Volume 33 No 4 **Fall 2023**

ION®
INSTITUTE OF NAVIGATION
Quarterly Newsletter

ION GNSS+ 2023

The International GNSS Community Returns to Denver, Colorado

One thousand attendees gathered for the second consecutive year in Denver, Colorado from 35 countries at the Hyatt Regency at the Denver Convention Center in downtown Denver, Colorado, for ION GNSS+ 2023. The full-sized technical program and commercial exhibit highlighted: autonomous and safety critical applications; status and future trends in navigation; navigation for the mass market; multisensor and autonomous navigation; algorithms and methods; and advanced GNSS technologies. An additional 100 attendees participated virtually, noting a decrease in virtual attendance and return to a full in-person event.

Dr. Brian "Bam" McClendon, Niantic, kicked off the plenary session with his "Where Pokémon GO: Building a Dynamic 3D AR Map of the World," presentation. McClendon shared the development of the 2005 Google Maps launch, the challenges in building maps, and the April Fool's joke that was the beginning of

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A U.S. PERSPECTIVE

Enhancing Dominance and Resilience for Space-Based Systems: The Ukrainian Example

Makena Young

Space underpins many important technologies and services that we use in our daily lives and on which U.S. safety and national security depend: from navigation applications in smartphones and financial transactions that rely on Global Positioning System (GPS) and communication satellites, to understanding changes in the environment such as weather forecasting and monitoring soil conditions for crop management.

The United States has long benefited—technologically, economically, societally, militarily, and diplomatically—from its dominance in space. But that advantage is eroding as the domain changes. Space is becoming more diverse, more disruptive, more disordered, and together these inherently make the domain more dangerous.

Space has Become More Dangerous

Our allies and partners have become much more dependent on space across the full spectrum of combat operations, as well as every day civilian uses, and we have become much more dependent on space. If you want to be able to project power over long distances, there really is no substitute for the capabilities that space provides.

Counterspace weapons vary significantly in the types of effects they create, how they are deployed, their detectability, their ability to be attributed to a source, and the level of technology and resources needed for their development and fielding.

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The Institute of Navigation
8551 Rixlew Lane, Suite 360
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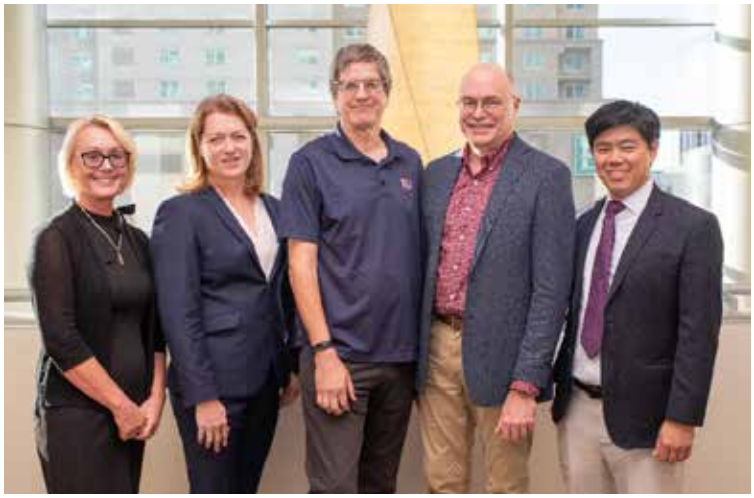
PRESIDENT'S COLUMN | DR. SHERMAN LO

GPS Commemorates 50 Year Anniversary at ION GNSS+

The ION's Satellite Division hosted ION GNSS+ 2023, September 11-15, 2023, with 1000 in-person attendees in Denver, Colorado, and a full-sized technical program. Highlights of the week's event included a fantastic plenary session with keynote addresses presented by Dr. Brian "Bam" McClendon, SVP Engineering, Niantic, *Where Pokémon GO: Building a Dynamic 3D AR Map of the World.* Dr. McClendon recounted the history of location-based mapping at Google and for various applications including both Pokémon GO and his most recent Monster Hunter series game. Additionally, ION past president and ION Fellow Dr. John Raquet provided a very astute comparison between the navigation performed in nature versus the man-made navigational systems in unmanned vehicles in his address, *UAVS Natural Autonomous Vehicles (NAVs)—Are We Closing the Gap?* Both addresses are available for free viewing through the ION's website and YouTube channel.

Other highlights of ION GNSS+ included the return of Monday's free short courses that were standing room only this year: GPS/GNSS 101 taught by Dr. John Raquet; Space Applications of GNSS taught by Dr. Penina Axelrad; GNSS Jamming and Spoofing – LEO as Fallback taught by Dr. Todd Humphreys; and LEO PNT – Architectures and Performance Trades taught by Dr. Tyler Reid. We are already planning to expand both the program and the seating in 2024!

I want to personally thank all the volunteers that made the technical event possible, including the Satellite Division officers and committee chairs, the technical program committee, all the tutorial and short course instructors, session chairs, exhibitors, sponsors, and the many speakers. Also, I'd like to thank all of the attendees for coming and making ION GNSS+ such a lively event.



Dr. Dorota Grejner-Brzezinska, Plenary Session Chair; Sandy Kennedy, Satellite Division Chair; Dr. Brian "Bam" McClendon, Plenary Speaker; Dr. John Raquet, Plenary Speaker; and Dr. Sherman Lo, ION President

Parkinson Commemorates 50 Years of GPS at CGSIC

As part of the Civil GPS Service Interface Committee (CGSIC) meeting on Tuesday, September 12, Dr. Bradford Parkinson presented the history of the GPS as 2023 marks the 50th anniversary of both the "Lonely Halls" meeting on Labor Day in September 1973 when the main design elements of the GPS proposal were finalized; and GPS gained initial approval as a DOD program in December 1973. Happy 50th birthday to GPS and congratulations to the entire community for helping raise this system as an invaluable part of our society.

ION Council Convenes

The ION Council met prior to the commencement of ION GNSS+ and approved a motion to begin using a portion of the ION Reserve Fund's annual returns to sustain specific ION programs on an annual basis, removing the need to fund the identified programs from the annual program revenues in the next budgeting cycle. In the past number of years, the Reserve Fund balance has

ION GNSS+ 2023 Program Committee: Dr. John Raquet, Tutorials Chair; Dr. Ilaria Martini, Track Chair; Dr. Andrew Neish, Track Chair; Deborah Lawrence, Track Chair; Ernesto Etienne; Program Co-Chair Commercial Tracks; Dr. Juan Blanch, Program Co-Chair Research Tracks; Dr. Simona Circiu, Track Chair; Dr. Seebany Datta-Barua, Track Chair; and Dr. Li-Ta Hsu, Track Chair

Parkinson presents at CGSIC, September 11, 2023, Denver, CO

exceeded the level identified to provide the required safety net. Parameters and controls were also reviewed and discussed.

Using a portion of the Reserve Fund's annual earnings will assist ION in combating inflationary pressure to either precipitously increase fees, or cut services to members/conference attendees, and enable ION to remain competitive in the marketplace. It was an optimistic report to see ION faring so well in a competitive post-COVID economy.

The Council is scheduled to meet again in January 2024 in conjunction with the ION's International Technical Meeting (ITM) and Precise Time and Time Interval (PTTI) Systems Meeting.

Follow us on Facebook, find us on X (formerly Twitter) at @ionavigation, and subscribe to youtube.com/@ionavigation

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the Pokémon GO craze in 2016.

Dr. John Raquet, the second keynote of the evening, presented "UAVs vs. Natural Autonomous Vehicles (NAVs)—Are We Closing the Gap?" Raquet compared current UAV technologies to navigators found in the natural world (primarily birds) based on various specifications. His conclusion? Manmade UAV's are advancing, but natural navigators were superior in almost every way. The ION has made this session available for complimentary viewing on the ION's YouTube channel: https://www.youtube.com/user/InstOfNavigation.

Dr. John Raquet, ION GNSS+ Plenary

Participants in the Status of GPS, Galileo, BDS, QZSS, KPS, and NavIC panel session: Dr. P.S. Sura, UR RAO Satellite Centre; Dr. Chris Hegarty, The MITRE Corporation; Taegyu Kim, Ministry of Science and ICT; Eric Chatre, European Commission; Cordel DeLaPena, Space Systems Command, USSF; Miguel Manteiga, ESA; Dr. José Ángel Ávila Rodríguez, ESA; Motohisa Kishimoto, QZSS Strategy Office, National Space Policy Secretariat, Cabinet Office. Not pictured: Dr. Xiaochun Lu, China Satellite Navigation Office (presentation made available virtually)

In addition to the plenary session, the conference hosted over 400 technical presentations (both in-person and virtually), a tutorials program, a return to the short course program, and a commercial exhibit. The panel discussions continued to be a highlight and were well attended with special interest in the Status of the Systems panel (see the GNSS Updates column for more information) as an annual favorite. Additionally, a new Smartphone Decimeter Challenge was announced (see details below). Attendee favorites this year, judging by crowd-sourcing, were sessions covering lunar PNT and sessions related to LEO-based satnav and signals of opportunity.

Mark your calendars for next year when ION GNSS+ 2024 will move to the Baltimore Inner Harbor, Baltimore, Maryland, September 16-20, 2024.

Smartphone Decimeter Challenge

Google, the Institute of Navigation's Satellite Division, and Kaggle are sponsoring the 3rd Smartphone Decimeter Challenge at ION GNSS+. The competition began September 12, 2023, and will end May 23, 2024. Over 150 new traces containing raw GNSS measurements, sensor data, and precise ground truth will be publicly available. Participation in the competition is open to everyone. Participants are encouraged to submit an abstract to the session titled "Smartphone Decimeter Challenge" which will take place at ION GNSS+ 2024.

Competition Description:

Teams develop high precision GNSS positioning using a pool of GNSS & IMU datasets collected from smartphones, accompanied by high accuracy ground truth. They compete to achieve the best location accuracy with the datasets provided. To be eligible for prizes, competitors must provide a technical paper, register for the ION GNSS+ 2024 conference and present their paper. Authors must submit a completed manuscript in proper form by June 30, 2024. See g.co/gnsstools for details.

The top three teams receive:

- Prize money ($7,000 first place; $5,000 second place; and $3,000 third place)
- A guaranteed speaking slot at ION GNSS+ 2024
- A complimentary registration for the presenting author
- Up to four nights complimentary lodging for the presenting author
- ION GNSS+ conference attendance incentive of $1,700 for the presenting author

Additional Information

- For more information, including rules and regulations, visit g.co/gnsstools.
- Presenting authors not placing first, second or third in the competition are required to register for the ION GNSS+ conference and pay applicable registration fees.

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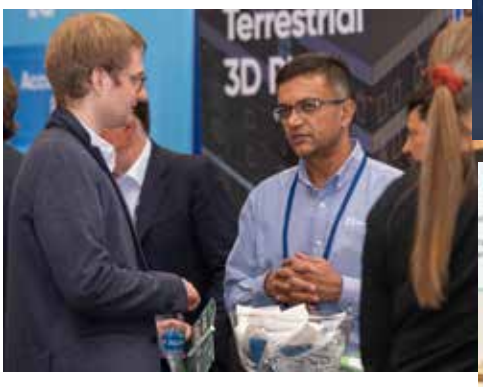



ION GNSS+ Award Winners

Dr. Todd Humphreys, 2023 Kepler Award winner

2023 Kepler Award

The 2023 Kepler Award was presented to Dr. Todd Humphreys for sustained contributions to the art and science of navigation signal processing; and for increasing the public awareness of the vulnerability of GNSS.

Dr. Todd Humphreys has made fundamental contributions to secure, precise, and robust PNT; and to GNSS software-defined receivers (SDRs).

In 2006 Dr. Humphreys developed the first GNSS SDR on a small general-purpose processor capable of continually tracking dozens of signals in real time. This C++-based receiver is now a highly optimized science-grade multicore GNSS SDR, which was the first of its kind to demonstrate centimeter-accurate GNSS positioning with a smartphone antenna.

Dr. Humphreys initiated the study of GNSS security in open literature through his publications on assessing the threat of civilian spoofers. He designed and studied diverse methods to detect and counteract spoofing attacks, and developed standardized test conditions for evaluating GNSS signal authentication concepts. As part of this work, he made the risks of GNSS jamming and spoofing known to a wider audience and increased public awareness of such vulnerabilities with live demonstrations and public addresses, including participating in international advisory boards and testifying before U.S. Congress.

Dr. Humphreys deserves credit for catalyzing the movement of precision carrier-phase-based GNSS into the mass market. His laboratory was the first to demonstrate cm-accurate real-time kinematic (RTK) positioning through a smartphone antenna.

Dr. Humphreys, together with former student Zak Kassas, laid the theoretical foundation for simultaneously mapping the signals-of-opportunity landscape and exploiting the signals and map for PNT. Additionally, he recently developed an interface specification for the Starlink signal structure that will enable the use of these signals for PNT.

Professor Humphreys is an outstanding educator and academic leader. His students have received multiple academic achievement awards, high-ranking industry positions, and professorial appointments at other universities. Prof. Humphreys has won several teaching awards, is a recognized technical expert who has addressed numerous academic and international policy and regulatory bodies, and participated in the governance and leadership of many PNT organizations. Dr. Humphreys holds an Institute of Navigation (ION) Thurlow Award (2014) and is a Fellow of the RIN and the ION.

Dr. Humphreys currently holds the Ashley H. Priddy Centennial Professorship in Engineering in Aerospace Engineering and Engineering Mechanics at the University of Texas at Austin where he directs the Radionavigation Laboratory and the Wireless Networking and Communications Group. He received his BS and MS from Utah State University, and PhD in Aerospace Engineering from Cornell University.

2023 Parkinson Award

The 2023 Parkinson Award was awarded to Dr. Maoran Zhu from Shanghai Jiao Tong University for his

Dr. Maoran Zhu, 2023 Parkinson Award winner

thesis Inertial-Based Navigation State Estimation by Polynomial Optimization and Applications.

The Bradford W. Parkinson Award is awarded annually to an outstanding graduate student in the field of Global Navigation Satellite System (GNSS). This award, which honors Dr. Parkinson for his leadership in establishing both the U.S. Global Positioning System and the Satellite Division of the Institute of Navigation, includes a personalized plaque and a $2,500 honorarium.

Red Pencil Recognition

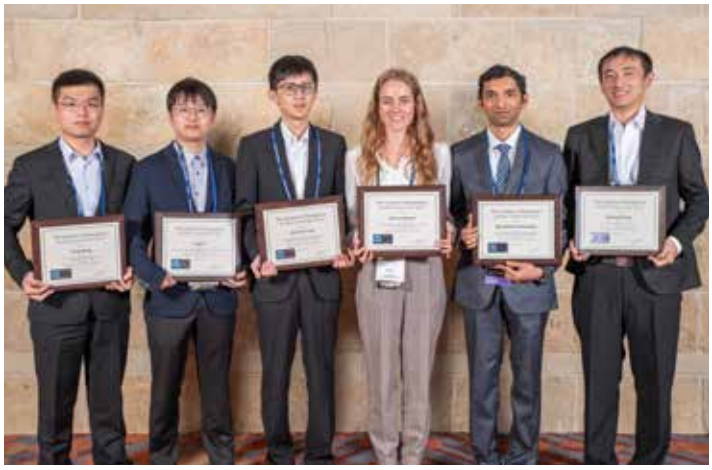
The following were recognized with a bouquet of red pencils and an Amazon gift card for their outstanding contributions to the Institute this past year in their role as a peer reviewer for various ION activities:

The ION would like to thank each of them for providing high-quality, timely reviews when called upon.

Red Pencil Recipients: Dr. Jihye Park (left) and Dr. Michael Coleman (right) recipients, pictured with ION president Dr. Sherman Lo (center). Recipient not pictured: Dr. Robert Lutwak

ION GNSS+ 2023 Student Paper Award Winners Recognized

The Satellite Division awarded six students with Student Paper awards. Recognized industry and academic experts selected the winners.



2023 Student Paper Award Winners: Feng Wang, Wuhan University; Ding Yi, York University; Shu-Hua Tsao, National Cheng Kung University; Emma Dawson, Queen's University; Shrivathsan Narayanan, Technical University of Berlin; Qiming Zhong, University College London

ION GNSS+ 2023 Best Presentation Awards

Track A: Autonomous and Safety Critical Applications

Session A1: Navigation and Positioning
Passive Localization Using Multipath Propagation of Low-Cost Ultra-Wideband Devices: Christian Gentner, Martin Schmidhammer, Benjamin Siebler, *German Aerospace Center (DLR);* Josef Krska, *Czech Technical University in Prague*

Session A2: Applications of GNSS Measurements from Smartphones
Detecting Single-Antenna Spoofing Attacks by Correlation in Time Series of Raw Measurements: Alex Minetto, Akmal Rustamov, Fabio Dovis, *Politecnico di Torino*

Session A4: Positioning Technologies and Machine Learning
Tightly Coupled Graph Neural Network and Kalman Filter for Smartphone Positioning: Adyasha Mohanty and Grace Gao, *Stanford University*

Session A5b: Harsh Urban and Indoor GNSS
Fast Time to Fine Time Method to Improve First fix Accuracy with Modernized Signals in Urban Canyons: Paul McBurney, *oneNav*

Session A6a: New Technologies, Opportunities and Challenges
Evaluating Performance of Meta-Signal Exploitation in End User: Carlos Moriana, Guillermo Ortas, Esteban Garbin, *GMV-ES;* Elisa Benedetti, Nicholas Boreham, *GMV-UK;* Pedro Boto, *GMV-PT;* Javier Miguez, Jose Antonio Garcia-Molina, Floor Melman, *European Space Agency (ESA)*

Session A6b: Urban and Indoor Radio Positioning
A Look at the Sky: Opportunistic Navigation with Multi-Constellation LEO Satellites: Sharbel Kozhaya, Haitham Kanj, and Zak (Zaher) M. Kassas; *The Ohio State University*

Track B: Status and Future Trends in Navigation

Session B1: Augmentation Services, Integrity, and Authentication
Authentication Security of Combinatorial Watermarking for GNSS Signal Authentication: Jason Anderson, Sherman Lo, Todd Walter, *Stanford University*

Session B2: Marine Applications, and Search and Rescue
Study on the Benefits and Uses of OSNMA in Maritime Navigation: Héctor Llorca, Marcos López, Enrique Domínguez, *GMV;* Tobias Tisell, *SAAB;* Philipp Scheidemann, *EUSPA*

Session B3: Autonomous Applications
Bounding GPS-Based Positioning and Navigation Uncertainty for Autonomous Drifting via Reachability: Asta Wu, Adyasha Mohanty, Anonto Zaman, Grace Gao, *Stanford University*

Session B5: Land-Based Applications
Galileo Synthetic Meta-Signals: Performance and Limitations: Daniele Borio, *European Commission, Joint Research Centre;* Ciro Gioia, *Independent Researcher*

Session B6: Aviation and Aeronautics
GNSS Radio Frequency Interference Mitigation in Collins Commercial Airborne Receivers: Angelo Joseph, Joseph Griggs, Patrick Bartolone, Bernard Schnaufer, Huan Phan, Vikram Malhotra, *Collins Aerospace*

Track C: Navigation for Mass Market

Session C2: Trends in GNSS Augmentation Systems
GNSS Signal Anomaly Detection Using DCB Estimates and Machine Learning Algorithms: Steffen Thoelert, *German Aerospace Center (DLR) and RWTH Aachen University;* Gerardo Allende-Alba and Peter Steigenberger, *DLR*

Session C3: Spectrum: Protection and Optimization
Detecting Space Based Interference on GNSS Signals: Akshata Patil, R. Eric Phelts, Yu-Hsuan Chen, Sherman Lo, and Todd Walter, *Stanford University*

Session C4: Trends in Future Satellite Navigation Technology, System Design and Development
A GNSS-Synchronized Satellite Navigation Payload for LEO PNT: Florian Kunzi, Benjamin Braun, Markus Markgraf, Oliver Montenbruck, *German Aerospace Center (DLR) / German Space Operations Center (GSOC)*

Session C5: GNSS Applications in Space
Single Frequency RTK Relative Navigation for Autonomous Formation Flying Mission of SNUGLITE-III CubeSat: Hanjoon Shim, Yonghwan Bae, Jae Woong Hwang, and Changdon Kee, *Seoul National University;* In Hoi Koo, *Korea Aerospace Research Institute*

Session C6: Technologies for Scientific and Sectorial Applications
Performance Monitoring at the DLR Galileo Competence Center: Katharina Lutz, Lukasz Greda, Marios Smyrnaios, Wolfgang Dilg, Thomas Schilling, Ilinca Ioanid, Sophie Schrade, Bernhard Röttgers, and Johann Furthner, *DLR Galileo Competence Center;* Steffen Thölert, Gerardo Allende Alba, *DLR Institute of Communications and Navigation;* Martin Kriegel, *DLR Institute for Solar-Terrestrial Physics;* Luca Spataro, Annika Meinecke, Rebecca Brydon, *DLR Institute for Software Technology*

Track D: Multisensor and Autonomous Navigation

Session D1: Alternative Technologies for GNSS-Denied Environments
First Field Trial Results of Hybrid Positioning with Dedicated 5G Terrestrial and UAV-Based Non-Terrestrial Networks: José A. del Peral-Rosado, Ali Yildirim, Susanne Schlötzer, Patric Nolle, *Airbus Defence and Space;* Sara M. Razavi, Ericsson; Sagar Parsawar, Rakesh Mundlamuri, Florian Kaltenberger, *Eurecom;* Niilo Sirola, *Exafore;* Stefano Garlaschi, Luca Canzian, *Qascom;* Jukka Talvitie, Tampere University; Ivan Lapin, *European Space Agency (ESA);* Detlef Flachs, *Airbus Defence and Space*

Session D3: GNSS Integrity Augmentation
Detection and Exclusion of Multiple Faults Using Euclidean Distance Matrices: Derek Knowles and Grace Gao, *Stanford University*

Session D4: Indoor and Urban Navigation and Mapping
Neural City Maps: A Case for 3D Urban Environment Representations Based on Radiance Fields: Mira Partha, Shubh Gupta, and Grace Gao, *Stanford University*

Session D5: Navigation Using Environmental Features
Neural City Maps for GNSS NLOS Prediction: Daniel Neamati, Shubh Gupta, Mira Partha, and Grace Gao, *Stanford University*

Session D6: Robust Navigation Using Alternative Navigation Sensors and Solutions
Integrity Assurance of LIRTK Using SS-RAIM Against Sensor Faults for UAV Applications: Noah Minchan Kim, Dongchan Min, and Jiyun Lee, *Korea Advanced Institute of Science and Technology*

Track E: Algorithms and Methods

Session E1: Advanced Processing of Terrestrial Signals of Opportunity
Commercial Radio Phase Difference of Arrival (PDOA) for GNSS-Independent PNT: David W.A. Taylor, *Setter Research, Inc.*

Session E2: High Precision and High Integrity Navigation
Accelerated SF-PPP Convergence of BDS-3 B1 Band by Wideband Signal Observations: Yunhan Qi, Tsinghua University; Zheng Yao, Mingquan Lu, *Tsinghua University, and Beijing National Research Center for Information Science and Technology*

Session E3a: All-Source Intelligent PNT Methods
Improvements to GNSS Positioning in Challenging Environments by 3DMA Lidar Informed Selective Satellites Usage: Russell Gilabert, Julian Gutierrez, Evan Dill, *NASA Langley Research Center*

Session E3b: High Precision GNSS Positioning in Challenging Environments
Differentiable Factor Graph Optimization with Intelligent Covariance Adaptation for Accurate Smartphone Positioning: Penghui Xu, Hoi-Fung Ng, Yihan Zhong, Guohao Zhang, Weisong Wen, Bo Yang, Li-Ta Hsu, *The Hong Kong Polytechnic University*

Session E3c: LEO for Positioning, Navigation, and Timing
Tracking GPS-Like Signals Transmitted from LEO Satellites and Propagated Through Ionospheric Plasma Irregularities: Jiawei Xu, Y. Jade Morton, *University of Colorado Boulder;* Dongyang

Xu, NovAtel; Yu Jiao, Trimble Navigation; Joanna Hinks, *Air Force Research Laboratory*

Session E4: GNSS Navigation in Challenging Environments
GNSS Multi-Frequency Combined Direct Position Estimation in the Urban Canyon Environment: Jihong Huang, Rong Yang, Xingqun Zhan, *Shanghai Jiao Tong University*

Session E6: Sensor Network and Cooperative Navigation
Swarm Navigation Using Signals of Opportunity from Uncooperative LEO Satellites: Dawson Beatty and Mark L. Psiaki, *Virginia Tech*

Track F: Advanced GNSS Technologies

Session F1: Remote Sensing, Timing, Space and Scientific Applications
Addressing Inaccurate Phase Center Offsets in Precise Orbit Determination for Agile Satellite Missions: Kevin Gutsche, Thomas Hobiger, *University of Stuttgart,* Stefan Winkler, *Airbus Defence and Space*

Session F2: Advanced Software and Hardware Technologies for GNSS Receivers
Acquisition and Tracking of Starlink LEO Satellite Signals in Low SNR Regime: Haitham Kanj, Sharbel Kozhaya, and Zak (Zaher) M. Kassas; *The Ohio State University*

Session F3: Lunar Positioning, Navigation, and Timing 1
Satellite Ephemeris Approximation Methods to Support Lunar Positioning, Navigation, and Timing Services: Marta Cortinovis, Keidai Iiyama, and Grace Gao, *Stanford University*

Session F4a: GNSS Robustness to Vulnerabilities 1
Fault-Robust GPS Spoofing Mitigation with Expectation-Maximization: Ashwin Vivek Kanhere and Grace Gao, *Stanford University*

Session F4b: Atmospheric Effects on GNSS
Residual Error Model to Bound Unmodeled Tropospheric Delays for Terrestrial Navigation Systems for Very Low Elevation Angles: Shrivathsan Narayanan, *Technical University of Berlin*

Session F5a: Lunar Positioning, Navigation, and Timing 2
Autonomous Lunar Orbit Determination in Support of a Lunar Positioning System: John R. Bowman and Mark L. Psiaki, *Virginia Tech*

Session F5c: GNSS Robustness to Vulnerabilities 2
Identifying Car Key Fobs as a Cause of Interference at GNSS Frequencies: Sandeep Jada, John Bowman, Mark Psiaki, *Virginia Tech;* Steven Langel, *The MITRE Corporation;* Mathieu Joerger, *Virginia Tech*

Joint Navigation Conference Breaks Attendance Records – Again!

ION's Joint Navigation Conference (JNC), hosted by the ION's Military Division on behalf of the DOD, broke attendance records for the second consecutive year. Held June 12-15 at the Town & Country Hotel in San Diego, California, nearly 1,200 attendees, representing a 10% increase from 2022, convened to focus on the strategic importance of PNT to the DOD's critical infrastructure and address the real-time needs of the warfighter; current innovation in the marketplace; and DOD's pending requirements and current policies.

The conference attracted 230 technical presentations on PNT advancements for DOD and the warfighter. Technical presentations were complemented by relevant and timely panel discussions, keynote presentations, and the popular warfighter panel.

Notable speakers this year included Dr. Jeffrey Hebert, Senior Scientist for PNT for the Air Force Research Laboratory; Dr. David Voss, Director of the Spectrum, Space warfighting Analysis Center; and Vice Admiral Frank Whitworth, Director of the National Geospatial-Intelligence Agency. Additionally, the community was informed on recent PNT impacts in the Ukraine by Makena Young from the Center for Strategic Studies (see the front-page article); and search and rescue accounts from CDR Maegan Schwartz, USCG.

ION JNC is organized by a group of dedicated volunteers that represent the various branches of the armed services as well as representatives supporting FFRDCs. Front Row (seated): Dr. Keith McDonald, Division Vice Chair; David Wolfe, Program Chair; Dr. Tom Powell, Division Chair; Dr. Greg Reynolds, Program Vice Chair; and John Langer, Division's Immediate Past Chair. Middle Row (standing): Amanda Humphreys, Dr. Madeleine Naudeau, Chad Pinkelman; Jan Anszperger; Dr. Jacob Campbell; Paul Olson; Joe Schnecker; Aaron Nascimento; and Brian Louie. Back Row: Greg Panas, John Del Colliano, Elliott Kaplan, Dr. Steven Lewis, and Dr. J.P. Laine

ION JNC 2023 Warfighter Panel: TSgt Antonio Cataldo, U.S. Air Force; 1st Lt Sarah Clancy, U.S. Space Force; QMCM Aurora Robles, U.S. Navy; Panel Co-chair Jaime Ayinde, Booz Allen Hamilton; Panel Chair, Sean Memmen, Booz Allen Hamilton; SGM Joshua Gendron, U.S. Army; LT Bryce Hawley, U.S. Navy; and LT Michael Halperin, U.S. Navy

ION JNC continued to host the popular warfighter panel – an interactive gathering of uniformed service members with recent operational experiences that discuss how to better formulate military PNT systems to meet the warfighters' operational needs.

From the Show Floor

ION's JNC Brings Industry Together to Solve PNT Challenges

Renee Knight, Inside GNSS

Reliable access to PNT is critical for the warfighter, but that's becoming more difficult as threats like jamming and spoofing continue to grow.

Manufacturers are focused on developing advanced PNT solutions that provide resilient GNSS, and many such technologies and others were on display during the Institute of Navigation's (ION) Joint Navigation (JNC) conference in San Diego. Attendees also had the chance to sit in on sessions during the event, with enhancing dominance and resilience for warfighting and homeland security PNT as this year's theme.

The show gives attendees and even exhibitors the chance to see and learn about the latest PNT innovations, with many of the same exhibitors returning year after year. VectorNav is among those companies, and, at this year's event, showcased its Tactical Series of external IMUs. The solutions can connect to external IMUs, SAASM or M-Code GPS receivers to provide a more robust solution in GPS contested environments.

"This is always an important event for us," VectorNav's Vice President, Business Development Jakub Maslikowski said. "We reconnect and engage with other companies, and learn about the latest developments in PNT technology and explore ways our technologies can benefit each other and ultimately provide benefit to the warfighter."

A Look at the Technology on Display

About 60 exhibitors were on hand to talk with attendees about their various solutions during the show, from receivers to antennas to simulators to IMUs.

Hexagon | NovAtel highlighted its GPS Anti-Jam Technology (GAJT) product line, which the company is continually improving, said Peter Soar, business development manager, military & defense at NovAtel. GAJT integrates easily into new platforms, and can be retrofitted onto existing platforms, providing protection from jamming as well as situational awareness messages when a jammer is detected.

Hexagon | NovAtel also showcased its OEM7 GNSS receivers during the conference. The company recently demonstrated that its receivers can track a Spirent Communications simulated signal that's identical to the PULSAR signal broadcast by Xona's low Earth orbit (LEO) satellites, Soar said, a significant development for alt-PNT. The new mini antennas, blade antennas and the Robust Dual-Antenna Receiver (RoDAR) for anti-jam were among the other products of interest to JNC attendees.

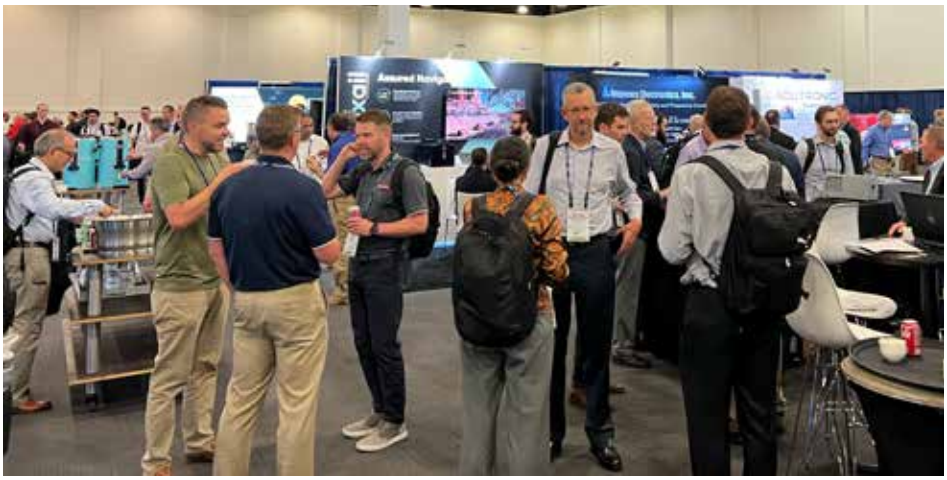
Jackson Labs, a VIAVI Solutions company, highlighted various products at their booth, including the new T/Rx, a compact, ruggedized system that can sense, capture, replay, alter and train RF signals. Military applications include Signal and Electronic Intelligence collection, electronic protection/support/attack, and interference detection and analysis.

The PNT-600 Series was also on display. The compact boxes can supplement or replace GPS signals based on connectivity to a range of timing sources, including LEO, GNSS, commercial satellite, terrestrial, wireline and atomic clock services.

The company's transcoder makes it possible to retrofit any legacy GPS equipment to a more resilient, secured PNT solution, VIAVI Solutions VP or Strategic Development Marvin Rozner said, and M-Code can be added for military applications.

"We take care of timing," Jackson Labs' Giovanni D'Andrea said. "We added anti-jamming and anti-spoofing. When you know something will happen, we take care of the issue. If L1 or L5 is blocked, we look at the other satellites and will move to another one."

ANELLO Photonics highlighted its Silicon Photonics Optical Gyroscope (SiPhOG) technology, which uses an on-chip waveguide manufacturing process integrated with a patented silicon photonic integrated circuit. This enables Fiber Optic Gyro performance with a standard silicon manufacturing process, and represents the first new gyro technology in 20 years, CEO Mario Paniccia said.



The company recently released the ANELLO GNSS INS optical gyro inertial navigation system. The system features ANELLO's optical gyro technology, which isn't sensitive to temperature or vibration, and an AI-based sensor fusion engine. It offers high-accuracy positioning and orientation for autonomous land vehicles, agriculture, and construction applications. ANELLO plans to launch a three-axis version for aircraft-like drones later this year.

"We've developed technology that allows us to operate in GPS denied environments," Paniccia said. "Because of its size, weight, power, and performance, we can apply the technology to broader applications. We're now looking at land and air and eventually sea."

JAVAD GNSS focused on two new products during the show: the TR-2S and the TR-3S. The commercial off the shelf (COTS) OEM GNSS boards, Tom Hunter said, have equivalent DOD classification and feature the company's patented anti-spoofing and anti-jamming technology.

GPS Networking displayed its military qualified GPS Splitters. The Mil-Spec antenna distributes GPS/GNSS signals throughout facilities, aircraft, and armored vehicles, splitting signals from a single antenna to two, four or eight receivers.

Boxes from GPS Networking are customizable and rugged, with about 200,000 units being used today—including those sold back in the 1990s. GPS Networking President Steve Waite said many JNC attendees visiting the booth have worked with the company before and are coming back for help with new projects.

GNSS/INS simulators like those from CAST Navigation make it possible to test in various environments and scenarios, including when jamming is present, allowing defense customers to model behaviors in any condition, said John Clark, CAST Navigation's vice president of engineering. Different vehicles, antennas, gains and jamming intensities can be used for the simulations, with various environmental factors that could impact signal reception, constellation and satellite availability also coming into play.

Ideal Aerosmith talked with attendees about its motion simulation test equipment, including rate and position tables, flight motion simulators and centrifuges. The company also offers a lab where customers can perform testing, Business Development Manager Jason Eder said.

LinQuest highlighted its GPS Interference and Navigation tool, GIANT, a mission level simulation that evaluates how PNT system performance impacts a benign or electronic combat environment. It was first developed 25 years ago, AVP/GM Matt Oliver said, but is constantly updated as PNT technology continues to evolve. GIANT supports the entire life cycle of development from concept to training to operation.

Oscilloquartz by Adtran supplies optical cesium technology, what Nino De Falcis, senior director of business development, Oscilloquartz, ADVA, describes as the next generation. He highlighted the OSA 3300, a high-performance optical cesium clock, as well as an assured PNT technology that combines the cesium clock and a grand master clock that can accept multiple sources, such as LEO, and validate them in real time and move to whichever is the best. "If there's no timing there is no PNT," he said. "Timing enables positioning and navigation. We happen to be the T."

BAE Systems introduced the NavGuide GPS receiver, an assured-positioning, navigation and timing (A-PNT) device, at the show. It will serve as a field-installable replacement for the Defense Advanced GPS Receiver (DAGR), providing access to assured M-Code PNT data and addressing the need for warfighters to have access to the anti-jam and anti-spoofing capabilities that M-Code provides. The device is built for vehicular, handheld, gun-laying, and sensor applications.

DAGR is currently used in many different mounted and dismounted platforms, BAE Director of Engineering for Navigation & Sensor Systems Todd Peterson said, so it was important to develop a replacement that's easy to integrate into current DAGR mounts and accessories.

NavGuide features a three-inch full-color graphical user interface and is easy to learn how to use.

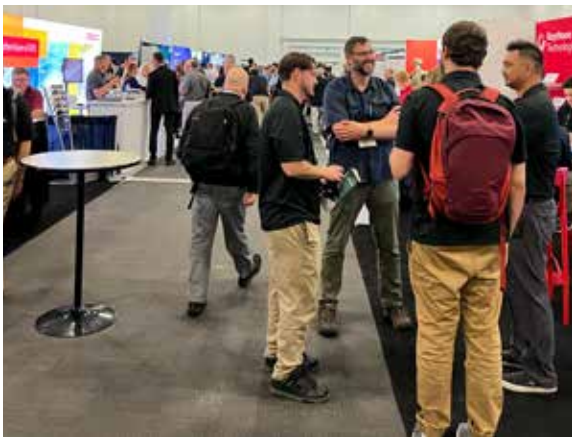
Orolia Defense & Security, a Safran Electronics & Defense company, announced that it's re-branding under a new name, Safran Federal Systems, during the show. This comes after its 2022 acquisition by Safran, a global aerospace and defense company. All that's changing is the name, Vice President of Sales and Marketing Tyler Hohman said. There will be no change in leadership, and customers will work with the same people they have for years.

Announcing the rebrand at JNC allowed the team to talk with many customers in person and to address any

questions they had. The company also showcased its Hemispherical Resonator Gyro (HRG) Crystal technology that can be integrated with M-Code. "You can now integrate a high-end navigation solution using HRG crystals and pair it with our M-Code PNT solutions," he said. "There aren't many groups in the market that can offer ultra high-end inertial paired with M-Code capability."

NavtechGPS exhibited at JNC for the first time, promoting upcoming courses. Seminar Manager Trevor Boynton provided information on their introductory courses, more advanced deep-dive offerings, as well as their hands-on courses.

SiTime, another first-time JNC exhibitor, is replacing quartz technology with semi-conductor technology in its oscillator chips, CEO Rajesh Vashist said. The company's Endura COTS Ruggedized MEMS Timing Solutions are engineered for harsh environments and are more rugged as well as more shock, vibration, and temperature resistant.



SWaP was certainly a concern for many attendees, Mayflower Communications CEO Triveni Upadhyay said, especially those looking for anti-jam solutions for small UAS. That's a focus for Mayflower, with its latest product offering a four channel GPS anti-jam solution with a small SWaP. Chelton, as the only UK-based company at the show, also spent a lot of time talking with attendees about anti-jam options. Chelton leverages its expertise in antennas to provide multi-channel anti-jam, Avionics Business Unit Manager David Collins said.

NextNav Director of Product Marketing Jay Patel was at the show to talk about TerraPoiNT, a 3D PNT solution that can provide resilient PNT without relying on satellite signals. Other exhibitors included Aevex Aerospace, Acutronic, Microchip Technology, the Air Force Research Laboratory, Psionic, Syntony GNSS, Spirent Federal Systems, L3Harris and Xona Space Systems.

While the show floor closed on Wednesday afternoon, sessions continued through Thursday, covering a variety of topics such as complementary PNT, IMU applications and simulation. Next year's JNC is slated for June 3 to 5 at the Northern Kentucky Convention Center in the greater Cincinnati area.

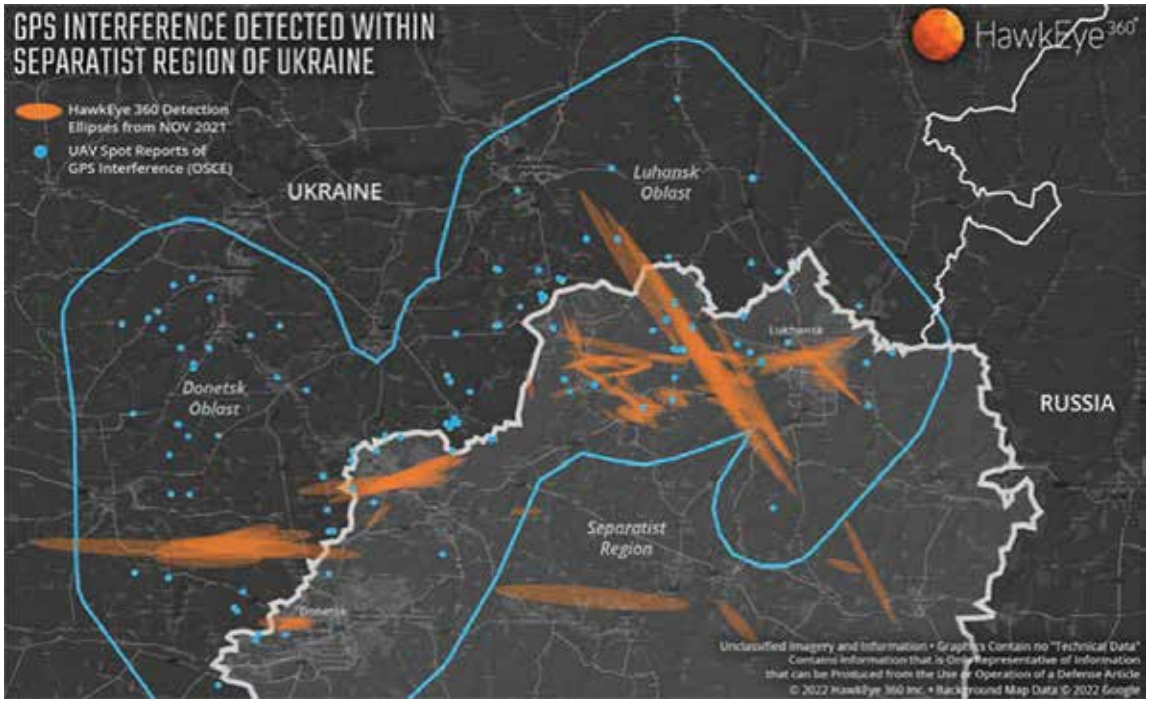
continued from page 1

The Ukrainian Example

Though as a whole Russia's space prowess is declining, Russia's attacks against space capabilities used by Ukraine are an example of how counterspace weapons can and will likely be used prior to and during future conflict, and how having a robust space-based broadband network can be vital to operations on the ground.

Months before the invasion, the Organization for Security and Cooperation in Europe was monitoring the Ukraine-Russia border using UAVs to perform overflight missions. The fleet of UAVs uses the unprotected civilian GPS signal to aid in their navigation. Throughout March and April 2021, over 60 percent of the UAV flights encountered GPS signal interference. These events were corroborated through RF signal sensing from a commercial space company which confirmed detection of GPS interference in the areas where UAVs were attempting to carry out the monitoring mission. The day before the invasion, on February 23, 2022, Ukrainian government sources stated that a long-range UAV experienced significant GPS interference, which caused a temporary loss of control of the aircraft.

Russian employment of GPS-jamming devices has continued throughout the conflict. Emissions from the GPS jammers were detected and geolocated by the Hawkeye360 constellation of satellites. The orange ellipses in the figure indicate the estimated locations of the RF interference, and overlapping ellipses from multiple satellite passes can be used to locate a jammer more precisely. The blue dots indicate reported interference.



Map of GPS interference in November 2021. Hawkeye360
Space Threat Assessment 2022, Center for Strategic and International Studies

Russia has used a host of counterspace capabilities in the two years. They have spanned jamming, co-orbital movements, a direct-ascent debris-creating ASAT in November of 2021, cyberattacks against Viasat, Starlink, and others, frequent jamming, and diplomatic measures.

Russia has moved to deny Ukrainian and allied assets before and during the conflict, including command and control systems enabled by commercial communications satellites.

An hour before Russian troops invaded on February 24, 2022, Russia conducted a cyberattack to deny connectivity between the Viasat communications network and its thousands of ground terminals. The attack entered through a virtual private network and deployed wiper malware that crashed terrestrial modems via the satellite downlink.

One of Viasat's customers was the target: the Ukrainian government and military. However, the attack indiscriminately affected other Viasat users in Europe, including disabling about one-fifth of wind turbines and internet users across Central Europe. Considering the attack against Viasat, the U.S. FBI and CISA released a joint statement to commercial satellite communications providers urging companies to reinforce the cybersecurity and resilience of their networks.

Not only will the U.S. military depend on advanced LEO broadband constellations for its own network operations, but LEO broadband is already being used—and targeted—on the battlefield in Ukraine. The Starlink terminals SpaceX sent have been used by the Ukrainian military and people alike, connecting a country whose other operating forms of communication were hacked and jammed in the initial days of the conflict—though SpaceX has had to devote additional funding and resources to protect the signals from attack.

Additional jamming has been observed throughout the conflict and in various locations. In March 2022, the European Union Aviation Safety Agency (EASA) released that in the current context of the Russian invasion of Ukraine, the issue of Global Navigation Satellite Systems (GNSS) jamming and/or possible spoofing has intensified in geographical

areas surrounding the conflict zone and other areas. Open-source data reports indicate GNSS interference (spoofing or jamming) that has intensified since the invasion. Locations as far as the Baltics and Mediterranean have all experienced significant interference with PNT systems GPS and Galileo. Data from commercial RF data analytics company, Spire Global, corroborated GNSS interference over the Eastern Mediterranean in the February 2022 time frame. Spikes indicate unusual GNSS interference in the Eastern Mediterranean. Higher frequency signals have been converted into lower frequency signals to expedite processing. Additionally, reports of GPS jamming emerged just after the Finnish president with U.S. president Joe Biden in Washington, D.C. Finnair also reported several occurrences of GPS jamming when its commercial airliners flew near Kaliningrad.

LEO is the Answer

The targeting of space-based communication in Ukraine has sent a clear message that establishing efficient and affordable broadband services based in LEO is not only a priority for privately funded industry but also for the U.S. military. From relaying massive amounts of intelligence, surveillance, and reconnaissance data to detecting and tracking missiles to providing command, control, and communications for unit, the U.S. military's demand for SATCOM continues to grow. DOD has been working to build its own satellite broadband networks, the most public of which is the National Defense Space Architecture (NDSA) which will consist of several layers of military constellations in LEO, each focusing on different aspects to enhance military connectivity, sensing, and communication. In addition to developing domestic military capability, the U.S. Space Force has shown interest in leveraging commercial services to increase the resiliency of military broadband networks and communications. The Space Force is currently working on a design to build a "space data backbone," a service that will be able to integrate military, commercial, civil, and possibly allied networks.

Lessons Learned from Ukraine's Use of Commercial Space Systems

Commercial data and communications services have been integral to Ukraine's resistance. The former chair of the State Space Agency of Ukraine stated at a December 2022 conference that almost 50 percent of intelligence supplied to Ukraine came from the commercial space industry. It is not surprising that Russia targeted and attacked commercial space systems such as Viasat and Starlink. Starlink has been called a "lifeline" for Ukrainian forces and civilians alike – and conversations have emerged of a blurring of lines for the commercial versus military use of these systems. As the commercial space sector continues to show its utility in peacetime and conflict for governments and their militaries, commercial operators will increasingly seek threat information from the government that would allow them to make informed decisions on how to better protect constellations or prepare procedures to respond to attacks, and we expect to see a sustained increase in electronic and cyber capabilities on future battlefields.

Ukraine's resistance against Russia is nothing short of remarkable, and ask if the addition of commercial space capabilities to military systems can enable David to beat Goliath. Will smaller nations invest in space capabilities to bolster their national security and resilience if attacked, especially by a more powerful nation? Ukraine's resistance has demonstrated that space capabilities can create an advantage over a more capable military power.

Proliferated LEO (pLEO) Constellations

Finally, the effectiveness of proliferated LEO (pLEO) constellations in coverage, cost, and resiliency have made pLEO constellations a popular option for many nations. We expect this trend to continue as more exquisite systems are re-designed to be proliferated.

The benefit that space capabilities provide in modern warfare may also provide the justification for adversaries to increase their counterspace weapons development and deny their opponents access to space during a conflict. Starlink's effectiveness in Ukraine has showcased the advantages of pLEO constellations. As more commercial companies and militaries develop pLEO systems, adversaries will seek to counter them. Constellations with satellites in the hundreds and thousands may necessitate a shift in an adversary's targeting calculus.

Makena Young, fellow with the Aerospace Security Project at the Center for Strategic and International Studies (CSIS) in Washington, D.C. CSIS is a non-profit bi-partisan think tank with over 200 scholars who focus on policy issues spanning intersecting issue areas around the globe. All work is conducted through open-source research. The Aerospace Security Project (ASP) focuses on space issues spanning national security space, civil and commercial space, as well as air power and cross-domain integration; looking at these issue areas largely through a U.S. perspective.

The CSIS full report can be found here: https://csis-website-prod.s3.amazonaws.com/s3fs-public/202304/230414_Bingen_Space_Assessment.pdf?VersionId=oMsUS8MupLbZi3BISPrqPCKd5jDejZnJ

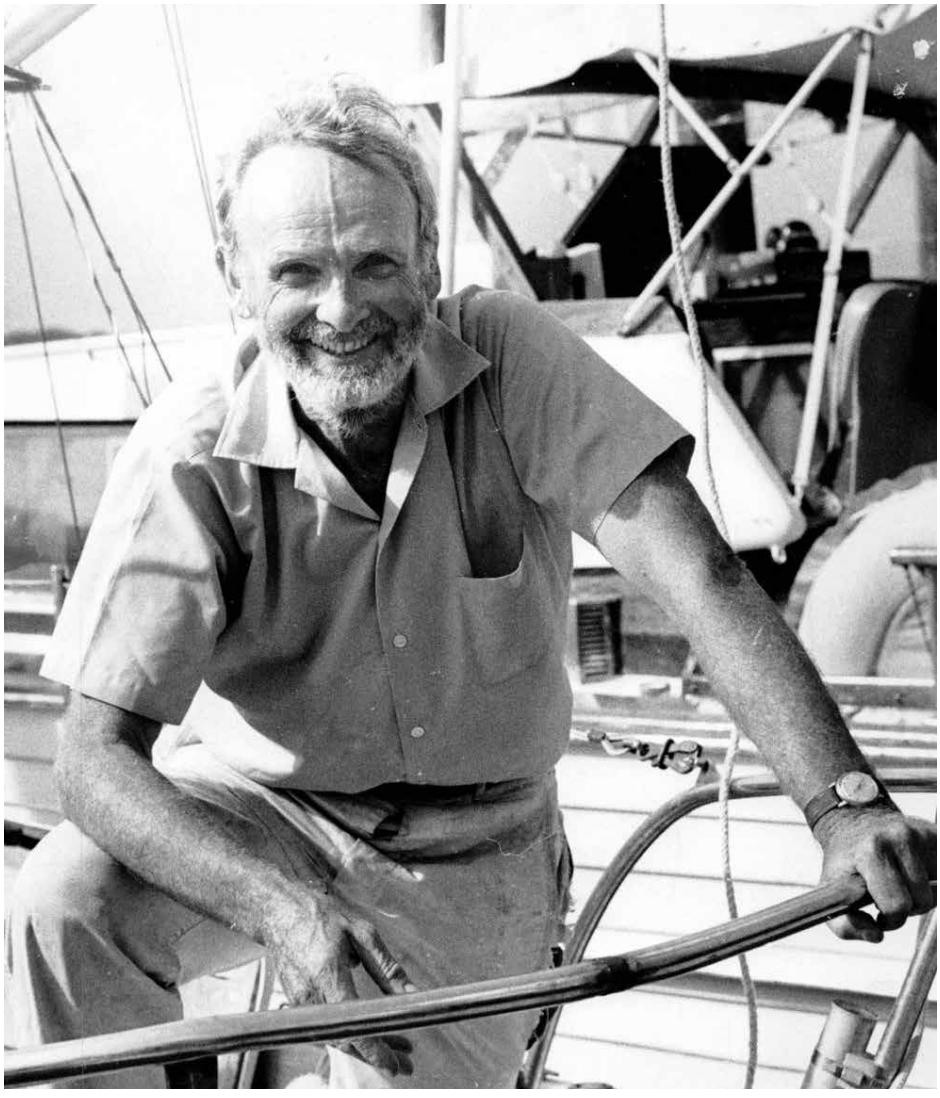
Marvin B. May

Marvin Creamer

The First Recorded Person to Sail Around the World Without Navigational Instruments

In the last *ION Newsletter* article, I described my abortive, and retrospectively silly, attempts as a naïve youngster to model myself after someone famous such as Willie Mays or Albert Einstein. As I grew into adulthood and beyond, I never gave up my tendency to try to emulate someone. I recently learned of someone whose attributes may match my tendencies and capabilities more closely than my previous attempts – his name is Marvin Creamer. Beyond the similarities in name, Marvin Creamer was a professor of geography, and an ardent practitioner and student of navigation, with an accompanying obsessive personality.

I first heard about Marvin Creamer in August 2020 when I accidentally came across his short obituary in the *New York Times.* The obituary's headline piqued my interest as it read: "Marvin Creamer, a Mariner Who Sailed Like the Ancients, Dies at 104." My interest was further ramped up when the obituary went on to state that he was the first recorded person to sail around the world without navigation instruments – no GPS (it was 1983), no LORAN, no sextant or astrolabe, no chronometer, not even a magnetic compass. As I researched further, wondering whether this Marvin was somebody I could emulate, a fascinating book was published in late 2022 chronicling his perilous sailing adventure departing Cape May, New Jersey, Southeast across the stormy Atlantic, around Africa's Cape of Good Hope, east through the Indian Ocean, around the Southern Coast of Australia, and Polynesian Islands, across the doldrums and stormy seas of the South Pacific, around South America's historic Cape Horn, continuing north along the East Coast of South America encountering the 1983 Falkland Island war scars, and finally the last leg of 7,400 nautical miles northwest to the original Cape May home port. Altogether, Creamer and his unpaid crew of two or three, commandeered the 35-foot sailboat, appropriately named Globe Star, 29,400 nautical miles while at sea for 351 days. The book, authored by Rod Scher, entitled *Sailing by Starlight: The Remarkable Voyage of Globe Star,* is primarily about Creamer's obsessions, courage, navigation ingenuity, and sailing skill, not necessarily in that order.



The Press of Atlantic City

Creamer's obsession was to demonstrate that ancient civilizations could have sailed across the oceans without modern propulsion, communication, or navigation equipment. The book describes how the Norsemen may have "discovered" North America (specifically Canada), 500 years before Columbus, with the aid of birds whose sightings often implied the presence of nearby land. No discussion of early navigators would be complete without including the Polynesians whose large, double-hulled canoes crossed the Indian and Pacific Oceans, settling Hawaii, Easter Island, and parts of New Zealand. In addition to the sun during daylight and stars at night, the Polynesians used their senses of smell, the appearance, and the taste of the water, as well as observing the prevail-

ing direction of the wind and currents to estimate their position and track angle. Creamer used his brain to integrate all the techniques of the ancients to maintain the Globe Star on its intended course.

It is noted that navigation for an ocean crossing by sail without instruments entails largely avoiding land falls, following the trade winds, and/or "parallel" sailing lines of constant latitude. Navigation accuracy, as most navigators understand it today, was not accomplished, nor was it an objective. For most of the journey, the Globe Star crew was able to establish latitude to an accuracy of about two degrees (120 nautical miles) using primarily periodic star sightings. Because finding longitude celestially is dependent on knowledge of Greenwich Mean Time, and the crew did not have any chronometers, dead reckoning from a prior known position using coarse estimates of speed and Course Made Good was employed to maintain current position. Post-time reconstruction (using data from an onboard Advanced Research and Global Observation Satellite (ARGOS) transmitter) revealed that the Globe Star's crew's estimates of longitude while in the open ocean were generally in error by about 400 nautical miles. These navigation errors were only important when nearing land. When navigation accuracy was more critical nearing land masses, Creamer observed birds, seaweed, outcrop of rocks, cloud cover, watercolor and temperature, and fish species as clues to the longitude.

The Press of Atlantic City

Sailing by Starlight is a well written sea story, in the mold of Thor Heyerdahl's "Kon Tiki," chronicling Marvin Creamer's lifelong obsession to demonstrate that ocean-crossing sailing could be done without the aid of any instrumentation. The book is liberally sprinkled with interesting anecdotes about equipment malfunctions, crew idiosyncrasies, fishing stories, star gazing and sailing lore. It is a highly recommended quick read especially for those fascinated by sailing and ancient navigation.


The Press of Atlantic City

The following were used in the preparation of this article:

Fox, M. (2020, August 17). Marvin Creamer, a Mariner Who Sailed Like the Ancients, Dies at 104. The New York Times. https://www.nytimes.com/2020/08/17/sports/sailing/marvin-creamer-a-mariner-who-sailed-like-the-ancients-dies-at-104.html

Scher, Rod. (2022). Sailing by Starlight. Sheridan House.

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Defense Matters

Leadership, Trust, and Integrity

The Underpinning of Why GPS is Still the GNSS Gold Standard

It serves no purpose for me to state that GPS is being challenged as the world's premier space-based PNT service. It is. But the foundation by which civil GPS has been made available to the world free of charge, since it was declared operational over 28 years ago, continues to keep it on a pedestal as the world's predominant space-based PNT system. It remains the system that all competitors are compared to – it is still the GNSS Gold Standard.

The Challenges

We live in a complex world of ever-increasing global competition where nations are focused on generating competitive advantages to enhance their national security and their economic prosperity.

Space-based PNT is an enabler for both these goals, and China's BeiDou is aggressively working to displace GPS and the United States as the world's premier space-based PNT provider.

China's goal is undoubtedly being pursued to further both their military capabilities and their global economic power. But China has one critical, underlying, foundational obstacle that will be problematic to overcome, and that is, to gain the world's trust.

From the perspective of projecting military might, Assistant Secretary of Defense for Space Policy, Dr. John F. Plumb (the ION's Congressional Fellow, 2005), stated at the 38th Space Symposium held in Colorado Springs, Colorado this past April, "China is the Department's pacing challenge in space – and that the pace is fast." He went on to state "China already employs a robust space-based reconnaissance capability, and its satellite navigation system provides position, navigation, and timing services."

From the perspective of stimulating the Chinese economy, BeiDou is being advertised as playing a key role in China's "One Belt One Road," plan to advance and extend their nation's railways, highways, agriculture, seaports, and energy corridors by financing similar major infrastructure initiatives in many countries.

As Dr. Plumb noted, BeiDou's fielding has been fast paced and has evolved rapidly from what was first thought to be used primarily for China's armed forces. However, today BeiDou's open service is available globally just like GPS, Galileo, and GLONASS – but will it be able to dethrone GPS?

If the fielding of space-based PNT capabilities is viewed as a business competition, there is no question that GPS is the system that other GNSS contenders are continually compared to.

The Competition's Approach

In the business world, if you beat your competition, the fruits of that achievement will result in more market share. If you have more market share, you will have more customers. More customers will bring you higher sales and profit.

But viewing the challenges to GPS from the business perspective – there are other things to consider. GNSS competitors are doing all they can to differentiate their services from what GPS offers.

A Google search using the query, "Which is better GPS or BeiDou?" yields this result, "The BeiDou constellation has more satellites than GPS or any other system. It also has more than ten times the monitoring stations in other countries than have been deployed for GPS. As a result, in many places, particularly in the developing world, BeiDou's accuracy is much better."

But a Google search query of "Which is trusted more, GPS or BeiDou?", results in multiple finds that are silent on the word "trust" and emphasize claims of BeiDou being more accurate, providing more coverage, etc. The takeaway – trust is earned – is not something that can be claimed.

The Playing Field

Most of the unsophisticated public who use PNT services, whether they know or care, have no awareness of how their respective PNT needs are being met.

How "GPS" fits into their applications is transparent to them. Their user equipment is expected to work and the underlying technology is expected to provide the expected results with no special selections or options required. It just happens. Trust has been established; it has been earned.

It is also not an exaggeration to suggest

Doug Taggart
President
Overlook
Systems
Technologies, Inc.

that when 99% of the public say "GPS", it universally applies to any or all the systems collectively. Knowing or caring what system is used is not important or even considered – they trust their device to work. If it doesn't work, GPS may or may not be blamed. But if they are presented with a bad location or their device results in an incorrect address – then the blame likely falls uniquely on GPS with no thought given to the underlying mapping company or the environment they are in, e.g., multi-path, interference, etc.

Moving Forward

In contrast, China is hiding more and more data from the rest of the world. China's recent abrupt decision to halt releasing data on its soaring youth jobless rate in China is just one of the latest signs the Asian giant is increasingly restricting sensitive information – especially when it's unflattering to the nation's faltering economy.

On the contrary, in the United States, yearly Gallup polls going back 30 years have asked adults to rank their confidence levels in trust of major U.S. societal institutions. These institutions include the military, police, businesses, schools, churches, banks, newspapers, television, justice system and Congress. Over the last 30 years the military has consistently ranked as one of the most trusted institutions. The least trusted institution for many years – Congress, but that is another story.

The "trust" acquired since GPS became operational in the mid-1990s has not only been earned, but it has become ubiquitous and expected. Here again, the unsophisticated public may or may not be aware, but that trust is traceable uniquely to the leadership and integrity of the stewards of GPS, the providers of GPS, the U.S. military, and more specifically the U.S. Air Force and since 2020, the U.S. Space Force.

The civil GPS services available today still have challenges to overcome. The on-orbit performance of the various blocks of satellites with various signal enhancements continues to surpass their design lives. Considering this and other competing factors, this extended service life has slowed the pace of launching and making available expanded signals under the 20 plus year modernization effort, but the underlying service provided by GPS continues to be the competitor to beat.

With 2023 noted to be the 50th anniversary of the Air Force gaining approval to proceed with the GPS concept, the hundreds, if not thousands of people who have contributed to the fielding of this great system can be proud of what they have accomplished. GPS is still the GNSS Gold Standard.

End Note: In early September of this year the U.S. Space Force, now stewards of GPS, announced their new mission statement – "secure our Nation's interests in, from, and to space." Clearly, GPS fits into each of these three domain mission areas.

ION's JOURNAL
NAVIGATION Spotlight
navi.ion.org

Optimized Position Estimation in Mobile Multipath Environments using Machine Learning

Nesreen I. Ziedan

GNSS signals often encounter obstacles in their path from a satellite to a receiver. This causes signal obstruction, reflection, or diffraction, which can result in multiple versions of the same signal arriving at a receiver via different paths, with different code delays. Therefore, multipath signals arriving with delays within 1.5 chips of the line-of-sight (LOS) signal correlate with the local replica signal, which leads to distortion in the cross-ambiguity function (CAF). The distorted CAF causes tracking errors, and consequently positioning errors. Similarly, positioning errors occur when the LOS signal is completely blocked and only non-LOS (NLOS) signals arrive at a receiver. A moving receiver faces an extra challenge due to the continuous change in the satellite signals status, which can be LOS, multipath, NLOS, or invisible.

When processing GNSS signals, a conventional tracking module does not distinguish between LOS signals, multipath, or NLOS signals. This means that a receiver continues to track a signal, regardless of its status and generates pseudorange measurements for the navigation solution. Erroneous pseudorange measurements lead to a degradation in the positioning accuracy.

This paper proposes an optimized position estimation (OPE) algorithm, which is designed to enhance the positioning accuracy in multipath urban environments. The OPE algorithm specifically includes the ability to detect and identify changes in the signal's status as the receiver moves. This ability is facilitated by the design of a machine learning algorithm called intelligent signal status estimation (ISE).

The fundamental of the OPE algorithm is based on finding optimal paths on a map. A sequence of positions with the highest transition probabilities between them forms a path with an optimal weight. The transition probabilities are used in the construction of the path weight function, which utilizes extracted information from the signal processing level and the measurement level in its computation.

The ISE algorithm is a novel probabilistic and supervised self-organizing map (SOM) algorithm. In contrast, the conventional SOM is an unsupervised approach that classifies input data into clusters with similar features. The ISE algorithm is designed to quantize the effect of a change in a signal status, with a probability, using various features. The ISE features are derived from the output of the tracking module. Analysis showed

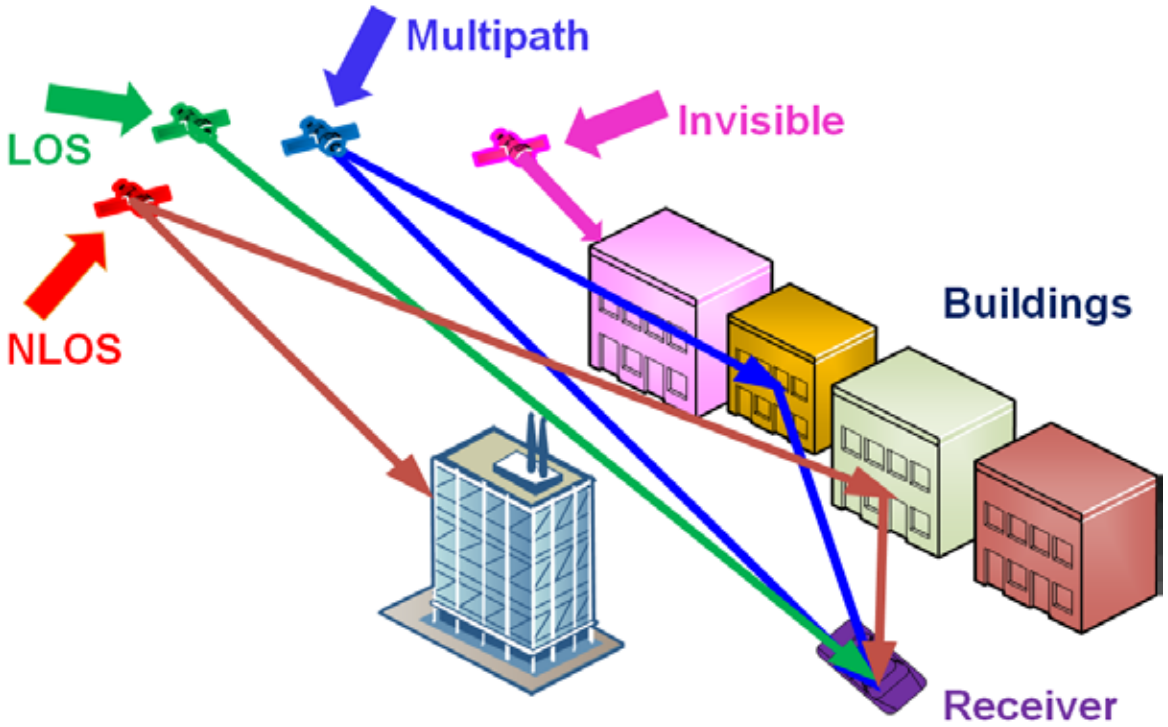


Figure 1. Illustration of how urban environments affect received signals

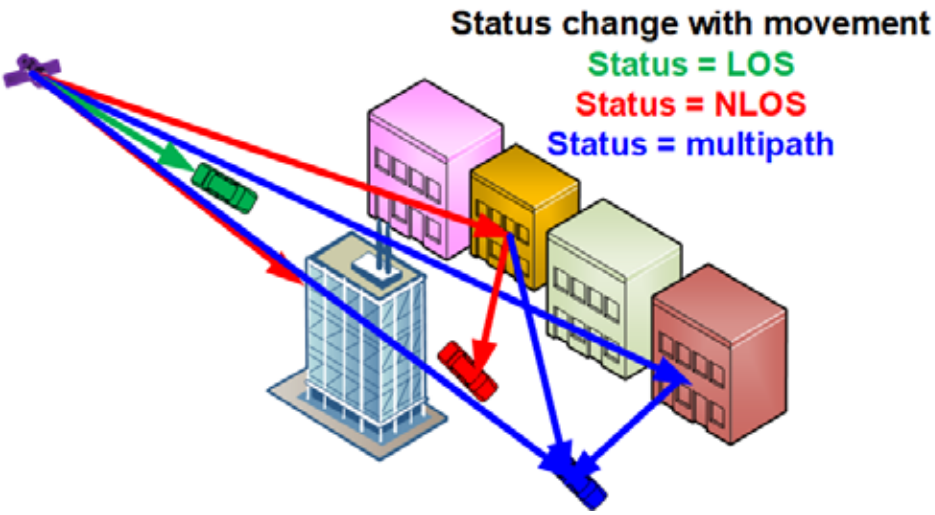


Figure 2. Illustration of a satellite signal's status change as a receiver moves

that the mean and variance of the estimated code delay error generated by the tracking module exhibit distinctive properties when a signal status changes. These properties are used in generating the ISE features.

The OPE algorithm operates on the measurement level, but it does require information from the tracking module, which resides in the signal processing level. Therefore, it can operate with any receiver, as long as the necessary information can be extracted from the tracking module. Furthermore, since the OPE algorithm estimates optimal paths, it can be classified as working with multiple epochs.

A key experiment to assess the performance of the proposed OPE algorithm was performed in an urban area with both a stationary and a moving receiver. The received signals encountered over 50 changes in their status during the experiment running time. This experiment was suitable to verify the performance of the OPE algorithm considering a challenging environment with a continuous change in the status of the signals. The positioning accuracy of the OPE algorithm was compared to a conventional navigation approach. The results showed an accuracy enhancement between 84% and 96% for the OPE algorithm compared to the conventional approach.

A notable segment in the experiment had only 2 LOS signals, 2 multipath signals, and 2 NLOS signals. The positioning accuracy of the conventional approach degraded fast during that segment. However, for the OPE algorithm, the positioning accuracy was high and stable.

The OPE algorithm can be a helpful addition to applications like unmanned systems or robots operating in challenging environments.

For the full article, and accompanying data and figures, please see:

Ziedan, N. I. (2023). Optimized position estimation in mobile multipath environments using machine learning. *NAVIGATION,* 70(2). https://doi.org/10.33012/navi.569

Real-Time Ionosphere Prediction Based on IGS Rapid Products Using Long Short-Term Memory Deep Learning

Jianping Chen

The availability of high-precision ionospheric corrections is essential for precise positioning using low-cost single-frequency GNSS receivers as the ionospheric delay is the most significant error source for GNSS measurements. Although the real-time global ionosphere maps (RT-GIM) product is available from the International GNSS Service (IGS), its ionospheric prediction still relies on networks of globally distributed GNSS stations and real-time data links. The IGS also has post-processing products with higher accuracy, but the delay in availability impedes applications. This technology takes the IGS rapid GIM products and predicts the products one day in the future by a long short-term memory (LSTM). In addition, the daily updated products from IGS can be used to update the already trained neural network model.

This paper describes how LSTM is used to make ionosphere predictions; predictions based on IGS rapid products. Experiments described include a training process with existing rapid products and predictions based on the trained model. Continuous updating based on new products is also investigated. A comparison was made between the proposed LSTM model with a rapid products, fully connected feed forward neural network (FFNN). The 7-day results show that the LSTM predicted products outperform FFNN and are very close to the rapid products. Additionally, the LSTM predicted products are used to do single-frequency positioning, and results show they are better than IGS RT-GIM products.

During the peak of the solar cycle there is strong geomagnetic activity or scintillations that will be problematic with GNSS positioning moving forward. This is especially true for low-cost receivers as they are vulnerable to inaccuracies of the provided ionosphere model. This technology can be implemented so that the generated daily predicted GIMs can be used without the need for complicated infrastructure.

For the full article, and accompanying data and figures, please see:

Chen, J., & Gao, Y. (2023). Real-time ionosphere prediction based on IGS rapid products using long short-term memory deep learning. *NAVIGATION,* 70(2). https://doi.org/10.33012/navi.581

Perspectives on the Systematic (Type B) Uncertainties of UTC-UTC(k)

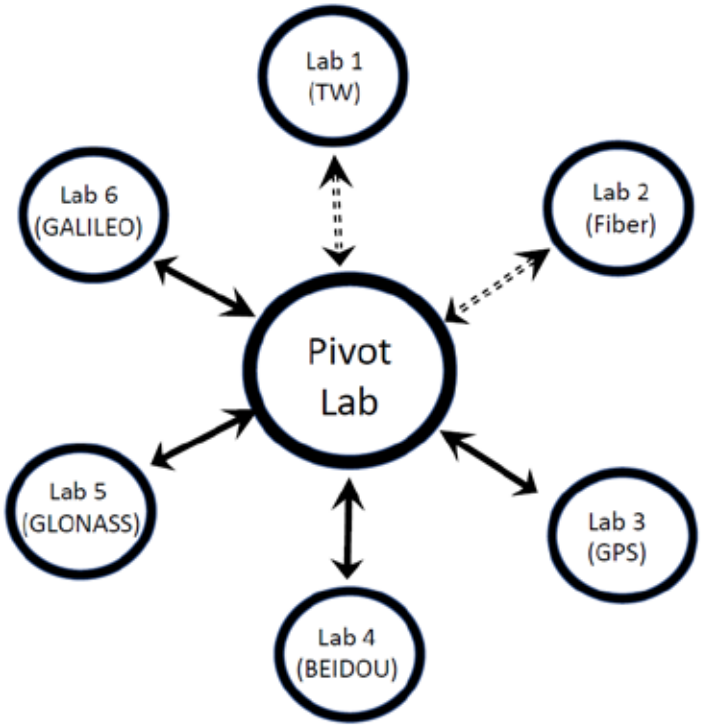
Demetrios Matsakis

Traceability to Coordinated Universal Time (UTC), or one of the UTC realizations, termed UTC(k) for a timing lab k, is a major issue for timing systems in the commercial, financial, and power sectors. To be traceable, it is necessary to measure the difference between the local clock and the UTC source with an unbroken chain of measurements, each of which has a known uncertainty. The International Bureau of Weights and Measures (BIPM) generates the difference between UTC and UTC(k) and also computes the uncertainty.

This paper suggests a better way to compute the uncertainty of UTC-UTC(k). This new way can be easily extended to handle the situation when the BIPM switches from its currently simple topology (figure below) to a more complex one involving redundant links and crosslinks. The algorithm has major differences, at the ns level with the current one; and has differences with an alternate proposal.

For the full article, and accompanying data and figures, please see:

Matsakis, D. (2023). Perspectives on the systematic (Type B) uncertainties of UTC-UTC(k). *NAVIGATION,* 70(2). https://doi.org/10.33012/navi.571



THE INSTITUTE OF NAVIGATION

2024 T-SHIRT

DESIGN CONTEST

Design should work on a white t-shirt

CONTEST

THEMED SHIRT: ION / GNSS / PNT

Bring your best design skills to create a new t-shirt for members of ION and the PNT community!

ENTER TO WIN!

THE WINNER WILL RECEIVE

$500 CASH PRIZE*

*Designs must be submitted by ION members.

THE RULES

- Each design submission should include the current ION logo.
- Designs should be created for the front of a white, crew neck, short sleeve t-shirt.
- Each design submission should include the designer's name and email address.
- Your artwork must be created and submitted at a minimum resolution of 300 DPI with dimensions of 12x16 inches (3600x4800 pixels) for optimal printing quality. If your design is selected, you will be asked to provide native files of the design.
- Designs must be submitted by ION members.
- Designs should be entirely your own original work. Use of digital and stock media is permissible. ION will own the exclusive rights to the winning designs.

THE JUDGING

ION headquarters will review all submissions. They will convene and vote on the top two submissions. The top designs will be featured on social media and in the Spring 2024 *ION Newsletter* for voting. The highest voted t-shirt will win. Announcement of winning t-shirt will be featured in the Summer 2024 *ION Newsletter*. The t-shirt will be available at ION GNSS+ 2024.

SCAN FOR MORE INFO

QUESTIONS?

Email: **blathrop@ion.org**

https://www.ion.org/about/2024-tshirt-design-contest.cfm

GNSS Program Updates
News from Systems Around the World

Kevin Dennehy

GNSS Annual Update: 50 Years of GPS

DENVER—The annual update of GNSS at the ION GNSS+ international technical meeting here highlighted 50 years of the U.S. Global Positioning System (GPS) with a status briefing of the constellation by Cordell DeLaPena, Space Systems Command (SSC) Program Executive Officer for Military Communications & Positioning, Navigation, and Timing Division. "In 50 years, that capability has evolved. We've gone through six versions of the GPS satellite vehicles," he said.

GPS

There are currently 38 GPS satellites on orbit, with 31 set healthy, for a baseline 24-satellite constellation, DeLaPena said. He said the U.S. Space Force has purchased 10 GPS Block IIIF (Follow-On) satellites and plans to buy 12 more.

"SV7 will launch in 2024. We have to increase our power and precision," DeLaPena said. "We have a business case for using one weapon for targeting—and we need GPS to accomplish that."

DeLaPena believes that the L5 signal for safety of life and civil aviation is the equivalent of the M-code to preclude military jamming. "Currently we have 24 M-code antisatellite jamming satellites. For L5, we have 17 satellites, but with the launch of GPS SV7, that will make it 18."

Despite the controversy surrounding the delays of the GPS next generation operational control system (OCX) program, DeLaPena said he is proud of the contractor team. "They've come a long way in the last year. We've focused on nothing but quality in the past year," he said.

ION GNSS+ 2023: Taegyu Kim, Miguel Manteiga, Eric Chatre, and Cordel DeLaPena

Galileo

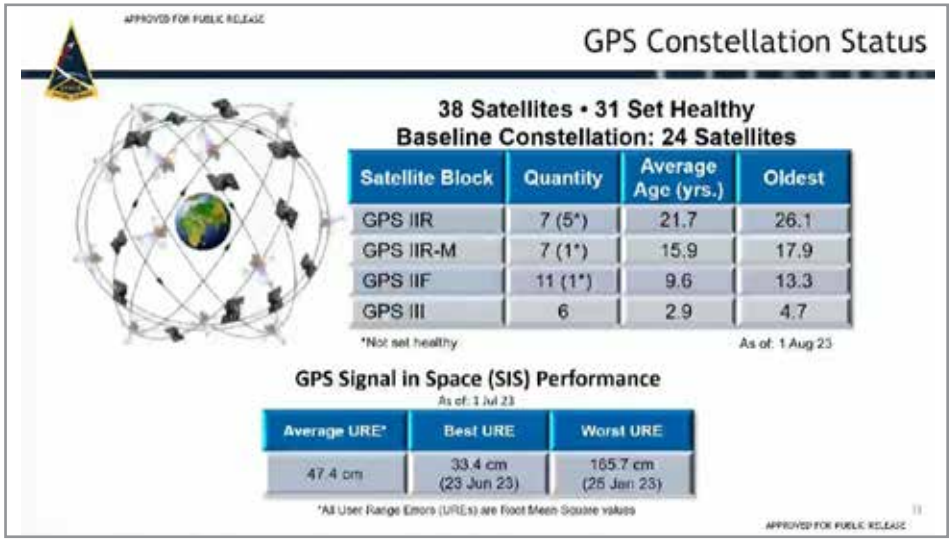
2023 has been a busy year for Galileo as it prepares for full operational capability (FOC) for its next generation satellites and ground segment, said Eric Chatre, Head of European Union GNSS Exploitation and Evolution, European Commission.

"We are moving toward FOC by deploying our next major ground segment release, increasing thwarting cyber threats and delivering a [Public Regulated Service] government service," he said.

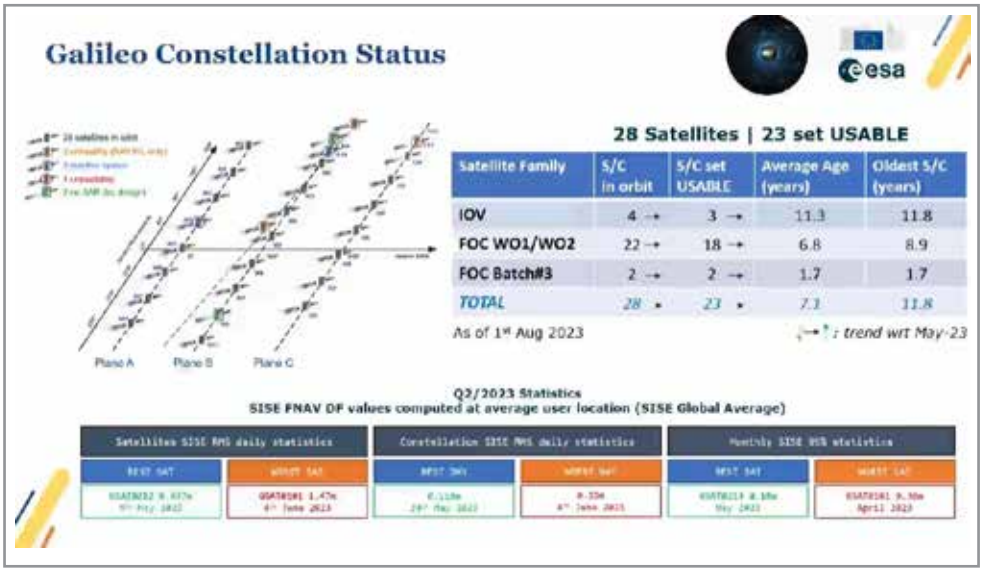
Chatre said that Galileo is forging ahead to launch its new satellites on the Ariane 6 rockets. However, that inaugural launch is postponed until 2024 because of the cancellation of two launches that were to be on the Russian Soyuz rockets.

Miguel Manteiga, Galileo Second Generation Project Manager, European Space Agency, touted Galileo as the world's most precise GNSS with 20-centimeter accuracy and 4 billion worldwide users. He said that the European Space Agency has committed more than 1 billion euros to companies developing the satellites and ground segment for the Galileo second generation (G2G).

There are currently 28 Galileo satellites, with 23 set usable, Manteiga said. The average satellite age is 7.1 years, with



GPS Constellation Status
Space Systems Command, U.S. Space Force



Galileo Constellation Status
European Space Agency

the oldest being 11.8 years, he said.

From 2028 to 2035 second batch of G2G satellites and ground segment will make the system achieve full operational capability (FOC), Manteiga said.

QZSS

Japan announced it will increase the number of its Quasi-Zenith Satellite System (QZSS) navigation satellites from seven to 11. The main reason for the dramatic increase was to improve stability and reliability by introducing backup systems and functions, improving high-precision positioning services and expand the constellation's usable area, said Motohisa Kishimoto, Senior Coordinator, QZSS Strategy Office, National Space Policy Secretariat, Japan Cabinet Office.

Currently, the four QZSS satellites, which operate in the Asia and Pacific regions, serve as a GPS complimentary service, GNSS augmentation service and a messaging service for disaster and crisis management, Kishimoto said. The initial seven satellites, with PNT and emergency capability, will be operational by next year, he said.

The most recent ground stations, completed in late August, have the ability to control seven QZSS satellites. Overall, there are two master control stations, 10 satellite tracking and control stations and 30 monitoring stations worldwide.

KPS

South Korea plans to launch its first Korean Positioning System (KPS) satellite in 2027, with the remaining four inclined geosynchronous orbit (IGSO) satellites and three in geostationary orbit (GEO) to be launched from 2029 to 2035, said Taegyu Kim, Satellite Navigation Development Strategy Team, Ministry of Science and ICT.

Kim said the country has launched its Korea augmentation satellite system (KASS) that augments GPS for aviation use. The service will start next year, he said.

The KPS project is estimated to cost anywhere from $3.1 billion to $3.5 billion. By 2035, there may be as many as seven or eight satellites in orbit, with payloads that include navigation, timing systems, space-based augmentation system (SBAS) and search and rescue, Kim said.

NavIC

The Indian Regional Navigation Satellite System, or NavIC, currently has eight satellites—four in GEO and four IGSO, said Dr. P.S. Sura, Indian Space Research Organization Satellite Navigation Program Director.

India launched a satellite, NVS-01, in late May. The satellite was the first generation of upgraded regional navigation satellites that are interoperable with other GNSS.

India launched nine first-generation satellites from 2013 to 2018—with a smaller launch vehicle. The current service offers L1, L5 and S-band signals. The restricted government use signal operates in the L1 and L5 bands, Sura said.

The overall service area is India, but has a reach that extends to about 1,500 kilometers from the country's borders, Sura said. In addition, Qualcomm and Mediatek, two major chip manufacturers, are now using NavIC services in their mobile handsets, he said.

BeiDou

China launched its most recent BeiDou satellite in May onboard a Long March 3B carrier. However, the launch was the first in nearly three years, according to published reports.

In the most recent ION BeiDou update, Dr. Xiaochun Lu of the China Satellite Navigation Office, said that the constellation's PNT global short message communication and search and rescue signals are available for all users. However, the regional short message communication (RSMC), precise point positioning (PPP), space-based augmentation system (SBAS) and ground augmentation system (GAS) are only available in the Asia-Pacific region.

The country has launched a total of 60 BeiDou satellites since 2000.

GLONASS

News out of Russia about the GLONASS satellite system has been sketchy at best since the start of the war in Ukraine. However, published reports indicate that the country launched its first GLONASS-K2 satellite on board a Soyuz-2 rocket on August 7.

The previous launch, in November 2022, saw a GLONASS-M satellite launched from the Plesetsk Cosmodrome. The spacecraft, designated Cosmos 2564, was the 61st and final GLONASS-M spacecraft.

Kevin Dennehy has been writing about GNSS for 30 years. He is editor of Location Business News, http://locationbusinessnews.substack.com. If your company has an idea for a business story contact kdennehy@locationbusinessnews.com.

The Business of GNSS

Kevin Dennehy

In one of the biggest GNSS industry deals this year, ION member Trimble announced it was selling its precision agriculture business to AGCO. Overall, Trimble said it expects $3 billion in value from the transaction from pre-tax cash proceeds, its 15 percent stake in the joint venture and related commercial agreements.

Under the terms of the deal, which is expected to close in the first half of 2024, Trimble will offer its precision agriculture business, Trimble Ag, but exclude certain GNSS and guidance technologies. For its part, AGCO will offer its JCA Technologies business, which includes autonomous software for farm machines, implement controls and electronic system components.

In another huge transaction, ION member BAE Systems purchased Ball Corp. for $5.6 billion to consolidate two major military GNSS players. BAE Systems, which is the United Kingdom's largest defense contractor, is involved in many space and defense markets, it has achieved a large market share in military GPS. In 2021, BAE Systems, with a U.S. subsidiary headquartered in Falls Church, Virginia, won a $247 million contract with the U.S. Space Force to manufacture an advanced GPS receiver.

Location Industry Rolls Out Products at ION GNSS+

The Institute of Navigation's ION GNSS+ 2023 conference had several product launches and company execs making business deals in Denver. One company, StarNav, revealed the first PNT results using ION member Xona's PULSAR signals.

"We created the radio front end specifically for the Xona signal. We've achieved 20-centimeter accuracy," said Joshua Morales, StarNav co-founder and CEO. "We were able to acquire and track the signal, with a cold start, with signals produced by a Safran simulator. In this example, that was 13 satellites simultaneously."

oneNav's Ellen Kirk and Greg Turetzky with pureL5 GNSS receiver system
Kevin Dennehy

Xona is developing PULSAR, a PNT service built on low Earth orbit (LEO) small satellites. The company said it will provide resilience and accuracy by augmenting GNSS, while operating with an independent navigation and timing system architecture.

ION member Spirent said it has concluded a review of PULSAR production signals for integration into its SimXona product line. Spirent says that the signal integration will be a part of the SimXona platform for existing and new customers throughout 2024.

Another ION member, oneNav, demonstrated its L5 GPS signal technology at its booth. The company, which recently closed a $17 million funding round, says its pureL5 GNSS receiver system is an RTL core that acquires and tracks satellites via L5, E5a, E5b, B2a. oneNav says it's the first company to develop a commercial GNSS acquisition and tracking solution that uses only L5-band signals.

ION member Racelogic rolled out its SatGen GNSS simulation software at the conference. The software, which is an update of previous solutions, allows companies to create custom scenarios with position, route, speed, data and time, said Racelogic's Jen Edis.

In other ION GNSS+ Business News…

ION member NextNav announced it is a member of TCCA-Critical communications association. NextNav is building an ecosystem of location-based applications through a terrestrial network to enhance the work of first responders, the company said.

Syntony announced that it has developed a GNSS receiver embedded in a controlled reception pattern antenna (CRPA) solution called CERBER. The unit's tech relies on the integration of

Syntony's CERBER
Kevin Dennehy

Calendar of Upcoming Events

JANUARY 2024

22-25: ION International Technical Meeting (ITM) & ION Precise Time and Time Interval (PTTI) Meeting 2024, Hyatt Regency Long Beach, Long Beach, California

Contact: ION

ion.org

MARCH 2024

20-22: Munich Satellite Navigation Summit 2024, Alte Kongresshalle, Munich, Germany

Contact: Munich Satellite Navigation Summit

https://www.munich-satellite-navigation-summit.org/

APRIL 2024

15-18: ION Pacific PNT, Hilton Waikiki Beach, Honolulu, Oahu, Hawaii

Contact: ION

ion.org

JUNE 2024

3-6: ION Joint Navigation Conference (JNC) 2024, Northern Kentucky Convention Center, Greater Cincinnati Ohio Area

Contact: ION

ion.org

SEPTEMBER 2024

16-20: ION GNSS+ 2024, Hilton Baltimore Inner Harbor, Baltimore, Maryland

Contact: ION

ion.org

OCTOBER 2024

28-31: International Association of Institutes of Navigation (IAIN) 18th World Congress, Beijing, China

Contact: IAIN

https://www.iainav.org

Business of GNSS continued

StarNav's Joshua Morales with receiver
Kevin Dennehy

CRPA treatment, with a 4-array antenna, and the GNSS receiver embedded, the company said. CERBER, developed to meet the growing demand for civil infrastructure, also has anti-jamming and anti-spoofing resilience.

ION member RX Networks demonstrated its TruePoint.io GNSS service at the conference. TruePoint.io is designed to offer a correction stream with a 99.9 percent Service Level Agreement, the company said.

Kevin Dennehy has been writing about GNSS for 30 years. He is editor of Location Business News, http://locationbusinessnews.substack.com. If your company has an idea for a business story contact kdennehy@locationbusinessnews.com.

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