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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 Colorado Convention Center

Denver, Colorado

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Conference and Local Area Information

Location and Parking

ION GNSS+ will be held at the Hyatt Regency Denver adjacent to Colorado Convention Center, 650 15th St., Denver, CO 80202. 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. Parking will be charged at posted rates.

Business Center

A business center will be provided near the ION GNSS+ regsitration desk on the 3rd floor of the hotel, to provide access to basic computer services including printing and internet access.

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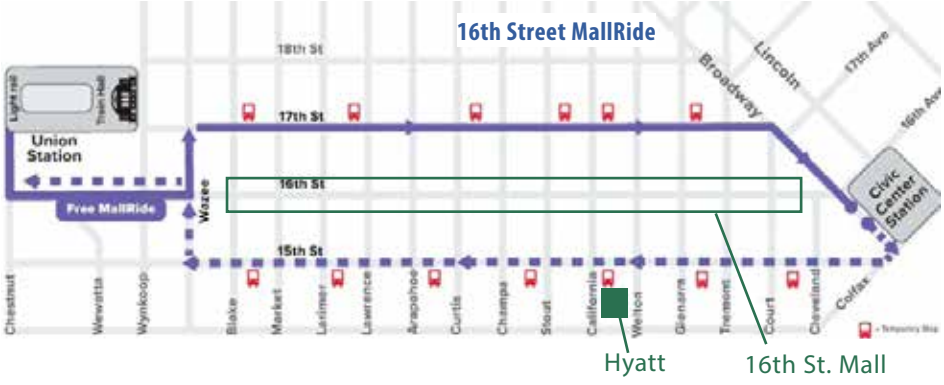
Ad hoc Meeting Space

Space for small meetings of 4-12 attendees is available on a first-come, first-served basis on the third floor. Attendees/organizations may sign up for a maximum of one hour per day total using the sign-up sheets in front of each room. See floor plan on page 22 for room locations.

Transportation

RTD's Free 16th Street MallRide connects you to the sights and sounds of downtown Denver. MallRide buses operate along 15th and 17th Streets, providing access to the 16th St. Mall and its great restaurants, shops, theatres, galleries, tourist attractions, and businesses. All rides are free, just hop on board! The Free MallRide runs seven days a week, starting at 4:59 a.m. on weekdays, 5:30 a.m. on Saturdays and 6:30 a.m. on Sundays/holidays. Service continues throughout the day with the last complete round-trip leaving at 1:19 a.m. from Union Station to Civic Center Station. The closest stop is located next to the hotel, on 15th St.



Proceedings

Official conference proceedings are scheduled for distribution in October to all eligible conference participants.

Online Job Board

Visit the ION's online job board at ion.org/job-board.cfm to view or post employment opportunities for the navigation community.

Conference Policies

Your presence at ION GNSS+ constitutes your agreement to be photographed, filmed, videotaped or otherwise recorded by conference management, or its agents, and your agreement that your image/voice may be distributed in print/electronic communications media without any compensation being paid to you.

No Video Recording

Video recording by participants is not allowed without permission of ION during any portion of the conference.

Photography Regulations

Photographs of copyrighted presentations are for personal use only and are not to be reproduced or distributed. Do not photograph images labeled as proprietary. Flash photography, or photography that disturbs those around you, is prohibited.

Code of Ethics/Code of Conduct

By registering for this event, you agree to abide by the ION Code of Ethics and Conference Code of Conduct available at ion.org.

Virtual Conference Content

Access to on-demand conference content is included with your in-person registration. On-demand presentations will utilize Vimeo.

What will you find online?
ION GNSS+ 2023 will record the **plenary session** and post it for on-demand access through the virtual meeting portal for 30 days after the conference.

Custom Conference Schedule
Visit the ION website to build a customized schedule of presentations you wish to attend.

Session Papers
Registered attendees may download copies of conference presentations and papers online for free by logging in to the virtual meeting portal at ion.org/gnss. Only presentations and papers provided to the ION by the presenting author will be available. If a desired document is not available, we recommend you contact the author directly.

Technical Sessions
Individual technical presentations will be pre-recorded and uploaded with slides to the virtual meeting portal for viewing beginning on Wednesday. Recordings will remain available for 30 days after the conference.

Technical Tutorials
If you have not already registered for a technical tutorial on Tuesday, consider augmenting your experience with a pre-conference tutorial designed to provide in-depth learning of specific GNSS related disciplines (additional fees apply). Courses will be taught in-person by some of the world's leading GNSS educators, and recorded for on-demand access by virtual attendees who purchase on-demand access. Recordings will not be available to in-person tutorial registrants who miss the in-person tutorial.

Exhibitor Information
ION GNSS+ will feature our industry partners in expanded exhibitor profiles that will allow you to see who you need to connect with, reach out to them and learn about their latest products and services. Many exhibitors have also uploaded exhibitor demonstrations or special announcements on their profiles.

Access online content at ion.org/gnss.

ION GNSS+

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 instructors. ION Instructors are internationally recognized GNSS experts and educators. All of the ION instructors 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 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

Mineral Hall D/E (3rd Floor)

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

Mineral Hall F/G (3rd Floor)

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 remove 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

Mineral Hall D/E (3rd Floor)

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

Mineral Hall F/G (3rd Floor)

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.

63rd Meeting of the Civil GPS Service Interface Committee

Included with all ION GNSS+ full-conference registrations

Monday Morning Session

International Information Subcommittee

Chair: John Wilde, CEO, SPACEKEYS
Capitol Ballroom 5-7 (3rd Floor)

9:00 Welcome Remarks / Introduction
9:10 Dr. Lasisi Salami LAWAL (CEng), Acting General Manager, Directorate of Technical Services and HOD, Navigation, Nigerian Communications Satellite Ltd., Abuja, Nigeria
9:30 CAVs and GNSS: A Relationship of Opportunities and Challenges: Dr. Sarah Jane Fox, Law/Policy and Risk Expert for Space and Air (UAV's) University of Leichester, United Kingdom
9:50 NANUs and NavCen Observations: Mr. John Wilde, CEO SPACEKEYS
10:10 Pakistan Space Based Augmentation System (Pak SBAS): Mr. Amer Sarfraz Ahmad, Member, Space and Upper Atmosphere Research Commission (SUPARCO), Islamabad, Pakistan
10:30 Break
10:50 International Committee on GNSS: Ms. Sharafat Gadimova, ICG Executive Secretariat, United Nations Office of Outer Space Affairs
11:10 Update on the Interoperable GNSS Space Service Volume: International PNT Activities of the ICG Space Use Subgroup: Mr. Joel Parker, Navigation and Mission Design Branch, National Aeronautics and Space Administration; Mr. Juan Pablo Boyero, Directorate-General for Defense Industry and Space, European Commission; Dr. Masaya Murata, Japan Aerospace Exploration Agency
11:30 Safety of Life for Urban Air Mobility (UAM): Time-Differenced Carrier Phase RAIM: Dr. Changdon Kee, Professor, Seoul National University, Seoul, Republic of Korea
11:50 Spoofing an Android Device: Mr. Francisco Jurado Romero, Research Scientist, German Aerospace Center (DLR)
12:10 Q&A: Presenters
12:30 Adjourn

Monday Afternoon Concurrent Sessions

Timing Subcommittee

Chair: Dr. Patricia Larkoski, Lead Sensor Engineer, The MITRE Corporation
Deputy Chair: Dr. Bijunath Patla, National Institute of Standards and Technology (NIST)
Capitol Ballroom 5-7 (3rd Floor)

2:00 Welcome Remarks / Introduction
2:10 Report from NIST: Dr. Bijunath Patla, Physicist, NIST
2:30 Report from NRL: Dr. Michael Coleman, Space PNT Branch, Naval Research Laboratory (NRL)
2:50 Optical Atomic Clocks for Enhanced Timing Performance: Dr. Judith Olson, Atomic Clocks Group Leader, Senior Physicist, Infleqtion
3:10 Best Practices in Solving PNT Cyberthreats in Critical Defense 5G Communications Infrastructure: Nino De Falcis, Senior Director, Sync Business Development Americas, Oscilloquartz
3:30 Break
3:40 Report from USNO: Mr. Arnold Colina, Precise Time Department, U.S. Naval Observatory
4:00 Electric Power Applications Enabled by Wide-Area Synchronized Time: Mr. Jeff Dagle, Chief Electrical Engineer, PNNL
4:20 Precision Time Synchronization in Data Centers: Dr. Ahmad Byagowi, Research Scientist, Meta
4:40 Detection and Classification of GNSS Signal Disturbances from Spaceborne Platforms: Prof. Y. Jade Morton, Head of the Satellite Navigation and Sensing (SeNSe) Laboratory, University of Colorado
5:00 Q&A: Presenters
5:30 Adjourn

Surveying. Mapping, and Geosciences Subcommittee

Chair: John Galetzka, CORS Branch Chief, NOAA National Geodetic Survey (NGS)
Deputy Chair: Neil Winn, GIS Specialist, National Park Service (NPS)
Capitol Ballroom 1-3 (3rd Floor)

2:00 Welcome Remarks/Introduction
2:10 How Early Ties to the National Spatial Reference System Have Advanced Science, Research and Decision Making for Management of the Colorado River: Keith Kohl, Geodesist, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center, USGS
2:30 GNSS-IR provides new insights into surface water dynamics: Prof. Kristy Tiampo, Director of Earth Science and Observation Center, CU Boulder
2:50 Advances in Ionospheric and Thermospheric Services at the NOAA Space Weather Prediction Center: Tzu-Wei Fang, PhD, Space Scientist at NOAA Space Weather Prediction Center
3:10 Partnerships and Program Building: A National Park Service Success Story: Scott Thompson-Buchanan, Chief Cartographer, National Park Service
3:30 Break
3:40 Opportunities, Challenges, and Solutions in Geodesy Education and Workforce Development: Beth Pratt-Sitaula, PhD, Engagement Program Manager, EarthScope Consortium
4:00 Rocky Mountain Regional Update: Brian Shaw, Rocky Mountain Regional Advisor, NOAA National Geodetic Survey
4:20 Galileo High Accuracy Service: Overview, Roadmap, and Initial Test Results: Jean-Yves Lauture, Chief Technology Officer, Eos Positioning Systems and Dr. Ignacio Fernández-Hernández, Galileo Authentication and High Accuracy Manager, European Commission
5:00 Q&A
5:30 Adjourn

Civil GPS Service Interface Committee Plenary: Tuesday, 9:00 a.m. - 5:00 p.m., Capitol Ballroom 5-7

Chair: Ms. Karen Van Dyke, Director, PNT and Spectrum Management, U.S. Dept. of Transportation
Deputy Chair: Captain Scott Calhoun, Commanding Officer, U.S. Coast Guard Navigation Center

9:00 Welcome/Opening
9:05 Meeting Overview
9:10 Keynote Address: Dr. Robert Hampshire, Deputy Assistant Secretary for Research and Technology and Chief Science Officer, U.S. Department of Transportation
9:30 History of the GPS Revolution on the Occasion of the 50th Anniversary of Gaining Initial Approval in December of 1973: Dr. Bradford Parkinson, Edward Wells Professor, Emeritus, Aeronautics and Astronautics (Recalled), Co-Director, Center for Position, Navigation and Time, Stanford University
10:10 GPS Acquisitions and Development Update: Colonel Andy Menshner, GPS Space and Ground (SML), Space Systems Command, U.S. Space Force
10:30 Break
10:50 GPS Architecture Resiliency: Lieutenant Colonel Robert Wray, Commander, Second Space Operations Squadron, U.S. Space Force
11:10 U.S. National Space-Based PNT Update: Mr. Harold Martin, Director, National Coordination Office for Space-Based PNT
11:30 GPS Civil Liaison Updates: Dr. Andrew Hansen and Mr. Shawn Skalski, U.S. DOT Volpe National Transportation Systems Center
11:50 Q&A Panel: Presenters
12:15 Lunch
Subcommittee Reports:
1:30 Timing Subcommittee: Dr. Patricia Larkoski, Chair
1:40 International Information Subcommittee: Mr. John Wilde, Chair
1:50 Surveying, Mapping, and Geosciences Subcommittee: Mr. John Galetzka, Chair
2:00 GPS International Activities: Mr. Jeffrey Auerbach, Senior GNSS Advisor, Office of Space Affairs, U.S. Dept. of State
2:20 U.S. Department of Transportation Update: Ms. Karen Van Dyke, Director, PNT and Spectrum Management, U.S. Department of Transportation
2:40 FAA Navigation Programs Update: Ms. Deborah Lawrence, Navigation Programs Manager, Federal Aviation Admin., U.S. Dept. of Transportation
3:00 U.S. Department of Homeland Security Update: Mr. Michael Roskind, Branch Chief, Strategic Defense Initiatives, U.S. Department of Homeland Security
3:20 Break
3:40 Nationwide Integration of Time Resiliency for Operations (NITRO): Dr. Laura Callahan, Special Advisor, National Guard
4:00 PNT Priorities to the Moon and Beyond: Mr. Joel Parker, Space Policy lead, NASA Goddard Space Flight Center
4:20 Q&A Panel
User Perspectives:
4:35 Receiving Precision Timing and Position from the Broadcast Network via ATSC 3.0: Dr. Patrick Diamond, Principal, Diamond Consulting, National Space-Based PNT Advisory Board
4:50 Innovation Alliance: Ms. Lisa Dyer, Director, GPS Innovation Alliance
5:05 User Industry Discussion
User Support Forum
5:15 Public Interface Control working Group (PICWG): Mr. Stephen Hillman, Senior Project Leader, C3 Engineering & Operations Dept (CEOD), The Aerospace Corporation
5:30 Adjourn

Pre-Conference Tutorials: Tuesday, September 12

Additional Tutorial Fee Required; register online or onsite

The ION GNSS+ pre-conference tutorials have been organized to provide in-depth learning of specific GNSS related disciplines prior to the start of the technical program. All courses will be taught in a classroom setting by some of the world's leading GNSS educators. Electronic course notes will be provided to attendees via the meeting website.

In-Person Attendance: Power will not be available for individual laptop computers.

Virtual Learning: Attendees who choose virtual participation will receive access to a recorded version of the tutorial. The recorded tutorial may be viewed one time within 72 hours. Those viewing the recording will not have real-time access to instructor(s) for live chat or question and answer.

LIVE TUTORIAL SCHEDULE

9:00 a.m.–12:30 p.m.

Room	Course	Instructor
Granite (3rd Fl)	Multi-constellation GNSS Signals and Systems	Dr. Chris G. Bartone, P.E.
Mineral Hall F/G (3rd Fl.)	GNSS Integrity	Dr. Mathieu Joerger
Mineral Hall D/E (3rd Fl.)	Factor Graphs	Dr. Ryan Watson / Dr. Clark Taylor
1:30 p.m.–5:00 p.m.		
Granite (3rd Fl)	GNSS in the National Airspace	Dr. Todd Walter
Mineral Hall D/E (3rd Fl.)	PNT for sUAVs	Dr. Robert Leishman
Mineral Hall F/G (3rd Fl.)	Introduction to Cryptography with Navigation	Dr. Joe J. Rushanan

TUTORIAL DESCRIPTIONS

Tutorials: Tuesday Morning
9:00 a.m.–12:30 p.m.

Multi-constellation GNSS Signals and Systems

Dr. Chris G. Bartone, P.E.

Course Level: Beginner

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 include:

- GNSS segments; space, ground, user segments
- GNSS link budget
- Fundamental concept of GNSS position, time determination
- GNSS coordinate frames, datums and time
- GNSS signal structure formats: carrier, code, data
- Direct sequence spread spectrum; auto/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/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
- GNSS user solutions

Dr. Bartone 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.

GNSS Integrity

Dr. Mathieu Joerger

Course Level: Intermediate

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. Joerger is an assistant professor at Virginia Tech, recipient of ION's Parkinson Award (2009) and Early Achievement Award (2014). He's 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 Inst. of Technology.

Factor Graphs

Dr. Ryan Watson & Dr. Clark Taylor

Course Level: Intermediate

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. 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. 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.

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

Dr. Y. Jade Morton

Course Level: Beginner to Intermediate

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 the 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 unique navigation signals to function as signals of opportunity for low cost, distributed, passive sensing in challenging propagation environments.

This tutorial first discusses the effects of the space and local environments on GNSS signals, followed by the latest technology development that 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.Ionospheric Effects, Monitoring, and Mitigation

Dr. 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.

Tutorials: Tuesday Afternoon 1:30 p.m.–5:00 p.m.

Indoor Navigation and Positioning

Dr. Li-Ta Hsu

Course Level: Beginner to Intermediate

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 popular technologies and sensors related. Then, an IPIN framework will be introduced that consists of the source sensor, algorithm space, and integration. After introducing single point positioning (SPP), we will discuss feature (Fingerprint, FDR).

Regarding the data source, we separate the sources into homogeneous (geometry based) ones and heterogeneous (scene matching, map matching) ones. The former ones contain the measurement model of RSS-ranging, AOA, TOA and TDOA. The latter ones contain the fingerprint and other information 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. 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.

GNSS in the National Airspace

Dr. Todd Walter

Course Level: Beginner

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. 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.

PNT for sUAVs

Dr. Robert Leishman

Course Level: Beginner to Intermediate

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. 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.

Introduction to Cryptography with Navigation

Dr. Joe J. Rushanan

Course Level: Beginner

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. 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+ Plenary Session

Tuesday, September 12, 2023 • 6:30 p.m.–8:30 p.m.
Capitol Ballroom 4 (4th Floor)

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

Keynotes

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

Brian "Bam" McClendon

DSVP Engineering, Niantic

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.

UAVs vs. Natural Autonomous Vehicles (NAVs) - Are We Closing the Gap?

Dr. John Raquet

Director, Dayton Business Unit, Integrated Solutions for Systems (IS4S)

Every day it seems like we hear about new and better technologies being developed, including in the UAV arena. However, sometimes it is helpful to step back and see how far we have come, and how far we have still to go... if we dare.

Dr. John Raquet is the director of the Dayton business unit of Integrated Solutions for Systems (IS4S), where for the past four years he has led a team developing modular, open approaches to PNT, including pntOS and ASPN. Prior to his time at IS4S, he was the founding director of the Autonomy and Navigation Technology Center at the Air Force Institute of Technology. He is a graduate of the US Air Force Academy (BS), the Massachusetts Institute of Technology (MS), and the University of Calgary (PhD). Dr. Raquet has been a Fulbright Scholar, is a past president of the Institute of Navigation, and is an ION Fellow.

Special Events and Programs

Tuesday, September 12

Smartphone Decimeter Challenge 2023: Workshop for Benchmark Competition, Sponsored by Google
1:30 p.m. - 3:30 p.m.
Capitol Ballroom 1-3 (4th Floor)
This event is included with all full conference/student regsitrations.

The goal of Smartphone Decimeter Challenge is to compute smartphones location down to the decimeter or even centimeter resolution which could enable services that require lane-level accuracy such as HOV lane ETA estimation. Solution will be developed based on raw location measurements from Android smartphones collected in opensky and light urban roads using datasets collected by the host.

Wednesday, September 13

Attendee Luncheon
12:15 p.m. – 1:15 p.m.
Exhibit Hall - Centennial Ballroom
This event is included with all full conference, student, exhibit only and Wednesday registrations.

Free Time in the Exhibit Hall
5:30 p.m. – 7:00 p.m.
Exhibit Hall - Centennial Ballroom
This event is included with all registrations.

Visit this year's exhibitors to review developments in GNSS technology, talk shop, get the specifics directly from the vendors, and learn about what has been happening in the GNSS marketplace during the past year. This event is included with any type of registration.

Thursday, September 14

Attendee Luncheon
12:15 p.m. – 1:15 p.m.
Exhibit Hall - Centennial Ballroom
This event is included with all full conference, student, exhibit only and Thursday registrations.

Friday, September 15

Kepler and Parkinson Awards Luncheon
12:15 p.m. – 1:30 p.m.
Centennial Ballroom

2022 Kepler Award Winner: Dr. Boris Pervan

The purpose of the Johannes Kepler Award is to honor an individual for sustained and significant contributions to the development of satellite navigation.

The Bradford Parkinson Award, which honors Dr. Parkinson for his leadership in establishing both the U.S. Global Positioning Systems and the Satellite Division of the Institute of Navigation, is given to an outstanding graduate student in the field of Global Navigation Satellite Systems. The deadline for submitting nominations for both awards is June 30. See ion.org/awards for application requirements.

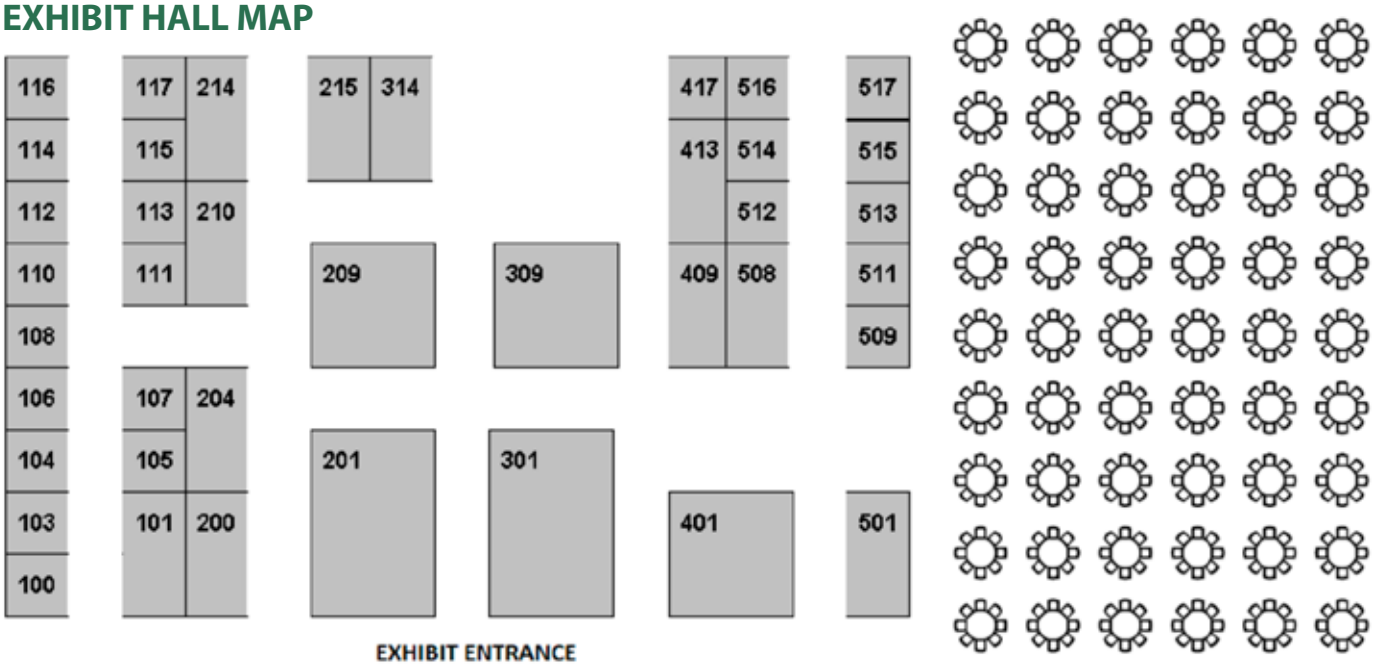
This event is included with a full, student, or Friday conference registration. Tickets for exhibitors/guests may be purchased by visiting the ION GNSS+ registration desk on the 3rd floor.

EXHIBIT HALL HOURS

Wednesday:
10:00 a.m. - 7:00 p.m. Hall Open
5:30 p.m. - 7:00 p.m. Evening Exhibit Hours

Thursday:
9:00 a.m. - 4:00 p.m. Hall Open

EXHIBIT HALL MAP



IN-PERSON EXHIBITORS

746th Test Squadron (Booth 103)
Acutronic USA Inc. (Booth 114)
Anello Photonics (Booth 112)
Applied Research Laboratories - UT Austin (Booth 116)
CAST Navigation, LLC (Booth 210)
FIBERPRO, Inc. (Booth 104)
Geo++ GmbH (Booth 110)
German Aerospace Center (DLR) (Booth 301)
GMV Aerospace and Defence S.A.U. (Booth 215)
GPS Networking, Inc. (Booth 117)
GPS Source / General Dynamics (Booth 517)
GPS World (Booth 214)
Hemisphere GNSS (Booth 107)
Hexagon | NovAtel (Booth 409) ❖
IAI (Booth 508)
Ideal Aerosmith (Booth 105)
Infleqtion (Booth 511)
Inside GNSS (Booth 501) ❖
ION Membership Booth (Booth 101A)
LabSat (Booth 401)
Lockheed Martin (Booth 209) ❖
Microchip Technology Inc. (Booth 111)
Munich Satellite Navigation Summit (Booth 514)
NAVIGATION: Journal of the Institute of Navigation (Booth 101B)
NavtechGPS (Booth 108)
NextNav (Booth 204)
oneNav (Booth 515)
Oxford Technical Solutions Inc. (Booth 100)
Rakon (Booth 512)
Rohde & Schwarz USA, Inc. (Booth 200)
Rx Networks, Inc. (Booth 509) ❖
Safran – Electronics & Defense (Booth 309)
SBG Systems (Booth 417)
Silicon Sensing Systems Ltd. (Booth 106)
Spirent Communications PLC (Booth 201B)
Spirent Federal Systems (Booth 201A)
Syntony GNSS (Booth 413)
Tower Semiconductor (Booth 113)
Trimble (Booth 513)
Tualcom Elektronik A.S. (Booth 314)
UHU Technologies LLC (Booth 516)
Xona Space Systems (Booth 115)

Bold = ION Corporate Member ❖= Partner

VIRTUAL

Coordinates Magazine ❖
GeoConnexion Magazine ❖

Visit our exhibitors at ion.org/gnss and:

- View company details, descriptions, and contact information
- Download brochures and materials
- View informational videos
- Contact exhibitors directly

Session A1: Navigation and Positioning
Room: Mineral Hall F/G (3rd Floor)


Brian Schipper
Honeywell


Dr. Terry Moore
University of Nottingham

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

8:57 A New Ionospheric Model for Galileo Open Service with Good Performance and Less Computation: M.M. Hoque, German Aerospace Center (DLR); M. Sgammini, F. Menzione, Joint Research Center/ European Commission (JRC/EC); R. Orus Perez, European Space Agency; J. A. Cahuasquí, DLR; E. Chatre, EC

9:20 AoA-Based Coarse Positioning for Snapshot GNSS Receivers: N. BniLam, P. Crosta, European Space Agency

9:43 DFMC SBAS Prototype in Africa: J-L. Demonfort, T. Authié, S. Trilles, G. Grèze, P. Giorgis, R. Lembachar, Thales Alenia Space; F. Dufour, C. Boulanger, CNES; J. Lapie, L. Bakienon, Agency for Air Navigation Safety in Africa and Madagascar; L.S. Lawal, Nigcomsat Ltd.

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

10:40 Sequential RF-SLAM for Rapid Construction of RF Map in Underground Parking Lot Using Smartphone Only: B. Shin, T. Kim, KIST; D. Shin, C. Yoo, TJLABS; H. Kyung, KIST; T. Lee, KIST & TJLABS

11:03 Passive Localization Using Multipath Propagation of Low-Cost Ultra-Wideband Devices: C. Gentner, M. Schmidhammer, B. Siebler, German Aerospace Center

11:26 Performance Improvement of Wearable GNSS Navigation with Smart Sensor Aiding: G-J. Tsai , S-Y. Li, Y-L. Chen, T-Y. Chen, Y-C. Lin, S-X. Yang, AIROHA Technology (Company of MediaTek Group)

11:48 Tolles-Lawson Coefficient Dependence Using F-16 Data Set: B. Blakely, J. Bonifaz, and A. Nielsen, Air Force Inst. of Technology/ANT Center

Alternate

1. **Tutorial on Inverse Mechanization:** D. Woodburn, ANT Center at the Air Force Institute of Technology

Virtual Only: View at ion.org/gnss

1. **Human Pose Recognition Based on Multi-View RGB-D Images:** J. Liu, H. Yu, University of Electronic Science and Technology of China
2. **Improving GNSS Positioning Correction Using Deep Reinforcement Learning with Adaptive Reward Augmentation Method:** J. Tang, Z. Li, R. Guo, H. Zhao, Q. Wang, Guangdong University of Technology; M. Liu, Hong Kong University of Science and Technology; S. Xie, Guangdong Key Laboratory of IoT Information Technology; M. Polycarpou, University of Cyprus
3. **Model Parameter Optimization for GNSS Point Positioning in a Kinematic Ocean Buoy Application:** M. Gonzalez and J. Gross, West Virginia University
4. **Real-Time Wide-Area Scene Reconstruction Based on Volume Fusion:** L. Zhu, H. 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.

View All Virtual Paper Presentations in the ION GNSS+ Virtual Portal at ion.org/gnss

Session B1: Augmentation Services, Integrity, and Authentication
Room: Mineral Hall D/E (3rd Floor)


Dr. Jianming She
The MITRE Corporation


Dr. Allison Kealy
Environment, Land Water & Planning

8:35 Practical Considerations in PSD Upper Bounding of Experimental Data: M. Joerger and S. Jada, Virginia Tech; S. Langel, The MITRE Corporation; O. García Crespillo, German Aerospace Center (DLR); E. Gallon, and B. Pervan, Illinois Institute of Technology

8:57 Mid-Latitude Ionospheric Scintillation Impact on Availability of Dual-Frequency GNSS Augmentation Systems: A.K. Sun, J. Chang, J. Lee, Korea Advanced Institute of Science and Technology (KAIST); B. Breitsch, Y.J. Morton, University of Colorado Boulder; F.S. Rodrigues, The University of Texas at Dallas

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

9:43 The First Satellite-Based Open PPP-RTK Service: Operational Experiences and Improvements: R. Hirokawa, S. Fujita, N. Hayase, Mitsubishi Electric Corporation

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

10:40 Kriging Based Ionospheric Grid Model and Threat Model for Single-Frequency BDSBAS: H. Wang, X. Lan, K. Fang, Z. Dan, Z. Wang, Y. Zhu, Beihang University

11:03 Effective Carrier Phase Anomaly Detection Using Short Baseline Double Difference and Machine Learning: Y. Lee, D-K. Lee, J. Song, B. Park, Sejong University

11:26 Authentication Security of Combinatorial Watermarking for GNSS Signal Authentication: J. Anderson, S. Lo, T. Walter, Stanford University

11:48 SBAS Time-Correlated Error Characterization for Sequential Position Error Overbounding: L. Montloin, F. Legrand, Airbus Defence and Space; F. Bauer, G. Buscarlet, M. Dall'Orso, C. Lopez de Echazarreta, ESA

Alternates

1. **Inter-Satellite and Inter-Receiver Aiding in the Verification of OSNMA:** J-C. Juang, Y-T. Chen, and C-K. Chua, National Cheng Kung University
2. **Performance Assessment of Galileo High Accuracy Service (HAS) with Low-Cost GNSS/IMU Sensors in Urban Driving Environments:** D. Yi, N. Naciri, S. Bisnath, York University; F. J. de Blas, EU Agency for the Space Programme; R. Capua, Sogei SpA
3. **Seasonality of Nominal Ionospheric Gradient Using Time-Step Method Based on GNSS CORS Observations in Hong Kong:** W. Li and Y. Jiang, The Hong Kong Polytechnic University
4. **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, ESA, ESTEC

Virtual Only: View at ion.org/gnss

1. **First Signal-in-Space for KASS Augmentation System:** J-R. De Boer, N. Bourry, C. Sarramiac, G. Comelli, Thales Alenia Space; B.S. Lee, M. Son, E. Lee, Korea Aerospace Research Institute; C.S. Sin, Electronics and Telecommunication Research Institute
2. **HMI Risk Without Over-Conservative Operation for Advanced RAIM Fault Detection and Exclusion:** H. Qi, X. Cui, M. Lu, Tsinghua University
3. **Protection Level of PPP-RTK Based on Regional Slant Ionospheric Integrity Error Bounds:** T. Tang, Y. Xiang, S. Lyu, W. Yu, Shanghai Jiaotong University

Session C1: PANEL: Status of GPS, Galileo, BDS, QZSS, KPS, and NavIC
Room: Capitol Ballroom 4 (4th Floor)


Dr. Chris Hegarty
The MITRE Corporation

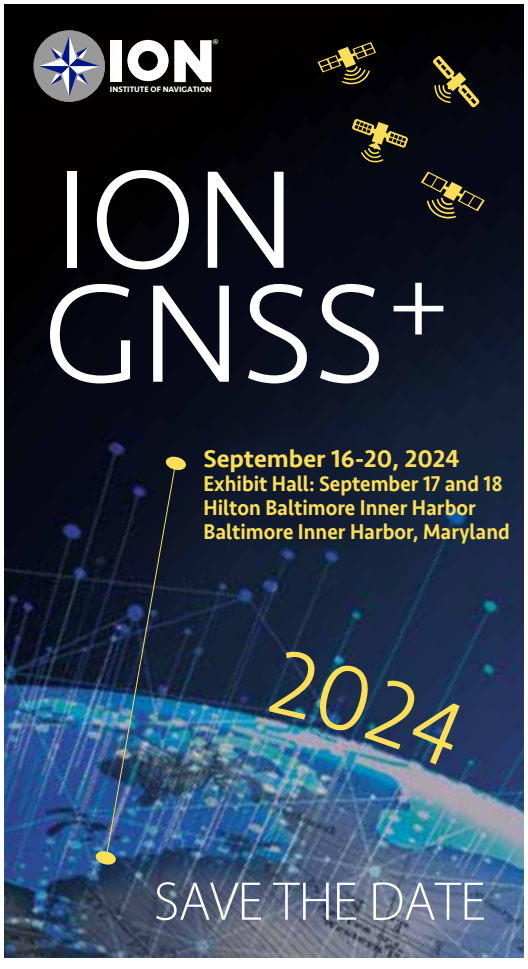

Dr. José Ángel Ávila Rodríguez
European Space Agency

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.

Panel Members

1. **GPS**: Mr. Cordell DeLaPena Jr., Program Executive Officer for Military Communications & Positioning, Navigation and Timing Division, Space Systems Command, U.S. Space Force
2. **Galileo**: Mr. Eric Châtre, Head of EU GNSS Exploitation and Evolution, European Commission and Mr. Miguel Manteiga, Galileo Second Generation Project Manager, European Space Agency
3. **BDS**: Dr. Xiaochun Lu, Deputy Director of International Cooperation Center, China Satellite Navigation Office
4. **QZSS**: Mr. Motohisa Kishimoto, Senior Coordinator, QZSS Strategy Office, National Space Policy Secretariat, Cabinet Office
5. **KPS**: Mr. Taegyu Kim, Head of Team, Satellite Navigation Development Strategy Team, Ministry of Science and ICT
6. **NavIC**: Dr. P.S. Sura, UR RAO Satellite Centre

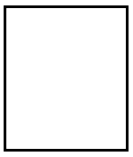
Buffet Lunch in Exhibit Hall, 12:15 p.m. - 1:15 p.m.
Free Time in Exhibit Hall, 1:15 p.m. - 1:45 p.m.



Session D1: Alternative Technologies for GNSS-Denied Environments

Room: Capitol Ballroom 1-3 (4th Floor)

Paolo Crosta
European Space Agency



Dr. Christina Selle
Apple

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

8:57 Multi-Layer PNT Solutions for Harsh User Conditions: J.A. Garcia-Molina, M. Cordero, R. Sarnadas, E. Plakidis, I. Lapin, A. Budianu, J. Miguez, F. Melman, M. Karpf, European Space Agency

9:20 First Field Trial Results of Hybrid Positioning with Dedicated 5G Terrestrial and UAV-Based Non-Terrestrial Networks: J. A. del Peral-Rosado, A. Yildirim, S. Schlötzer, P. Nolle, Airbus Defence and Space; S. M. Razavi, Ericsson; S. Parsawar, R. Mundlamuri, F. Kaltenberger, Eurecom; N. Sirola, Exafore; S. Garlaschi, L. Canzian, Qascom; J. Talvitie, Tampere University; I. Lapin, European Space Agency; D. Flachs, Airbus Defence and Space

9:43 Neural Radiance Maps for Extraterrestrial Navigation and Path Planning: A. Dai, S. Gupta, G. Gao, Stanford University

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

10:40 Pseudorange-Based IR-UWB Localization: V. Navratil, J. Krska, Czech Technical University in Prague

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

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

11:48 Improving Land Vehicle Navigation: A Study on RIDR and Kalman Filters: P. R. Marques de Araujo, Queen's University; E. Mounier, Queen's University and Ain Shams University; M. Elhabiby, Micro Engineering Tech Inc.; S. Givigi, Queen's University; A. Noureldin, Royal Military College and Queen's University

Alternates

1. **LIWO-SLAM:** A LiDAR, IMU, and Wheel Odometry Simultaneous Localization and Mapping System for GNSS-Denied Environments Based on Factor Graph Optimization: E. Reitbauer, C. Schmied, F. Theurl, M. Wieser, Graz University of Technology
2. **An Enhanced WIFI Indoor Positioning Method Based on SNGAN:** C. Shuyu, D. Jiabin, H. J. Gyu, L. Rana, L. JinLong, P.J. Goo, Kyungpook National University
3. **Path Planning for UAV-Aided Wireless Positioning System Calibration:** Z. Wu, Z. Yao, M. Lu, Tsinghua University
4. **Performance Analysis of INS Dead Reckoning Aided by LIDAR, Visual SLAM or Wheel Odometry Under Challenging Autonomous Applications:** P. Bénet, L. Zaid, F. Houssen, M. Saidani, A. Guinamard, SBG Systems

Virtual Only: View at ion.org/gnss

1. **Emerging Wireless Technologies for Reliable Indoor Navigation in Industrial Environments:** M. Elsanhoury, A. Siemuri, P. Valisuo, J. Koljonen, University of Vaasa; H. Kuusniemi, University of Vaasa & Finnish Geospatial Research Institute; M. Elmusrati, University of Vaasa
2. **Evaluation of Zero Velocity Detectors Using Motion Capture System:** A. Kumar, Indian Institute of Technology, & University of Melbourne; K. Khoshelham, University of Melbourne; S. Goel, Indian Institute of Technology
3. **Localization Accuracy Analysis for Roadside Sensing System:** Z. Gong, Z. Liao, X. Bao, B. Yu, Y. Ge, China Academy of Information and Communications Technology

Blue Text: Student Paper Award Winner

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.

Session E1: Advanced Processing of Terrestrial Signals of Opportunity

Room: Capitol Ballroom 5-7 (4th Floor)

Dr. Christian Gentner
German Aerospace Center (DLR)

Dr. Yiran Luo
University of Calgary

8:35 Grid-Based Hybrid 3DMA GNSS and Terrestrial Positioning: P. Schwarzbach, A. Michler, O. Michler, Dresden University of Technology

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

9:20 Commercial Radio Phase Difference of Arrival (PDOA) for GNSS-Independent PNT: D.W.A. Taylor, Setter Research, Inc.

9:43 Joint Doppler and Azimuth DOA Tracking for Positioning with Iridium LEO Satellites: S. Shahcheraghi, F. Gourabi, M. Neinavaie, Z.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: D. Shen, G. Chen, Intelligent Fusion Technology, Inc.; K. Pham, Air Force Research Lab., Space Force

11:03 Centimeter-Level Carrier Phase Positioning with Asynchronous Ground-Based Positioning Systems: X. Zhang, T. Wang, Z. Yao, Tsinghua University; Y. Wang, C. Li, Huawei Technologies Co., Ltd.; M. Lu, Tsinghua University

11:26 Experimental Performance of a Cellular LTE and GPS L1 C/A Vector Tracking Receiver: S. Morgan, J. Tanner Koza, and S. Martin, Auburn University

11:48 A Step Closer Towards 5G mmWave-Based Multipath Positioning in Dense Urban Environments: Q. Bader, S. Saleh, Queen's University; M. Elhabiby, Micro Engineering Tech Inc.; A. Noureldin, Queen's University; Royal Military College of Canada

Alternates

1. **Performance Analysis of GNSS Signal Based on SFBOC Modulation:** S. Cho, H-W. Seok, S-H. Kong, Korea Advanced Institute of Science and Technology
2. **A Method for Estimating the Approximate Position of a Receiver Using Visible Satellites:** J. Zhang, P. Wu, R. Li, Z. Ren, C. Yang, J. Gan, L. Feng, H. Tong, X. Xiao, Y. Chen, ChangSha University
3. **Precise LTE Transmitter Localization Using CRS Carrier Phase Tracking with an On-Board Atomic Clock and LTE Double-Difference Observations:** M.S. Hameed, M. Arizabaleta-Diez, M. Philips-Blum, D. Dötterböck, T. Pany, Universität der Bundeswehr München

Virtual Only: View at ion.org/gnss

1. **Multiple-Epoch Joint Localization and Synchronization in a 5G System:** L. Bai, C. Sun, Beihang University; A.G. Dempster, University of New South Wales; W. Feng, 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.

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

Room: Agate (3rd Floor)

Dr. Rebecca Bishop
The Aerospace Corporation

Dr. Sebastian Mrak
University of Colorado Boulder

8:35 Pulsar Timing for Clock Stability – Exploring an Autonomous and Resilient Approach to Timing Using Radio Pulsars: J. Critchley-Marrows, The University of Sydney; C. Ambatali, The University of Tokyo; X. Wu, The University of Sydney; S. Nakasuka, The Univ.of Tokyo

8:57 Doppler Compensation Algorithm for Highly Accurate Inter-Satellite and Satellite-to-Ground Frequency Transfer: M. Dassié, G. Giorgi , P. Nahuel Dominguez, L. Blümel, German Aerospace Center (DLR); C. Gohle, OHB System AG

9:20 Addressing Inaccurate Phase Center Offsets in Precise Orbit Determination for Agile Satellite Missions: K. Gutsche, T. Hobiger, University of Stuttgart; S. Winkler, Airbus Defence and Space

9:43 Sensing Thermospheric Density Using COSMIC-2 Satellite GNSS Data: J. Yao, J-P. Weiss, University Corporation for Atmospheric Research (UCAR); T-W. Fang, E. Sutton, and T. 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: Y. Wang, University of Colorado Boulder

11:03 Improving GNSS-Based Tropospheric Delay Estimation for Airborne Quantum Gravimetry: First Results Using NWM Forecasting: F. Darugna, T. Wübbena, G. Wübbena, H. Albers, and J.B. Wübbena, Geo++ GmbH

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

11:48 GNSS Reflectometry Correlation with Camera Images for Surface Type Determination: S. Datta-Barua, R. Parvizi, Illinois Institute of Technology; A.F. Banwell, University of Colorado Boulder; S. Khan, Illinois Institute of Technology

Alternates

1. **Snapshot Tracking of GNSS Signals in Space: A Case Study at Lunar Distances:** A. Nardin, A. Minetto, Politecnico di Torino; S. Guzzi, Qascom s.r.l.; F. Dovis, Politecnico di Torino; L. Konitzer, J.J.K. Parker, Goddard Space Flight Center (GSFC) NASA
2. **Integrating Spaceborne GNSS-R Measurements in 3D Ionospheric Imaging: A Simulation Study:** B. Royersmith, B. Breitsch, Y.J. Morton, University of Colorado Boulder
3. **The Effect of the Ballistic Coefficient on Satellite Orbit Prediction:** M. McDougal, S. Martin, K. Underwood, Auburn University
4. **A GNSS–Based Technique to Investigate the Black-Out During Space Vehicles' Re-Entry:** G. B. Palmerini, P. Kapilavai, Sapienza Università di Roma
5. **Validation Methods to Study the Consistency and Quality of Radio Occultation Electron Density Profiles: Application to COSMIC:** G. O. Jerez, Sao Paulo State University (UNESP), & Universitat Politècnica de Catalunya (UPC); M. Hernández-Pajares, UPC; D. B. M. Alves, and J. F. G. Monico, UNESP

Virtual Only: View at ion.org/gnss

1. **A Calibration Algorithm of Ultra-rapid Orbit Boundary Discontinuity Based on Adaptive Orbital Arc Length:** Z. Lin, X. Lu, H. Li, R. Wang, and Z. Gao, Harbin Engineering University
2. **Water Vapor Retrieved from Ground-Based GNSS and its Applications to Lightning Weather in Hong Kong:** T. Ni, H. Guo, Nanchang University; M. Yu, Jiangxi Normal University; J. Xiong, Nanchang University; Q. Tian, Guangzhou Inst. of Tropical and Marine Meteorology; L. Lv, Nanchang Univ.; S. Du, Meteorological Bureau of Chenghai

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.

Session A2: Applications of GNSS Measurements from Smartphones

Room: Capitol Ballroom 1-3 (4th Floor)

Dr. Mohammed Khider
Google Inc.

Ivan Ng
Hong Kong Polytechnic University

1:50 Elevating Android GNSS Raw Measurement Processing: A Universal RINEX Converter for Precise Post-Processing Solutions: J. Yun, B. Park, Sejong University; D-K. Lee, D. M. Akos, University of Colorado Boulder

2:12 The S-GNSS (R) API for Smartphones and Smartwatches: R. Faragher, P. Esteves, M. Evans, R. Grey, C. Higgins, S. Mole, M. 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

2:58 Detecting Single-Antenna Spoofing Attacks by Correlation in Time Series of Raw Measurements: A. Minetto, A. Rustamov, F. Dovis, Politecnico di Torino

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

4:00 RTK-GNSS with Smartphone in Moving Vehicles Using GNSS Repeater: N. Kubo, T. Ozeki, K. Kobayashi, Tokyo University if Marine Science and Technology

4:23 Real-Time GNSS+IMU Smartphone Positioning with Trimble RTX Corrections: F. Eisenlohr, S. Junker, C. Rodriguez-Solano, D. Rüegg, Trimble Inc., Germany

4:46 Preliminary Assessment of Improved Smartphone GNSS Quality Control Methods Based on Range Errors: J. Hu and S. Bisnath, York University

5:08 MediaTek GNSS Solution with 3DMA: D.M. Chou, C. Y. Chong, D. Yang, P-H. Jau, MediaTek Inc.

Alternates

1. **IP3-Mobile: A GNSS Real-Time Precise Point Positioning APP for Android Smartphones**: F. Liu, M. Elsheikh, Y. Jiang, Z. Lyu, F. Z. Nejad, Y. Gao, N. El-Sheimy, Profound Positioning Inc.
2. **Performance Analyses of the Stonex S70 Android Tablet Using Different Tri-Constellation GNSS Solutions:** J. Rajavarathan, Sabaragamuwa University of Sri Lanka (SUSL); G. Retscher, TU Wien – Vienna University of Technology; T. L. Dammalage, University of New England; V. Abeyratne, SUSL
3. **A Method for Adaptive GNSS/PDR Integrated Navigation:** R. Shiraiwa, F. Odai and Y. Kubo, Ritsumeikan University

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

Session B2: Marine Applications, and Search and Rescue

Room: Agate (3rd Floor)

Dr. Alan Grant
General Lighthouse Authorities

Dr. Gregory Johnson
Serco, Inc.

1:50 Potential LEO Satellite Augmentation for Rescue-21 in Alaska: D. McGarry, R.J. Hartnett, U.S. Coast Guard Academy; P.F. Swaszek, University of Rhode Island; B. Chan, B. Evans, and A. Kenna, U.S. Coast Guard Academy

2:12 VDE-Terrestrial Channel Performance Assessment: G. Johnson, K. Dykstra Serco, Inc.; J. Forster, J. Spilsbury USCG Research and Development Center

2:35 VDES - R-Mode Advanced User Technologies for Alternative PNT: M. Bransby, T. Whitworth, L. Mercy, Telespazio UK

2:58 R-Mode – Terrestrial Navigation for Maritime Users: S. Gewies, F. Giacomo Rizzi, L. Grundhöfer, N. Hehenkamp, German Aerospace Center (DLR); M. 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: F. Mistrapau, R. Mihaela Clopot, C-V. Circu, V.G. Olteanu, GMV; I.B. Stefanescu, M. Bivolaru, ROSA RC; L. Dumitrache, P. 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, H. Llorca, GMV; M. Nisi, SISTEMATICA S.p.A; M. Lopez, EUSPA

5:08 Enhancing Global PPP Service Reliability with Hemisphere Atlas (R) and Galileo HAS: A Dual Redundant Approach: J. Chen, V. Duong, A. Kanji, Hemisphere GNSS

Alternate

1. **GNSS and PNT Related Work Within IALA:** J. Alvarez, M. Jeon, IALA

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

Session C2: Trends in GNSS Augmentation Systems

Room: Capitol Ballroom 5-7 (4th Floor)

Deborah Lawrence
Federal Aviation Administration

Dr. Todd Walter
Stanford University

1:50 Brief History of GPS Backward Compatibility (BC) Requirements for Psat & Pconst: K. Kovach, The Aerospace Corporation; C. Miles, U.S. Federal Aviation Administration; K. 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. Mabilleau, E. Canestri, N. Castrillo, European GNSS Agency

2:35 Implementation of the Baseline Advanced RAIM User Algorithm: J. She, K. Misovec, The MITRE Corporation; J. Blanch, Stanford University; N. Cacciopoli, D. Duchet, EUROCONTROL; E. Domínguez Tijero, GMV; F. Liu, FAA; D. Racelis, M. Joerger, Virginia Tech; M. Sgammini, European Commission, Joint Research Centre

2:58 GNSS Signal Anomaly Detection Using DCB Estimates and Machine Learning Algorithms: S. Thoelert, German Aerospace Center (DLR) and RWTH Aachen University; G. Allende-Alba, P. 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: N. Caccioppoli, D. Duchet, A. Lipp, EUROCONTROL

4:23 Evaluating Performance of Ionospheric Anomaly Monitor for DFMC GBAS with Flight Data in Ionospheric Disturbed Conditions: S. Saito, T. Yoshihara, ENRI; T. Murphy, M. Harris, G. Balvedi, Boeing; J. Wichgers, Collins Aerospace; L. Lavik, M. Topland, M. Tuffaha, Indra Navia

4:46 Prototyping Message Authentication on L1 SBAS: T. Sakai, M. Kitamura, and A. Kezuka, National Institute of Maritime, Port and Aviation Technology

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

Alternates

1. **Extensibility of the GBAS VHF Datalink to the Needs of DFMC GBAS:** A. Lipp, D. Duchet, EUROCONTROL; N. Caccioppoli, CNsworks
2. **Wide Area Network (WAN) Connectivity Validation on Installed Sites of Korea Augmentation Satellite System (KASS):** C. Choi, E. Lee, D. Won, Korea Aerospace Research Institute
3. **Evaluation for BDSBAS Ionospheric Grid Augmented by LEO Constellations:** X. Lan, H. Wang, K. Fang, Y. Zhu, Z. Wang, Beihang University
4. **Advanced RAIM for Rail, Maritime and UAS Sectors:** J. Fidalgo, E. Domínguez, A. Cezón, G. Moreno, F. Buendía, J. de Toro, GMV; F. Mistrapau, R. Clopot, GMV-RO; M. Snijders, H. Engwerda, J. Casals, NLR; A. Luciano, K. Callewaert, M. Bolchi, VVA; S. Damy, I. Martini, M. Sgammini, J. P. Boyero, EC
5. **An Approach to Eliminating the Space Discontinuities of Network RTK Corrections:** X. He and Z. Huang, Shanghai Huace Navigation Technology Ltd.

Virtual Only: View at ion.org/gnss

1. **Integrity for Future SBAS Users: Concept and Experimentations:** O. Maliet, J. Antic, S. Trilles, M. Abbal, H. Delfour-Cormier, Thales Alenia Space; M. Dall'orso, N. Giron, G. Buscaret, F. Bauert, C. Lopez de Echazarreta, European Space Agency

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

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

Room: Capitol Ballroom 4 (4th Floor)

Dr. Dorota Grejner-Brzezinska
The Ohio State University

Dr. Zak Kassas
The Ohio State University

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.

Panel Members

1. Karen Van Dyke, Director, Positioning, Navigation, and Timing (PNT) & Spectrum Management, USDOT
2. Dr. Timothy Seitz, Research Team Lead, Transportation Research Center (TRC) Inc.
3. Dr. Eldar Rubinov, Positioning & Geodesy Technical Lead, FrontierSI
4. Dr. Ilaria Martini, Principl Research Engineer, u-blox AG
5. Dr. Clark Taylor, Director, Autonomy & Navigation Technology (ANT) Center, Air Force Institute of Technology

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

Session E2: High Precision and High Integrity Navigation

Room: Mineral Hall D/E (3rd Floor)

Dr. Sriramya Bhamidipati
NASA/JPL

Dr. Jianghui Geng
Wuhan University

1:50 PPP Performance Assessment Setup for Galileo High Accuracy Service: J. Miguez, F. De Oliveira Salgueiro, P. Zoccarato, D. Psychas, E. Galletti, D. Blonski, European Space Agency

2:12 Galileo High Accuracy Service SDR Implementation: C. Q. Alfonso, F. Taylor, D. M. Akos, University of Colorado Boulder

2:35 Accelerated SF-PPP Convergence of BDS-3 B1 Band by Wideband Signal Observations: Y. Qi, Z. Yao, M. Lu, Tsinghua University, and Beijing National Research Center for Information Science and Technology

2:58 Real-Time Precise Orbit and Clock Errors Bounding for High Integrity PPP: Y. Xiao, X. Zhan, Y. Zhai, Shanghai Jiao Tong University

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

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

4:23 Mitigation of Receiver Biases to Derive Ionospheric SSR Corrections for Multi-GNSS PPP-RTK Under High Ionospheric Activity: P. S. de Oliveira Jr., Federal University of Paraná; J. F. Galera Monico, 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: Y. Cha, C. Lim, Y. Lee, Y. Jo, B. Park, Sejong University; J. Song, Suwon University;

5:08 SS-RAIM Based Integrity Architecture for CDGNSS Systems Against Satellite Measurement Faults: D. Min, N. M. Kim, J. Kim, J. Lee, Korea Advanced Institute of Science and Technology, S. Pullen, Stanford University

Alternates

1. **Receiver Bias Estimation Strategy in the Uncombined Triple-Frequency PPP-AR Model:** Y. Liu, Robert Bosch GmbH, Technical University of Munich; U. Hugentobler, B. Duan, Technical University of Munich; N. Mikhaylov, J. Simon, 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**: C. Parra, Technical University of Munich (TUM); A. Schütz, University of the Bundeswehr Munich; U. Hugentobler, TUM; T. Pany, University of the Bundeswehr Munich; S. Baumann, Industrieanlagen-Betriebsgesellschaft mbh (IABG)
4. **Prototyping Integrity Monitors for PPP Corrections:** Y-F. Lai, J. Blanch, T. Walter, E. Kahr, E. Leahy, P. Silva, C. Ellum, Stanford University

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

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

Session F2: Advanced Software and Hardware Technologies for GNSS Receivers

Room: Mineral Hall F/G (3rd Floor)

Dr. Yu (Joy) Jiao
Trimble

Dr. Roohollah Parvizi
Hemisphere GNSS

1:50 Future GNSS Acquisition Strategies and Algorithms: A. Cismaru, N. Spens, D. Akos, University of Colorado Boulder

2:12 Bicomplex Kalman Filter Tracking for GNSS Meta-Signals: D. Borio, European Commission, JRC; M. Susi, Topcon Positioning Systems Inc.

2:35 Weiss-Weinstein Bound of Frequency Error Considering von Mises Distribution as Prior for Very Weak GNSS Signals: X. Zhang, X. Zhan, J. Huang, J. Liu, Y. Xiao, Shanghai Jiao Tong University

2:58 A New GNSS Ambiguity Resolution Method Through Mixed Integer Non-Linear Programming: H. Zhang, W. Wen and L-T. Hsu, The Hong Kong Polytechnic University

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

4:00 Acquisition and Tracking of Starlink LEO Satellite Signals in Low SNR Regime: H. Kanj, S. Kozhaya, and Z.M. Kassas; The Ohio State University

4:23 Configurable Multi-Band GNSS Receiver and Antenna for Robust Handheld Devices: S. Urquijo, F. Garzia, A. Popugaev, A. Rügamer, W. Felber, Fraunhofer Institute for Integrated Circuits IIS

4:46 Fully Reconfigurable Lab-Scale Testbed for Assistance of New Satellite Navigation System Developments: Y-J. Song, B.H. Choi, S. Lee, J-H. Won, Inha University

5:08 In-Situ Calibration of Antenna Arrays for Improved Spatial Signal Processing using In-Space GNSS Signals: T. 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

Alternates

1. **Galileo-SDR-SIM: An Open-Source Tool for Generating Galileo Satellite Signals:** H. Sathaye, M. Motallebighomi, A. Ranganathan, Northeastern University
2. **Development of Kalman Filter-Based Software Receiver for QZSS L6 and Galileo E6-B Signals:** C-W. Wang, S-S. Jan, National Cheng Kung University
3. **Evaluation of Actual Performance of PPP in Urban Areas Using Pocket SDR:** T. Ozeki, N. Kubo, T. Takasu, Tokyo University of Marine Science and Technology; T. Suzuki, Chiba Institute of Technology; T. Ebinuma, Chubu University
4. **Digital Twin Platform for BDS-3 Satellite Navigation Using Digital Twin Intelligent Visualization Technology:** R. Li, P. Wu, J. Zhang, Z. Ren, C. Yang, J. Gan, L. Feng, H. Tong, X. Xiao, Y. Chen, Changsha University

Virtual Only: View at ion.org/gnss

1. **Analysis of Correlation Loss for MBOC Signals:** D. Arora, P. Patidar, ISRO
2. **Dynamic Carrier Tap Selection (DyCaTS): A Novel Approach for GPS M-Code Pull-in:** R.S. Cassel, L. Elentukh, S.D. Miller, The MITRE Corporation
3. **High Order DPLL for High Order Doppler Dynamics Tracking:** S. Roche, Thales Alenia Space France

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

Session A3: PANEL: Extended Reality and PNT

Room: Capitol Ballroom 4 (4th Floor)


Dr. Andrew Hansen
DOT/Volpe-Center


Dr. Sherman Lo
Stanford University

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.

Panel Members

1. Dr. Mahesh Ramachandran, Google
2. Mr. Karl Kovach, Principal Engineer at The Aerospace Corporation

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.

Session B3: Autonomous Applications

Room: Capitol Ballroom 5-7(4th Floor)


Dr. Boubeker Belabbas
Bosch


Mitch Narins
Strategic Synergies LLC

8:35 Supercorrelation for Autonomous Platforms, Providing Increased Accuracy, Sensitivity and Integrity: R. Faragher, P. Esteves, J. Garcia, J. R. van der Merwe, D. Jamal, S. Benmendil, C. Higgins, R. Grey, M. Crockett, Focal Point Positioning Ltd.

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

9:20 Sensor Fusion of Precise GNSS/INS with Lidar Map-Based Localization: D. Rüegg, K. Leung, D. Gumerov, L. Görcke, Trimble Inc.

9:43 Extended Results of Single Epoch Position Bound (SEPB) for High Integrity Automotive Applications: O. Julien, H. Dorahy, C. Hide, u-blox; I. Sheret, Polymath Insight Ltd.

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

10:40 High-Altitude Aircraft Navigation via Radio SLAM with Terrestrial Signals of Opportunity: Z.M. Kassas, The Ohio State University; N. Khairallah, SpaceX; J. Khalife, Univ. of California, Irvine; C. Lee, J. Jurado, S. Wachtel, J. Duede, Z. Hoeffner, T. Hulsey, and R. Quirarte, US Air Force; R.X. Tay, Republic of Singapore Air Force

11:03 Obscuration Modelling for Autonomous Vehicle Operation Using GNSS: M. Pottle, P. Hansen, E. Anyaegbu, J. Bennington, Spirent Communications PLC

11:26 Bounding GPS-Based Positioning and Navigation Uncertainty for Autonomous Drifting via Reachability: A. Wu, A. Mohanty, A. Zaman, G. 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: T. Ulrich, N. El Gemayel and B. Belabbas, Bosch GmbH

Alternates

1. **LDACS APNT Service Area Analysis with Barometric Altimeter Augmentation and Ground Station Selection Constraints:** G. Zampieri, German Aerospace Center (DLR) & RWTH; G. McGraw, Consultant; A. Filip-Dhaubhadel, B. Weaver, O. Osechas, DLR; M. Meurer, DLR & RWTH
2. **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

Virtual Only: View at ion.org/gnss

1. **A Novel Data-Driven Adaptive Robust Filter Based on TCN-ACKF Method for Autonomous Train Localization System:** W. Wang, J. Liu, W. Shangguan, Beijing Jiaotong University
2. **Multi-Sensor Fusion and Real-Time FDE for UGVs Based on Factor Graph Optimization:** J. Xu, H. Wang, Z. Dan, Z. Wang, Y. Zhu, Beihang University

Session C3: Spectrum: Protection and Optimization

Room: Granite (3rd Floor)


Dr. Christophe Macabiau
ENAC


Rick Niles
The MITRE Corporation

8:35 Detecting Space-Based Interference on GNSS Signals Using FFT Observations: A. Patil, R.E. Phelts, S. Lo, T. Walter, Stanford University

8:57 Interference Effects on a Multi-GNSS Receiver on Board of a CubeSat in LEO: A. McKibben, R. McKnight, B.C. Peters, Z. Arnett, and S. Ugazio, Ohio University

9:20 A Test Set for Evaluating GNSS Radio Frequency Interference Monitors: S. Lo, Y. H. Chen, N. R. San Miguel, H. Chinchinian, T. Walter, Stanford University; D. Akos, University of Colorado, Boulder

9:43 U.S. DOT IDM Real World Concepts & Case Comparison: J.S. Aviles, K.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 RNSS in the L6-Band: S. Lee, H-J. Hong and J-H. Won, Inha University

11:03 SDR Receivers Robust to Jamming and Spoofing: From Single Antenna to Multi-Antenna Processing: G. Carrié, C. Gernot, J. Korsakissok, Syntony GNSS

11:26 Staggered Examination of Non-Trusted Receiver Information (SENTRI) Algorithm for Spoofer Detection and Integrity Monitoring in GNSS Receivers: B. Schnaufer, A. Joseph, H. Phan, Collins Aerospace

11:48 No GPS No Problem: Exploiting Cellular OFDM-Based Signals for Accurate Navigation in a GPS-Jammed Environment: Z. M. Kassas, The Ohio State University; A. Abdallah, Univ. of California, Irvine; C. Lee, US Air Force

Alternates

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

Virtual Only: View at ion.org/gnss

1. **An Interference Detection Algorithm for GNSS Frequency-Hopping Signal Based on Multi-Node Collaboration and Multi-Segment Spectral Clustering:** C. Guo, Q. Zhao, University of Electronic Science and Technology of China (UESTC)

Session D3: GNSS Integrity Augmentation

Room: Agate (3rd Floor)


Dr. Michael Felux
Zurich University of Applied Science


Dr. María Caamano Albuerne
German Aerospace Center (DLR)

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: W. da Costa Silva, C. Menezes da Silva, F. T. Linhares de Souza, J. F. Galera Monico, São Paulo State University – UNESP; N. Caccioppoli, EUROCONTROL

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

9:43 Performance Analysis of Orbit and Clock Correction of Wide Area Differential Regional Navigation Satellite System: J. Park, B-G. Kim, C. Kee, Seoul National University; D. Kim, Agency for Defense Development

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

10:40 Approaches to Improve Advanced RAIM Protection Levels: J. Blanch and T. Walter, Stanford University

11:03 Detection and Exclusion of Multiple Faults Using Euclidean Distance Matrices: D. Knowles and G. Gao, Stanford University

11:26 Research on the Impact of DME on the Integrity of BDS B2a Signal: Y. Liu, K. Fang, Z. Dan, Y. Zhu, Z. Wang, 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: Y. Zhang, Y. Jiang, Y. Gao, University of Calgary

Alternates

1. **GBAS for UAV Operations – The Positioning Service, Vertical Integrity and Operational Lessons Learned:** V. Fischer, S. Jochems, M. Jäger, L. Sarperi, M. Felux, Zurich University of Applied Sciences
2. **A Robust Navigation Solution to Enable Safe Autonomous Aerospace Operations:** M. Kaplan, infiniDome
3. **POMELO: A 4G Prototype Testbed to Demonstrate Scalable and Bandwidth Efficient Broadcast of GNSS Corrections:** L. Guerriero, E. Benedetti, L.E. Aguado Bayón, M.L. Ivanovici, GMV; F-C. Grec, European Space Agency (ESA)
4. **Occurrence of Critical Satellites in GAST-D+ Processing:** M. Nietlispach, M. Felux, Zurich University of Applied Sciences

Virtual Only: View at ion.org/gnss

1. **Assessing the Performance of Dual-Frequency Multi-Constellation GBAS Architectures During Periods of Ionospheric Scintillation in Brazil:** C. Menezes da Silva, W. da Costa Silva, F. Tintino Linhares de Souza, J.F. Galera Monico, D. Barroca Marra Alves, São Paulo State University (UNESP); G. Balvedi, T. Murphy, Boeing; S. Saito, ENRI; J. Wichgers, Collins Aerospace
2. **Vailability Assessment of ARAIM FDE With Time-Correlated Error:** J. Du, H. Wang, K. Fang, Y. 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.,

View All Virtual Paper Presentations in the ION GNSS+ Virtual Portal at ion.org/gnss

Session E3a: All-Source Intelligent PNT Methods (8:30 a.m. – 10:05 a.m.)

Room: Capitol Ballroom 1-3 (4th Floor)


Dr. Weisong Wen
The Hong Kong Polytechnic University


Dr. Ryan Watson
The Johns Hopkins University APL

8:35 Improvements to GNSS Positioning in Challenging Environments by 3DMA Lidar Informed Selective Satellites Usage: R. Gilabert, J. Gutierrez, E. Dill, NASA Langley Research Center

8:57 Seamless Navigation for Indoor-Outdoor Positioning Using GNSS-Aided UWB/WiFi/IMU System: A. Siemuri, M. Elsanhoury, K. Selvan, P. Välisuo, H. Kuusniemi, M.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: P. Geragersian, I. Petrunin, W. Guo, Cranfield University; R. Grech, Spirent Communications PLC

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

Alternates

1. **Android GNSS/INS Using Complementary Filter:** D-K. Lee, J. Yun, E. Gattis, D. Akos, B. Park, University of Colorado
2. **Exploring the Benefits of Deep Learning-Based Sensors Error Estimation for Improved Attitude and Position Accuracy:** E. Mounier, Queen's Univ., Ain Shams Univ.; P. R. Marques de Araujo, Queen's Univ.; M. Elhabiby, Micro Engineering Tech Inc.; M. Korenberg, Queen's Univ.; A. Noureldin, Royal Military College, Queen's Univ.

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

Session E3c: LEO for Positioning, Navigation, and Timing (10:35 a.m. – 12:15 p.m.)

Room: Capitol Ballroom 1-3 (4th Floor)


Dr. Kazuma Gunning
Xona Space Systems


Dr. Kirsten Strandjord
University of Minnesota

10:40 Signal Simulator for Starlink Ku-Band Downlink: Z. M. Komodromos, W. Qin, T. E. Humphreys, The University of Texas at Austin

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

11:26 Evaluation of Orbit Errors and Measurement Corrections in Differential Navigation with LEO Satellites: J. Saroufim, S. Hayek, Z.M. Kassas, The Ohio State University

11:48 An Agile, Portable, Antenna System for LEO Megaconstellation-Based PNT: W. Qin, Z. M. Komodromos, T. E. Humphreys, Univ. of Texas at Austin

Alternate

1. **Performance Analysis of LEO Multi-Constellation Aided GNSS Positioning under Weak Signals Environments:** Y-X. Yang, S-S. Jan, National Cheng Kung University

Virtual Only: View at ion.org/gnss

1. **Custom GNSS Signal Simulator for LEO GNSS Augmentation System:** M. Abduljawad, United Arab Emirates University; A.M. Hasbi, National Space Science and Technology Center; J-I. Issler, CNES
2. **Time Delay of Arrival Based Orbit (TDOA) Determination of Geosynchronous Signals of Opportunity (SoOp):** S.S. Subramanyam, J.L. Garrison, Purdue University; P. Smith, Y. Zhang, C.K. Shum, The Ohio State University

Session E3b: High Precision GNSS Positioning in Challenging Environments

Room: Mineral Hall F/G (3rd Floor)


Dr. YuXiang (Phillip) Peng
Qualcomm Technologies Inc.


Dr. Michael Fu
Google

8:35 Resilient High Precision Positioning Using RTK and Distributed GNSS Antenna Subarrays: C. Özmaden, M. Brachvogel, Chair of Navigation, RWTH Aachen University; T. Bamberg, Chair of Navigation, RWTH Aachen University & German Aerospace Center (DLR); M. Niestroj, Chair of Navigation, RWTH Aachen University; M. Meurer, Chair of Navigation, RWTH Aachen University & DLR

8:57 All-Frequency GNSS PPP-RTK Using Observable-Specific Signal Biases for Urban Environments: F. Wang, K. Zhang, Wuhan University

9:20 Towards GNSS Ambiguity Resolution for Smartphones in Realistic Environments: Characterization of Smartphone Ambiguities with RTK, PPP, and PPP-RTK: J. Hu, York University; P. Li, Chang'an University; S. Bisnath, York University

9:43 Testing the Galileo High Accuracy Service in Different Operational Scenarios: L. Cucchi, S. Damy, C. Gioia, B. Motella, M. 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: N. Green, Coherent Technical Services, Inc.

11:03 Validation of RTK and PPK Solutions Assisted with Random Sample Consensus: Z. Zhu, C. Dickerson, A. Hindi, East Carolina University; E. Vinande and J. Pontious, Air Force Research Lab

11:26 Precise Positioning of Smartphones Using a Robust Adaptive Kalman Filter: A. Raghuvanshi, S. Vana, S. Bisnath, York University

11:48 Differentiable Factor Graph Optimization with Intelligent Covariance Adaptation for Accurate Smartphone Positioning: P. Xu, H-F. Ng, Y. Zhong, G. Zhang, W. Wen, L-T. Hsu, The Hong Kong Polytechnic University

Alternates

1. **Analysis of Smartphone Based Dynamic User RTK Performance Using Portable RF Shielded Box:** B-G. Kim, C. Kee, Seoul National University
2. **Map-Aided Particle Filter for Improved Multi-Hypothesis Ambiguity Resolution:** R. Manzano-Islas, K. O'Keefe, University of Calgary

Virtual Only: View at ion.org/gnss

1. **Robust Regional Ionospheric Augmentation Based on IRIM for PPP-RTK:** S. Lyu, Y. Xiang and W. 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.

Blue Text: Student Paper Award Winner

Session F3: Lunar Positioning, Navigation, and Timing 1

Room: Mineral Hall D/E (3rd Floor)


Dr. Cosimo Stallo
Thales Alenia Space


Dr. Angela Stickle
Johns Hopkins University APL Civil Space

8:35 NavCube3-mini Lunar GNSS Receiver: M. A. Hassouneh, D. Midkiff, L. M.B. Winternitz, S. R. Price, L. Thomas, D. Hatke, NASA; T. Lee, W. Bamford, Emergent Space Technologies; J. W. Mitchell, NASA

8:57 Multi-Sensor Fusion for Improved Navigation in Lunar Landing Missions: G. Tomasicchio, L. Andolfi, M. Brancati, A. Maria Di Donna, Telespazio S.p.A; R. Del Prete, A. Renga, M. Grassi, L. Ostrogovich, University of Naples Federico II; M. Ceresoli, M. Lavagna, Politecnico di Milano; S. Giannattasio, University of Rome – La Sapienza

9:20 LunaNet Navigation Services and Signal, Enabling the Future of Lunar Exploration: P. Giordano, R. Swinden, ESA; C. Gramling, J. Crenshaw, NASA; J. Ventura-Traveset, ESA

9:43 Lunar South Pole Region Navigation Using Lunar Navigation Satellite System: M. Murata, K. Akiyama, and N. Satoh, Japan Aerospace Exploration Agency

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

10:40 Early Artemis Surface Navigation: Challenges, Approaches, and Opportunities: E. Anzalone, NASA/MSFC; L. Carpenter, NASA/LARC; C. Gramling, L. Mann, NASA/GSFC; T. Moody, NASA/JSC

11:03 Development of a Lunar Surface Navigation Pseudolite Testbed: B. Wallace, S. Palo, P. Axelrad, J. Marino, N. Rainville, R. Kingsbury, J. Ditomas, University of Colorado Boulder; D. Ogbe, M. Shihabi, Jet Propulsion Laboratory

11:26 Cooperative DGNSS Positioning in Space: Application Based on NaviMoon Receiver Measurements: A. Delépaut, A. Minetto, F. Dovis, Politecnico di Torino; P. Giordano, European Space Agency

11:48 Satellite Ephemeris Approximation Methods to Support Lunar Positioning, Navigation, and Timing Services: M. Cortinovis, K. Iiyama, G. Gao, Stanford University

Alternates

1. **Future SSV for the Moon and Beyond:** S. Corvo, F. Paggi, E. E. Zini, C. Cristodaro, Thales Alenia Space Italy
2. **Performance Analysis of an Extended Lunar Radio Navigation System:** C. Stallo, M. Carosi, L. De Leo, D. Musacchio, M. Cappa, TAS-I; H. Boomkamp, TPZ-G
3. **Moon Navigation: Development of a Moon RFCS and Preliminary Concept of a Moon Station:** M. Nardini, S. Garlaschi, M. Rotoloni, L. Canzian, A. Dalla Chiara, Qascom
4. **Using HEO Spacecraft Data to Investigate Navigating Cis Lunar Space:** F. Cornish, K. Strandjord, University of Colorado Boulder
5. **Lunar Navigation - Where do we go From Here?:** J. Ware, N. Bickus, Lockheed Martin Space
6. **Identifying the Technical and Economic Challenges of Position, Navigation, and Timing in a Lunar Environment:** D. Mortensen, S. Withee, Johns Hopkins University/APL

Virtual Only: View at ion.org/gnss

1. **Analysis of PNT Algorithms and Related Performance for Lunar Navigation Service Users:** F. Rodriguez, A. Martinelli, L. Spazzacampagna, C. Albanese, Telespazio SpA; G. B. Palmerini, M. Sabatini, Sapienza Università 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.

Session A4: Positioning Technologies and Machine Learning

Room: Capitol Ballroom 1-3 (4th Floor)

Dr. Diana Fontanella
AirBus Defence and Space

Dr. Naser El-Sheimy
University of Calgary

1:50 High-Solar Activity Ionospheric Modelling Using Machine Learning: A Comparison Against Classical Models: S. Priyadarshi, W. P. Syam, A. A. García Roqué, D. Payne, A. Pérez Conesa, GMV; G. Buscarlet, R. Orús Pérez, M. Dall'Orso, European Space Agency (ESA)

2:12 Assessing Machine Learning Approach for GNSS Satellite Orbit Prediction: K. Selvan, A. Siemuri, F.S. Prol, P. Välisuo, H. Kuusniemi, University of Vaasa

2:35 Ionosphere VTEC Map Forecasting Based on Graph Neural Network with Transformers: R. Liu, Y. Jiang, The Hong Kong Polytechnic University

2:58 A Deep Learning Approach for a Real-Time Ionospheric Delay Forecasting Map System: A. L.A. Silva, M. S. Freitas, Instituto Tecnológico de Aeronáutica (ITA); C. Faria Jr., Universidade Estadual Paulista; P. R.P. Silva, ITA; A. O. Moraes, Instituto de Aeronáutica e Espaço; B. C. Vani, Instituto Federal de Educação, Ciência e Tecnologia de São Paulo; J. Sousasantos, The University of Texas at Dallas; J. F.G. Monico, Univ. Estadual Paulista

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

4:00 Transformer Deep Learning for Real-Time Precise Orbit Corrections: W. P. Syam, S. Priyadarshi, A. A. García Roqué, D. Payne, A. Pérez Conesa, GMV; G. Buscarlet, M. 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: L-H. Chu, Y-L. Lo, Y-C. Lin, S-X. Yang, AIROHA Technology

4:46 Tightly Coupled Graph Neural Network and Kalman Filter for Improving Smartphone GNSS Positioning: A. Mohanty and G. 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: S. Li, Robert Bosch GmbH and Bundeswehr University Munich; M. Mikhaylov, ITMO University; N. Mikhaylov, R. Bosch GmbH; T. Pany, M. Bochkati, Bundeswehr Univ. Munich

Alternates

1. **Inter-System Bias Estimation Using the MAFA Method:** D. Kwasniak, S. Cellmer, The University of Warmia and Mazury in Olsztyn
2. **GSSC Now: Data-Centric Digital Platform to Boost Exploitation of GNSS Science Opportunities: V. Navarro**, ESA; S. del Rio, L. Mendes, J. Prados, E. Fraile, RHEA for ESA; M. del Mar Millán, A. Messina, M. Barragán, M. Castro, GMV; J. Ventura-Traveset, ESA

Virtual Only: View at ion.org/gnss

1. **A Machine Learning-Based Approach for Correcting Cooperative DGNSS Differential Corrections:** G. Zeng, H. Zhao, C. Zhuang, S. Hu, Beihang Univ.
2. **A Robust RF Fingerprint Extraction Scheme for GNSS Spoofing Detection:** C. Guo and Z. Yang, University of Electronic Science and Technology of China
3. **Effectiveness of Neural Network Approaches for the Acquisition of Non-Periodic Spreading Codes:** M. Trombini, D. Leone, A. Bruno, M. D'Addezio, G. Falco, E. Falletti, Leonardo S.p.A.
4. **Efficient Graph Neural Network driven Recurrent Reinforcement Learning for GNSS Position Correction:** H. Zhao, J. Tang, Z. Li, Z. Wu, Guangdong University of Technology; S. Xie, Guangdong Key Laboratory of IoT Information Technology; Z. Wu, Techtotop Microelectronics Technology Co. Ltd.; M. Liu, Hong Kong University of Science and Technology; B. T.G.S. Kumara, Sabaragamuwa University of Sri Lanka
5. **Incremental Learning for LOS/NLOS Classification of Global Navigation Satellite System:** Y. Sun, S. Li, Z. Deng, Beijing University of Posts and Telecommunications

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

Room: Capitol Ballroom 4 (4th Floor)

Dr. Tyler Reid
Xona Space Systems

Marcus Graf von Wilamowitz
u-blox

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

Session C4: Trends in Future Satellite Nav Technology, System Design and Development

Room: Granite (3rd Floor)

Dr. Takeyasu Sakai
National Institute of Maritime, Port and Aviation Technology

Dr. Sophie Damy
European Commission JRC

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, F. Melman, C. Vazquez, J. Hahn, G. Lopez-Risueno, European Space Agency; M. Paonni, EC/JRC; M. Caparrini, EUSPA

2:35 Preliminary Evaluation of Galileo ACAS Using Existing E1-E6 Open Signals and a Low-Cost SDR Platform: R. Terris-Gallego, J.A. López-Salcedo, G. Seco-Granados, Universidad Autonoma de Barcelona/IEEC; I. Fernandez-Hernandez, European Commission

2:58 Internet-Based GNSS Signal Authentication: D. Manandhar, 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: J. Critchley-Marrows, The University of Sydney; Q. Verspieren, The University of Tokyo

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

4:46 A GNSS-Synchronized Satellite Navigation Payload for LEO PNT: F. Kunzi, B. Braun, M. Markgraf, O. Montenbruck, German Aerospace Center (DLR)/GSOC

5:08 GNSS Augmentation by Low-Earth-Orbit (LEO) Satellites: Integrity Performance Under Non-Ideal Conditions: S. Pullen, S. Lo, S. Oak, I. Colobong, J. Blanch, T. Walter, Stanford University; M. Crews and R. Jackson, Lockheed Martin

Alternates

1. **Increasing the Resilience of Multi-Constellation Multi-Frequency Mass Market Receiver by Taking Advantage of Galileo OSNMA:** J. Zamora, M. Rouseti, C. Schmid, u-blox AG
2. **Assessment of Galileo High Accuracy Service (HAS) Using the Galileo High Accuracy Reference Algorithm and User Terminal (HAUT):** E. González, P. Pintor, A. Senado, N. Dhital, Spaceopal GmbH; S. Lagrasta, J. de Blas, EUSPA
3. **EGNOS V3 Single Frequency and Dual Frequency Multi Constellation – Preliminary Performances:** R. Braun, Airbus Defence & Space Gmbh; M. Boyer, Airbus Defence & Space SAS; M. Dall'Orso, N. Giron, C. López de Echazarreta, EGNOS Project Office - ESA

Virtual Only: View at ion.org/gnss

1. **Considerations in SSR Corrections Format Design:** S. Vana, V. Bellad, Rx Networks Inc.; G. Zhou, TruePoint Technology Inc.

Session D4: Indoor and Urban Navigation and Mapping

Room: Capitol Ballroom 5-7 (4th Floor)

Stefan Wallner
European Space Agency

Irma Rodríguez Pérez
GMV

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

2:12 Attitude Determination in Urban Canyons: A Synergy Between GNSS and 5G/6G Observations: P. Zheng, X. Liu, T. Ballal, and T. 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: J. Liu, C. Chi, X. Zhan, and X. Zhang, Shanghai Jiao Tong University

2:58 Neural City Maps: A Case for 3D Urban Environment Representations Based on Radiance Fields: M. Partha, S. Gupta, G. 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: Y. Takayama, FURUNO ELECTRIC CO., Ltd.; T. Urakubo, H. Tamaki, Kobe University

4:23 Indoor Mapping Structure Based on Cloud Platform for Seamless and Effective Indoor Localization: T. Kim, KIST & Korea University; B. Shin, KIST; C. G. Kang, Korea University; D. Shin, C. Yu, TJ LABS Corp.; H. Kyung, T. Lee, KIST & TJ LABS Corp.

4:46 RSS Signal Modeling-Based Rapid and Accurate Fingerprinting Database Construction of Indoor Localization Technology: J.H. Lee, Electronics and Telecommunications Research Institute (ETRI); T. Kim, Korea Institute of Science and Technology (KIST); Y. Cho, J. Jeon, K. Han, ETRI; T. Lee, KIST

5:08 Neural Network-Based Multipath Mitigation Method for Precise Indoor Positioning: M-J. Kim, K-H. Kim, O-J. Kim, Sejong University

Alternates

1. **Positioning in the GNSS Signal Disconnection Area Based on Multiple Pseudolites:** S. Song, J. Moon, J. Lee, D. Kim, NGII
2. **Building Update Monitoring with Sky Pointing Images and GNSS Measurements:** H-S. Xu, G. Zhang, L-T. Hsu, The Hong Kong Polytechnic University

Virtual Only: View at ion.org/gnss

1. **Tightly Coupled GNSS/INS Integration Accurate Location Algorithm Under Urban Canyons Based on Factor Graph Optimization:** Y. Sun, Q. Li, Z. Deng, Beijing University of Posts and Telecommunications

Blue Text: Student Paper Award Winner

Session E4: GNSS Navigation in Challenging Environments

Room: Mineral Hall D/E (3rd Floor)


Dr. Nesreen Ziedan
Zagazig University


Dr. Paul Groves
University College London

1:50 Extending 3DMA GNSS with Diffraction Features in Urban Areas: Feasibility Analysis and Preliminary Results: G. Zhang, D. Hai, H-F. Ng, and L-T. Hsu, The Hong Kong Polytechnic University

2:12 3D Mapping Aided GNSS Positioning Using Doppler Frequency for Urban Areas: L. Zhang, H-F. Ng, G. Zhang, and L-T. Hsu, The Hong Kong Polytechnic University

2:35 Experimental Investigation of GNSS Direct Position Estimation in Densely Urban Area: S. Vicenzo, B. Xu, L-T. Hsu, The Hong Kong Polytechnic University; A. Dey, Birla Institute of Technology and Science

2:58 GNSS Multi-Frequency Combined Direct Position Estimation in the Urban Canyon Environment: J. Huang, R. Yang, X. Zhan, Shanghai Jiao Tong University

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

4:00 Effect of Signal Quantization on Robust Anti-Jamming in Snapshot Receivers: H. Calatrava, Northeastern University; A Gusi-Amigó, Albora Technologies; F Melman, European Space Agency (ESA/ESTEC); P. Closas, Northeastern University

4:23 Normalized Bandwidth Control Algorithm for Robust GNSS Adaptive Tracking: I. Cortés, F. Garzia, N. Conde, Fraunhofer IIS; E.S. Lohan, J. Nurmi, Tampere University; W. Felber, Fraunhofer IIS

4:46 Improving Tracking Robustness Through Interference Using Pilot Signals with a Deeply Coupled Estimator: L. Bednarz, S. Khanafseh, B. Pervan, Illinois Institute of Technology

5:08 Time-Differenced Carrier Phase Based Integrity Monitoring for Urban Air Mobility Using 3D City Model: H. Jeong, C. Kee, Seoul National University; J. Song, University of Suwon; J. Kim, Samsung Electronics System LSI

Alternates

1. **Hopular-Based GNSS Signal Reception Classification Algorithm with Optimal Feature Selection and Environmental Pattern Recognition:** Z. Zhou, H. Yang, University of Calgary
2. **Towards Accurate GNSS Receiver Clock Calibration: Robust Wavelet Variance-Based Stochastic Analysis of Instantaneous Code Phase-Based Oscillator Instability**: C. Minaretzis, Y. Luo, University of Calgary; S. Guerrier, University of Geneva; N. El-Sheimy, M. Sideris, University of Calgary
3. **Evaluating GNSS Ray Tracing Performance in Urban Canyons:** P. Xie, OpenLoopNav Inc.
4. **Data Interpolation Method for 3D City Modeling to Aid Satellite Navigation:** E. Mc Cabe, K. Strandjord, C. Graney-Dolan, University of Minnesota

Virtual Only: View at ion.org/gnss

1. **A Solution Separation Algorithm for Velocity Estimation in Rail and Road Applications:** M. Brizzi, Roma Tre University; A. Neri, Roma Tre University & RADIOLABS; F. Rispoli, RADIOLABS
2. **Features Effectiveness Verification Using Machine-Learning-Based GNSS NLOS Signal Detection in Urban Canyon Environment:** N. Yin, D. He, Y. Xiang, Shanghai Jiao Tong University; F. Zhu, Guangdong Communications & Networks Institute; W. Yu, Shanghai Jiao Tong University
3. **GNSS Positioning using Cost Function Regulated Triangulation and Graph Neural Networks:** A. Jalalirad, D. Belli, B. Major, Qualcomm AI Research; S. Jee, H. Shah, W. Morrison, Qualcomm Technologies, Inc.

Session F4a: GNSS Robustness to Vulnerabilities 1

Room: Mineral Hall F/G (3rd Floor)


Dr. Anna B. O. Jensen
Swedish Maritime Administration


Jason Anderson
Stanford University

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

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

2:35 Hybrid Autoencoder for Interference Detection in Raw GNSS Observations: K. Mascher, S. Laller, P. Berglez, Graz University of Technology

2:58 A Satellite-Based Two-Way Ranging Protocol for GNSS Positioning Authentication and Time Transfer: F. Rozzi, L. Canzian, O. Pozzobon, Qascom; R. Jamal, M. Espinasse, Thales Alenia Space France; N. Laurenti, Università degli Studi di Padova; G. Caparra, ESA

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: T. Hammarberg, J. M. Vallet Garcia, J. Alanko, M. Zahidul H. Bhuiyan, Finnish Geospatial Research Institute

4:23 GPS Spoofing Detection and Exclusion by DCCAF with INS Aiding: S. Ahmed, S. Khanafseh, B. Pervan, Illinois Institute of Technology

4:46 Blind Spoofer Detection and Mitigation using an Array of Spatially Distributed Subarrays: M. Brachvogel, M. Niestroj, C. Özmaden, Chair of Navigation, RWTH Aachen University; T. Bamberg, M. Meurer, Chair of Navigation, RWTH Aachen University, & German Aerospace Center (DLR)

5:08 Fault-Robust GPS Spoofing Mitigation with Expectation-Maximization: A. V. Kanhere and G. Gao, Stanford University

Alternates

1. **Testing a Coherent Software Defined Radio Platform for Detection of Angle of Arrival of RF Signals:** L. Trapani, T. Taylor, E. Gattis, Univ. of Colorado Boulder; Y. Chen, S. Lo, T. Walter, Stanford Univ.; D. Akos, Univ. of Colorado Boulder & Stanford Univ.
2. **Advantages of a Robust Multi-Antenna GNSS Receiver in UAV Flight Jamming Scenarios:** P. Rudnik, L. Kurz, A. Winterstein and M. Cuntz, German Aerospace Center (DLR)
3. **Multi-Frequency, Multi-Constellation INS-Assisted GNSS for Improved Navigation Under Jamming Conditions:** A. Elmezayen, Royal Military College of Canada (RMCC), Tanta Univ.; H. Elghamrawy, M. Karaim, RMCC; A. Noureldin, RMCC, and Queen's Univ.
4. **On the Parameterization of Single Pole Adaptive Notch Filter Against a Wide Range of Linear Chirp Interference:** S. A. Kazim, J. Marais, N. 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:** I. Ebrahimi M., A. Minetto, and F. Dovis, Politecnico di Torino

Virtual Only: View at ion.org/gnss

1. **A Modified Sparse Bayesian Learning Method for High-Accuracy DOA Estimation with TCN Under Array Imperfection:** Y. Jin, D. He, Shanghai Jiao Tong Univ.; S. Wei, Shanghai Normal Univ.; L. Tian, Shanghai Jiao Tong Univ.; F. Zhu, Communications & Networks Institute; W. Yu, Shanghai Jiao Tong University; Z. Xiao, University of Electronic Science and Technology of China
2. **Novel Replay Attacks Against Galileo Open Service Navigation Message Authentication:** H. Wang, Y. Zhang, Xidian University; J. Zhu, Toyo University; Y. Chen, Reitaku University; Y. Shen, Xidian University; X. Jiang, Future University Hakodate

Session F4b: Atmospheric Effects on GNSS

Room: Agate (3rd Floor)


Dr. Susan Skone
University of Calgary


Dr. Endawoke Yizengaw
The Aerospace Corporation

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

2:12 Connection between Stratospheric Gravity Waves, Mesospheric Winds and Traveling Ionospheric Disturbances: S. Derghazarian, L. P. Goncharenko, S-R. Zhang, A. J. Coster, MIT Haystack Observatory; V. L. Harvey, C. Randall, University of Colorado Boulder

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

2:58 Ionosphere TEC Observation Over Ocean Using Single-Frequency Wideband GNSS Signal Reflectometry: Y. Wang, 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: S. Krishnamoorthy, L. Martire, Jet Propulsion Laboratory (JPL), California Institute of Technology (Caltech); F. Luhrmann, J. Park, Oregon State University; A. Komjathy, B. Szilágyi, L. Romans, P. Vergados, JPL, Caltech

4:23 Comparative Study of the Equatorial Plasma Bubbles Using VHF Radar Images and Spatial ROTI Maps at Low-Latitude Region: N. Tongkasem, L. M.M. Myint, P. Supnithi, King Mongkut's Institute of Technology Ladkrabang; K. Hozumi, M. Nishioka, National Institute of Information and Communications Technology

4:46 Effects of Equatorial Plasma Bubbles over Real-Time Kinematic Positioning in Low-Latitude Region: P. C Thu, P. Supnithi, L. M. M. Myint, J. Budtho, King Mongkut's Institute of Technology Ladkrabang; S. Saito, National Institute of Maritime, Port and Aviation Technology

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

Alternates

1. **Transient Intermediate-Scale Irregularities and GPS Scintillation Associated with Mid-Latitude Trough:** S. Mrak, University of Colorado Boulder
2. **Analysis of an Ionospheric Free Dual Frequency Vector Tracking GPS L1/L5 Software Defined Radio:** C. Anderson Givhan, S. Martin, Auburn University
3. **Reporting Abnormally High Amplitude Scintillation with GLONASS L1 During Low Solar Activity:** M. M. Shaikh, A. M. Darya, I. Fernini, University of Sharjah

Virtual Only: View at ion.org/gnss

1. **Comparison of Global TEC Prediction Performance with Two Deep Learning Frameworks:** K. Yang, Beihang University; Y. Liu, Beihang University, Marconi Lab, Science, Abdus Salam International Centre for Theoretical Physics
2. **Comparison of Ionospheric Responses in America Induced by two Different Geomagnetic Storms in 2015:** Y. Liu, Beihang Univ., Marconi Lab, Science, Abdus Salam International Centre for Theoretical Physics; K. Yang, Beihang University
3. **Non-Isotropic Definition and Characterization of GNSS Tropospheric Delay Based on IGGIII:** H. Zhou, Y. Xu, Z. Yang, Shandong University of Science and Technology

Blue Text: Student Paper Award Winner

Session A5a: BeiDou - The Next Generation (8:30 a.m. – 10:05 a.m.)

Room: Mineral Hall F/G (3rd Floor)

Dr. Xiaochun Lu
CSNO/National Time Service Center, Chinese Academy of Sciences (NTSC, CAS)

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

8:57 Communication and Navigation Integration: H. Zhao and F. Ma, Chinese Academy of Space Technology

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

9:43 Time and Frequency System: S. Zhang, J. Han, S. Gao, National Time Service Center, Chinese Academy of Sciences

10:05-10:35, Break. Refreshments in Foyer

Session A5b: Harsh Urban and Indoor GNSS (10:35 a.m. – 12:15 p.m.)

Room: Mineral Hall F/G (3rd Floor)

Dr. Thomas Powell
The Aerospace Corporation

Dr. Nacer Naciri
Jet Propulsion Laboratory

10:40 A Feasibility Study on 3DMA GNSS in GNSS Accessible Indoor Areas: H-F. Ng, G. Zhang, The Hong Kong Polytechnic University; J-R. Rizzo, New York University; L-T. Hsu, The Hong Kong Polytechnic University

11:03 Synergistic Fusion of GNSS Multipath Map and CMC-Based Multipath Estimation for Enhanced GNSS Positioning in Urban Canyon: Y. Lee, B. Park, Sejong University

11:26 Towards Integrity Monitoring of GNSS Velocity Estimates in Urban Environment: D. Kulemann, S. Schön, Leibniz University Hannover

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

Alternates

1. **On the Impact of Co-Op Tracking on Multi-Frequency GNSS Synthetic Aperture Processing:** J. Dampf, M. Bochkati, T. Pany, University of the Bundeswehr Munich
2. **Benefits of CNN-Based Multipath Detection for Robust GNSS Positioning:** A. Guillard, 3D Aerospace / ENAC; P. Thevenon, C. Milner and C. Macabiau, ENAC

Virtual Only: View at ion.org/gnss

1. **Crowdsourcing Radar Maps with AUTO's Integration of Multiple Imaging Radars and INS/GNSS for Autonomous Applications:** A. Ali, D. Krupity, N. Giustini, H. Duan, J. Georgy, and C. Goodall, TDK Trusted Positioning Inc.
2. **Improving Prediction of GNSS Satellite Visibility in Urban Canyon Based on Graph Transformer:** S. Zheng, Z. Li, Guangdong Univ. of Technology; Q. Wang, Techtotop Microelectronics Technology Co. Ltd.; X. Kan, Guangdong Univ. of Technology; M. Liu, Hong Kong Univ. of Science and Technology; S. Xie, Guangdong Univ. of Technology; M. Polycarpou, Univ. of Cyprus

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

Session B5: Land-Based Applications

Room: Capitol Ballroom 5-7 (4th Floor)

Ed Olson
John Deere

Tara Mina
Stanford University

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: C. Gioia, Independent Researcher; D. Borio, European Commission, Joint Research Centre

9:20 Commercial Satellite Navigation Architecture, Trades, & Roadmap: K. Zimmerman, S. Banville, B. Chan, K. Gunning, B. Manning, T. Marathe, A. Neish, A. Perkins, A. Sibois, T. G. R. Reid, Xona Space Systems

9:43 An ASIC-Based Receiver of PULSAR Low-Earth Orbit PNT Demonstration Signals: W. De Wilde, J-M. Sleewaegen, S. De Bast, F. Boon, B. Bougard, Septentrio NV

10:05-10:35, Break. Refreshments in Foyer

10:40 ITHACA: A Feasibility Study of a Potential Integrity Service Complementing European GNSS (EGNSS) High Accuracy: A. González Sainz, H.S. Martinez 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: P. Xu, M. Noizet, Université de Technologie de Compiègne, CNRS; L. Vilalta, Idneo; J. Ibañez-Guzmán, E. Stawiarski, Renault; P. Nemry, Septentrio; S. Y. Voon, Artisense; W. Fox, K. Callewaert, VVA

11:26 Cloud Centric Architecture for Precise Positioning in Automotive Industry: T. Höijer, HERE Technologies; L. Mussot, Orange Innovation; M. Desaeger, Toyota Motor Europe NV/SA

11:48 Multipath Estimation of Dynamic Users in Urban Environment Using Time Differential Code-Minus-Carrier: Y. Bae, H. Jeong, C. Kee, Seoul National University; J. Kim, Samsung Electronics System LSI; O-J. Kim, Sejong University

Alternates

1. **Real Time Sensor Based Spoofing Detection and Mitigation for Mass Market Automotive GNSS Receivers:** E. Moncasi and A. Somieski, u-blox AG
2. **PPP-RTK Supporting Low-Cost Inertial Navigation System for Land Vehicle Navigation:** M. Cutugno, University of Benevento Giustino Fortunato; U. Robustelli, University of Naples Parthenope; G. Pugliano, Univ. of Naples Federico II
3. **AIPLAN (Artificial Intelligence for Land Planning):** S. Roberts, P. Bhatia, C. Hill, Geospatial Ventures Ltd.; C. Hancock, University of Loughborough
4. **Galileo OSNMA-Enabled MediaTek GNSS Solution:** W-C. Shih, H-W. Chen, A. Chou and P-H. Jau, MediaTek Inc.
5. **SBTides – A Modular Tool for Modeling Viscoelastic Solid Body Tides in Python:** W. J. Durkin, C. Davis, The MITRE Corporation

Virtual Only: View at ion.org/gnss

1. **A Real-Time Clock Offset Datum Maintenance Method Based on Short-Term Clock Offset Prediction:** J. Cheng, X. Liu, H. Li, N. Li, and W. Peng, Harbin Engineering University
2. **Improving the Railway Through a European GNSS Based Safety Service:** J. Vuillaume, Z. El Aissaoui, E. Lakour, F. Piednoir, P. Church, J-B. Schomann, S. Placzek, V. Huzurbazar, Egis; M. Hutchinson, G. Moreno Lopez, GMV; H. Delfour-Cormier, C. Rénaze, TAS; J. Ostolaza, S. Porfili, E. Canestri, G. De Pasquale, D. Lopour, EUSPA

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

Session C5: GNSS Applications in Space

Room: Capitol Ballroom 1-3 (4th Floor)

Joel Parker
NASA

Dr. Oliver Montenbruck
German Aerospace Center (DLR)

8:35 Characterization of Multi-GNSS Receiver Biases and Their Temperature-Induced Variations in LEO: Z. Arnett, B. C. Peters, R. McKnight and S. Ugazio, Ohio University

8:57 Single Frequency RTK Relative Navigation for Autonomous Formation Flying Mission of SNUGLITE-III CubeSat: H. Shim, Y. Bae, J. W. Hwang, C. Kee, Seoul National University

9:20 Plasmaspheric Correction with Global Core Plasma Model (GCPM) for GPS-Based GEO Precise Orbit Determination: T. Matsumoto, T. Sakamoto, A. Nakajima, K. Hamada, and S. Nakamura, Japan Aerospace Exploration Agency

9:43 NAVIMOON: Performance and Characteristics of GNSS Spaceborne Receiver in Representative Lunar Orbit: P. Giordano, ESA; M. Scotti, SpacePNT; B. Kieniewicz, EECL; A. Delepaut, Politecnico di Torino; R. Swinden, ESA; C. Botteron, SpacePNT; J. Ventura-Traveset, ESA

10:05-10:35, Break. Refreshments in Foyer

10:40 LuPNT: Open-Souce Simulator for Lunar Positioning, Navigation, and Timing: K. Iiyama, G. Casadesus Vila, and G. Gao, Stanford University

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

11:26 Exploring the Use of GNSS Beyond the Moon: B. C. Peters, R. McKnight, Z. Arnett, S. Ugazio, M. Braasch, Ohio University

11:48 Improving GNSS Navigation Messages Performance Using Inter Satellite Links Technology: M. Laurenti, P. Roldan, J. Anton, P. Guerin, S. Trilles, L. Maisonobe, Thales Alenia Space

Virtual Only: View at ion.org/gnss

1. **A Pre- and Post-Correlation Comparative Analysis to Assess Resilience Against Jamming for GNSS Space Receivers:** S. Bandagadde Umesha, C. Maia, M. Bochkati, J. Dampf, T. Pany, University of the Bundeswehr Munich

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

View Virtual Paper Presentations for all sessions in the ION GNSS+ Virtual Portal at ion.org/gnss

Session D5: Navigation Using Environmental Features

Room: Agate (3rd Floor)


Dr. Clark Taylor
Air Force Institute of Technology


Dr. Zhen Zhu
East Carolina University

8:35 ME4VIO: Manifold Encapsulation for Visual Inertial Odometry with Application to Vehicle Navigation in Urban Environments: S.I. Kaoud Abdelaziz, S. Givigi, Queen's University; M. Elhabiby, Micro Engineering Tech Inc.; A. 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: S-H. Tsao, National Cheng Kung University

9:20 Performance Evaluation of Image-Aided Navigation in GNSS-Challenged Environments with Deep-Learning Local Features: L. Morelli, 3D Optical Metrology (3DOM) & University of Trento; F. Menna, 3DOM; A. Vitti, University of Trento; F. Remondino, 3DOM; C. Toth, The Ohio State University

9:43 Tightly Integrated Smartphone GNSS and Visual Odometry for Enhanced Urban Pedestrian Positioning: Y. Jiang, Y. Zhang, Z. Lyu, S. Guo, Y. Gao, University of Calgary

10:05-10:35, Break. Refreshments in Foyer

10:40 Neural City Maps for GNSS NLOS Prediction: D. Neamati, S. Gupta, M. Partha, A. Mohanty, and G. Gao, Stanford University

11:03 Trusted Inertial Terrain-Aided Navigation (TITAN): T. Haydon, Sandia National Labs; T. Humphreys, The University of Texas at Austin

11:26 Tightly Integrated Map Based Train Localization: A. Wenz, S. Ohrendorf-Weiss, Swiss Federal Railways

11:48 Ephemeris Error Modeling in Opportunistic LEO Satellite Tracking: S. Hayek, J. Saroufim, Z.M. Kassas, The Ohio State University

Alternates

1. **LiDAR Odometry with Pre-filtering of Plane Feature Points:** H. Lee, J. H. Jung, C. G. Park, Seoul National University
2. **A Robust Localization Solution for an Uncrewed Ground Vehicle in Unstructured Outdoor GNSS-Denied Environments:** W. J. Wagner, I. Blankenau, M. De La Torre, A. Purushottam, A. Soylemezoglu, Engineer Research and Development Center
3. **GNSS Measurement-Based Context Recognition for Vehicle Navigation Using Gated Recurrent Unit:** S. Liu, Z. Yao, X. Cao, X. Cai, Xiangtan University

Virtual Only: View at ion.org/gnss

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

Blue Text: Student Paper Award Winner

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

Session E5: PANEL: Algorithms and Methods for GNSS Cyber Physical Security (8:30 a.m. – 10:05 a.m.)

Room: Capitol Ballroom 4 (4th Floor)


Dr. Ramsey Faragher
Focal Point Positioning


Dr. Pau Closas
Northeastern 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?

Panel Members:

1. Dr. Todd Humphreys, University of Texas at Austin
2. Mr. Logan Scott, Logan Scott Consulting
3. Dr. Cillian O'Driscoll, Independent consultant
4. Dr. Aanjhan Ranganathan, Northeastern University

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

Session F5b: PANEL: International Civilian Agency Lunar PNT Systems (10:35 a.m. – 12:15 p.m.)

Room: Capitol Ballroom 4 (4th Floor)


Dr. Evan Anzalone
NASA


Giuseppe D'Amore
Agenzia Spaziale Italiana

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:

1. Dr. Javier Ventura-Traveset: European Space Agency (ESA)
2. Ms. Cheryl Gramling: National Aeronautics and Space Administration (NASA)
3. Dr. Masaya Murata: Japan Aerospace Exploration Agency (JAXA)

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

Session F5a: Lunar Positioning, Navigation, and Timing 2 (8:30 a.m. – 10:05 a.m.)

Room: Mineral Hall D/E (3rd Floor)


Dr. Cosimo Stallo
Thales Alenia Space


Erin E. Fowler
Johns Hopkins University APL

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

8:57 Local Geoid Model to Enable Navigation for the Lunar South Pole Region: A. Sanchez and G. Gao, Stanford Univ.

9:20 Orbit Determination and Time Synchronization Performance Assessment of Low Lunar Orbit Satellites Using a Dedicated Lunar Radio Navigation Satellite System: S. Molli, P. Tartaglia, A. Sesta, M. Plumaris, Sapienza University of Rome; Y. Audet, F. Thomas Melman, P. Zoccarato, R. Swinden, P. Giordano, J. Ventura-Traveset, ESA

9:43 Improving the Performance of Lunar Satellite Navigation Systems by Exploiting Inter-Satellite Distance Information: G. Sirbu, M. Leonardi, Tor Vergata Univ.of Rome; C. Stallo, M. Carosi, Thales Alenia Space Italia

Alternates

1. **High Performance Orbit Determination and Time Synchronization for Lunar Radio Navigation Systems:** 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 Wrocaw University of Environmental and Life Sciences; J. Belfi, Leonardo S.p.A; P. Giordano, R. Swinden, J. Ventura-Traveset, ESA
2. **Analysis of Precise Orbital Determination Approaches for Lunar Navigation Services:** C. Albanese, G. Lambiase, F. Rodriguez, G. Tomasicchio, Telespazio SpA; L. Iess, A. Sesta, La Sapienza University
3. **A Strategy for Initial Orbit Determination of Lunar Navigation Satellite Based on Range and Doppler Measurements from a Lunar Ground Station:** S. Kim, B. Park, Sejong University

10:05-10:35, Break. Refreshments in Foyer

Session F5c: GNSS Robustness to Vulnerabilities 2 (10:35 a.m. – 12:15 p.m.)

Room: Mineral Hall D/E (3rd Floor)


Dr. Brady O'Hanlon
The MITRE Corporation


Shubh Gupta
Stanford University

10:40 Identifying Car Key Fobs as a Cause of Interference at GNSS Frequencies: S. Jada, J. Bowman, M. Psiaki, Virginia Tech (VT); S. Langel, The MITRE Corporation; M. Joerger, VT

11:03 Using Filtered ADS-B Data to Monitor and Detect GPS Interference Events: Z. Liu, S. Lo, J. Blanch, T. Walter, Stanford University

11:26 Preliminary Analysis of GNSS Radio Frequency Interference Events Detected in Canada and Impacts on GNSS Based Applications: A. Raghuvanshi, S. Bisnath, York University; J. Bond, CanadianPNT Office

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

Alternate

1. **Jamming and Spoofing Impact on GNSS Signals for Railway Applications:** R. Ehrler, A. Wenz, Swiss Federal Railways; S. Baumann, P. Mendes, N. Dütsch, A. Martin, C. Hinterstocker, IABG

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

Session F5c continued: Virtual Only: View at ion.org/gnss

1. **Civil Aviation GNSS Interference Detection and Location Based on Genetic Algorithm Using ADS-B Data:** J. Li, H. Wang, Z. Dan, J. Xu, Z. Wang, Y. Zhu, Beihang University
2. **Jammer on the Horizon: A Robust Method for GPS Jammer Localization Using ADS-B Data:** M. Schäfer, SeRo Systems GmbH; S. Sõeruer, T. Kippak, Estonian Air Navigation Services; E. Sadrak, Estonian Consumer Protection and Technical Regulatory Authority
3. **The Evolving GNSS RFI Threat Space:** A. Morrison, N. Sokolova, A. Diez, SINTEF

Session A6a: New Technologies, Opportunities and Challenges (1:45 p.m. – 3:20 p.m.)

Room: Mineral Hall F/G (3rd Floor)


Courtney Mario
Draper


Dr. Eric Phelts
Stanford University

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

2:12 **Delivering PPP-RTK in Australia Using 3GPP LPP and 5G:** E. Rubinov, C. Marshall, L. Elneser, L. Ng, D. Woodrow, FrontierSI; F. Gunnarsson, P-G. Andersson, J. Wase, B. Chaudhry, Ericsson; A. Chamorro, E. Bartolome Calvo, D. Calle, GMV; S.Y. Wong, Optus

2:35 **Cloud Based GNSS IoT Solution: From Simulation to Actual Measurement on the Field:** T. Torlotin, M. Villion, J. Korsakissok, Syntony GNSS

2:58 **Evaluating Performance of Meta-Signal Exploitation in End User:** C. Moriana, G. Ortas, E. Garbin, P. Boto, E. Benedetti, N. Boreham, GMV; J. Miguez, F. Melman, J.A. Garcia-Molina, ESA

Alternates

1. **Impact of Payload Distortions on BeiDou B1I-B1C Meta-Signal Ranging Performance:** F. C. Beck, German Aerospace Center (DLR) & RWTH; C. Enneking, S. Thölert, M. Meurer, DLR & RWTH
2. **Cloud-Based High Precision Asset Tracking:** T. Höijer, HERE Technologies; S. Beck, Sony Semiconductor Solutions Europe
3. **onocoy: Enabling Mass Adoption of High Precision Positioning:** L. Icking, D. Ammann, U. Kalabic, G. Seepersad, M. Ballandies, onocoy Association
4. **Unlocking the Benefits of Model-Based Systems Engineering (MBSE) and Digital Engineering (DE):** V. Aguilar, MBSE Services at Strategic Technology Consulting

Virtual Only: View at ion.org/gnss

1. **A Novel Approach for NavIC & Pseudolite Combined User Position Algorithm:** A.K. Shukla, Space Applications Centre, ISRO; H.M. Patel, C.S. Patel Institute of Technology; G. Khare, D.C. Mehta, Space Applications Centre, ISRO
2. **Design and Assessment of a LEO GNSS Mini-Constellation for Positioning, Navigation, and Timing (PNT):** M. Alrais, United Arab Emirates University; A. Hasbi, National Space Science and Technology Center; J-L. Issler, Centre National D'Etudes Spatiales; H. AlAli, National Space Science and Technology Center
3. **Multi-Frequency Interference Detection & Mitigation Using COTS RFSOC Platform for Automotive Applications:** M.A. Akhtar, H. Saijd, National Univ. of Science and Technology

Session A6b: Urban and Indoor Radio Positioning (3:20 p.m. – 4:50 p.m.)

Room: Mineral Hall F/G (3rd Floor)


Ryan Dixon
Hexagon


Dr. Pai Wang
Shanghai Jiao Tong University

3:20 **A Look at the Sky: Opportunistic Navigation with Multi-Constellation LEO Satellites**: S. Kozhaya, H. Kanj, and Z.M. Kassas; The Ohio State University

3:42 **Resilient 3D Navigation and Timing System using Terrestrial Beacons and Cellular Signals:** R. Chrabieh, A. Raghupathy, S. Deshpande, V. Le, M. Hoang, NextNav

4:04 **Jupiter: Indoor Localization Platform for Vehicle in Underground Parking Lot**: D. Shin, TJLABS Corp.; T. Kim, KIST & Korea Univ.; C. Yu, TJLABS Corp.; H. Kyung, B. Shin, KIST; C.G. Kang, Korea Univ.; T. Lee, KIST & TJ LABS Corp.

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

Session B6: Aviation and Aeronautics

Room: Capitol Ballroom 5-7 (4th Floor)


Dr. Sai Kalyanaraman
Collins Aerospace


Stefan Wallner
European Space Agency

1:50 **Approximating Regional GNSS Interference Sources as a Conic Hull Using ADS-B Data:** M. Dacus, Z. Liu, T. Walter, S. Lo, Stanford University

2:12 **Baseline Spoofing Detection Technique for Aircraft with Standard Navigation Hardware:** M. Blois, University of Calgary; J. Studenny, CMC Electronics; K. O'Keefe, B. Liu, University of Calgary

2:35 **GNSS Radio Frequency Interference Mitigation Techniques in Collins Commercial Airborne Receivers:** A. Joseph, J. Griggs, P. Bartolone, B. Schnaufer, H. Phan, V. Malhotra Collins Aerospace

2:58 **Impact of Meaconers on Aircraft GNSS Receivers During Approaches:** M. Hussong, E. Ghizzo, C. Milner, A. Garcia-Pena, J. Lesouple, C. Macabiau, ENAC

3:20 **SBAS DFMC Receiver RFI Test Conditions:** A. Garcia-Pena, C. Macabiau, ENAC; D. Bouvet, Thales AVS; G. Novella, DSNA/DTI; M. Mabilleau, 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:** M. Caamano and D. Gerbeth, German Aerospace Center, (DLR)

4:26 **Managing Long Time Constant and Variable Rate Carrier Smoothing for DFMC GBAS:** T. Murphy, M. Harris, G. Balvedi, Boeing; G. McGraw, PNT and Systems Engineering Consultant; J. Wichgers, Collins Aerospace; L. Lavik, M. Topland, M. Tuffaha, Indra Navia; S. Saito, ENRI

Alternates

1. **An ARAIM experimental Test User Receiver. Final Review of Project DARP:** M. Wis, A. Fernández, Elecnor Deimos
2. **Navigation for UAVs in Harsh GNSS Environments Using a High-Performance IMU:** K. Schauble, W. Stockwell, M. Horton, ANELLO Photonics
3. **Worldwide SBAS Broadcasts Between 2017 and 2023: A Comparative Study:** A. Calabrese, S. Domenech, N. Álvarez, J. Barrios, J.G. Pericacho, GMV

View Virtual Paper Presentations for all sessions in the ION GNSS+ Virtual Portal at ion.org/gnss

Session C6: Technologies for Scientific and Sectorial Applications

Room: Agate (3rd Floor)


Dr. Omar García Crespillo
German Aerospace Center (DLR)


Dr. Juliette Marais
Université Gustave Eiffel

1:50 **Performance Monitoring at the DLR Galileo Competence Center:** K. Lutz, L. Greda, M. Smyrnaios, W. Dilg, T. Schilling, I. Ioanid, S. Schrade, B. Röttgers, DLR Galileo Competence Center; S. Thölert, G. Allende Alba, DLR Institute of Communications and Navigation; M. Kriegel, DLR Institute for Solar-Terrestrial Physics; L. Spataro, A. Meinecke, R. Brydon, DLR Institute for Software Technology; J. Furthner, DLR Galileo Competence Center

2:12 **State Estimation and Fault Detection Baselines From an Open-Source Python GNSS Library:** D. Knowles, A.V. Kanhere, and G. 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:** F. Legrand, L. Montloin, N. Mendoza Pila, F. Fabozzi, A. Rodriguez Veiga, P. Grandjean, V. Fouquet, A. Sfeir, AIRBUS Defence and Space; V. Barreau, SNCF

3:20 **MADOCA Disciplined Oscillator for Effective Utilization of Radio Resources:** T. Yamamoto, H. Araki, K. Terao, K. Takahashi, CORE Corporation; Y. Yano, R. Ichikawa, National Institute of Information and Communications Technology

3:42 **TRNAV: An Integrated Communications and Navigation Solution to Provide ADHOC Mesh Network and Support or Replace GNSS for Precise PNT:** E. Keçe, G. Afsin Peker and M. Efe, TUALCOM Elektronik 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:** N. Gambale, C. Basnayake, D. Small, H. Roth, Locata Corporation

4:26 **Standardisation of Galileo Timing Receivers:** J. Fidalgo, R. Píriz, G. Ortas, GMV; J. Bárcena, Alter; F.L. Arribas, UNE; K. Callewaert, VVA; M. Aguilera, J.P. Boyero, European Commission; V. Catalano, EUSPA; G-J. Pauwels, M. Sgammini, J. Fortuny, B. Motella, JRC

Alternates

1. **Alternative PNT Using 5G-Broadcasting via TV Transmitters:** S. Maier, T. Janner, L. Oestreicher, A. Bart, S. Busching, L. Jassoume, A. Phillips, H-P. Keil, Rohde & Schwarz
2. **Transforming a Legacy DME to a High Accuracy DME for Aircraft APNT Through Software Changes:** E. Kim, Hongik University; J. Park, J. Seo, Yonsei University
3. **An SNR Correction for GNSS Scintillation Index Measurements:** C. Rino, K. Groves, C. Carrano, Boston College, Institute for Scientific Research; B. Breitsch, J. Morton, University of Colorado

Session A6b continued:

Alternates

1. **Scalable 3D Indoor and Urban Global Positioning:** T. Vyunova, H. Nurminen, HERE Technologies
2. **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 Only: View at ion.org/gnss

1. **Research on UWB/Inertial Guided Fusion Localization Based on Convolutional Neural Network:** Y. Sun, Y.J. Zhang, Z.L. Deng, Beijing University of Posts and Telecommunications
2. **Tuti: An Advanced GNSS-Based Repeater for Seamless Indoor/Outdoor Positioning**: A. Tabatabaei, CTO of IGASPIN GmbH

Session D6: Robust Navigation Using Alternative Nav Sensors and Solutions

Room: Capitol Ballroom 1-3 (4th Floor)

Dr. Okuary Osechas
German Aerospace Center (DLR)

Dr. Yang Wang
University of Colorado at Boulder

1:50 Exploring the Potential of Low Earth Orbit Satellites for Precise Navigation and Timing Solutions: J. Durán, D. Socías, E. Carbonell, A. González, G. Tobías, I. Rodriguez, P. Navarro, F. Sobrero and D. Calle, GMV

2:12 Analysis of Concepts for Ultra Low Power Device Positioning Based on LEO Satellites: L.E. Aguado Bayon, M. Powe, B. Toz, K. Roll, A. Pérez Conesa, GMV

2:35 Concept and Benefits of a Technology-Agnostic Dynamic Alert Limit Framework for a VTOL Autoland System: F. Hübner, M. Gäbel, L. Scholz, U. Bestmann, Technische Universität Braunschweig

2:58 3D LiDAR Aided GNSS NLOS Correction with Angle of Arrival Estimation Using Doppler Measurements: X. Liu, W. Wen, L-T. Hsu, The Hong Kong Polytechnic University

3:20 GNSS Satellite Fault Detection and Exclusion for Integrated GNSS/INS Systems: B. Kujur, S. Khanafseh, and B. Pervan, Illinois Institute of Technology

3:42 Hybridization of Smartphone GNSS PPP/RTK with Native IMU in Realistic Driving Scenarios: D. Yi and S. Yang, York University

4:04 Integrity Assurance of INS-Integrated Single-Epoch RTK against IMU Faults to Support Unmanned Aerial Vehicle Applications: N.M. Kim, D. Min, N. Woo, and J. 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: B. Xiwei, L-T. Hsu, The Hong Kong Polytechnic University

Alternates

1. **Relieve Gaussian Assumptions: A Bayesian Approach to Detect Faults in Localization Systems Based on Gaussian Mixture Model:** P. Yan, L-T. Hsu, W. Wen, F. Huang, and J. Zhang, 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 GNSS Map-Modulation with Inertial Navigation Over Hundreds of Hours of Ral-Life Data:** P. d'Harcourt, J-B. Lacambre, T. Barford, L. Poletti, S. Glevarec, Exail
3. **Integrity Monitoring of GNSS With LEO Satellites to Reduce the Time to Alarm:** C. Catalán, A. Juez, E. Fernández, C. Pisonero, A. Monreal, M. Paüls, E. Arnal, M. D. Laínez, L. García, J. Bruno, J. Caro, GMV

Virtual Only: View at ion.org/gnss

1. **Improving LEO Satellite Onboard SPP Orbits with Dynamic Models:** H. Su, National Time Service Center (NTSC), Chinese Academy of Sciences (CAS); K. Wang, NTSC, CAS, University of Chinese Academy of Sciences (UCAS); X. Yang, NTSC, CAS, UCAS
2. **Integer Ambiguity Resolution in Multi-Constellation GNSS for LEO Satellite POD:** K. Wang, National Time Service Center (NTSC), Chinese Academy of Sciences (CAS), University of Chinese Academy of Sciences (UCAS); A. El-Mowafy, Curtin University; X. Yang, NTSC, CAS, UCAS

Blue Text: Student Paper Award Winner

Session E6: Sensor Network and Cooperative Navigation

Room: Mineral Hall D/E (3rd Floor)

Dr. Taro Suzuki
Chiba Institute of Technology

Dr. Alex Minetto
Politecnico di Torino

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

2:12 Multi-Receiver Precise Baseline Determination: Coupled Baseline and Attitude Estimation with a Low-Cost off-the-Shelf GNSS Receiver: M.B. Stucke, T. Hobiger, University of Stuttgart; G. Möller, ETH Zurich; K. Gutsche, University of Stuttgart; S. Winkler, Airbus Defence and Space

2:35 Intent- and Fault-Based Trajectory Prediction for Cooperative Localization and Collision Avoidance in Swarms: I. Torres and G. 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: Y. Zhong, W. Wen, L-T Hsu, The Hong Kong Polytechnic University

3:20 Integrity Monitoring on Collaborative Navigation: X. Wang, C. Toth, D. Grejner-Brzezinska, The Ohio State University

3:42 A Multi-Agent Multi-Sensor Scalable Collaborative Positioning Approach: A. Masiero, University of Florence; C. Toth, The Ohio State University; F. Remondino, Fondazione Bruno Kessler, FBK

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

4:26 The Power of Many: Multi-User Collaborative Indoor Localization for Boosting Standalone User-Based Systems in Different Scenarios: A. Mansour, W. Chen, H. Luo, D. Weng, The Hong Kong Polytechnic University

Virtual Only: View at ion.org/gnss

1. **A Cooperative Positioning Algorithm Based on BiLSTM:** Y. Sun, J. Liu, Z. Deng, Beijing University of Posts and Telecommunications
2. **A Multi-Vehicle Cooperative Positioning Method Based on Factor Graph Optimization Using the Error Information of Cooperators:** T. Wang, H. Zhao, C. Zhuang, S. Hu, Beihang Univ.

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

Room: Capitol Ballroom 4 (4th Floor)

Dr. Sanjeev Gunawardena
Air Force Institute of Technology

Dr. Joanna Hinks
AFRL Space Vehicles Directorate

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.

Panel Members:

1. Dr. Todd Humphreys, University of Texas at Austin
2. Dr. Y. Jade Morton, University of Colorado Boulder
3. Dr. Tyler Reid, Xona Space Systems
4. Dr. Pietro Giordano, European Space Agency
5. Dr. Christian Tiberius, Delft University of Technology
6. Dr. Ali Khalajmehrabadi, Qualcomm Technologies Inc.

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Submit your nominations today at ion.org/awards.

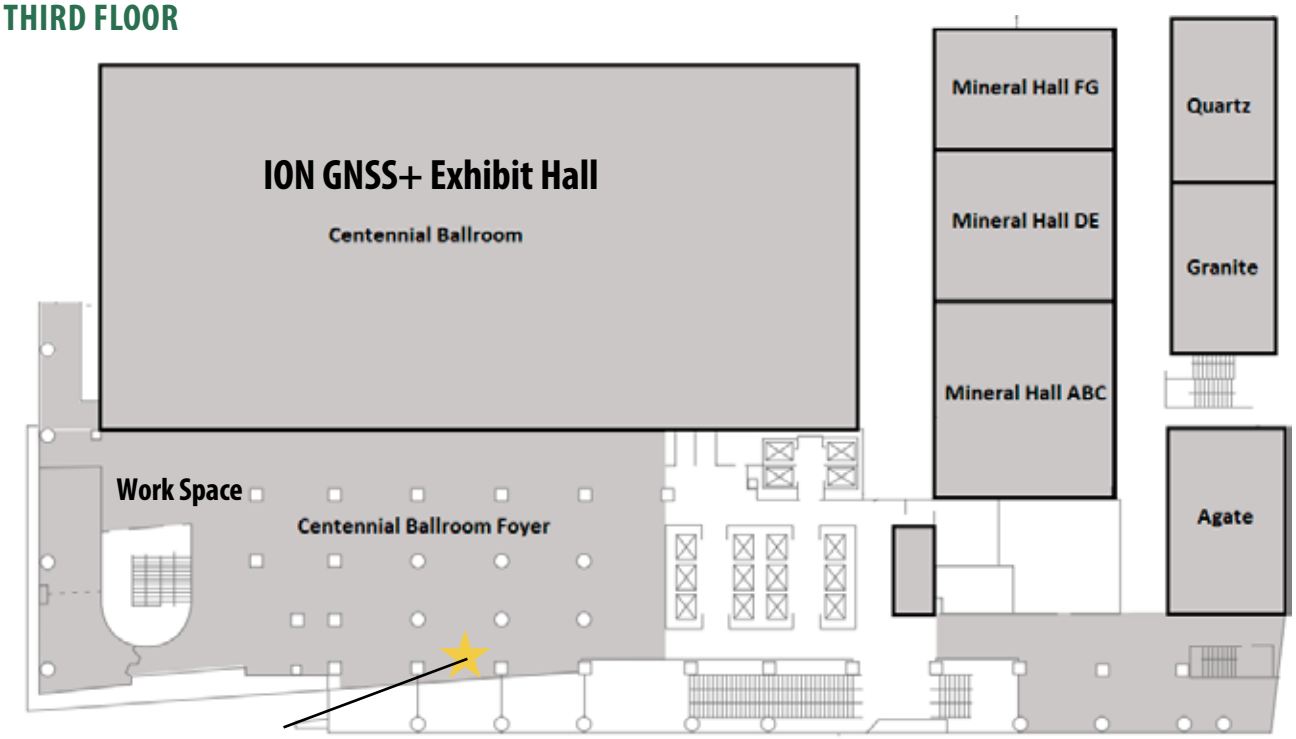
All nominations must conform to ION nomination guidelines. Details of the nomination process and forms are available at ion.org/awards. Nominations must be received in proper form by October 15 to be considered. The Institute accepts nominations for the following annual awards:

- **Per Enge Early Achievement Award**: recognizing an individual early in their career who has made an outstanding achievement in the art and science of navigation
- **Superior Achievement Award**: recognizing individuals who are practicing navigators and have made outstanding contributions to the advancement of navigation
- **Distinguished PTTI Service Award**: recognizing outstanding contributions related to the management of PTTI systems
- **Captain P.V.H. Weems Award**: recognizing contributions to the art and science of navigation
- **Tycho Brahe Award**: recognizing outstanding contributions to the science of space navigation
- **Norman P. Hays Award**: recognizing outstanding encouragment, inspiration, and support contributing to the advancement of navigation
- **Colonel Thomas L. Thurlow Award**: recognizing outstanding contributions to the science of navigation

Election to Fellow membership recognizes the distinguished contribution of ION members to the advancement of the technology, management, practice and teaching of the arts and sciences of navigation, and/or for lifetime contributions to the Institute

Hotel Floor Plan

THIRD FLOOR



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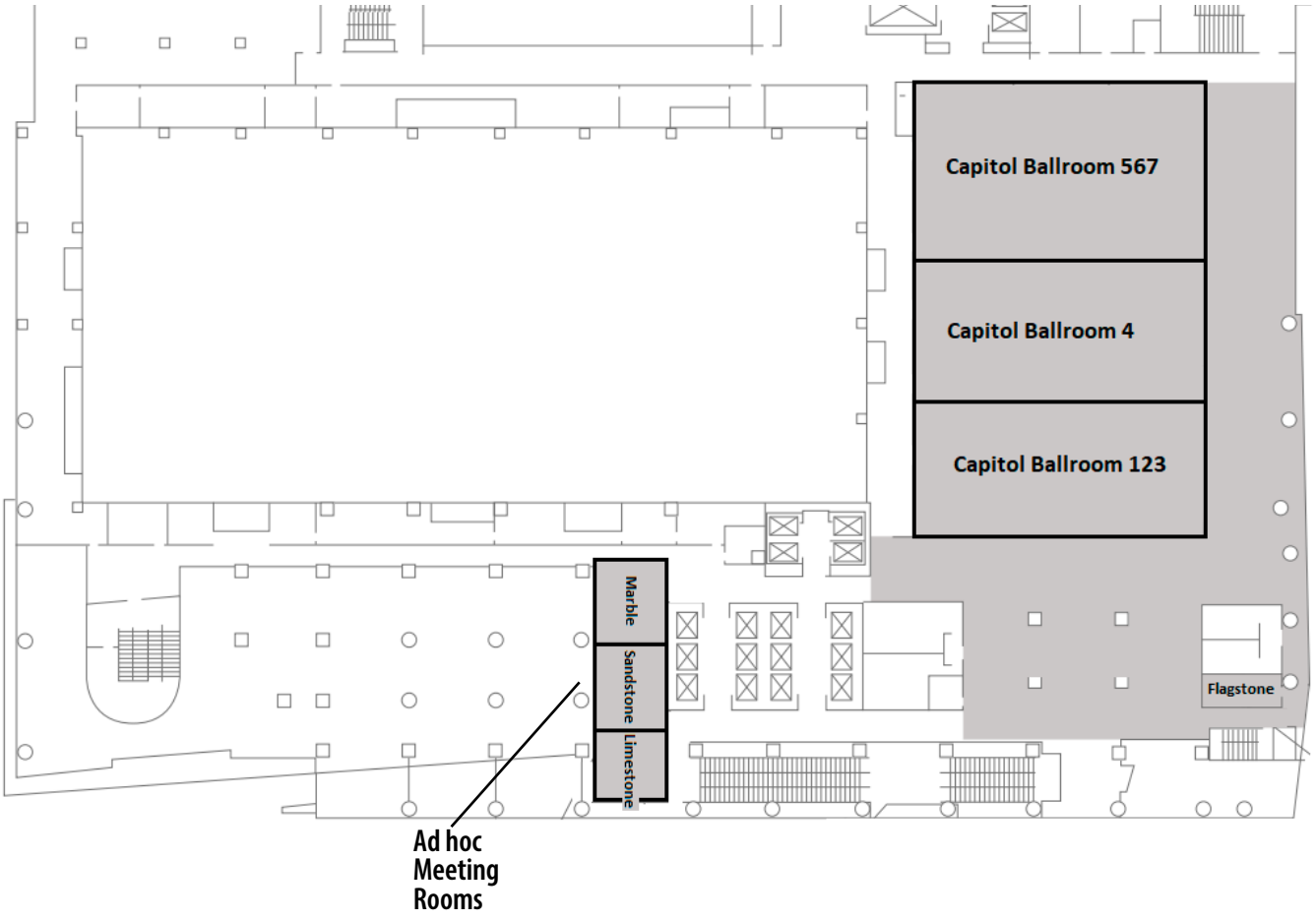

MONDAY, SEPTEMBER 11 • PRE-CONFERENCE SHORT COURSES
(included in full in-person registrations)

9:00 a.m. - 5:30 p.m. CGSIC Subcommittee Meetings - for full schedule visit www.gps.gov/cgsic/meetings

1:30 p.m. - 3:00 p.m., Mineral Hall D/E **Short Course**: GPS/GNSS 101, Dr. John Raquet	1:30 p.m. - 3:00 p.m., Mineral Hall F/G **Short Course**: Space Applications of GNSS, Dr. Penina Axelrad
3:30 p.m. - 5:00 p.m., Mineral Hall D/E **Short Course**: GNSS Jamming and Spoofing – LEO as Fallback, Dr. Todd Humphreys	3:30 p.m. - 5:00 p.m., Mineral Hall F/G **New and Now**: LEO PNT – Architectures and Performance Trades, Dr. Tyler Reid

TUESDAY, SEPTEMBER 12 • PRE-CONFERENCE TUTORIALS
(additional registration and fee required)

9:00 a.m. - 5:00 p.m. CGSIC General Sessions - for full schedule visit www.gps.gov/cgsic/meetings

9:00 a.m. - 12:30 p.m., Granite Multi-constellation GNSS Signals and Systems Dr. Chris G. Bartone	9:00 a.m. - 12:30 p.m., Mineral Hall F/G GNSS Integrity Dr. Mathieu Joerger	9:00 a.m. - 12:30 p.m., Mineral Hall D/E Factor Graphs Dr. Ryan Watson / Dr. Clark Taylor	9:00 a.m. - 12:30 p.m., Granite GNSS [illegible] CANCELLED Dr. Y. Jade Morton
Lunch on Your Own • 12:30 p.m. - 1:30 p.m.			
1:30 p.m. - 5:00 p.m., Agate Ir[illegible] CANCELLED Dr. Li-Ta Hsu	1:30 p.m. - 5:00 p.m., Granite GNSS in the National Airspace Dr. Todd Walter	1:30 p.m. - 5:00 p.m., Mineral Hall D/E PNT for sUAVs Dr. Robert Leishman	1:30 p.m. - 5:00 p.m., Mineral Hall F/G Introduction to Cryptography with Navigation Dr. Joe J. Rushanan

1:30 p.m.-3:30 p.m. Smartphone Decimeter Challenge Workshop, Sponsored by Google

6:30 p.m. – 8:30 p.m. ION GNSS+ 2023 Plenary Session

WEDNESDAY, SEPTEMBER 13

TRACK A Autonomous and Safety Critical Applications	TRACK B Status and Future Trends in Navigation	TRACK C Navigation for Mass Market	TRACK D Multisensor and Autonomous Navigation	TRACK E Algorithms and Methods	TRACK F Advanced GNSS Technologies
8:30 a.m. - 12:15 p.m. A1: Navigation and Positioning Mineral Hall F/G	8:30 a.m. - 12:15 p.m. B1: Augmentation Services, Integrity, and Authentication Mineral Hall D/E	8:30 a.m. - 12:15 p.m. C1: PANEL: Status of GPS, GLONASS, Galileo, BDS, QZSS, and UK GNSS Capitol Ballroom 4	8:30 a.m. - 12:15 p.m. D1: Alternative Technologies for GNSS-Denied Environments Capitol Ballroom 1-3	8:30 a.m. - 12:15 p.m. E1: Advanced Processing of Terrestrial Signals of Opportunity Capitol Ballroom 5-7	8:30 a.m. - 12:15 p.m. F1: Remote Sensing, Timing, Space and Scientific Applications Agate
12:15 p.m. - 1:15 p.m., Buffet Lunch in Exhibit Hall • 1:15 p.m. - 1:45 p.m., Free Time in Exhibit Hall					
1:45 p.m. - 5:30 p.m. A2: Applications of GNSS Measurements from Smartphones Capitol Ballroom 1-3	1:45 p.m. - 5:30 p.m. B2: Marine Applications, and Search and Rescue Agate	1:45 p.m. - 5:30 p.m. C2: Trends in GNSS Augmentation Systems Capitol Ballroom 5-7	1:45 p.m. - 5:30 p.m. D2: PANEL: Autonomous Navigation for Ground, Seaborne, and Airborne Vehicles Capitol Ballroom 4	1:45 p.m. - 5:30 p.m. E2: High Precision and High Integrity Navigation Mineral Hall D/E	1:45 p.m. - 5:30 p.m. F2: Advanced Software and Hardware Technologies for GNSS Receivers Mineral Hall F/G
Free Time in Exhibit Hall • 5:30 p.m. - 7:00 p.m.					

THURSDAY, SEPTEMBER 14

8:30 a.m. - 12:15 p.m. A3: PANEL: Extended Reality and PNT Capitol Ballroom 4	8:30 a.m. - 12:15 p.m. B3: Autonomous Applications Capitol Ballroom 5-7	8:30 a.m. - 10:05 a.m. C3: Spectrum: Protection and Optimization Granite	8:30 a.m. - 12:15 p.m. D3: GNSS Integrity Augmentation Agate	8:30 a.m. - 10:05 a.m. E3a: All-Source Intelligent PNT Methods Capitol Ballroom 1-3 10:35 a.m. - 12:15 p.m. E3c: LEO for PNT Capitol Ballroom 1-3	8:30 a.m. - 12:15 p.m. E3b: High Precision GNSS Positioning in Challenging Environments Mineral Hall F/G	8:30 a.m. - 12:15 p.m. F3: Lunar Positioning, Navigation, and Timing 1 Mineral Hall D/E
12:15 p.m. - 1:15 p.m., Buffet Lunch in Exhibit Hall • 1:15 p.m. - 1:45 p.m., Free Time in Exhibit Hall						
1:45 p.m. - 5:30 p.m. A4: Positioning Technologies and Machine Learning Capitol Ballroom 1-3	1:45 p.m. - 5:30 p.m. B4: PANEL: Emerging Autonomous Application - Challenges and Prospects Capitol Ballroom 4	1:45 p.m. - 5:30 p.m. C4: Trends in Future Satellite Nav Technology, System Design and Development Granite	1:45 p.m. - 5:30 p.m. D4: Indoor and Urban Navigation and Mapping Capitol Ballroom 5-7	1:45 p.m. - 5:30 p.m. E4: GNSS Navigation in Challenging Environments Mineral Hall D/E	1:45 p.m. - 5:30 p.m. F4a: GNSS Robustness to Vulnerabilities 1 Mineral Hall F/G	1:45 p.m. - 5:30 p.m. F4b: Atmospheric Effects on GNSS Agate

FRIDAY, SEPTEMBER 15

8:30 a.m. - 10:05 a.m. A5a: BeiDou - The Next Generation Mineral Hall F/G 10:35 a.m. - 12:15 p.m. A5b: Harsh Urban and Indoor GNSS Mineral Hall F/G	8:30 a.m. - 12:15 p.m. B5: Land-Based Applications Capitol Ballroom 5-7	8:30 a.m. - 12:15 p.m. C5: GNSS Applications in Space Capitol Ballroom 1-3	8:30 a.m. - 12:15 p.m. D5: Navigation Using Environmental Features Agate	8:30 a.m. - 10:05 a.m. E5: PANEL: Algorithms and Methods for GNSS Cyber Physical Security Capitol Ballroom 4 10:35 a.m. - 12:15 p.m. F5c: GNSS Robustness to Vulnerabilities 2 Mineral Hall D/E	8:30 a.m. - 10:05 a.m. F5a: Lunar Positioning, Navigation, and Timing 2 Mineral Hall D/E 10:35 a.m. - 12:15 p.m. F5b: PANEL: International Civilian Agency Lunar PNT Systems Capitol Ballroom 4
Awards Luncheon • 12:15 p.m. - 1:30 p.m. (Lunch served until 12:30 p.m.; late arrivals will not be served)					
1:45 p.m. - 3:20 p.m. A6a: New Technologies, Opportunities and Challenges Mineral Hall F/G 3:20 p.m. - 4:50 p.m. A6b: Urban and Indoor Radio Positioning Mineral Hall F/G	1:45 p.m. - 4:50 p.m. B6: Aviation and Aeronautics Capitol Ballroom 5-7	1:45 p.m. - 4:50 p.m. C6: Technologies for Scientific and Sectorial Applications Agate	1:45 p.m. - 4:50 p.m. D6: Robust Navigation Using Alternative Navigation Sensors and Solutions Capitol Ballroom 1-3	1:45 p.m. - 4:50 p.m. E6: Sensor Network and Cooperative Navigation Mineral Hall D/E	1:45 p.m. - 4:50 p.m. F6: PANEL: Beyond GNSS: Emerging Trends in LEO-Based Satnav and Signals of Opportunity for PNT Capitol Ballroom 4

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GPS Modernization

GPS IIIF delivers resilient capabilities,
including improved anti-jamming, to toughen
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to complete missions with precision and accuracy,
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