies or methods to ensure cyber physical security?**

Awards Luncheon • 12:15 p.m. - 1:30 p.m. (Lunch served until 12:30 p.m.; late arrivals will not be served)

# ION GNSS+ Technical Sessions

## F5a: Lunar Positioning, Navigation, and Timing 2

Date: Friday, September 15, 2023

Time: 8:30 a.m. - 10:05 a.m.

### Session Chairs



**Dr. Cosimo Stallo**

Thales Alenia Space



**Erin E. Fowler**

Johns Hopkins University APL

### Track Chair



**Dr. Seebany Datta-Barua**

Illinois Institute of Technology

8:35. Autonomous Lunar Orbit Determination in Support of a Lunar Positioning System, John R. Bowman, Mark L. Psiaki, Virginia Tech

8:57. Local Geoid Model to Enable Navigation for the Lunar South Pole Region, Alana Sanchez, Grace Gao, Stanford University

9:20. Orbit Determination and Time Synchronization Performance Assessment of Low Lunar Orbit Satellites Using a Dedicated Lunar Radio Navigation Satellite System, Yoann Audet, ESA; Serena Molli, Sapienza University of Rome; Floor Thomas Melman, Paolo Zoccarato, Richard Swinden, Pietro Giordano, Javier Ventura-Traveset, ESA

9:43. Improving the Performance of Lunar Satellite Navigation Systems by Exploiting Inter-Satellite Distance Information, Gherghe Sirbu, Mauro Leonardi, Tor Vergata University of Rome; Cosimo Stallo, Mattia Carosi, Thales Alenia Space Italia

10:05-10:35, Break. Refreshments served outside of session rooms

## Alternate Presentations

1. Orbit Determination and Time Synchronization for the ESA Moonlight Lunar Radio Navigation System, L. Iess, M. Di Benedetto, G. Boscagli, P. Racioppa, A. Sesta, F. De Marchi, P. Cappuccio, D. Durante, S. Molli, M. K. Plumaris, P. Tartaglia, D. Pastina, Sapienza, Università di Roma; A. Fienga GéoAzur, CNRS, Observatoire de la Côte d'Azur, Université Côte d'Azur Valbonne; N. Linty, Argotec s.r.l.; K. Sosnica Wroclaw University of Environmental and Life Sciences; J. Belfi, Leonardo S.p.A, Viale Europa snc
2. Orbit Determination and Time Synchronization Performance Assessment of Different User Scenarios on the Moon Using a Dedicated Lunar Radio Navigation Satellite System, Serena Molli, Department of Mechanical and Aerospace Engineering, Sapienza University of Rome; Yoann Audet, Floor Thomas Melman, Paolo Zoccarato, Richard Swinden, Pietro Giordano, European Space Research and Technology Centre (ESTEC), European Space Agency; Javier Ventura-Traveset, ESA Toulouse, Centre Spatial de Toulouse, European Space Agency
3. Analysis of Precise Orbital Determination approaches for Lunar Navigation Services, Carlo Albanese, Gabriele Lambiase, Filippo Rodriguez, Giuseppe Tomasicchio, Telespazio SpA; Luciano Iess, Andrea Sesta, La Sapienza University
4. A Strategy for Initial Orbit Determination of Lunar Navigation Satellite Based on Range and Doppler Measurements from a Lunar Ground Station, Sungik Kim, Byungwoon Park, Sejong University

Awards Luncheon • 12:15 p.m. - 1:30 p.m. (Lunch served until 12:30 p.m.; late arrivals will not be served)

# ION GNSS+ Technical Sessions

## F5b: PANEL: International Civilian Agency Lunar PNT Systems

Date: Friday, September 15, 2023

Time: 10:35 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Evan Anzalone**  
NASA



**Giuseppe D'Amore**  
*Agenzia Spaziale Italiana*

### Track Chair



**Dr. Seebany Datta-Barua**  
*Illinois Institute of Technology*

To support safe sustained operations on the lunar surface and in orbit, international civilian agencies are investing in multiple in-situ navigation capabilities. This panel provides an overview of the various efforts in development and their status, insights into implementation challenges, and approaches to interoperability, including lunar reference systems.

### Panel Members:

- Dr. Javier Ventura-Traveset, European Space Agency (ESA)
- Cheryl Gramling, National Aeronautics and Space Administration (NASA)
- Dr. Masaya Murata, Japan Aerospace Exploration Agency (JAXA) (invited)

Awards Luncheon • 12:15 p.m. - 1:30 p.m. (Lunch served until 12:30 p.m.; late arrivals will not be served)

# ION GNSS+ Technical Sessions

## F5c: GNSS Robustness to Vulnerabilities 2

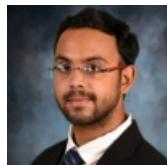
Date: Friday, September 15, 2023

Time: 10:35 a.m. - 12:15 p.m.

### Session Chairs



**Dr. Brady O'Hanlon**  
The MITRE Corporation



**Shubh Gupta**  
Stanford University

### Track Chair



**Dr. Seebany Datta-Barua**  
Illinois Institute of Technology

10:40. Identifying Car Key Fobs as a Cause of Interference at GNSS Frequencies, Sandeep Jada, John Bowman, Mark Psiaki, Virginia Tech; Steven Langel, The MITRE Corporation; and Mathieu Joerger, Virginia Tech

11:03. Using Filtered ADS-B Data to Monitor and Detect GPS Interference Events, Zixi Liu, Sherman Lo, Juan Blanch, Todd Walter, Stanford University

11:26. Preliminary Analysis of GNSS Radio Frequency Interference Events Detected in Canada and Impacts on GNSS Based Applications, Anurag Raghuvanshi, Sunil Bisnath, York University; Jason Bond, Canadian Positioning, Navigation and Timing Office

11:48. Discrete Mathematical Model for GNSS Interference Detection Using ADS-B Quality Parameters, Jakub Steiner and Ivan Nagy, Czech Technical University in Prague

## Alternate Presentations

1. Civil Aviation GNSS Interference Detection and Location Based on Genetic Algorithm Using ADS-B Data, Jinqi Li, Hongxia Wang, Zhiqiang Dan, Zhipeng Wang, Yanbo Zhu, Beihang University
2. Jamming and Spoofing Impact on GNSS Signals for Railway Applications, Roman Ehrler, Andreas Wenz, Swiss Federal Railways; Stefan Baumann, Paulo Mendes, Nikolas Dütsch, Alice Martin, Christian Hinterstocker, IABG

## Virtual Presentations

1. Jammer on the Horizon: A Robust Method for GPS Jammer Localization Using ADS-B Data, Matthias Schäfer, SeRo Systems GmbH; Steve Söeruer and Taavi Kippak, Estonian Air Navigation Services; Erkki Sadrank, Estonian Consumer Protection and Technical Regulatory Authority
2. The Evolving GNSS RFI Threat Space, Aiden Morrison, Nadia Sokolova, Anja Diez, SINTEF

Awards Luncheon • 12:15 p.m. - 1:30 p.m. (Lunch served until 12:30 p.m.; late arrivals will not be served)

# ION GNSS+ Technical Sessions

## A6a: New Technologies, Opportunities and Challenges

Date: Friday, September 15, 2023

Time: 1:45 p.m. - 3:20 p.m.

### Session Chairs



**Courtney Mario**  
Draper



**Dr. Eric Phelts**  
Stanford University

### Track Chair



**Deborah Lawrence**  
Federal Aviation Administration

**1:50. Highest Performance, Lowest CSWAP Chip Scale 3-Axis, Robert M Boysel, Louis J Ross, MEI Micro, Inc.**

**2:12. Delivering PPP-RTK in Australia Using 3GPP LPP and 5G, Eldar Rubinov, Chris Marshall, Luis Elneser, Lachlan Ng, Dan Woodrow, FrontierSI; Fredrik Gunnarsson, Per-Gunnar Andersson, Jonathan Wase, Babar Chaudhry, Ericsson; Adrian Chamorro, Eduardo Bartolome Calvo, David Calle, GMV; Seong Yin Wong, Optus**

**2:35. Cloud Based GNSS IoT Solution: From Simulation to Actual Measurement on the Field, Thierry Torlotin, Mathieu Villion, Joel Korsakissok, Syntony GNSS**

**2:58. Evaluating Performance of Meta-Signal Exploitation in End User, Carlos Moriana, Guillermo Ortas, Esteban Garbin, Pedro Boto, Elisa Benedetti, Nicholas Boreham, GMV; Javier Miguez, Floor Melman, ESA**

## Alternate Presentations

1. Impact of Payload Distortions on BeiDou B1I-B1C Meta-Signal Ranging Performance, Florian C. Beck, German Aerospace Center (DLR) & RWTH; Christoph Enneking, Steffen Thörlert, Michael Meurer, DLR & RWTH
2. Cloud-Based High Precision Asset Tracking, Tony Höijer, HERE Technologies; Steve Beck, Sony Semiconductor Solutions Europe; Jani Käppi, HERE Technologies
3. onocoy: Enabling Mass Adoption of High Precision Positioning, Lucy Icking, Daniel Ammann, Uroš Kalabic, Garrett Seepersad, Mark Ballandies, onocoy Association
4. Unlocking the Benefits of Model-Based Systems Engineering (MBSE) and Digital Engineering (DE), Victor Aguilar, MBSE Services at Strategic Technology Consulting

## Virtual Presentations

1. A Novel Approach for NavIC & Pseudolite Combined User Position Algorithm, Ashish K Shukla, Space Applications Centre, ISRO; Heer M Patel, C.S. Patel Institute of Technology; Girish Khare, Deval C Mehta, Space Applications Centre, ISRO
2. Design and Assessment of a LEO GNSS Mini-Constellation for Positioning, Navigation, and Timing (PNT), Mariya Alrais, United Arab Emirates University; Alina Hasbi, National Space Science and Technology Center; Jean-Luc Issler, Centre National D'Etudes Spatiales; Hassan AlAli, National Space Science and Technology Center
3. Multi-Frequency Interference Detection & Mitigation Using COTS RFSOC Platform for Automotive Applications, Muhammad Ali Akhtar, Huzaifa Saijd, National University of Science and Technology
4. Proof Of Concept Of User Segments Technologies For Complementary Low Earth Orbit System., Rami Ali Ahmad, Romain Crapart, Lea Castel, Simon Naws, Thales Alenia Space France; Fran Fabra, Gonzalo Seco-Granados, Institut d'Estudis Espacials de Catalunya

# ION GNSS+ Technical Sessions

## A6b: Urban and Indoor Radio Positioning

Date: Friday, September 15, 2023

Time: 3:20 p.m. - 4:50 p.m.

### Session Chairs



**Ryan Dixon**  
Hexagon



**Dr. Pai Wang**  
Shanghai Jiao Tong University

### Track Chair



**Deborah Lawrence**  
Federal Aviation Administration

**3:20. Resilient 3D Navigation and Timing System using Terrestrial Beacons and Cellular Signals, Rabih Chrabieh, Arun Raghupathy, Sameet Deshpande, Vinh Le, Minh Hoang, NextNav**

**3:42. A Look at the Sky: Opportunistic Navigation with Multi-Constellation LEO Satellites, Sharbel Kozhaya, Haitham Kanj, and Zak (Zaher) M. Kassas; The Ohio State University**

**4:04. Jupiter for Vehicle in Underground Parking-Lots, Donghyun Shin, TJLABS corp.; Taehun Kim, KIST & Korea University; Changsoo Yu, TJLABS corp.; Hangyul Kyung, Beomju Shin, KIST; Chung G. Kang, Korea University; and Taikjin Lee, KIST & TJ LABS corp.**

**4:26. Optimizing LOS/NLOS Modeling and Solution Determination for 3D-Mapping-Aided GNSS Positioning, Qiming Zhong, Paul D Groves, University College London**

## Alternate Presentations

1. Scalable 3D Indoor and Urban Global Positioning, Tatiana Vyunova, Henri Nurminen, HERE Technologies
2. PicoRanger: A Miniature Access Point for Creating Compact and Distributed Arrays to support Wi-Fi RTT Positioning, Wil Myrick, ENSCO Inc.
3. A Probabilistic Fingerprinting Method Using Pseudo LTE Measurements From the Similarity of Short Range Nodes, Y. Cho, J. Jeon, K. Han, J. Lee, ETRI

## Virtual Presentations

1. Research on UWB/Inertial Guided Fusion Localization Based on Convolutional Neural Network, Yuan Sun, Yun Jia Zhang, Zhong Liang Deng, Beijing University of Posts and Telecommunications
2. Tuti: An Advanced GNSS-Based Repeater for Seamless Indoor/Outdoor Positioning, Amir Tabatabaei, CTO of IGASPIN GmbH

# ION GNSS+ Technical Sessions

## B6: Aviation and Aeronautics

Date: Friday, September 15, 2023

Time: 1:45 p.m. - 4:50 p.m.

### Session Chairs



**Dr. Sai Kalyanaraman**  
Collins Aerospace



**Stefan Wallner**  
European Space Agency

### Track Chair



**Dr. Andrew Neish**  
Xona Space Systems

**1:50. Approximating Regional GNSS Interference Sources as a Conic Hull using ADS-B Data**, Michael Dacus, Zixi Liu, Todd Walter, Sherman Lo, Stanford University

**2:12. Baseline Spoofing Detection Technique for Aircraft with Standard Navigation Hardware**, Michael Blois, University of Calgary; John Studenny, CMC Electronics; Kyle O'Keefe, Baoyu Liu, University of Calgary

**2:35. GNSS Radio Frequency Interference Mitigation Techniques in Collins Commercial Airborne Receivers**, Angelo Joseph, Joseph Griggs, Patrick Bartolone, Bernard Schnaufer, Huan Phan, Vikram Malhotra, Collins Aerospace

**2:58. Impact of Meaconers on Aircraft GNSS Receivers During Approaches**, Mathieu Hussong, Emile Ghizzo, Carl Milner, Axel Garcia-Pena, Julien Lesouple, Christophe Macabiau, École Nationale de l'Aviation Civile - ENAC

**3:20. SBAS DFMC Receiver RFI Test Conditions**, A. Garcia-Pena, C. Macabiau, Ecole Nationale de l'Aviation Civile; D. Bouvet, Thales AVS; G. Novella, DSNA/DTI; M. Mabilieu, EUSPA; S. Kalyanaraman, Collins Aerospace

**3:42. Technological Maturity and Gaps of Current GNSS Antennas for DFMC Aviation Applications**, S. Caizzone, V. Tripathi, W. Elmarissi, German Aerospace Center (DLR)

**4:04. L5/E5a-Based Fallback Mode for Dual-Frequency Multi-Constellation GBAS**, Maria Caamano and Daniel Gerbeth, German Aerospace Center, (DLR)

**4:26. Managing Long Time Constant and Variable Rate Carrier Smoothing for DFMC GBAS**, Tim Murphy, Matt Harris, Glaucia Balvedi, Boeing; Gary McGraw, PNT and Systems Engineering Consultant; Joel Wichgers, Collins Aerospace; Linda Lavik, Morten Topland, Mutaz Tuffaha, Indra Navia; Susumu Saito, ENRI

## Alternate Presentations

1. An ARAIM experimental Test User Receiver. Final Review of Project DARP, Mariano Wis, Antonio Fernández, Elecnor Deimos
2. Navigation for UAVs in Harsh GNSS Environments Using a High-Performance IMU, Kirstin Schauble, Walter Stockwell, Mike Horton, ANELLO Photonics
3. Worldwide SBAS Broadcasts Between 2017 and 2023: A Comparative Study, Alessandra Calabrese, Susana Domenech, Nerea Álvarez, Julián Barrios, José Gabriel Pericacho, GMV

# ION GNSS+ Technical Sessions

## C6: Technologies for Scientific and Sectorial Applications

Date: Friday, September 15, 2023

Time: 1:45 p.m. - 4:50 p.m.

### Session Chairs



**Dr. Omar García Crespillo**  
German Aerospace Center (DLR)



**Dr. Juliette Marais**  
Université Gustave Eiffel

### Track Chair



**Dr. Ilaria Martini**  
U-blox

**1:50. Performance Monitoring at the DLR Galileo Competence Center**, Katharina Lutz, Lukasz Greda, Marios Smyrnaios, Wolfgang Dilg, Thomas Schilling, Ilinca Ioanid, Sophie Schrade, Bernhard Röttgers, DLR Galileo Competence Center; Steffen Thölert, Gerardo Allende Alba, DLR Institute of Communications and Navigation; Martin Kriegel, DLR Institute for Solar-Terrestrial Physics; Luca Spataro, Annika Meinecke, Rebecca Brydon, DLR Institute for Software Technology; Johann Furthner, DLR Galileo Competence Center

**2:12. State Estimation and Fault Detection Baselines From an Open-Source Python GNSS Library**, Derek Knowles, Ashwin Vivek Kanhere, and Grace Gao, Stanford University

**2:35. European Commission A-PNT Test Campaign**, L. Bonenberg, J. Fortuny Guasch, B. Motella, European Commission, Joint Research Centre (JRC); and I. Alcantarilla Medina, European Commission, DEFIS

**2:58. GNSS-Based Train Localization Integrity Performance Evaluation – Impacts of SBAS Residual Error Time Correlation and GNSS Satellites Velocity and Clock Drift Monitoring**, Fabrice Legrand, Leslie Montloin, Nicolas Mendoza Pila, Fabio Fabozzi, Alejandro Rodriguez Veiga, Pierrick Grandjean, Vivien Fouquet, Arnault Sfeir, AIRBUS Defence and Space. Valentin Barreau, SNCF

**3:20. MADOCA Disciplined Oscillator for Effective Utilization of Radio Resources**, Takahiro Yamamoto, Hidehiko Araki, Kazuhiro Terao, Kengo Takahashi, CORE Corporation; Yuichiro Yano, Ryuichi Ichikawa, National Institute of Information and Communications Technology

**3:42. LinkPNT: An Integrated Communications and Navigation Solution to Provide ADHOC Mesh Network and Support or Replace GNSS for Precise PNT**, Haluk Erdem Bingöl, Eren Keçe, and Murat Efe, TUALCOM A.S. and Ankara University

**4:04. Locata as an Alternative Position, Navigation and Timing (Alt-PNT) Service - Independent Test Results Generated by the European Commission's Search for an Effective Backup in the Event of GNSS Disruption**, Nunzio Gambale, Chaminda Basnayake, David Small, Hartmut Roth, Locata Corporation

**4:26. Standardisation of Galileo Timing Receivers**, Javier Fidalgo, Ricardo Píriz, Raúl Nieto, Ana Cezón, GMV; Javier Bárcena, Alter Karel Callewaert, VVA; Miguel Aguilera, Juan Pablo Boyero, EC; Valeria Catalano, Gert-Jan Pauwels, EUSPA; Joaquim Fortuny, Matteo Sgammini, JRC

## Alternate Presentations

1. **Alternative PNT Using 5G-Broadcasting via TV Transmitters**, Stefan Maier, Thomas Janner, Lars Oestreicher, Alex Bart, Stephanie Busching, Laila Jassoume, Abhay Phillips, Hans-Peter Keil, Rohde & Schwarz
2. **Transforming a Legacy DME to a High Accuracy DME for Aircraft APNT Through Software Changes**, Euiho Kim, Hongik University; Jongmin Park, Jiwon Seo, Yonsei University
3. **An SNR Correction for GNSS Scintillation Index Measurements**, Charles Rino, Keith Groves, Charles Carrano, Boston College, Institute for Scientific Research; Brian Breitsch, Jade Morton, University of Colorado, Smead Aerospace and Engineering Sciences

# ION GNSS+ Technical Sessions

## D6: Robust Navigation Using Alternative Navigation Sensors and Solutions

Date: Friday, September 15, 2023

Time: 1:45 p.m. - 4:50 p.m.

### Session Chairs



**Dr. Okuary Osechas**

German Aerospace Center (DLR) University of Colorado at Boulder



**Dr. Yang Wang**

### Track Chair



**Dr. Simona Cinciu**

ESA

1:50. Exploring the Potential of Low Earth Orbit Satellites for Precise Navigation and Timing Solutions, Jorge Durán, Damián Socías, Enrique Carbonell, Ana González, Guillermo Tobías, Irma Rodriguez, Pedro Navarro, Francisco Sobrero and David Calle, GMV

2:12. Analysis of Concepts for Ultra Low Power Device Positioning Based on LEO Satellites, Luis Enrique Aguado Bayon, Matthew Powe, Baris Toz, Katie Roll, Alejandro Pérez Conesa, GMV

2:35. Concept and Benefits of a Technology-Agnostic Dynamic Alert Limit Framework for a VTOL Autoland System, Finn Hübner, Mario Gäbel, Lukas Scholz, Ulf Bestmann, Institute of Flight Guidance, Technische Universität Braunschweig

2:58. 3D LiDAR Aided GNSS NLOS Correction with Angle of Arrival Estimation Using Doppler Measurements, Xikun Liu, Weisong Wen, Li-Ta Hsu, Department of Aeronautical and Aviation Engineering, the Hong Kong Polytechnic University

3:20. Optimal GNSS Satellite Fault Detection and Exclusion for Integrated GNSS/INS Systems, Birendra Kujur, Samer Khanafseh, and Boris Pervan, Illinois Institute of Technology

3:42. Hybridization of Smartphone GNSS PPP/RTK with Native IMU in Realistic Driving Scenarios, Ding Yi and Sihan Yang, Department of Earth and Space Science and Engineering, York University

4:04. Integrity Assurance of INS-Integrated Single-Epoch RTK against IMU Faults to Support Unmanned Aerial Vehicle Applications, Noah Minchan Kim, Dongchan Min, Namkyu Woo, and Jiyun Lee, Korea Advanced Institute of Science and Technology

4:26. GVIM: GNSS/Visual/IMU/Map Integration Via Sliding Window Factor Graph Optimization in Urban Canyons, Bai Xiwei, Li-Ta Hsu, Department of Aeronautical and Aviation Engineering, The Hong Kong Polytechnic University

## Alternate Presentations

1. Relieve Gaussian Assumptions: A Bayesian Approach to Detect Faults in Localization Systems Based on Gaussian Mixture Model, Penggao Yan, Li-Ta Hsu, Weisong Wen, Feng Huang, and Jiachen Zhang, Department of Aeronautical and Aviation Engineering, The Hong Kong Polytechnic University, Hong Kong
2. Improving Accuracy and Algorithm Integrity for Train Localization in Harsh Urban Environments Using GNSS Time-Difference Carrier-Phase Displacement and Inertial Navigation, Pierre d'Harcourt, Jean-Baptiste Lacambre, Tim Barford, Laurent Poletti, Sophie Glevarec, Exail
3. Coupling GNSS and R-Mode Observations for Resilient Maritime Navigation, Filippo Giacomo Rizzi, Xiangdong An, Daniel Medina, Lars Gründhofer, Stefan Gewies, German Aerospace Center (DLR)
4. Integrity Monitoring Of GNSS With LEO Satellites To Reduce the Time To Alarm, Carlos Catalán, Andrés Juez, Eduardo Fernández, César Pisonero, Adrián Monreal, Mar Paüls, Eric Arnal, María D. Laínez, Luis García, Jon Bruno, GMV
5. Analysis of Precise Timing and Synchronization for GPS Independent LEO Based PNT Systems, Megan O. Moore, William C. Headley, R. Michael Buehrer, Virginia Tech

## Virtual Presentations

1. Improving the LEO Satellite Onboard SPP Orbits with Dynamic Models, Hang Su, National Time Service Center (NTSC), Chinese Academy of Sciences (CAS); Kan Wang, NTSC,CAS, University of Chinese Academy of Sciences (UCAS); Xuhai Yang, NTSC, CAS, UCAS
2. Integer Ambiguity Resolution in Multi-Constellation GNSS for LEO Satellite POD, Kan Wang, National Time Service Center (NTSC), Chinese Academy of Sciences (CAS), University of Chinese Academy of Sciences (UCAS); Ahmed El-Mowafy, School of Earth and Planetary Sciences, Curtin University; Xuhai Yang, NTSC, CAS, UCAS

# ION GNSS+ Technical Sessions

# ION GNSS+ Technical Sessions

## E6: Sensor Network and Cooperative Navigation

Date: Friday, September 15, 2023

Time: 1:45 p.m. - 4:50 p.m.

### Session Chairs



**Dr. Taro Suzuki**

Chiba Institute of Technology



**Dr. Alex Minetto**

Politecnico di Torino

### Track Chair



**Dr. Li-Ta Hsu**

The Hong Kong Polytechnic University

1:50. Swarm Navigation using Signals of Opportunity from Uncooperative LEO Satellites, Dawson Beatty and Mark Psiaki, Virginia Tech

2:12. Multi-Receiver Precise Baseline Determination: Coupled Baseline and Attitude Estimation with a Low-Cost Off-The-Shelf GNSS Receiver, Marvin B. Stucke, Thomas Hobiger, Institute of Navigation, University of Stuttgart; Gregor Möller, Institute of Geodesy and Photogrammetry, ETH Zurich; Kevin Gutsche, Institute of Navigation, University of Stuttgart; Stefan Winkler, Airbus Defence and Space

2:35. Intent- and Fault-Based Trajectory Prediction for Cooperative Localization and Collision Avoidance in Swarms, Isabella Torres and Grace Gao, Stanford University

2:58. Towards Accurate Vehicle-to-pedestrian Relative Positioning Aided by Inter-frame and Inter-agent GNSS Measurement Collaboration Using Factor Graph Optimization for Smart Summon, Yihan Zhong, Department of Aeronautical and Aviation Engineering, the Hong Kong Polytechnic University; Weisong Wen, Department of Aeronautical and Aviation Engineering, the Hong Kong Polytechnic University; Li-ta Hsu, Department of Aeronautical and Aviation Engineering, the Hong Kong Polytechnic University;

3:20. 3D Simultaneous Localization and Calibration for Cooperative Radio Navigation, Robert Pöhlmann, Siwei Zhang, Emanuel Staudinger, Fabio Broghammer, Armin Dammann, German Aerospace Center (DLR)

3:42. Decentralized Cooperative Localization in GNSS-Degraded Environments using UAVs, Cagri Kilic and Jason Gross, West Virginia University

4:04. Analyzing the Impact of GNSS Spoofing on Swarms of Unmanned Systems, Aanjanan Ranganathan, Pau Closas, Northeastern University

4:26. The Power of Many: Multi-User Collaborative Indoor Localization for Boosting Standalone User-Based Indoor Positioning in Different Scenarios, Ahmed Mansour and Wu Chen, Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University

## Alternate Presentations

1. sUAV Swarm Navigation Test Results for Flights in Challenging Environments using Cooperative UWB, GNSS, and Inertial Fusion, Mats Martens, Georgy Kalandadze, Kevin Kotinkar and Maarten Uijt de Haag, TU Berlin
2. Integrity Monitoring on Collaborative Navigation, Xiankun Wang, Charles Toth, Dorota Grejner-Brzezinska, The Ohio State University
3. A Multi-Agent Multi-Sensor Scalable Collaborative Positioning Approach, A. Masiero, University of Florence; C. Toth, X. Wang, The Ohio State University; F. Remondino, Fondazione Bruno Kessler, FBK

## Virtual Presentations

1. A Cooperative Positioning Algorithm Based On BiLSTM, Yuan Sun, Jianchao Liu, Zhongliang Deng, School of Electronics Engineering, Beijing University of Posts and Telecommunications
2. A Multi-Vehicle Cooperative Positioning Method Based on Factor Graph Optimization Using the Error Information of Cooperators, Tongtong Wang, Hongbo Zhao, Chen Zhuang, Shan Hu, Beihang University

# ION GNSS+ Technical Sessions

F6: PANEL: Beyond GNSS: Emerging Trends in LEO-Based Satnav and Signals of Opportunity for PNT

Date: Friday, September 15, 2023

Time: 1:45 p.m. - 4:50 p.m.

## Session Chairs



**Dr. Sanjeev Gunawardena**

Air Force Institute of Technology AFRL Space Vehicles Directorate



**Dr. Joanna Hinks**

Air Force Institute of Technology AFRL Space Vehicles Directorate

## Track Chair



**Dr. Seebany Datta-Barua**

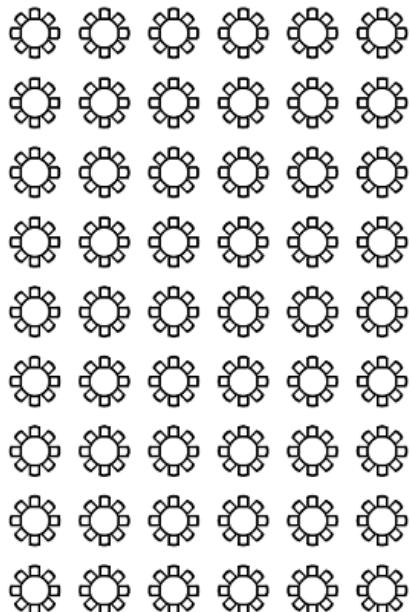
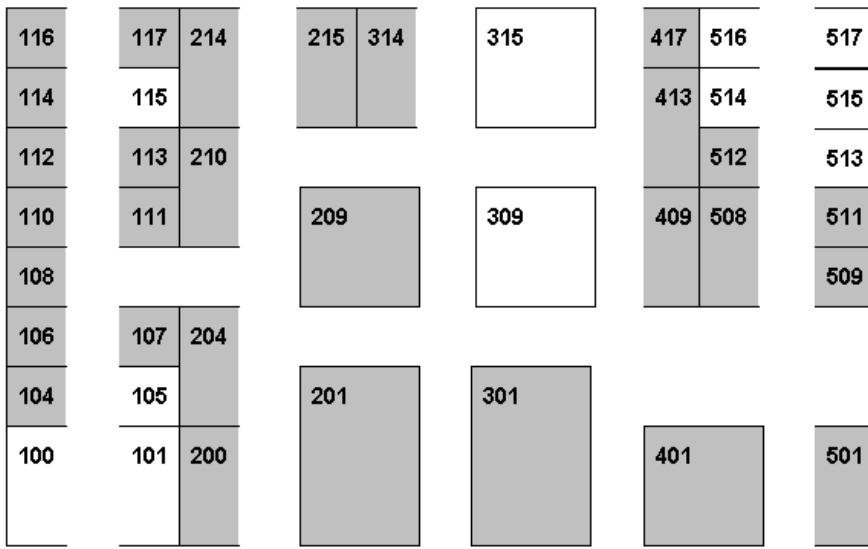
Illinois Institute of Technology

The rapid deployment of LEO-based mega constellations for broadband has given us a myriad of signals from space with unprecedented availability and frequency diversity. Early research has shown that these signals can be used opportunistically for navigation. Furthermore, several entities are working on LEO-based constellations that are purpose built for PNT. Other terrestrial signal sources offer promising navigation performance – in some cases potentially outperforming space-based sources. Together, these technologies represent the exciting future of radionavigation-based technologies for PNT. They promise to augment the pros and overcome the cons of GNSS. Our panel of experts will describe these technologies, their expected performance, technical and policy challenges yet to overcome, and when we can expect operational capabilities.

# EXHIBIT HALL INFORMATION

## EXHIBIT HALL FLOOR PLAN

Unshaded booths were available as of April 4



## CURRENT EXHIBITORS

Acutronic USA Inc.  
Anello Photonics  
Applied Research Laboratories - UT Austin  
CAST Navigation, LLC  
FIBERPRO, Inc.  
German Aerospace Center (DLR)  
GMV Aerospace and Defence S.A.U.  
GPS Networking, Inc.  
GPS World  
Hemisphere GNSS  
IAI  
Inflection  
Inside GNSS  
L3Harris  
Labsat By Racelogic  
Lockheed Martin  
Microchip Technology Inc.  
NavtechGPS  
NovAtel, Inc.  
Orolia USA  
Rakon  
Rohde & Schwarz USA, Inc.  
Rx Networks, Inc.  
Silicon Sensing Systems Ltd.  
Spirent Communications PLC  
Spirent Federal Systems  
Syntony GNSS  
Tower Semiconductor  
Tualcom Elektronik A.S.  
WORK Microwave GmbH

## EXHIBIT HALL HOURS

### Wednesday:

10:00 a.m. – 7:00 p.m. Hall Open

### Thursday:

9:00 a.m. – 4:00 p.m. Hall Open

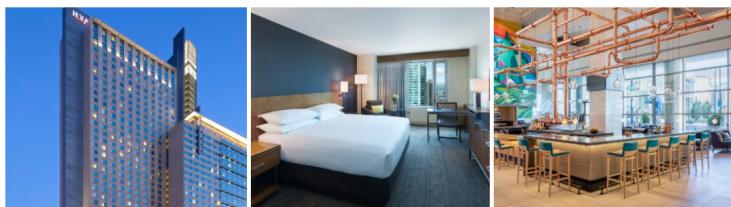


To reserve your booth, contact:

Megan Andrews  
ION National Office  
Phone: 1-703-366-2776  
E-mail: [mandrews@ion.org](mailto:mandrews@ion.org)



## Reserving Your Hotel Room



### Headquarters Hotel/Conference Location

#### Hyatt Regency Denver

650 15th Street

Denver, Colorado 80202

(Adjacent to Colorado Convention Center)

**Phone:** 1-303-436-1234

Experience the culture of downtown from Hyatt Regency Denver. Located one block from the 16th Street Mall and walking distance to Denver Center for the Performing Arts, our hotel offers a stylish stay in downtown Denver with access to the 27th-floor Peaks Lounge, the highest-rising lounge in the city with spectacular Rocky Mountain views.

**All ION GNSS+ Session and Events are located at this hotel.**

**Rate:** \$230 single/double, limited government rate availability\*

**In-Room Internet:** Free for guests in ION room block.

**Parking:** For your convenience, our hotel offers self-parking, subject to availability. Underground hotel covered self-parking is located off 14th and Welton Streets. The parking office for vehicle departure is adjacent to the parking elevators on the lobby level.

\*Government rates are only for U.S. government personnel paying for a room with a U.S. government issued credit card. Failure to pay with a U.S. government issued credit card will result in your reservation being honored at the group rate. Government contractors not traveling with government travel orders are not eligible for this rate. MITRE/Aerospace personnel do qualify.

#### Book your hotel with ION and save \$200 in registration fees!

Save \$200 on your conference registration fee by staying in the Hyatt Regency Denver (Adjacent to Colorado Convention Center). To qualify for the discount, make your hotel reservation before you register for the conference. Enter your hotel confirmation number on the registration form to receive the discount.

### How to Reserve Your Room

- Online: Go to [ion.org/gnss/hotel.cfm](http://ion.org/gnss/hotel.cfm)
- Phone: 1-303-436-1234

### Hotel Discount Deadline is August 11

August 11 is the last day that this rate will be available, but rooms at the discounted rates may fill up before then. Make your reservations now to avoid missing out on discounted room rates!

## Register for the Conference

### How to Register

1. **Make your hotel reservation** at the official conference hotel. Make your reservation at [ion.org/gnss](http://ion.org/gnss) or by calling the hotel directly.
2. **Record your hotel confirmation number.** All attendees staying at the official conference hotel are eligible to receive \$200 off their conference registration fees. Attendees must provide their valid hotel confirmation number at the start of the registration process to claim this discount; it cannot be applied retroactively.
3. **Register for ION GNSS+** at [ion.org](http://ion.org). Rates for attendees registering by August 11 and staying in an official conference hotel start at:
  - Full Technical Registration: \$1100.00
  - Single Day: \$600.00
  - Student: \$700.00
  - Virtual Registration: \$699
  - Tutorials (per course): \$450

**In-person Registration** includes all ION GNSS+ live technical sessions, access to the exhibit hall, meal functions and events, all virtual conference content listed below, and conference proceedings.

**Virtual Registration** offers access to on-demand conference content and a recording of the plenary session. ION GNSS+ technical and panel sessions will not be live-streamed or recorded for virtual viewing.

4. **Complete the online registration process.** Be sure to input your hotel confirmation number during the registration process to claim your discount.

For more information, or to register, visit [ion.org/gnss](http://ion.org/gnss)