ONSITE PROGRAM

September 11 - 15, 2023
Exhibit Hall: September 13 -14
Hyatt Regency Denver Colorado Convention Center
Denver, Colorado

FREE WI-FI in meeting rooms
Network: iongnss23
Password: iongnss23
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+ registration desk on the 3rd floor of the hotel, to provide access to basic computer services including printing and internet access.

Sponsored by:

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.
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 Colorado Boulder.

**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 remote sensing – especially in spaceborne applications. She is a past ION president, a Fellow of ION and AIAA, and a member of the National Academy of Engineering.

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

**Masters Course**

**GNSS Jamming and Spoofing – LEO as Fallback**
**Dr. Todd Humphreys, The University of Texas at Austin**
**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. Pridddy 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.
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 HQD, 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 (UAVs)’s University of Leicester, United Kingdom
9:50 NANUS and Navigation 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 Gadimad, 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. Chandgdon 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

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, NIF
3:30 Break
3:40 Report from USNO: Mr. Arnold Collina, 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

Monday Afternoon Concurrent Sessions

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 Tilampo, Director of Earth Science and Observation Center, CU Boulder
2:50 Advances in Ionosonde 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 Advisor, NOAA National Geodetic Survey
4:20 Galileo High Accuracy Service: Overview, Roadmap, and Initial Test Results: Jean-Yves Latour, 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 (SMI), Space Systems Command, U.S. Space Force
10:30 Break
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
12:15 Lunch
12:15 Q&A Panel: Presenters
12:45 Break
13:00 Timing Subcommittee Reports:
13:30 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: Mr. 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
3:20 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
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**

<table>
<thead>
<tr>
<th>Time</th>
<th>Room</th>
<th>Course</th>
<th>Instructor</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 a.m.–12:30 p.m.</td>
<td>Granite (3rd Fl)</td>
<td>Multi-constellation GNSS Signals and Systems</td>
<td>Dr. Chris G. Bartone, P.E.</td>
</tr>
<tr>
<td></td>
<td>Mineral Hall F/G (3rd Fl)</td>
<td>GNSS Integrity</td>
<td>Dr. Mathieu Joerger</td>
</tr>
<tr>
<td></td>
<td>Mineral Hall D/E (3rd Fl)</td>
<td>Factor Graphs</td>
<td>Dr. Ryan Watson / Dr. Clark Taylor</td>
</tr>
<tr>
<td>1:30 p.m.–5:00 p.m.</td>
<td>Granite (3rd Fl)</td>
<td>GNSS in the National Airspace</td>
<td>Dr. Todd Walter</td>
</tr>
<tr>
<td></td>
<td>Mineral Hall D/E (3rd Fl)</td>
<td>PNT for uSVs</td>
<td>Dr. Robert Leishman</td>
</tr>
<tr>
<td></td>
<td>Mineral Hall F/G (3rd Fl)</td>
<td>Introduction to Cryptography with Navigation</td>
<td>Dr. Joe J. Rushanan</td>
</tr>
</tbody>
</table>

**TUTORIAL DESCRIPTIONS**

### 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
- Satellite clock and orbit classification
- 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
- GALILEO
- QZSS S/V versions
- Legacy C/A, P codes and FDMA signals
- Modernized COA 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
- WAAS 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. in Electrical Engineering from Ohio University, a M.S. in Electrical Engineering from the Naval Postgraduate School, and a B.S. 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 Grounded-Augmentation System (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 developments 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.

### 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 consuming a vast space to reach receivers on the Earth's surface. Numerous interferes with the signals along the propagation path, including ionosphere plasma, molecular oxygen, water vapor, troposphere, and multipath reflections on the Earth's surface. Understanding these effects is critical navigation signals is the pre-requisite for development of new GNSS technologies. Moreover, these effects enable the navigation signals to function as a robust, low cost, distributed, passive sensor to pass through propagation environments. This tutorial will discuss the effects of the local and space environment on the GNSS signals, followed by the latest technology developments to utilize GNSS signals for space weather monitoring, oceanic profiling, ocean wind and soil moisture retrieval, and precision altitude 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 Ph.D. 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 tutorial will provide an overview of the Indoor Positioning and Navigation (IPIN) system. Starting from the basics of markets and applications using IPIN, we will look at indoor positioning technologies and sensors related. Then, an introduction to IPIN will be introduced that consists of the indoor positioning space and integration. After explaining the single point position (SPP), we will discuss the sensor integration.

Regarding the data sources, we will concatenate the sources into homogeneous information infrastructure. One type of the sources used to match with pre-stored data is the error and limitation of the SPP will be discussed. Physical 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 FDO 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 tutorial 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, 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 different 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 a wide variety of applications, for example: remote-control flying, photography and videography, infrastructure/construction/construction site inspection, product/medical delivery, racing, mapping, intelligence, surveillance, reconnaissance, and defense. These methods were 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, we will discuss the various places cryptography is used in navigation applications, including current implementations.

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 that will begin with 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, we will discuss 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 LTC 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.
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
Dr. 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.
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

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 2018)
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

IN-PERSON EXHIBITORS

Coordinates Magazine ✷
GeoConnexion Magazine ✷

VIRTUAL

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
3.6 Comparison of Ambiguity Resolution Methods for RTK and PPP-IAU Under Challenging Environments: M. Duong, Hemisphere GNSS (USA) Inc.

3.7 A New Ionospheric Model for Galileo Open Service with Good Performance and Less Computation: M. Grosse, German Aerospace Center (DLR); M. Sgammini, F. Mezioz, Joint Research Center/European Commission (JRC/EC); R. Oros Perez, European Space Agency; J. A. Cahauasqui, DLR; E. Chatre, EC

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


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, TILABS; H. Kyung, KIST; T. Lee, KIST & TILABS

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


11:48 Tolles-Lawson Coefficient Dependence Using F-16 Data Set: B. Blakeley, 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


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.

6. A New Ionospheric Model for Galileo Open Service with Good Performance and Less Computation: M. Grosse, German Aerospace Center (DLR); M. Sgammini, F. Mezioz, Joint Research Center/European Commission (JRC/EC); R. Oros Perez, European Space Agency; J. A. Cahauasqui, DLR; E. Chatre, EC


9. Tolles-Lawson Coefficient Dependence Using F-16 Data Set: B. Blakeley, 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


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

4:00 Resilient PNT for the Black Sea and Danube Region: F. Mistrapau, R. Mihaela Clopat, C-V. Circa, V.G. Olteanu, GMV; I.B. Stefanescu, M. Bivolaru, ROSA RC; L. Dumitratc, P. Popov, MHD

4:23 Study on the Benefits and Uses of OSNMA in Maritime Navigation: H. Llorca, M. Lopez, E. Dominguez, GMV; T. Tisel, SAAB; P. Scheidemann, EUSPA


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

5:25 - 5:55, Break. Refreshments in Exhibit Hall

5:00 Potential LEO Satellite Augmentation for Rescue-21 in Alaska: D. McGarry, R.J. Hartnett, U.S. Coast Guard Academy; P.F. Swazek, University of Rhode Island; B. Chan, B. Evans, and A. Kenna, U.S. Coast Guard Academy

5:12 VDE- Terrestrial Channel Performance Assessment: G. Johnson, K. Dykstra Serco, Inc.; J. Forster, J. Spilbury USCG Research and Development Center

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

2:58 R-Mode – Terrestrial Navigation for Maritime Users: S. Gewies, F. Giacomo Rizzi, L. Grundhüfer, N. Hehenkamp, German Aerospace Center (DLR); M. Hoppe, German Federal Waterways and Shipping Administration

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

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


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


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


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


Alternates


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. Domna Gepner-Brezinska
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:
2. Dr. Timothy Seitz, Research Team Lead, Transportation Research Center (TRC) Inc.
3. Dr. Eldar Rubinov, Positioning & Geodesy Technical Lead, FrontiersSI
4. Dr. Ilaria Martini, Principal 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.

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

Free Time in the Exhibit Hall
5:30 p.m. – 7:00 p.m
ION GNSS+ Exhibit Hall
Centennial Ballroom, 3rd Floor

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 registration.
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
  Johns Hopkins University


8:57 Seamless Navigation for Indoor-Outdoor Positioning Using GNSS-Aided UWB/WiFi/IMU System: A. Siemun, M. Eliashoury, K. Selvan, P. Vallsuo, H. Kuusniemi, M.S. Elmersat, 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. Geraghty, J. 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


2. Exploring the Benefits of Deep Learning-Based Sensors Error Estimation for Improved Accuracy and Positioning: E. Mounier, J. Shum, University of Colorado Denver

3. Performance Analysis of LEO Multi-Constellation Aided GNSS Tracking GPS-like Signals Transmitted from LEO Satellites Usage: M. Abduljawad, United Arab Emirates University; A.M. Brack, 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

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

5. 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. Biondi, York University


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

Session E3b: High Precision GNSS Positioning in Challenging Environments (8:30 a.m. – 10:05 a.m.)
Room: Mineral Hall F/G (3rd Floor)

- Dr. Yu-Xiang (Phillip) Peng
  QualiComm Technologies Inc.

- Dr. Michael Fu
  Google

8:35 Resilient High Precision Positioning Using RTK and Distributed GNSS Antenna Subarrays: C. Ozmaden, M. Brachwold, 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. Biondi, York University

9:43 Testing the Galileo High Accuracy Service in Different Operational Scenarios: L. Cucchi, S. Damy, C. Giovanna, B. Motella, M. Paolini, European Commission Joint Research Centre

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. Karen Standjord
  University of Minnesota

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


11:48 An Agile, Portable, Antenna System for LEO Megastation-based PNT: W. Qin, Z. M. Komodoros, 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

3. Robust Regional Ionospheric Augmentation Based on IRIM for PPP-RTK: S. Lyu, X. Xiang and W. Yu, Shanghai Jiao Tong University

Buffer 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

Alternate 2: Future SSV for the Moon and Beyond: S. Corvo, F. Paggi, E. Zini, C. Cristodaro, Thales Alenia Space ITALIA


4. Using HEO Spacecraft Data to Investigate Navigating a Lunar Spacecraft: F. Cornish, K. Strandjord, University of Colorado Boulder

5. Lunar Navigation - Where do we go from Here?: J. Ware, N. Bicks, Lockheed Martin Space


Virtual Only: View at ion.org/gnss


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)


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 System: A. L.A. Silva, M. S. Freitas, Instituto Tecnológico de Aeronáutica (ITA); C. Faria Jr., Universidade Estadual Paulista; P. P.P. Silva, ITA; A. D. Moraes, Instituto de Aeronáutica e Espaço; B. C. Vani, Instituto Federal de Educação, Ciência e Tecnologia de São Paulo; J. Sousasans, 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. PriyaPradhan, A. A. García Roquej, D. Payne, A. Pérez Conesa, GMG; 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, AIRHUA 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, Robert Bosch GmbH; T. Paný, M. Bochktai, Bundeswehr Univ. Munich

Alternates

1. Inter-System Bias Estimation Using the MAFA Method: D. Kwasniak, S. Cellmer, The University of Warmania and Mazury in Olszyn


Virtual Only: View at ion.org/gnss


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. Tronbini, D. Leone, A. Bruno, M. D’Adzedo, G. Fado, 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, Tectotop Microelectronics Technology Co. Ltd.; M. Liu, Hong Kong University of Science and Technology; B. T.G.S. Kamara, 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)

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 SAT Level 4-5 autonomous driving. This panel discussion will look at emerging applications, their tradeoffs including cost, complexity, maturity and long-term viability, and their promise for the future.

Panel Members

1. Ms. Irma Rodriguez 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 Navigation Technology, System Design and Development
Room: Granite (3rd Floor)


2:58 Internet-Based GNSS Signal Authentication: D. Manandhar, The University of Tokyo

Virtual Only: View at ion.org/gnss

5:08 Asymmetric Positioning for NLOS Mitigation: O. Moraes, Instituto de Aeronáutica e Espaço; B. C. Vani, Stanford University; O-J. Kim, Sejong University; Q. Verspieren, The University of Sydney

Virtual Only: View at ion.org/gnss

Session D4: Indoor and Urban Navigation and Mapping
Room: Capitol Ballroom 5–7 (4th Floor)

1:50 Asymmetric Positioning for NLOS Mitigation: O. Moraes, Instituto de Aeronáutica e Espaço; B. C. Vani, Stanford University; O-J. Kim, Sejong University; Q. Verspieren, The University of Sydney

2:12 Attitude Determination in Urban Canyons: A Synergy Between GNSS and 56/66 Observations: P. Zheng, X. Liu, T. Ballal, and T. Y. Al-Naffouri, King Abdullah University of Science and Technology (KAUST)


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, IT LABS Corp.; H. Kyung, T. Lee, KIST & T.I 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 Mitigation Method for Precise Indoor Positioning: M.-J. Kim, K.H. Kim, O-J. Kim, Sejong University

Virtual Only: View at ion.org/gnss

Alternates

1. Positioning in the GNSS Signal Disconnection Area Based on Multiple Pseudolites: S. Song, J. Moon, J. Lee, D. Kim, NoLL


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
ION GNSS+ Technical Sessions - Friday Morning
8:30 a.m. - 12:15 p.m.

Session A5a: BeiDou - The Next Generation (8:30 a.m. – 10:05 a.m.)
Room: Mineral Hall F/G (3rd Floor)


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

11:48 Fast Time to First fix Time Method to Improve First Fix Accuracy of Modernized Signals In Urban Canyons: P. McBuney, oreNav

Alternates
1. On the Impact of Co-Op Tracking on Multi-Frequency GNSS Synthetic Aperture Processing: J. Dampf, M. Bochkati, T. Panay, University of the Bundeswehr Munich

2. Benefits of CNSS-Based Multipath Detection for Robust GNSS Positioning: A. Guillard, 3D Aerospace / ENAC; P. Thevenon, C. Milner and M. Cacabiau, ENAC

Virtual Only: View at ion.org/gnss

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 Canyons: 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 First Fix Method to Improve First Fix Accuracy of Modernized Signals In Urban Canyons: P. McBuney, oreNav

Alternates
1. On the Impact of Co-Op Tracking on Multi-Frequency GNSS Synthetic Aperture Processing: J. Dampf, M. Bochkati, T. Panay, University of the Bundeswehr Munich

2. Benefits of CNSS-Based Multipath Detection for Robust GNSS Positioning: A. Guillard, 3D Aerospace / ENAC; P. Thevenon, C. Milner and M. Cacabiau, ENAC

Virtual Only: View at ion.org/gnss

Session B5: Land-Based Applications (8:30 a.m. – 10:05 a.m.)
Room: Capitol Ballroom 5-7 (4th Floor)

Ed Olson
John Deere

Tara Mina
Stanford University

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

8:57 Galileo Synthetic Meta-Signal Observations: Performance and Limitations: C. Cois, Independent Researcher; D. Bonio, European Commission, Joint Research Centre


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. Martínez Rade, J. D. Calle Calle, G. Garcia 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. Villalta, Irdno; J. Ibáñez-Guzmán, E. Stawiarski, Renault; P. Nemry, Septentrio; S. Y. Yoon, Astarsense; W. Fox, K. Calle Calle, VVA

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


Alternates
1. Real Time Sensor Based Spoofing Detection and Mitigation for Mass Market Automotive GNSS Receivers: E. Moncasi and A. Samisieki, u-block AG

2. PPP-RTK Supporting Low-Cost Inertial Navigation System for Land Vehicle Navigation: M. Cutugno, University of Benevento Giusto di Fortunato; U. Robustelli, University of Naples Parthenope; G. Puglialo, Univ. of Naples Federico II

3. AirPLan (Artificial Intelligence for Land Planning): S. Roberts, P. Bhatia, C. Hill, Geospatial Ventures Ltd.; C. Hancock, University of Loughborough


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

Session C5: GNSS Applications in Space (8:30 a.m. – 12:15 p.m.)
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. McNichnt, and S. Ugazio, Ohio University

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


9:43 NAVIMOON: Performance and Characteristics of GNSS Spaceborne Receiver in Representative Lunar Orbit: P. Giers, ESA; M. Scotti, SpacePNT; B. Kieniewicz, ELECL. A. Lepleaut, Politecnico di Torino; R. Swindell, ESA; C. Botton, SpacePNT; J. Ventura-Traveset, ESA

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


Virtual Only: View at ion.org/gnss

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. Panay, 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)

8:35 ME40: Manifold Encapsulation for Visual Inertial Odometry with Application to Vehicle Navigation in Urban Environments: S. Kouda 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. Viti, University of Trento; F. Remondino, 3DOM; C. Toth, The Ohio State University

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


11:03 Trusted Inertial Terrain-Aided Navigation (TITAN): T. Haydon, Sandia National Labs; T. Humphreys, The Ohio State University

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


Alternates

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


Session A6b: Urban and Indoor Radio Positioning (3:20 p.m. – 4:50 p.m.)
Room: Mineral Hall F/G (3rd Floor)

Courtnay Maria Draper
Dr. Erc Pehls
Stanford University

Saif Yaman Zaman
Collins Aerospace

Sven Walner
European Space Agency

View Virtual Paper Presentations for all sessions in the ION GNSS+ Virtual Portal at ion.org/gnss
Session D6: Robust Navigation Using Alternative Nav Sensors and Solutions
Room: Capitol/Ballroom 1-3 (4th Floor)


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


3:42 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- Ephemeris 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 GVM: 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


Virtual Only: View at ion.org/gnss

1. Improving LEOSatellite 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); Y. Yang, NTSC, CAS, UCAS

2. Integer Ambiguity Resolution in Multi-Constellation GNSS for LEOSatellite 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

Dr. Okary Orzech
German Aerospace Center (DLR)

Dr. Yang Wang
University of Colorado at Boulder

Session E6: Sensor Network and Cooperative Navigation
Room: Mineral Hall D/E (3rd Floor)

1:50 Swarm Navigation using Signals of Opportunity from Uncooperative LEO Satellites: D. Beauty and M. Pasiuk, 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


2:58 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


3:42 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


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


Dr. Taro Suzuki
Chiba Institute of Technology
1:50 Swarm Navigation using Signals of Opportunity from Uncooperative LEO Satellites: D. Beauty and M. Pasiuk, Virginia Tech

Dr. Alex Minetto
Politecnico di Torino
1:50 Swarm Navigation using Signals of Opportunity from Uncooperative LEO Satellites: D. Beauty and M. Pasiuk, Virginia Tech

Dr. Tammy L. Hinks
Air Force Institute of Technology
1. Superior Achievement Award: recognizing individuals who are practicing navigators and have made outstanding contributions to the advancement of navigation

2. Distinguished PTTI Service Award: recognizing outstanding contributions related to the management of PTTI systems

3. Captain P. V. H. Weems Award: recognizing contributions to the art and science of navigation

4. Tycho Brahe Award: recognizing outstanding contributions to the science of space navigation

5. Norman P. Hays Award: recognizing outstanding contributions related to the management of PTTI systems

6. Captain P. V. H. Weems Award: recognizing contributions to the art and science of navigation

7. Tycho Brahe Award: recognizing outstanding contributions to the science of space navigation

8. Norman P. Hays Award: recognizing outstanding contributions related to the management of PTTI systems

9. Captain P. V. H. Weems Award: recognizing contributions to the art and science of navigation

10. Tycho Brahe Award: recognizing outstanding contributions to the science of space navigation

11. Norman P. Hays Award: recognizing outstanding contributions related to the management of PTTI systems

12. Captain P. V. H. Weems Award: recognizing contributions to the art and science of navigation

13. Tycho Brahe Award: recognizing outstanding contributions to the science of space navigation

14. Norman P. Hays Award: recognizing outstanding contributions related to the management of PTTI systems

15. Captain P. V. H. Weems Award: recognizing contributions to the art and science of navigation

16. Tycho Brahe Award: recognizing outstanding contributions to the science of space navigation

17. Norman P. Hays Award: recognizing outstanding contributions related to the management of PTTI systems

18. Captain P. V. H. Weems Award: recognizing contributions to the art and science of navigation

19. Tycho Brahe Award: recognizing outstanding contributions to the science of space navigation

20. Norman P. Hays Award: recognizing outstanding contributions related to the management of PTTI systems

Session F6: PANEL: Beyond GNSS: Emerging Trends in LEO-Based Satnav and Signals of Opportunity for PNT
Room: Capitol Ballroom 4 (4th Floor)

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.

Dr. Samjey Gurunawardana
Air Force Institute of Technology

Dr. Joanna Hinks
AFLR Space Vehicles Directorate

Nominating a Colleague for ION Fellows and Annual Awards
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 encouragement, 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
THIRD FLOOR

ION GNSS+ Exhibit Hall
Centennial Ballroom

Work Space
Centennial Ballroom Foyer

ION GNSS+ Registration
Business Center

FOURTH FLOOR

Capitol Ballroom 567
Capitol Ballroom 4
Capitol Ballroom 123

Ad hoc Meeting Rooms
## MONDAY, SEPTEMBER 11 • PRE-CONFERENCE SHORT COURSES
(included in full in-person registrations)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1:45 p.m. - 3:30 p.m.</td>
<td>A5a: Beidou - The Next Generation (Mineral Hall F/G)</td>
<td>B8: Land-Based Applications (Capitol Ballroom 5-7)</td>
<td>B9: Space Applications (Capitol Ballroom 5-7)</td>
<td>C5: GNSS Applications in Space (Capitol Ballroom 1-3)</td>
<td>D5: Navigation Using Environmental Features (Agate)</td>
<td>E5: PANEL: Algorithms and Methods for GNSS Cyber Physical Security (Capitol Ballroom 4)</td>
</tr>
<tr>
<td>5:00 p.m. - 6:00 p.m.</td>
<td>A6b: Urban and Indoor Radio Navigation (Capitol Ballroom 1-3)</td>
<td>B14: Land-Based Applications (Capitol Ballroom 5-7)</td>
<td>B15: Space Applications (Capitol Ballroom 5-7)</td>
<td>C8: Navigation Using Environmental Features (Agate)</td>
<td>D8: Indoor and Urban Navigation and Mapping (Capitol Ballroom 5-7)</td>
<td>E8: GNSS Navigation in Challenging Environments (Mineral Hall D/E)</td>
</tr>
</tbody>
</table>

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

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

GPS IIIF delivers resilient capabilities, including improved anti-jamming, to toughen and protect the technology that allows our customers to complete missions with precision and accuracy, and to return home safely.

AHEAD OF READY

©2023 Lockheed Martin Corporation