ION
Quarterly Newsletter

INSTITUTE OF NAVIGATION

International GNSS Community Reconvenes in Denver

Dr. Daniele Borio, European Commission, JRC, presenting

Returning to its origins in the state of Colorado, 900 people attending in person from 36 countries convened at the Hyatt Regency adjacent to the Denver Convention Center in downtown Denver, Colorado, for ION GNSS+ 2022. 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; multisensory and autonomous navigation; algorithms and methods; and advanced GNSS technologies. An additional 200 attendees participated

U.S. TECHNICAL COMPETITIVENESS

The Geodesy Crisis

Everett Hinkley

In January 2022, a white paper entitled *America's loss of capacity and international competitiveness in geodesy, the economic and military implications, and some modes of corrective action* was released (Bevis et al.). This collaborative paper paints an alarming picture of the dwindling pool of trained geodesists within the United States. The report highlights America's loss of capacity and international competitiveness in geodesy and states:

"The U.S. is on the verge of being permanently eclipsed in geodesy and the downstream geospatial technologies. This decline in capability threatens our national security and poses major risks to an economy strongly tied to the geospatial revolution, on Earth and, eventually, in space."

Though the word *crisis* correctly describes the dire predicament well, it didn't occur overnight. Due to several converging trends, the geodesy crisis has been decades in the making. A national lack of geodetic expertise presents a significant challenge with downstream impacts on positioning, navigation, mapping, and dependent geospatial technologies. The Department of Defense, intelligence community, and federal civil agencies' mapping entities rely on accurate and precise maps for a broad range of purposes, and reliable maps depend on an accurate geodetic underpinning.

The geospatial community relies on geodesists, though few in the community are fully aware of this connection nor understand the importance of geodesy to their work. With the loss of geodetic knowledge in the United States, a deterioration of the down-

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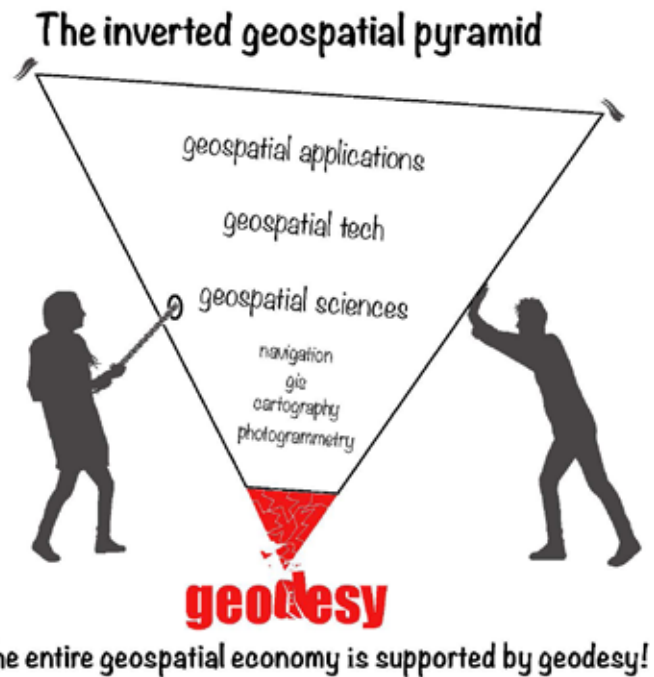
Highlights From a Week at ION GNSS+

ION GNSS+ 2022 Satellite Division Officers Host ION GNSS+ 2022: Dr. Mohammed Khider, Secretary; Sandy Kennedy, Chair; Dr. Frank van Diggelen, ION President; and Dr. Chris Hegarty, Immediate Past Chair. (Not pictured: Dr. Demoz Gebre-Egziabher, Treasurer; Dr. Stefan Schlueter and Dr. Jiyun Lee; Technical Advisors)

Above all, the outstanding highlight of the week at ION GNSS+ was the joy of being back at a full-strength ION conference with over 1,000 registrants. Attendees reveled in the in-person environment unique to conferences like these. Among many other highlights, including a plenary session that was literally out of this world, let me give you some detail about two notables: the Smartphone Decimeter Challenge and ION Council business.

The 2nd Smartphone Decimeter Challenge

This summer, the ION Satellite Division partnered with Google and Kaggle to host the 2nd Smartphone Decimeter Challenge. Designed to advance research in smartphone GNSS positioning accuracy, teams computed location using GNSS and inertial measurement unit (IMU) data from Android smartphones. Winners were selected based on the accuracy of the results compared to highly accurate ground truth.

While standard GNSS receivers in smartphones provide accuracy between three to five meters (and worse in urban environments), much better location positioning was obtained by processing carrier-phase measurements, IMU data, and base station corrections. The median accuracy achieved by the winners was well below one meter.

A total of 571 teams competed, with a total of 676 competitors. In the end, the top three were declared victorious and received cash, travel, and conference registration prizes valued at over $20,000. See the conference proceedings for the winners' descriptions of their approaches.

Mobile users will benefit in many ways from the increased accuracy resulting from this research, with applications limited only by our imagination.

ION's Council Convenes

The ION Council met before the start of the ION GNSS+ meeting. In the spirit of inclusivity, the Council adopted a best practices inclusive language document to assist ION authors with more thoughtful writing. These writing guidelines will be included in the ION's online author kits and are recommended as a valuable resource in the preparation of technical papers, presentations, award nominations, etc.

3rd Place Winner, Tim Everett, RTK Consultants LLC, Colorado; Dr. Frank van Diggelen, ION President; and 1st Place Winner, Dr. Taro Suzuki, Chiba Institute of Technology, Japan (Not pictured: 2nd Place Winner, Shubin Dai, a Kaggle "Competition Grandmaster," China)

The Purpose of the ION®

Founded in 1945, the Institute of Navigation is the world's premier non-profit professional society advancing the art and science of positioning, navigation, and timing.

Opinions expressed in *ION Newsletter* articles and columns do not necessarily reflect an official policy of the ION or the views of any other individual ION member(s).

ION recognizes that the best practices inclusive language document will continue to evolve. ION members are encouraged to review the document and send proposed amendments to membership@ion.org.

Council also approved an update to the ION Ethics Addendum A (publications policy) that further defined publication misconduct to include plagiarism, fabrication, and falsification. The approved revision of the Code of Ethics: Addendum A outlined the process of removing access to content when necessary.

The Council is scheduled to meet again in January 2023 in conjunction with the ION's International Technical Meeting (ITM) and Precise Time and Time Interval (PTTI) Systems Meeting. ✷

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Open-Source Innovation: Public Invention

Public Invention, a nonprofit humanitarian organization revolving around a mission to create for the public, was founded by Robert L. Read in 2019. He is a professional computer programmer, manager, amateur scientist, physicist, mathematician, mycologist, electrical engineer, and serves as Head Coach for the organization. As the name might suggest, this organization's goal is the invention and innovation for the public by the public.

"We challenge the notion that inventions should be reserved for patents and profits. Rather, we invite fellow builders of the future to use their skills for humanitarian purpose." With such a mentality, you'll find those in league with Public Invention removing legal barriers like patents that maintain exclusivity of a given design.

The organization encourages collaboration above all else, and is well on track to change the landscape of innovation with 60 open-source projects defined in just three short years. "Our ethos is to share everything we do as we do it, including our mistakes … We are trying to do for hardware invention what the Free Software Foundation has done for software."

Public Invention has published and presented numerous papers on their work and mission and, more recently, secured a contract with NASA. Even so, they remain fully transparent on their work, linking their website to current projects. Take a look at their mission at https://www.pubinv.org/mission. Interested parties can contact founder Robert Read at read.robert@gmail.com. ✷

virtually.

The plenary session had the theme of navigation challenges in remote places—in Earth's oceans and on Mars. GNSS is ideal on the surface of our oceans, but not as needed for underwater operations or sea floor mapping. Mike Korotinsky of Ocean Infinity shared how they navigate uncrewed vessels to efficiently and safely operate at sea. And Mars is not the globe referred to in GNSS! Dr. Michael McHenry of NASA's Jet Propulsion Laboratory described how the Perseverance rover navigates, using what Earthbound engineers in 2022 would consider extremely limited computing resources and a well-known IMU: the LN200. The plenary session's question-and-answer exchange was lively as moderator Sandy Kennedy refereed a lively session reflecting everyone's excitement to be back together in person. The ION has made this session available for complimentary

ION GNSS+ Emerging Trends in LEO-Based Satnav and Signals of Opportunity for PNT *panel members Psiaki, Gunawardena, Hinks, Corvo, and Kassas*

viewing on the ION's YouTube channel: https://www.youtube.com/user/InstOfNavigation.

In addition to the plenary session, the conference hosted over 400 technical presentations (both in person and virtually), a tutorial program, and 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, but with additional popularity in panels dealing with autonomous navigation both for autonomous vehicles and the challenges of various autonomous applications. However, the most popular panel of 2022 was hands down the panel *Emerging Trends in LEO-Based Satnav and Signals of Opportunity for PNT* chaired by Dr. Sanjeev Gunawardena and Dr. Joanna Hinks.

ION GNSS+ Award Winners

2022 Kepler Award

The 2022 Kepler Award was presented to Dr. Boris Pervan for his pioneering contributions to high-integrity GNSS-based aviation navigation and his dedication to education. Dr. Pervan is a pioneer and technical leader in transformative research programs dedicated to ensuring safe aircraft navigation.

In 2007, as GPS Evolutionary Architecture Study (GEAS) panelist for the FAA, Dr. Pervan performed the first feasibility studies that helped define the Advanced Receiver Autonomous Integrity Monitoring (ARAIM) architecture. He authored *ARAIM Integrity Assertions*, which set the foundations for ARAIM, and accelerated ARAIM development. A driving force behind the US-EU cooperative effort for dual-frequency multi-constellation ARAIM, he spearheaded international efforts to rigorously account for ARAIM fault-exposure durations. From 2007 to the present, his group established new airborne and ground-based algorithms to empirically model and monitor ARAIM error sources. These methods are currently coded, verified, and validated by global avionics manufacturers. By 2025, ARAIM will facilitate air traffic management by providing unprecedented levels of global navigation satellite system (GNSS) integrity.

Dr. Pervan is a pioneer of the Local Area Augmentation System

(LAAS), the U.S. Ground-Based Augmentation System (GBAS), and was at the forefront of the development of the first LAAS prototype in 1996. As FAA Key Technical Advisor and LAAS Integrity Panelist, his contributions ranged from developing GBAS proof-of-concept all the way to Category III certification. From 1996 to 2016, he designed, evaluated, and tested ground monitors protecting aircraft against satellite orbit, clock, and code-carrier divergence; reference receiver faults; and ionospheric fronts. His group devised anti-interference and anti-spoofing methods for LAAS-capable receivers coupled with chip-scale atomic clocks and inertial sensors.

From 2001 to 2015, Dr. Pervan was a technical leader on carrier-phase differential GPS applications, including the Joint Precision Approach and Landing System (JPALS) and Autonomous Airborne Refueling (AAR) system for the U.S. Navy and Air Force. He developed carrier-phase-based fault monitors and the first analytical method to quantify safety risks caused by incorrect cycle ambiguity resolution. His work demonstrated that high accuracy and high integrity were simultaneously achievable worldwide using differential GPS.

Dr. Pervan also contributed to the Integrity Beacon Landing System, a radar-based Unmanned Air System Sense and Avoid Iridium-augmented GPS, which has provided foundational implementations for current and future terrestrial radionavigation, collision warning, and mega-constellation-augmented GNSS systems.

As an educator from 1999 to the present, Prof. Pervan has supervised 12 MS and 20 PhD students who have been recognized

Dr. Boris Pervan pictured with current and former students present at the Awards Luncheon.

with organizational awards and built successful careers in government, industry, and academia. Additionally, Prof. Pervan has been serving the international PNT community for more than 25 years, including as Editor-in-Chief of *NAVIGATION: Journal of the Institute of Navigation* from 2006 to 2019. During his tenure, *NAVIGATION's* content expanded and became indexed among top-ranked journals in aerospace engineering.

Dr. Boris Pervan is currently a professor of mechanical and aerospace engineering at the Illinois Institute of Technology (IIT) in Chicago. He holds a BS from Notre Dame (1986), MS from Caltech (1987), and PhD from Stanford University (1996). He was elected a Fellow of the Institute of Navigation in 2010.

2022 Parkinson Award

The 2022 Parkinson Award was presented to Dr. Yang Wang of the University of Colorado Boulder for his thesis *Advanced GNSS Receiver Signal Processing and Remote Sensing Applications.*

The Bradford W. Parkinson Award is awarded annually to an outstanding graduate student in the field of

Dr. Bradford Parkinson, 2022 Parkinson winner Dr. Yang Wang, and his PhD supervising professor Dr. Y. Jade Morton

global navigation satellite systems (GNSSs). This award, which honors Dr. Parkinson for his leadership in establishing both the U.S. Global Positioning System and the Satellite Division of the ION, 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 peer reviewer for various ION activities:

Dr. Lucilla Alfonsi, INGV
Dr. Andrew Neish, Xona Space
Dr. Joseph Rushanan, The MITRE Corporation
Dr. Safoora Zaminpardaz, RMIT University

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

Recognition of the ION GNSS+ 2022 Technical Program Organizers

ION Volunteers Recognized, with the Support of

Held with the support of our sponsor, *Inside GNSS*, this year our ION GNSS+ volunteers were treated to a competition centered on teamwork, ingenuity, and sportsmanship to see who could build an unmanned car from a kit in 10 minutes, later racing it on a custom track. Teams were given extra points if they could make their vehicle fly. What ensued was a hilarious spectacle array of tricked-out and fascinating vehicle designs. The Institute of Navigation extends a special thank you to all our volunteers who work tirelessly throughout the year.

Dr. Mohammed Khider, Track Chair; Dr. Daniele Borio, Track Chair; Laura Norman, Track Chair; Dr. Zainab Syed, Program Co-Chair; Dr. Sandy Kennedy, Satellite Division Chair; Dr. Mathieu Joerger, Program Co-Chair; Dr. Fabio Dovis, Track Chair; Dr. Juan Blanch, Proxy for Track Chair Dr. Rong Yang; and Dr. Sanjeev Gunawardena, Proxy for Track Chair Dr. Zhen Zhu

Dr. Li-Ta Hsu and Dr. John Raquet prepare for a vehicle race-off.

The thrill of victory! Dr. Hauschild, Dr. Gross, Dr. Borio, and Dr. Walter at the track

The dynamic duo who engineered the winning vehicle was Dr. Sanjeev Gunawardena and Dr. Robert Leishman (pictured with members of the Inside GNSS *staff, Christine Waring, Renee Knight, and Gina McGuiness).*

Special recognition was awarded to any team that engineered a vehicle that could fly (without human assistance). Dr. Richard Langley, Dr. Sherman Lo, and Dr. Todd Walter managed to make part of their vehicle fly and were recognized for their vehicle's flying wheels. (We won't share the fate of the rest of their vehicle's parts.)

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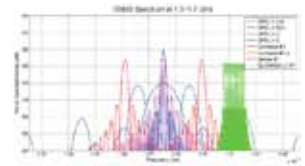
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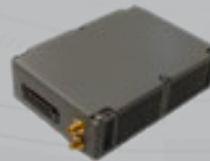- ☑ Update and future proof legacy navigation systems to meet emerging threats
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Altmetrics From the Technical Program

Top 10 Most-Watched Videos

1. PULSAR: A New Generation of Commercial Satellite Navigation: Tyler Reid
2. Enabling Smartphone Lane-Level Positioning with Trimble High-Precision RTX Technology: David Rüegg
3. 1st Place Winner of the Smartphone Decimeter Challenge: Two-Step Optimization of Velocity and Position Using Smartphone's Carrier Phase Observations: Taro Suzuki
4. Characterizing GPS Signal Deformations using the WAAS Signal Quality Monitor: R. Eric Phelts
5. Software-Defined GNSS is Ready for Launch: Hailey Nichols
6. Evaluation of Satellite Clock and Ephemeris Error Bounding Predictability for Integrity Applications: Xinwei Liu
7. Fault-Free Integrity and Continuity for Driverless Urban Vehicle Navigation with Multi-Sensor Integration: A Case Study in Downtown Chicago: Kana Nagai
8. Field Testing of 5G Based High-accuracy Positioning using RTK and PPP-RTK: A. Chamorro; and Outlier Detection for 3D-Mapping-Aided GNSS Positioning: Qiming Zhong
9. PPP and Galileo High Accuracy Service with Satellite Selection Strategies for Kinematic Applications: Ilaria Martini; and GEODNET: Secure Geo-Spatial Infrastructure & Service for Business and Metaverse: Mike Horton
10. A Lunar Navigation and Communication Satellite System with Earth-GPS Time Transfer: Design and Performance Considerations: Sriramya Bhamidipati; and Learning GNSS Positioning Corrections for Smartphones using Graph Convolution Neural Networks: Adyasha Mohanty

Top 10 Most-Downloaded Papers

1. *Characterizing GPS Signal Deformations Using the WAAS Signal Quality Monitor*: R. Eric Phelts
2. 1st Place Winner of the Smartphone Decimeter Challenge: *Two-Step Optimization of Velocity and Position Using Smartphone's Carrier Phase Observations*: Taro Suzuki
3. *Multipath Rejection Using Multi-Correlator Based GNSS Receiver in Vector Tracking Loops:* Christian Siebert
4. *Design of Estimators with Integrity in the Presence of Error Model Uncertainty:* Juan Blanch
5. *Permanent VRS Network and Positioning Engine for Mass-Market Scalable Precise Navigation:* Xavier Banqué-Casanovas
6. *Fault-Free Integrity and Continuity for Driverless Urban Vehicle Navigation with Multi-Sensor Integration: A Case Study in Downtown Chicago:* Kana Nagai
7. *Learning GNSS Positioning Corrections for Smartphones using Graph Convolution Neural Networks*: Adyasha Mohanty
8. *Evaluation of a Complementary Navigation Filter Steering a UAS Autopilot in a GNSS Contested Environment:* Andrew Appleget; and *Outlier Detection for 3D-Mapping-Aided GNSS Positioning*: Qiming Zhong
9. 3rd Place Winner: 2022 Smartphone Decimeter Challenge: *An RTKLIB Open-Source Based Solution:* Tim Everett; and *Tightly Coupled GNSS/IMU/UWB Kalman Filter Supporting UAS Autoland in GNSS Harsh Environment:* Cheolmin Lee
10. *A New Approach for Single Antenna INS Alignment in Multirotors Allows Faster Time-to-Application:* Payam Nazemzadeh

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GNSS+ 2023

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

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ION GNSS+ 2022 Best Presentation Awards

Session A1: Augmentation Services, Integrity and Authentication

Evaluation of Satellite Clock and Ephemeris Error Bounding Predictability for Integrity Applications: Xinwei Liu, Juan Blanch, Todd Walter, *Stanford University*

Session C1: New Technologies, Opportunities and Challenges

Protecting the Skies: GNSS-LESS Accurate Aircraft Navigation with Terrestrial Cellular Signals of Opportunity: Zak M. Kassas, *The Ohio State University;* Ali Abdallah, *University of California, Irvine;* Chiawei Lee and Juan Jurado, *US Air Force Test Pilot School*; Jacob Duede, Zachary Hoeffner, Thomas Hulsey, Rachel Quirarte, and Steven Wachtel, *US Air Force*; and RunXuan Tay, *Republic of Singapore Air Force*

Session D1: Alternative Technologies for GNSS-Denied Environments

Fault-Free Integrity and Continuity for Driverless Urban Vehicle Navigation: A Case Study in Downtown Chicago: Kana Nagai, Matthew Spenko, Ron Henderson, Boris Pervan, *Illinois Institute of Technology*

Session E1: Accurate Navigation in Challenging Environments

A Standardizeable Integrity Concept for Terrestrial RNP: Okuary Osechas, Gianluca Zampieri, *German Aerospace Center (DLR)*; Maurizio Scaramuzza, *Skyguide;* Valeriu Vitan, Gerhard Berz, *EUROCONTROL*

Session F1: Atmospheric Effects on GNSS

GUARDIAN: A Near Real-Time Ionospheric Monitoring System for Natural Hazards Early Warnings: Léo Martire, S. Krishnamoorthy, L. J. Romans, B. Szilágyi, P. Vergados, A. W. Moore, A. Komjathy, Y. E. Bar-Sever, A. B. Craddock, *NASA/JPL, California Institute of Technology*

Session A2: Aviation and Aeronautics

Evaluating New and Current Horizontal Protection Levels in the Baseline RAIM Algorithm: Danielle Racelis and Mathieu Joerger, *Virginia Tech*

Session B2: GNSS Applications in Space

A Lunar Navigation and Communication Satellite System with Earth-GPS Time Transfer: Design and Performance Considerations: Sriramya Bhamidipati, Tara Mina, and Grace Gao, *Stanford University*

Session E2a: Smartphone Decimeter Challenge (Co-sponsored by Google)

1st Place Winner: Two-Step Optimization of Velocity and Position Using Smartphone's Carrier Phase Observations: Taro Suzuki, *Chiba Institute of Technology*

Session E2b: Advanced Processing of Signals of Opportunity for Positioning, Navigation, and Timing

Blind Doppler Tracking and Beacon Estimation for Navigation With Multi-Constellation LEO Satellites: Sharbel Kozhaya and Zak M. Kassas, *The Ohio State University*

Session F2: Advanced Software and Hardware Technologies for GNSS Receivers

Hypercomplex Representation and Processing of GNSS Signals: Daniele Borio, *European Commission/Joint Research Center (JRC)*

Session A3a: Autonomous Applications

Long Term Dead-Reckoning Using Silicon Photonic Optical Gyroscope: Mike Horton and Yu Yi, *Anello Photonics*

Session B3: Future Trends in GNSS Augmentation Systems

Computing K Factors for all Integrity Needs: Julie Antic, Odile Maliet, Sébastien Trilles, *Thales Alenia Space*

Session C3b: Indoor Navigation and Positioning

A Novel Bluetooth Based Ranging and Positioning Approach Considering Multipath Propagation: Christian Gentner, Julia Schmid, Armin Dammann, *German Aerospace Center (DLR);* Philipp Kindt, *Chemnitz University of Technology*

Session D3: GNSS Augmentation and Robustness for Autonomous Navigation

Performance Assessment of Fault Free Recursive ARAIM With High-Integrity Time-Correlated Measurement Error Models: Elisa Gallon, Samer Khanafseh, *Illinois Institute of Technology*; Mathieu Joerger, *Virginia Tech;* Boris Pervan, *Illinois Institute of Technology*

Session E3: All-Source Intelligent PNT Method

Integer Ambiguity Resolution for Frequency-Varying Carrier Phase Signals: Theory and Numerical Results: Amir Khodabandeh, *The University of Melbourne;* and Peter J.G. Teunissen, *Delft University of Technology*

Session F3: GNSS Authentication and Anti-Spoofing

Time Synchronization for TESLA-Based GNSS-Enabled Systems: Jason Anderson, Sherman Lo, Todd Walter, *Stanford University*

Session A4: Land-Based Applications

GNSS Antenna Calibration for Cars–Challenges and Prospects: Jannes B. Wübbena, Alexander Nietsch, Norbert Matzke, Temmo Wübbena, Gerhard Wübbena, *Geo++ GmbH*

Session B4: Trends in Future Satellite Navigation Technology, System, and Services

PULSAR: A New Generation of Commercial Satellite Navigation: Tyler G. R. Reid, Simon Banville, Bryan Chan, Kazuma Gunning, Brian Manning, Thyagaraja Marathe, Andrew Neish, Adrien Perkins, Aurore Sibois, *Xona Space Systems*

Session C4: Urban and Indoor GNSS

Set-Based Ambiguity Reduction in Shadow Matching With Iterative GNSS Pseudoranges: Daniel Neamati, Sriramya Bhamidipati, and Grace Gao, *Stanford University*

Session D4: Robust Navigation Using Alternative Navigation Sensors and Solutions

Robust Navigation for Urban Air Mobility via Tight Coupling of GNSS With Terrestrial Radionavigation and Inertial Sensing: Robert Tenny and Todd E. Humphreys, *University of Texas Austin*

Session F4: Remote Sensing, Timing, Space, and Scientific Applications

Autonomous Satellite System Synchronization Schemes via Optical Two-Way Time Transfer and Distributed Composite Clock: Christian Trainotti, Manuele Dassié, Gabriele Giorgi, *German Aerospace Center (DLR);* Amir Kodabandeh, *The University of Melbourne;* Christoph Günther, *DLR*

Session A5: Marine Applications, and Search and Rescue

Galileo RETURN LINK SERVICE Evolutions: Chiara Scaleggi, Sylvain Delattre, *CNES;* Pol Novel, *EUSPA;* Antonio Rolla, *European Commission*

Session C5: Positioning Technologies and Machine Learning

Designing Deep Neural Networks for Sequential GNSS Positioning: Shubh Gupta, Ashwin V. Kanhere, Akshay Shetty, and Grace Gao, *Stanford University*

Session D5: Indoor and Urban Navigation and Mapping

Algorithms for Mapping the Urban Signal Environment for Navigation of Ground Vehicle Operations: Emma Zeller, Kirsten Strandjord, *University of Minnesota*; Pai Wang, *Shanghai Jiao Tong University*

Session E5: High Precision and High Integrity Navigation Algorithm

Temperature-Induced Bias Variations of Multi-Frequency Receivers: André Hauschild, *German Aerospace Center (DLR), German Space Operations Center (GSOC);* M. Bradke, M. Ramatschi, *German Research Centre for Geosciences (GFZ);* S. Yudanov, *JAVAD GNSS*

Session B6a: Technologies for Scientific and Sectorial Applications

A Modular and Extendable GNSS Python Library: Derek Knowles, Ashwin Vivek Kanhere, Sriramya Bhamidipati, and Grace Gao, *Stanford University*

Session B6b: Spectrum: Protection and Optimization

Joint Detection and Tracking of Unknown Beacons for Navigation With 5G Signals and Beyond: Mohammad Neinavaie and Zak Kassas, *The Ohio State University*

Session C6: Advances in High Precision Positioning

Triple-Frequency Multi-GNSS PPP-AR Convergence Under Different Environments: Viet Duong, *Hemisphere GNSS (USA) Inc.;* Jianping Chen, *Hemisphere GNSS (Canada) Inc.;* Suelynn Choy, *RMIT University;* Chris Rizos, *University of New South Wales*

Session D6: Navigation Using Environmental Features

Observability Analysis for Opportunistic Receiver Localization With LEO Satellite Signals: Ralph Sabbagh, *University of California, Irvine;* Zak M. Kassas, *The Ohio State University*

Session E6: Sensor Network and Cooperative Navigation

Simultaneous Localization and Calibration for Radio Navigation on the Moon: Results From an Analogue Mission: Robert Pöhlmann, Emanuel Staudinger, Siwei Zhang, and Armin Dammann, *German Aerospace Center (DLR)*

Session F6: GNSS Receivers Robust to Vulnerabilities

Exotic FMCW Waveform Mitigation With an Advanced Multi-Parameter Adaptive Notch Filter (MPANF): Johannes Rossouw van der Merwe, Iñigo Cortés, Fabio Garzia, Alexander Rügamer, and Wolfgang Felber, *Fraunhofer Institute for Integrated Circuits IIS*

Student Paper Awards

The Satellite Division awarded five students with Student Paper awards. Recognized industry and academic experts selected the winners: Surachet Srinara, *National Cheng Kung University;* Hoi-Fung Ng, *The Hong Kong Polytechnic University*; Nacer Naciri, *York University*; and Junjie Zhang, *The University of Melbourne.* Not pictured: Qiyuan Zhang, *Wuhan University.*

A huge thank you goes out to our ION GNSS+ exhibitors and sponsors for their support:

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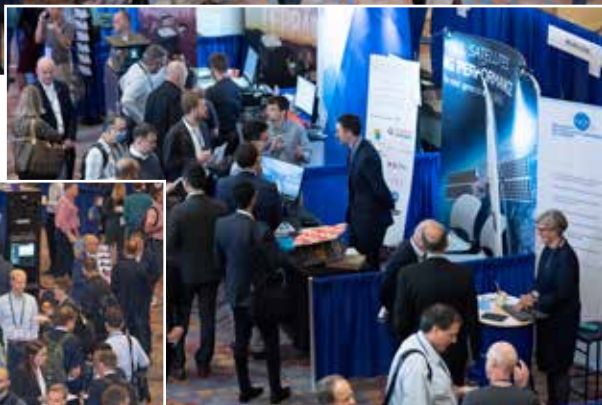Xona Space Systems

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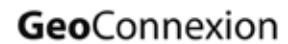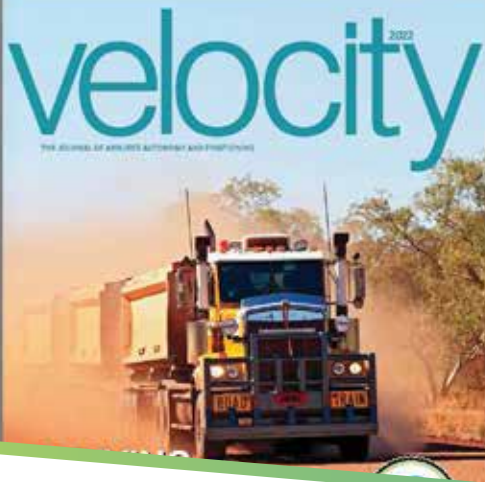
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stream geospatial activities will surely follow until maps, surveys, and positioning become unreliable or will be wholly reliant upon the geodesists of other nations, possibly those in adversarial positions to the United States.

Lack of Geodesy Students in Academia

University students in the United States are no longer pursuing advanced degrees in geodesy in meaningful numbers. Members of the previous generation of trained geodesists are retired or are on the threshold of retirement. Geodesy has been so fundamental to mapping and navigation that people in the geospatial community assume it will always be there. By the time we collectively realize how broken things are, there will be no viable path to solving the problem. In truth, we are already at a critical stage with fundamental geospatial science. We face significant challenges in rebuilding programs that have supported the training of new geodesists, but we must rebuild them.

The National Geodetic Survey (NGS) has indicated that they've had very limited success in hiring qualified candidates for internal geodesy positions. When positions become available, the survey receives few, if any, applications, and the individuals who apply rarely make the cut. Applicants are referred by Human Resources based on their written narrative, but they are uniformly lacking in the needed technical skills.

In the short term, the NGS, unable to secure trained geodesists, has tried creative approaches, bringing in surveyors or others from related fields, educating them on the job, and sending them for advanced training. However, there aren't sufficient funds in the NGS budget to do this training properly, nor are there a lot of places in the U.S. to send personnel for the desired specialized training. The NGS has also tried hiring qualified geodesy professors for advanced jobs, but as one geodesist noted, "It's like eating your seed corn. It will get you through the moment, but the future is put further in doubt."

It is also important to note that inter-national geodesy professionals are not eligible to apply for geodesy positions that require U.S. citizenship and, often, security clearances. This gap is where much of the demand for geodesists lies.

U.S. Government Divested From Geodetic Research

So, how did we get here? The January 2022 white paper notes that in the early 1990s, "the U.S. government largely disinvested in academic research and academic sponsorship in geodesy." At the same time, there seemed to be an underlying sense that: *Now that we have GPS, why do we need to continue to improve our geodetic models? Doesn't GPS give us precise positioning?*

Academic institutions that traditionally supported geodetic programs in the past have since cut programs that did not have sufficient attendance, eyeing the bottom line while ignoring the importance of this critical science.

In parallel to the decline in support for U.S. academic programs, other countries around the globe have maintained and strengthened healthy geodetic training and research programs, namely China, Germany, England, Japan, Canada, Australia, and New Zealand. Several of these countries are now launching GNSS satellites with capabilities that equal or surpass those of the U.S. constellation.

Error Correction in the U.S. Government

What can we do to right the ship? The white paper serves the purpose of ringing the alarm bell and has led to broader awareness of the significant geodesy challenges faced by the U.S. Since the paper's introduction, the Civil Applications Committee, PNT Advisory Board, and federal government departments have hosted presentations and discussions on the geodesy crisis, but a more concrete call to action at the highest levels of government is needed and needed now.

Regarding the loss in capacity in the federal civil government, there is limited awareness of the problem and insufficient strategic planning to address the issue and work toward solutions. A general lack of understanding of geodesy, a seemingly complicated arcane science, and the perception that it doesn't tangibly contribute to agency core missions further handicaps the discussions and education of leadership relative to its importance. Even within the geospatial community, there is often a lack of nuanced understanding of the importance of geodesy as a foundational component of the geospatial enterprise.

The Federal Geographic Data Committee (FGDC), which develops or adopts geospatial standards for implementing the National Spatial Data Infrastructure (NSDI), has begun to mandate geospatial data be "FAIR" by making federal geodesy data "Findable, Accessible, Interoperable, and Reusable." Geospatial data becomes more interoperable through being in the same reference system or at least having the ability to transform the data accurately. Once FAIR is more entrenched, the FGDC may have better success conveying the importance of geodesy to decision makers. Still, there is the urgency to move more quickly on this than the usual speed of government.

Looking to the Next Generation of U.S.-Trained Geodesists

An underlying and fundamental question is: *Why aren't university students choosing careers in geodesy?* To answer this question, we must examine the reinforcing trends at play.

The first trend is that U.S. students lag behind their international peers in mathematics. America has a smaller-than-average share of top-performing math students, and scores have been flat for two decades. There is an awareness that the geodesy crisis is a specific example of the overall STEM education crisis in the United States. Discussions at the National Science and Technology Council (NSTC) should weave the geodesy issue into topic areas concerned with improvement to STEM education plans.

Erin Richards of *USA Today* remarks

that "classes here [in the U.S.] often focus on formulas and procedures rather than teaching students to think creatively about solving complex problems involving mathematics. That makes it harder for students to compete globally in careers that are math-based like geodesy."

The second reinforcing trend is the decline of broad U.S. government support to academic institutions that host programs in geodesy, as noted above.

So how do we build and educate the next generation of geodesists?

- Make the White House and Congress aware of this crisis, particularly its national security implications; seek direct support in the federal budget to correct this issue. It has become clear that, without the engagement at the highest echelons of the U.S. government, averting this current crisis and its eventual outcome is unlikely.
- Teach rigorous math in our public schools; follow the scholastic math approach used in many Asian and European countries.

- Encourage creative thinking!
- Actively market geodesy in high schools as a rewarding career for the math stars before college entry.
- Build back, support, and sponsor geodesy programs at select universities. This support needs to be strategic with backing from the highest levels of the U.S. government.
- Break our cultural trend of reactions to crises and seize the opportunity to be proactive and prevent the foreseen consequences of this crisis.
- Encourage U.S. government support in the form of grants, professional development of staff, and research collaborations/affiliations.

There are early efforts underway to bring new talent into the pipeline:

- The National Geospatial-Intelligence Agency (NGA) is forming an emerging scientist consortium (ESCON) with partnerships that exist with Ohio State, UT-Austin, and other industry/academic/government partners.
- A pilot PhD Geodesy educational

program with 3 NGA and 1 NGS employee is in place. The NGA expects to continue growing this program.

- The NGA's new western headquarters in St. Louis will bring 350 companies and organizations into the regional GEOINT ecosystem.

If we answer this call to action collectively, there is hope that a new cadre of U.S. geodesists can be cultivated before it's too late to recover. ✳

Everett works for the federal government, serves as a subject matter expert on several high level boards, and is a concerned citizen geodesist.

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Congressional Fellow

Dr. Benjamin Ashman

The Urban Crisis

Growing up in Dayton, Ohio, in the 90s, I could tell the city was struggling. My parents' generation reminisced about Christmas shopping in the bustling department stores downtown, but I saw too many of the city's beautiful old buildings standing empty. The General Motors plant near my house downsized several times and finally closed in 2008. Two years later, NCR Corporation, my mom's employer and a cornerstone of the community for 125 years, announced it would be moving to Atlanta. The company's New-York-based CEO complained that "we had a very difficult time recruiting people to live and work in Dayton." Residents were infuriated by his portrayal of the city as backwater. While parts of Dayton remained strong, I was clearly witnessing a transition.

I'm an aerospace engineer, but through the ION Congressional Fellowship, I hoped to better understand what author Thomas Sugrue calls "the urban crisis." Dayton is not unusual, suffering the economic downturn experienced by many mid-sized cities, especially post-industrial cities in the Midwest. A 2018 *ProPublica* article,

"How Struggling Dayton, Ohio, Reveals the Chasm Among American Cities," explored this problem, describing the trend towards ever-larger (but fewer) superstar cities—and the cities that were being left behind. My brother and I saw this contrast firsthand when we moved to Portland, Oregon, and Washington, DC, respectively. On my first Portland visit, I remember my brother gesturing excitedly to the cranes downtown, "Look, they're building things here!"

As a legislative fellow in Senator Brown's (D-OH) office, I worked on two portfolios: NASA and economic development. I initially thought of these as separate, but I soon realized they were driven by the same goal that drove everything the office does: economic growth in the form of good jobs.

Jump-Starting America

At the start of my fellowship, my mentor told me to read the book *Jump-Starting America.* The authors, two MIT economists, claimed that in the rush to a handful of superstar cities, governments and companies were overlooking other regions primed for investment: mid-sized cities poised for growth that could maximize returns. They proposed three criteria for identifying these cities: low cost of living, a large population of young people, and the availability of good universities. Several Ohio cities made their list, including Dayton.

The authors made two other important claims. First, that economic growth comes from innovation and that innovation, while impossible to create outright, reliably arises from federal investment in fundamental research and development (R&D). Second, they argued that policymakers have a responsibility to pursue economic growth for everyone—not just superstar cities.

The China Competition Bill

Members of Congress and their staffers, many inspired by *Jump-Starting America,* developed the United States Innovation and Competition Act (USICA) to put these ideas into action. The bill was promoted as a call to arms in the United States' economic competition with China (a rare area of bipartisan agreement). Like any large piece of legislation, it consisted of many bills focused on specific aspects of the issue, each with their own sponsors and advocates.

One of USICA's most visible elements was the CHIPS Act. This was an act to provide over $50 billion to increase domestic manufacturing of semiconductors. The bill even had an Ohio connection: In January, Intel announced plans to build a chip fabrication facility outside Columbus, investing $20 billion and creating 10,000 jobs with the promise of more if the CHIPS Act passed. This was a big deal, garnering presidential visits to the state and a shout-out at the State of the Union Address. It was arguably the single biggest issue for Senator Brown during my fellowship year.

The Senate passed USICA just before my fellowship began and, in February, the House passed its version (the America COMPETES Act). Congress then set up a bicameral conference to resolve the many differences between the bills. Although this is often described as the normal process for finalizing legislation, a full conference committee is actually rare in today's highly polarized political environment. Usually the less efficient "ping-pong" method is used in which the chambers pass versions of the bill back and forth, iterating until something passable develops. But competing with China had appeal across the political spectrum, so legislators from both parties were willing to hold a formal conference.

I followed the process closely: conference participants' public opening remarks, the sometimes-faltering deliberation behind the scenes, and the eventual emergence of a compromise bill. I

Senator Brown's chief of staff, another legislative fellow, and Benjamin Ashman in the Capitol rotunda

watched from the Senate floor as the bill passed on July 27, and within a week, the President had signed it into law.

Growth Through Innovation

My interest was more than procedural—the compromised bill touched on almost everything I worked on as a fellow. In addition to the CHIPS Act, the bill included a "Science Title" with a wide array of legislative initiatives intended to spur economic growth through federal investment in R&D, especially in underserved communities like rural or rust belt regions. These initiatives included funding for manufacturing and innovation hubs, funding for fundamental research at the

National Science Foundation, and a NASA Authorization Act—the first since 2017.

The challenges faced by mid-sized post-industrial cities like Dayton (or Cumberland, Maryland, or Troy, New York, etc.) have many causes. Some of these are self-inflicted (e.g., gutting the city center with redlining—Dayton has consistently been identified as one of the most segregated cities in the country) while others stem from damaging federal policies (e.g., trade agreements that incentivize the exploitation of cheap labor abroad). But over the course of my fellowship year, I've come to appreciate the unique opportunity a

federal research facility like Ohio's NASA Glenn Research Center presents to the surrounding community.

A Role for ION Members

For most of my career, I've focused on improving the performance of spacecraft navigation, especially using GNSS. Many of you are engaged in similar research. But we, the members of ION, also have an important role to play in the communities where we live and work. As engineers and scientists working at the forefront of technological development, we are a critical part of the innovation that drives economic growth.

NASA colleagues sometimes complain that Congress views the agency as a glorified job program. In some ways I share this complaint—NASA's work to expand our understanding of the universe is important in its own right. But the agency also provides good jobs; jobs that support families, provide people the chance to grow, and bring life to the cities where they live. It's hard to think of anything more important than that.
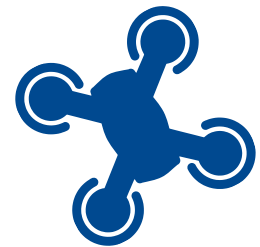
Navigation Heaven

Marvin B. May

It was a marriage made in navigation heaven. The bride and groom formed a perfect couple. The groom provided long-term performance, integrity, and endurance, as well as robust protection against adversaries. The bride, although somewhat fragile, brought exquisite accuracy and availability. Together, they were a pair that could overcome all navigation obstacles that had hitherto not been conquered.
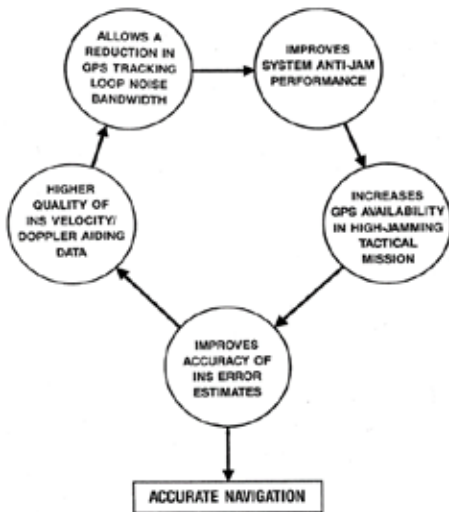
Synergistic improvements by GPS/INS system

The pairing promised the attributes of an ideal navigation system: high relative and absolute accuracy; complete global coverage; efficient real-time response in the presence of high user dynamics; a capability of providing 3D position, velocity, and attitude; remaining unaffected by the environment; resistance to intentional and unintentional electronic jamming and spoofing; deniability to an enemy; inclusion of wide user applicability; autonomous timely failure detection and correction; high reliability; compatibility with avionics suite requirements; and affordability. This article is about embedded GPS inertials, their history, long engagement, diverse methods of coupling, and continuing attempts to consummate the marriage.

INS Meets GPS

Fifteen years before GPS achieved initial operational capability, a few scientists recognized that inertial navigation technology would be complementary and synergistic with GPS. For example, the first GPS *Red Book*, published in 1980, included an article by Duncan Cox of Draper that addressed the possible benefits of coupling GPS with an inertial navigator.

These couplings proceeded somewhat slowly as the GPS radio engineers were reluctant to accept the entreaties of the inertial navigation community. The emphasis was on completing the GPS constellation and equipping the military with Phase 1 and Phase 2 GPS receivers. GPS had intoxicating accuracy and was eminently successful toward its original goal of replacing and reducing the proliferation of other radionavigation systems. Until the 1990s, there was little attention paid to its susceptibility to electronic warfare countermeasures, signal obscuration, limited dynamic velocity, limited attitude capability, and the issues associated with failure detection and identification.

Loosely Coupled Mechanization

The first engagements of the GPS and inertial technologies were accomplished with loosely coupled mechanization. In loosely coupled mechanization, the GPS receiver and INS maintain separate position and velocity solutions utilizing separate Kalman filters. GPS geographic positions and velocities were sent to the INS's Kalman filter for error bounding and instrument calibration. INS positions and velocities might have also been sent to the GPS receiver where they would be resolved into line-of-sight ranges and range rates for code loop aid-
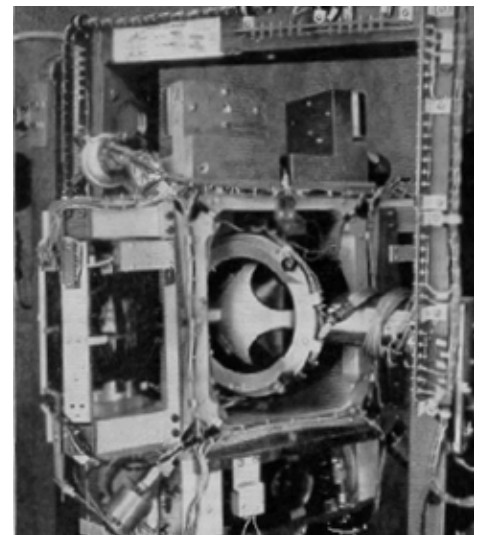
First Successful All-Inertial Navigator

ing and acquisition.

Loosely coupled configuration was the first step in their romance. It was primarily applicable when physically discrete GPS and/or INS equipment already existed in the aircraft's avionics suite, often interfacing through relatively slow mission computer data busses. Under these circumstances, logistical factors and cost considerations associated with existing component modifications often dictated a loosely coupled system.

Tightly Coupled Mechanization

In tightly coupled mechanization, however, measurements of GPS pseudo-range and delta range along with satellite ephemerides provide to a single navigation processor that mechanizes INS navigation equations and collectively estimates all observable system errors. Kalman filters are external to the high iteration rate loops associated with the accumulation of the inertial sensor assembly's outputs to create the nominal velocities and positions; instead, the dynamics upon which the filter is based are the low-frequency INS error growth modalities such as the characteristic 84-minute Schuler errors. The INS-related Kalman filter estimates are then fed back into the INS mechanization equations creating an optimal hybrid GPS-INS solution. Corrected INS positions and velocities are then provided to the GPS receiver tracking loops for aiding and reacquisition under jamming conditions

The benefits of tight coupling were best

realized when the GPS receiver and INS cohabited, or as is presently known *embedded*, in a single box that minimizes data bus traffic and latency; and for systems employing the GPS precise positioning service, confining data transfers of encrypted quantities. The concomitant benefits of reduced size, weight, power, and under most cases, cost, made embedded systems particularly attractive.

The GINA

By the early 1990s, the U.S. Department of Defense (DoD) had several embedded GPS-INS systems under development or in procurement. The Navy program, procured and tested by the Naval Air Development Center in Warminster, Pennsylvania, was designated the GPS Inertial Navigation Assembly (GINA). The GINA was initially targeted for the McDonnell Douglas British Aerospace T-45 jet trainer—the first aircraft scheduled to have a production embedded GPS-INS.

The contract was let in April 1993 with initial production units for integration testing expected for delivery in late 1993 and production deliveries scheduled to start in March 1996. The GINA had a five-channel embedded precise positioning service (PPS) GPS receiver and an inertial measurement unit (IMU) featuring ring laser gyroscopes. It was procured with a competitive contract won by Litton for the IMU teaming with Rockwell-Collins for the embedded PPS GPS receiver.

The GINA accommodated an avionics suite with a physical envelope 7-inches high and 7-inches deep, with a nominal weight of 23 pounds and power requirements of 42 watts at 28 volts DC. It incorporated several interesting features that were meant to enhance its overall flexibility and utility. The first was the continuous maintenance of a GPS-only solution in addition to the hybrid GPS-INS solution. Another feature was the requirement of accepting aid to its code loop tracking loop from an external INS or Doppler navigation system. This may have been desirable under circumstances when Doppler was considered superior to the IMU or in the event of an inertial component failure within the embedded IMU.

The third, and probably most important, feature called for the ability to input from an external simulation device some level of dynamic simulated IMU data during laboratory testing using a GPS satellite signal generator. Satellite signal generator simulations had been used for the laboratory testing of GPS receivers since the late 1980s (see *Early GPS Simulation: It All Began on Yuma's Desert Floor* in the Summer 2012 *ION Newsletter*).
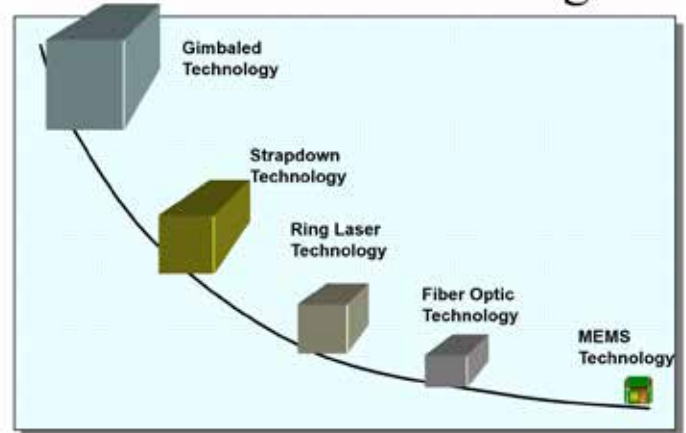
The challenge for laboratory testing of an embedded GPS-INS was to generate simulated IMU data senescent with the same platform dynamics that the GPS satellite signal generator was programmed for. This capability enabled a laboratory system level testing alternative to expensive flight testing on an instrumented test range. This laboratory testing capability, designated the Simulated Inertial GPS Navigation Laboratory (SIGNAL), was developed by the Naval Air Development Center in cooperation with the Honeywell and Litton Corporations.

Development of the GGP

The GPS Guidance Package (GGP), sponsored by the Advanced Research Project Agency, was one of the first embedded systems designed from the start as a totally integrated package. It included a ten-channel PPS and tightly coupled embedded systems aimed at a variety of DoD manned and unmanned platforms. The GGP exploited technologies for monolithic microwave integrated circuits, fiber-optic gyroscopes, solid-state accelerometers, and integrated optical circuits.

The Phase 1 GGP had a volume of 295 cubic inches and a weight of 14.9 pounds and was scheduled for completion in 1994. The GGP Phase 1 contract under the sponsorship of DARPA was awarded by Naval Ocean Systems Center (NOSC) to Litton/Rockwell-Collins and Honeywell/Texas

Instruments. The Phase 2 contract was awarded to Litton/Rockwell-Collins and Honeywell/Rockwell-Collins.

The Phase 2 contracts were awarded in 1996 by the Army Missile Command in Huntsville, Alabama. Its main goals were to achieve 0.8 nautical mile/hour unaided inertial performance and miniaturization of the system to 100 cubic inches and a 7-pound package. The Phase 2 design provided capabilities of high dynamics and low jamming susceptibility as well as adaptability to multiple military and commercial applications with a low production cost.

By any standard, the marriage of GPS and INS has been hugely impactful to navigation. As may be shown in future articles, the early GPS-INS embedded systems, such as the GINA and GGP, bore progeny that have been fielded in virtually all applications. ✹

This article is an edited and updated version of [Inertial Navigation and GPS, September 1993] by the same author. Republished with permission from GPS World.

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Evolution of Inertial Navigation

Gimbaled Technology

Strapdown Technology

Ring Laser Technology

Fiber Optic Technology

MEMS Technology

Defense Matters

A Time for Action
Countered by Two Kinds of Truth

A precursory note to all readers: The material that follows includes an overabundance of cited references. For all practical purposes, these can be chalked up to employing some tongue-in-cheek satire and a sprinkling of sarcasm to woefully reflect on the ongoing handwringing surrounding the truth about the U.S. national PNT posture.

This quarterly *Defense Matters* submission was inspired by a recent commentary provided by Logan Scott in the August 2, 2022 edition of *Inside GNSS* entitled *Time for Action: We Must Fail Before We Can Succeed.*[1] In my view, it is a well-written, thoughtful piece that suggests that, in the United States, we have lost the inventive spirit of years gone by in which American ingenuity confronted challenges head-on.

Cargo Cults

I have to disclose that upon reading Logan's opening paragraph where he employs the term *Cargo Cults* in the statement, "The Cargo Cults of Washington D.C., while well intentioned, are slowing progress…like the Cargo Cults of the South Seas waiting for those airplanes to land," forced me to investigate the meaning and the use of the term.[1]

I found that Logan's reference to the South Seas is consistent with the historical derivation of the term in a subregion of Melanesia where there was a belief in the "imminence of a new age of blessing to be initiated by the arrival of a special 'cargo' of goods from supernatural sources."[2]

I asked myself: *Was Logan suggesting that those here in the Washington D.C. area think that some magical force is going to make the well-documented and increasingly dangerous 20+ year reliance on GPS simply vanish or become a non-issue because GPS will be blessed or protected because it is special? If one were to believe that, then how could it be that those "well intentioned are slowing progress?"* Not completely convinced that I had it correct, I decided to look further and the appropriateness of that potential addition will become apparent.

A more recent application of the term is found in the world of computer programming where, "cargo cult programming…describes the ritual inclusion of code which may serve no purpose in the program, but is believed to be a workaround for some software bug, or to be otherwise required for reasons unknown to the programmer."[3]

Doug Taggart
President
Overlook
Systems
Technologies, Inc.

The Role of Ritual

Armed with this more recent derivation, maybe Logan's application was meant to infer that delays are being experienced because of an ongoing ritual conducted by those here in Washington, D.C. Setting off to investigate further, I found that the term *ritual* can fall into any of three main types.

The first is: "A mythological reenactment or a long-standing religious ritual that reenacts a sacred story." The second is: "A rite of passage which is a culturally significant marker of a new stage of life." The third is: "A family ritual which are often less religious- and community-oriented and more relaxed. Such rituals are unique, and usually have deep emotional significance throughout the generations."[4]

Is it possible that the slowing progress by the those well-intentioned here in Washington, D.C., has been caused by the repetition of a sacred story that downplays the pitfalls of overreliance on a single source of PNT? Is this storytelling a rite of passage that carries a deep emotional significance that can only be fully understood when each new administration fully absorbs the 1,200+ slides in the GPS slide deck referenced by Logan's commentary? Have we reached the point where everything regarding the need for a diverse national PNT architecture has been said, but not everyone has said it? Is this too far-fetched to be the truth? I'll get back to that question in a minute.

And for those that are still reading—don't lose sight of the fact that I have only taken a stab at dissecting the first sentence of the first paragraph in Logan's article.

Leadership's Call to Action

But taking a less sarcastic tone and seeking to progress, I believe that Logan's

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1 https://insidegnss.com/time-for-action-we-must-fail-before-we-can-succeed/

2   https://www.britannica.com/topic/cargo-cult

3 https://www.newworldencyclopedia.org/entry/Cargo_cult#Critiquing_the_Notion_of_.22Cargo_Cults.22

4 https://study.com/academy/lesson/rituals-definition-types-challenges.html

true purpose is found in his reference to the historical leadership offered when President Kennedy set the national vision of putting a man on the moon in a speech he gave at Rice University on September 12, 1962 (Author's note: 60 years ago to the day while drafting this issue of *Defense Matters)*.

In this speech Kennedy said, "We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard; because that goal will serve to organize and measure the best of our energies and skills; [and] because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win."[5]

This historic call to action of sending a man to the Moon and bringing him safely back was well beyond the challenge of establishing a more diverse national PNT architecture, but there is a great deal of relevance when you consider that setting a goal is one thing, but seeing it through requires leadership. Here is where the Washington Cargo Cults fall short.

A Failure of Recent Legislation

An opportunity to bring resources to the task of pursuing a diverse national PNT architecture to complement GPS services and reduce the risk of overreliance on them recently missed when Congress passed the Infrastructure Investment and Jobs Act and President Biden signed it into law shortly thereafter[6].

The White House press release states, "The legislation will help ease inflationary pressures and strengthen supply chains by making long overdue improvements for our nation's ports, airports, rail, and roads." The statement goes on to claim that the Bipartisan Infrastructure Deal is a "once-in-a-generation investment in our

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5 https://spacecenter.org/exhibits-and-experiences/starship-gallery/kennedy-podium/

6 https://www.whitehouse.gov/bipartisan-infrastructure-law/

nation's infrastructure."[7]

Unfortunately, the idea of a national PNT infrastructure is not found in the bill, even though no less than eight of the 10 showcased areas in the press release directly depend on use of resilient PNT services for their operation. Such services take part in a vast list including high-speed internet; roads and bridges; public transit; upgraded airports and ports; passenger rails; electric vehicles; power grid infrastructure; and, moreover, resilient infrastructure with no more lead pipes and environmental remediation remaining outside of the direct PNT realm of dependency.

The Truth of the Matter

Logan's commentary reveals elements of a foundational truth—endless streams of studies on the vulnerabilities associated with GPS overreliance. He wisely suggests to take lessons from the Chinese initiative to field BeiDou and, at the same time, invest in a diverse national PNT architecture which includes their own two Loran-C systems.[8] Take lessons from SpaceX—set lofty goals and keep working to meet the objectives; learn from your mistakes and keep forging ahead. We need leaders to, not only set these goals, but to take the lead to get it done.

There are clearly those in the Cargo Cults here in Washington with the capacity to raise the issue to a level in which something can be done. There is clearly an opportunity for someone in government to step up to the challenge of displaying greater leadership and demonstrating a fearless willingness to set a vision and to take bold steps to do something beyond continuing to simply admire the problem.

To tee up the topic of truth, one might recognize that there are two kinds of truth in this world. The truth that is the unalterable bedrock of fact: Reliance for continuous operation of our critical

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7 https://www.whitehouse.gov/bipartisan-infrastructure-law/

8 https://rntfnd.org/wp-content/uploads/2018/04/China-eLoran.pdf

infrastructures on a space-based system as a single source of PNT information is neither prudent nor responsible. The other truth is the more malleable form favored by politicians in making unfulfilled promises which are bolstered by willing charlatans pretending to move the effort forward but lacking the commitment to do so. Unfortunately, the latter practice seems to have found root in Washington and is embodied in the new Cargo Cults noted by Logan.

Returning to Logan's article's title and focus—*Time for Action: We Must Fail Before We Can Succeed*—let us all hope that a future commentary doesn't carry the message, *The Time for Action has Passed: We Will Suffer Because We Did Nothing.*

GNSS Update: Ukraine War Disruption

Kevin Dennehy

DENVER—The annual update of GNSS at the ION GNSS+ international technical meeting here offered a glimpse of how the war in Ukraine is affecting Galileo launches and any reliable updates on the Russian GLONASS system.

Galileo

Galileo 2nd generation satellites
Image: Airbus

While Europe's Galileo satellite navigation constellation is well on its way to achieving full operational capability (FOC) for both the satellites and ground stations, officials say that 2022 has been a tough year for deployment.

"2022 has not been the best year for us, but a lot happened behind the scenes. While we went through COVID rather unscathed, what was dramatic for us is that we were to reach [FOC] this year," said Eric Chatre, European Commission Head of Galileo Second Generation Project Office. "We had a couple of launches planned for mid-2022—and were ready to launch [onboard Russian Soyuz launch vehicles]. Then the war in Ukraine started."

Galileo currently has 28 satellites in orbit, with two unhealthy and one spare. One satellite is unavailable and two, by design, do not have search-and-rescue capability. "We are planning new capabilities that are unrelated to the number of satellites in the constellation. We should have new service definition documentation by early 2023," Chatre said.

Chatre said that the high accuracy service, or HAS, has been available since May 2022. "We are working with chipset manufacturers and application developers. While we are targeting HAS as a regional service, but most definitely it is a global high accuracy service," he said.

In terms of what's happening to the Galileo 2nd Generation (G2G) efforts, Miguel Manteiga Bautista, European Space Agency Head of Galileo Second Generation Project Office, said that between 2025 and 2026, the first G2G satellites will be launched. By 2028, initial operational capability (IOC) will be achieved, while FOC is expected in 2031 or later.

Manteiga Bautista said that FOC Batch 3 satellites 223 and 224 entered into service on August 29, 2022, and are providing services. He said six more satellites have been completed and four are undergoing tests.

Overall, Galileo has:
  2 redundant control centers;
  13 worldwide sensor stations;
  8 telemetry and tracking stations; and
  5 real-time uplink stations.

NavIC

The Indian Regional Navigation Satellite System, or NavIC, currently has seven satellites—three in geostationary orbit (GEO) and four are in inclined geosynchronous orbit (IGSO), said Dr. P.S. Sura, Indian Space Research Organization Satellite Navigation Program Director. Sura said the constellation, which covers the India region, has two ground segment centers, 17 ranging stations and five two-way ranging stations.

According to published reports, India wants tech companies to make their smartphones compatible with NavIC by January 2023. Critics say that the changes would require more testing and would disrupt planned product launches.

Another point of contention is the Indian government's reliance on the L5 frequency, which is not as common in smartphones. Like many countries who have launched GNSS to reduce dependence on GPS, India has expanded its use of NavIC, which went operational in 2018.

BeiDou

China's BeiDou constellation currently has three geostationary satellites, three in IGSO, and 24 in medium Earth orbit (MEO), said Dr. Lu Xiaochun of the China Satellite Navigation Office.

BeiDou's PNT global short message communication and search-and-rescue signals (SAR) are available for all users, Lu said. 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.

Artist impression of NavIC satellite
Image: Indian Space Research Organization

GPS Constellation Status

37 Satellites • 31 Set Healthy
Baseline Constellation: 24 Satellites

Satellite Block	Quantity	Average Age (yrs)	Oldest
GPS IIR	12 (5*)	20.7	25.1
GPS IIR-M	8 (1*)	14.9	16.9
GPS IIF	12	8.6	12.3
GPS III	5	2.4	3.7

*Not set healthy   As of 27 Aug 22
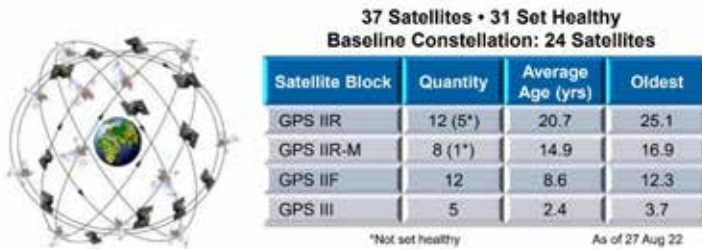
GPS Signal in Space (SIS) Performance
Week ending on 3 Sept 22

Average URE*	Best Day URE	Worst Day URE
49.1 cm	31.5 cm (20 Apr 21)	64.8 cm (20 May 22)

*All User Range Errors (UREs) are Root Mean Square values

Current GPS satellites in orbit
Image: Space Systems Command.

Lu said that six MEO satellites are available for SAR, while three GEO sats are dedicated to SBAS for China and surrounding areas.

Commercially, BeiDou supports more than 100 million chips and modules, Lu said. She said that 93.5 percent of smartphones in China support BDS positioning, which has meter-level accuracy for its ground-based augmentation service.

Despite the war in Ukraine, China is working with Russia and its GLONASS system on interoperability, joint testing, and precision agriculture projects, Lu said.

BeiDou plans to launch backup satellites, optimize production, standardize solutions, and gain PNT information autonomously, Lu said.

QZSS

While Japan's QZSS currently covers the Asia-Pacific region, the augmentation service only covers Japan, said Satoshi Kogure, Japan Aerospace Exploration Agency's Senior Chief Officer of Satellite Navigation Technology and Director of the Satellite Navigation Unit.

Kogure said that there is one GEO satellite, three QZO sats in IGSO, and one spare. There are two master control stations located in Hitachi-Ota and Kobe, Japan. In addition, there are seven satellite TTC stations located in Japan's southwestern islands and 30 worldwide monitoring stations.

QZSS, which had its last launch on October 26, 2021, plans to add three more satellites "around 2023," Kogure said.

He also said that the constellation will offer several services in 2023-2024. These include a PNT service schedule that will offer targeted one-meter accuracy, a PPP that covers parts of the eastern hemisphere on the L6 signal, and an emergency warning service (AWS) that will operate on four out of the seven proposed satellites.

KPS

While South Korea's Korean Positioning System (KPS) has been planned for years, recent government announcements signal that the local satellite navigation constellation will soon be a reality, 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 KPS project, estimated to cost anywhere from $3.1 billion to $3.5 billion, proposes to launch its first navigation satellite in 2027. By 2035, there may be as many as seven or eight satellites in orbit.

Currently, the constellation will have 3 GEO and 5 IGSO satellites. Payloads include navigation, timing systems, SBAS, and SAR, Kim said.

GLONASS

According to the system's website, GLONASS has 26 satellites, including one unavailable and three in maintenance. However, the information is nearly six months old and has not been updated by the government.

Public information about the GLONASS system and its uses have been nonexistent since the war in Ukraine began earlier this year. Reports about Russian pilots using GPS for navigation have been distributed widely in the press.

GPS

The next GPS III satellite launch (SV6), planned for January 18, 2023, will complete the number of satellites required for the civilian L2 (L2C) signal, said Cordell DeLaPena, Space Systems Command (SSC) Program Executive Officer for Military Communications & Positioning, Navigation, and Timing Division.

DeLaPena said that L2C is less susceptible for interference, has higher precision, and gives civil users access to dual frequency, or speed. He also said that the next launch will include a safety-of-life (L5) signal.

Around the late 2020s, DeLePena said a new civilian L1 (L1C) will be designated for GNSS interoperability. The signal will improve GPS reception in congested or challenged areas, he said.

At the Civil GPS Service Interface Committee meeting, Col. Heather Anderson, Space Systems Command CGX Transition Director, said while the baseline constellation includes 24 satellites, there are 37 satellites in orbit—and 31 are healthy. "Our oldest satellite is from 1997—older than some of our operators on the floor today," she said.

Currently, five GPS III satellites are operational, Anderson said. Three GPS III satellites are in storage and one (SV10) is in production. "We got rid of some of the older satellites to make way for GPS III. This is the heaviest time of modernization for GPS in the past 25 years." ✴

Kevin Dennehy has been writing about GNSS for 30 years. He is editor of Location Business News, *https://locationbusinessnews.substack.com.*

The Business of GNSS

By Kevin Dennehy

One of the biggest GNSS business stories this year has been the partnership between ION member Topcon Positioning Systems and Vodafone, who

Topcon and Vodafone partner to locate IoT devices
Photo: Vodafone

plan to develop a mass-market precise positioning system that will locate Internet of Things (IoT) devices, machinery, and vehicles. The companies say the new positioning system, called Vodafone GNSS Corrections, will have better accuracy than current GNSS.

Vodafone and Topcon, which each have terrestrial footprints in Europe, plan to invite select customers to join pilot projects in Germany, Spain, and the United Kingdom. The companies say the tests will use a variety of devices that are connected to Vodafone's IoT network, which consists of 150 million connections across 12 countries, to offer a single module configuration that can reach across national borders.

Vodafone believes higher positioning accuracy is critical to Vehicle to Anything (V2X), autonomous machinery, lawnmowers, scooters, e-bikes, and robots. The company plans to offer precise positioning to complement its new Safer Transport for Europe platform, which will be available later this year.

For its part, Topcon offers its Topnet Live GNSS solution that sends cloud-based corrections to vehicles and devices to improve accuracy in open sky conditions that are free from obstructions. There are thousands of GNSS reference stations in Topcon's European network.

Vodafone is no stranger to testing location technology as it and Sapcorda (now owned by ION member ublox) tested its positioning service to remotely track a vehicle to within 10 centimeters.

Companies Make Display Products at ION GNSS+

In other business news, Silicon Valley-based oneNav demonstrated its L5 GPS signal technology outside of the Hyatt at the Colorado Convention Center during ION GNSS+ in Denver.

"Right now, there is higher-end stuff on the market that offer L1 and L5 signals, but the RF and filters are not cheap. L5 has inherent advantages in that it is better in urban canyons and has AI techniques that mitigate multipath," said oneNav's Jim DeLoach. "We have our fully autonomous version of the software

oneNav demonstrated the results of its L5 technology in downtown Denver
Photo: Kevin Dennehy

in the lab now."

The L5 AI engine also allows the company to free up device space, which is the innovator's dilemma as the small device market is growing, said Ellen Kirk, oneNav's Vice President of strategic marketing. "Drones and fitness devices have no space. Companies use L1 to get a first (satellite) fix and then it just sits there," she said. "Using L5 alone is lower-power and less expensive."

In recent tests, oneNav said it averaged six times' better accuracy than a leading Android smartwatch in recent side-by-side test results that compared its pureL5 GNSS receiver customer evaluation system.
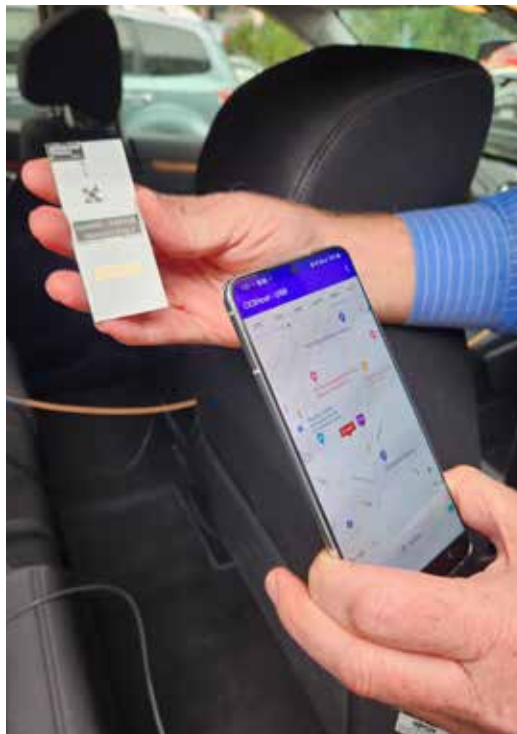
The company said it used only GNSS measurements in the tests, which were conducted in a "challenging urban environment," while the smartwatch was augmented by inertial systems. Both the oneNav unit and the smartwatch used commercial antennas during the testing.

In other ION GNSS+ news, Rx Networks announced the release of its next-generation GNSS modules from Unicore. Based on the new NebulasIV SoC, the UM960/980/982 and UT986 products offer all-constellation multi-frequency high-precision RTK positioning and/or heading capabilities.

The new modules are ideal for use in reference stations, survey/mapping, precision agriculture, heading applications, machine control, drones and robotics, vehicle navigation, precision timing, and more, the company said.

In Other Business News

ION Member HERE Technologies is working with leading commercial

Rx Network's Patrick Casiano displays new GNSS modules.
Photo: Kevin Dennehy

vehicle manufacturers to implement intelligent speed assistance (ISA) technology to support new European Union regulations. Since July, the EU regulations require drivers in trucks, vans, and cars to have legal speed limits always displayed, the company said.

The HERE ISA Map has been adopted by 15 global automakers, representing more than 30 brands, the company said. HERE's ISA Map includes speed limits visible on road signs and implicit speed limits derived from road signs without numerical values, the company said.

Thalwil, Switzerland-based u-blox said its PointPerfect GNSS augmentation services recently launched in South Korea. The company says it's the first precise point positioning, real-time kinematic solution to be commercialized in the country.

The service, accessible through Thingstream, provides GNSS augmentation data service for such applications as unmanned aerial vehicles, service robots, machinery automation, micro mobility, and other navigation apps. In addition,

the service supports automated driving and advanced driver assistance systems (ADAS), lane-accurate navigation and telematics, the company said.

The service, which is delivered through the internet or L-band satellite systems, offers decimeter-level positioning accuracy in seconds, the company said. It uses the SPARTN message format with MQTT IoT delivery protocols, the company said.

ION member Orolia has released the GSG-7, the latest GNSS signal testing solution offered through the Skydel-based simulators product line. The GSG-7 features a small form factor, an internal RF combiner, and high-end performance with a 1000-Hz simulation iteration rate, the company said.

Powered by Orolia's Skydel simulation engine, the GSG-7 can be programmed

Orolia's new GSG-7 GNSS testing solution
Image: Orolia

to simulate operations with all current GNSS signals, the company said.

ION member Xona Space Systems recently announced that they have raised "an oversubscribed financing round" that brings the company's total funding to more than $25 million. In this latest round, led by First Spark Ventures, such companies as Lockheed Martin Ventures, SRI Ventures, Velvet Sea Ventures, Gaingels, Airstream Venture Partners and Space VC made investments.

Xona, which did not specifically say how much money was raised during the round, said the new capital will help it develop the pulsar low Earth orbit satellite navigation system, which it hopes to achieve worldwide centimeter-level positioning. In addition, the company said it will grow its number of personnel and build out its Burlingame, Califorinia research and development facility.

It's been an eventful year for Xona. The company said it has doubled its full-time employees to 30, launched the Huginn orbital mission, and signed deals with such GNSS companies as Hexagon | NovAtel and Spirent Federal.

The government of Australia has awarded Lockheed Martin a $1.18 billion contract to establish the Southern Positioning Augmentation Network (SouthPAN). The system, expected to be fully operational by 2028, will be provided as a service for 19 years with an option to extend, the company said.

The program will use the Lockheed Martin-developed, second-generation satellite-based augmentation system (SBAS), which will broadcast on two frequencies to augment signals from GNSS, GPS, and the European Union's Galileo system. ✳

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

Impact Factor Growth for ION's Open Access Journal

The Institute of Navigation is pleased to share that *NAVIGATION: Journal of the Institute of Navigation* has recorded its fifth consecutive year of growth of its Journal Impact Factor (JIF) now reported to be 2.472. The JIF, an index that calculates the yearly average number of citations to recent articles published in a journal, is considered a metric of the relative importance of a journal within its field. A journal with a higher impact factor generally is viewed as being more important than those with a lower impact factor due to its citation rate. *NAVIGATION* is the leading peer-reviewed scientific indexed journal publishing articles on all areas related to the science and art of positioning, navigation and timing (PNT). The increase in the *NAVIGATION's* JIF again places the journal in the top ten academic engineering and aerospace journals. *NAVIGATION*'s JIF growth reflects the continued focus and leadership of the journal's editor, Richard B. Langley, and the entire editorial board, which has included: Penina Axelrad, Michael Braasch, Liang Chen, Pau Closas, James Curran, Naser El-Sheimy, Paul Groves, André Hauschild, Christopher Hegarty, Li-Ta Hsu, Changdon Kee, Jiyun Lee, Sherman Lo, Gary Mc-Graw, Michael Meurer, Y. Jade Morton, Thomas Pany, Santiago Perea, Boris Pervan, Jason Rife, Fabian Rothmaier, Andrey Soloviev, Todd Walter, Zhe Yang, Zheng Yao, Zhen Zhu, and the journal's managing editor, Lisa Beaty, and assistant editor, Rachel Sutton.

Neish Joins Editorial Board

Dr. Andrew Neish joined *NAVIGATION's* Editorial Board in September 2022. Neish is the director of Signals Architecture and a co-founder at Xona Space Systems where he works on next-generation Low Earth Orbiting GNSS systems. His interests include modern communication and navigation waveforms, advanced forward error correction techniques, and low-bandwidth authentication for navigation code and data. He completed his PhD in Aeronautics and Astronautics from Stanford University.

Coherent Combining and Long Coherent Integration for BOC Signal Acquisition under Strong Interference

Dr. Chun Yang

Coherent combining and long coherent integration is a technology that provides an effective means for GNSS receivers equipped with a single, and possibly multi-band, antenna to boost the reception of the signal of interest, while averaging out noise and interference. Straightforward combining and integration quickly become counterproductive if the differences among signal components are left unreconciled in coherent combining and/or the signal changes during the long time period over which the integration carried out remains uncompensated for incoherent integration. Accommodation for such differences and changes may become computationally prohibitive if done by brute force. The technology is made practical with an efficient implementation that consists of staged frequency refinement, time alignment, and phase compensation.

Implementation Using a Spirent GPS Simulator

The technology was implemented on a software-defined radio (SDR) platform consisting of field programable gate array (FPGA) logic fabric, double data rate (DDR) memory, and an ARM processor. In one experiment, a GPS signal with BOC(10, 5) modulation was generated by a Spirent GPS Simulator, to which they were injected with a matched-spectrum interference signal with an interference-to-signal-power ratio (ISR) of 51 dB and a band-limited noise interference signal with ISR of 10 dB within ±10 MHz in the band center. The embedded implementation performed coherent integration up to 1 second. The proposed technology produced a correlation function with a power-to-noise floor peak power ratio (PPR) of 8 dB, despite some hardware impairments for reliable detection, thus enabling successful acquisition of the signal under stressful conditions.

The simultaneous attack by matched-spectrum interference and band-limited noise in the band center represents one of the most difficult combinations that a GPS receiver can be subjected to in a harsh electromagnetic environment. The technology enables a receiver to rapidly acquire and reacquire GPS signals to improve its solution availability. When applied in the tracking mode, the technology can enhance the solution continuity.

How the Technology is Being Used Today

Demands for higher accuracy and better availability for GPS positioning keep growing. Yet new threats, both naturally occurring and manmade, continue to emerge. This creates situations with low signal-to-noise ratios (SNRs) that remain difficult for conventional GPS technology to cope with. The low SNR level occurs because the signal of interest is weak due to a multitude of attenuations on its way to the receiver, or the equivalent noise floor as an aggregation of noise and interference is high, or both. Coherent combining and long coherent integration is an answer to the call for toughening GPS.

Future Applications

The methodology behind this technology is making its way into practical products for acquisition and tracking in different variants and simplifications. It is expected that as the demand for high performance grows and GPS application extends its arenas to more difficult environments, the technology will be adopted in one form or another.

First, let's take the enhancement of GNSS synergy. GNSS signals are now broadcast from multiple constellations at different frequencies per constellation and with different codes at the same frequency. Despite the disparity in power, bandwidth, modulation, and chipping rate, these signals can be combined coherently to maximize the synergy of multi-GNSS signals that are presently processed individually in most GNSS receivers. Since the signal components are subject to different uncertainties in signal propagation and group delay, antenna and analog electronic impairment, and frequency and phase offsets, the benefits of coherent combining are maximized with proper compensation for time, frequency, and phase differences among the signals.

Second, look at high sensitivity. Long coherent integration of a signal over time, beyond a conventional spreading code period and even over several data bits, is one of the techniques to strengthen the signal for high-sensitivity GNSS receivers. Long coherent integration is the most gainful among the classical combination of coherent and non-coherent integrations, semi-coherent and differentially coherent schemes, as well as generalized detection methods. Implementation of long coherent integration for acquisition is more challenging than for tracking because it needs to handle large initial uncertainties in time, frequency, sign reversals of data bits, and secondary codes. It also needs to take into account clock instability during the long integration, especially during high dynamics.

Third, let's look at interference mitigation. Long coherent integration de-spreads the desired signal (a PRN code) for a large processing gain while spreading unwanted signals. It acts like a low-pass filter, averaging out matched-spectrum interference and broadband noise. Because of its extremely narrow bandwidth (e.g., ±½ Hz for 1-s integration), long coherent integration helps guard against close-in multipath signals that may have a Doppler frequency shift opposite of the direct signal. By the same token, it forces spoofers to deploy a means that could get to know a targeted receiver well enough to fabricate a counterfeit signal, only off by a fraction of Hz, in order to sneak in and capture the victim receiver, which is technically difficult if not impossible.

The three features are desirable for commercial applications. For military receivers, the coherent combining and long coherent integration technology further enables direct acquisition of M-code without going through C/A-code (in cases in which C/A-code is not available) or a puncture code as an intermediate acquisition aid.

Extending the Research

Extension from acquisition to tracking is the next step to reap the full benefits of coherent combining and long coherent integration. In a typical embedded implementation, signal samples over 1 second are stored in local memory and repeatedly processed, faster than real time, to search through a rather large time-frequency uncertainty zone that may take hundreds of seconds to find the first satellite. The overall receiver design is, therefore, to ensure that the 3σ interval of predicted time and frequency is well within the coverage of tracking correlators so the code and carrier tracking loops can be closed once a signal is acquired. The resulting tracking loops also need to better handle dynamic stress and clock instability. It may necessitate higher order processing to ease operations, which is an interesting aspect to pursue.

Coherent combining and long coherent integration in this study is treated as a standalone technology, but it can be fused with other sensors such as low-cost inertial sensors. This would ease tracking in dynamics in addition to other integrated GPS-INS benefits. It can also be used in conjunction with an antenna array to explore the spatial degrees of freedom for interference suppression and attitude determination in diverse applications.

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

Yang, C., Soloviev, A., Vadlamani, A., & Ha, J. (2022) Coherent combining and long coherent integration for BOC signal acquisition under strong interference. *NAVIGATION*, 69(1). https://doi.org/10.33012/navi.508 ✴

Patricia Doherty, In Memoriam

Patricia Helen Doherty, Boston College, passed away Thursday, July 14, at age 72. Patricia was employed by Boston College for many years, serving as the Director of the Institute for Scientific Research at the time of her passing. Her research included studies of space physics, space weather, ionospheric and atmospheric effects on space-based systems with an emphasis on GNSS, ionospheric measurement techniques, chemical reactions in space, and magnetospheric physics. Pat Doherty has made pioneering and sustainable contributions to advance our understanding of ionospheric effects on satellite navigation. She was involved in the early assessment of ionospheric delay impact on GPS measurement errors. She played an important role in evaluating ionospheric limitation of FAA's Wide Area Differential GPS (WADGPS) and performances of algorithms to correct ionospheric errors for WAAS. During the past two decades, she and her collaborators have studied the ionospheric impact on GNSS at every continent and every region of the world. In recent years, she focused her attention on the broader field of space weather phenomena and its impact on technology and society.

Patricia's personal passion project encompassed promoting research and education in the science of navigation in developing countries. For over ten years, she started and led an initiative to help developing countries derive social and economic benefits from the satellite-based technology of positioning, navigation, and timing by organizing and chairing prominent ION members to teach and interact with teams of professors and scientists from African universities and other developing countries. Due to these outreach efforts, sustainable developments have been made in Africa and other developing nations. Numerous academic programs are operational or in the process of development, and societal benefits in developing nations have been achieved because of Pat's leadership and efforts.

Patricia was an ION member that was active in leadership for the past twenty years, serving as ION president (2013 and 2014) and the current chair of the Satellite Division at the time of her passing. She was an ION Fellow (2012) and recipient of the Burka Award (1995), Weems Award (2014), and Distinguished Service Award (2014). She is also the recipient of the 2017 GPS World Leadership Award and 2018 American Geophysical Union (AGU)'s Space Physics & Aeronomy Richard Carrington (SPARC) Award.

Her involvement in several international scientific organizations and her numerous outreach efforts allowed her to fulfill her passion for traveling the world. She will be missed by her husband of 49 years (Charles), as well as by her children, family, friends, and colleagues the world over. She is known throughout the PNT and space sciences community as an exemplary and generous leader, role model, and mentor. The absence of her elegant grace will be sorely missed.

Satellite Division Election Results

This past summer, the Satellite Division held its election for Satellite Division Officers who took office on September 23 at the conclusion of ION GNSS+ 2022. The following individuals were elected and will serve on the Satellite Division Executive Committee for a two-year term of office.

Chair: Sandy Kennedy, Hexagon

Vice Chair: Dr. Dorota Grejner-Brzezinska, The Ohio State University

Treasurer: Dr. Paul McBurney, OneNav

Secretary: Dr. Jiyun Lee, KAIST

Additionally, Dr. Takeyasu Sakai, National Institute of Maritime/Port and Aviation Technology, will serve as an invited international technical advisor; and Dr. Chris Hegarty will continue to serve for an additional two years as the Immediate Past Chair.

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Impact of GNSS-Band Radio Interference on Operational Avionics
Dr. Michael Felux and Dr. Okuary Osechas

Mapping Bit to Symbol Unpredictability with Application to Galileo Open Service Navigation Message Authentication
Dr. Cillian O'Driscoll and Dr. Ignacio Fernández-Hernández

National Strategy for Ocean Mapping
Meredith Westington and CDR Briana Hillstrom

WAAS and the Ionosphere – A Historical Perspective: Monitoring Storms
Dr. Lawrence Sparks

To be notified of future webinars, sign up for ION's email list or follow ION on social media.

Calendar of Upcoming Events

NOVEMBER 2022

16-18: 13th China Satellite Navigation Conference (CSNC) 2022, Beijing, China (rescheduled from May)
Contact: CSNC
Web: http://english.aircas.ac.cn/ne/events/202109/t20210903_282415.html

JANUARY 2023

23-26: ION International Technical Meeting (ITM) & ION Precise Time and Time Interval (PTTI) Meeting 2023, Hyatt Regency Long Beach, Long Beach, California
Contact: ION
Web: ion.org

MARCH 2023

13-15: Munich Satellite Navigation Summit 2023, Munich, Germany
Contact: Bundeswehr University Munich
Web: https://www.munich-satellite-navigation-summit.org/

APRIL 2023

24: AFRL/ION Magnetic Navigation Workshop
Contact: ION
Web: ion.org/magnav

24-27: ION/IEEE Position, Location, and Navigation Symposium (PLANS) 2023, Hyatt Regency Monterey, Monterey, California
Contact: ION
Web: ion.org

MAY 2023

31-2 June: European Navigation Conference (ENC) 2023, Noordwijk, The Netherlands
Contact: European Group of Institutes of Navigation (EUGIN)
Web: https://www.enc2023.eu/

JUNE 2023

12-15: ION Joint Navigation Conference (JNC) 2023, Town and Country Hotel, San Diego, California
Contact: ION
Web: ion.org

SEPTEMBER 2023

5-8: The 2nd International Symposium of Commission 4: Positioning, the Wissenschaftsetage Potsdam, Germany
Contact: International GNSS Service (IGS)
Web: www.iag-commission4-symposium2022.net

11-15: ION GNSS+ 2023, Hyatt Regency Denver at Colorado Convention Center, Denver, Colorado
Contact: ION
Web: ion.org

2023-2025 ION National Nominations Notice

Nominations for ION officers were submitted by the 2023-2025 Nominating Committee of the Institute of Navigation (ION). The ION's Nominating Committee was chaired by Dr. Y. Jade Morton and included three representatives from each region.

Additional Nominees

Pursuant to Article V of the Institute of Navigation's bylaws, "additional nominations may be made by petition, signed by at least 25 members entitled to vote for the office for which the candidate is nominated." All additional nominees must fulfill nomination requirements as indicated in the ION bylaws and the nomination must be received at the ION National Office by November 7.

Voting

Voting will be conducted electronically via the ION website. Online ballots will be available after November 16. Online voting must be completed by December 1 to be counted.

Election Results

Results will be announced at the ION 2023 ITM/PTTI Meeting, January 23-26, 2023. Newly elected officers will take office on January 26, at the conclusion of the meeting and serve for two years. Election results will be reported in the *ION Newsletter.*

PRESIDENT
Dr. Sherman Lo

EXECUTIVE VICE PRESIDENT
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Dr. Gary McGraw

TREASURER
Dr. Frank van Graas

EASTERN VICE PRESIDENT
Dr. Jacob Campbell
Dr. Seebany Datta-Barua

WESTERN VICE PRESIDENT
Mr. Jeff Martin
Dr. Alex Stratton

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MEMBER-AT-LARGE
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Mr. Ernesto Etienne
Dr. Zak Kassas
Dr. Sabrina Ugazio

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Dr. Mohammed Khider
Ms. Laura Norman
Dr. Tyler Reid

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Dr. Fabio Dovis
Mr. Ryan Dupuis
Dr. Ignacio Fernández-Hernández
Dr. Christoph Günther
Dr. Patrick Henkel
Dr. Joanna Hinks
Dr. Samer Khanafseh
Dr. Nobuaki Kubo
Dr. Heidi Kuusniemi
Dr. Alexander Mitelman
Dr. Okuary Osechas
Dr. José Ángel Ávila Rodríquez
Dr. Kirsten Strandjord
Dr. Rong Yang

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