Volume 34 No 3 **Summer 2024**

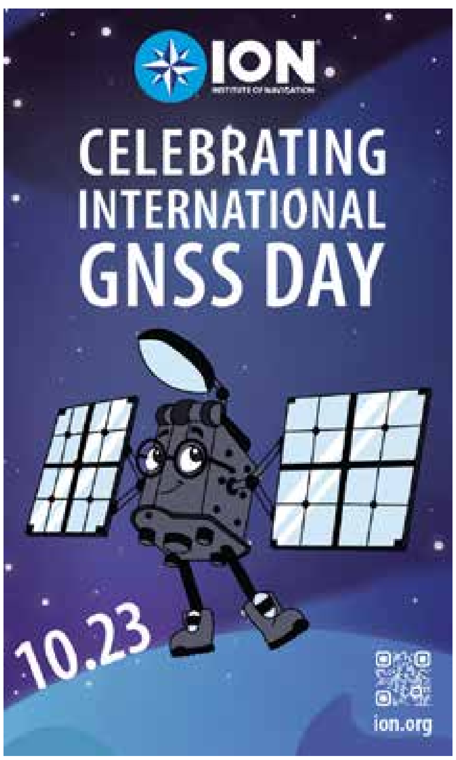
Quarterly Newsletter

ION®
INSTITUTE OF NAVIGATION

PREPARING FOR OCTOBER 23 (10.23)

Celebrating International GNSS Day

As we approach the second observance of International GNSS Day on October 23 (10.23), the Institute of Navigation invites its membership and the larger positioning, navigation, and timing (PNT) community to reflect on the profound impact that global navigation satellite systems (GNSS) have had on the modern world. Instituted on the date symbolizing the foundational GPS frequency of 10.23



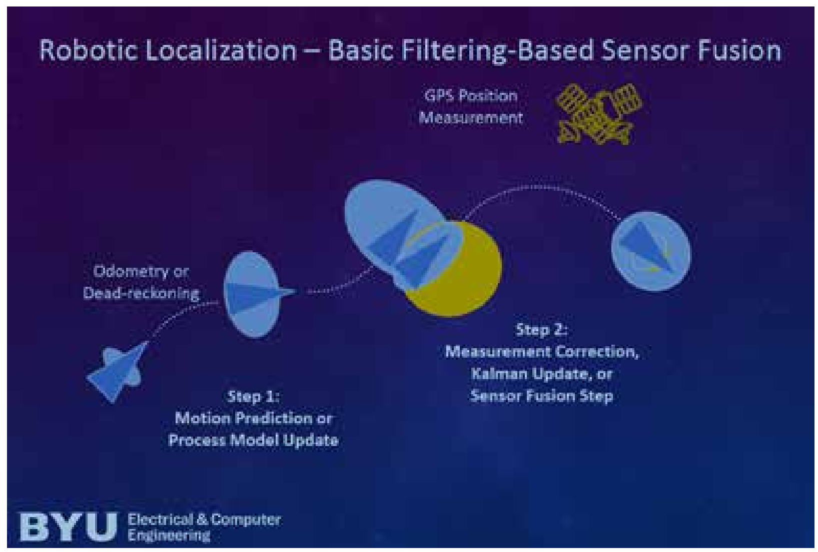
continued on page 14

CONSERVING NATURAL HAWAIIAN RESOURCES

Using Location Technology to Conserve Hawaii's Mountains and Reefs

Kevin Dennehy

Centuries of Native Hawaiian and Pacific Islander (NHPI) navigation and wayfinding has evolved into modern positioning, navigation, and timing techniques that are assisting the efforts to preserve the mountains and coral reefs of Hawaii.



Robotic localization techniques used by the BYU team to gather coral reef information
Brigham Young University

To restore damaged coral reefs from decades of erosion, two Brigham Young University professors are working with their counterparts at BYU-Hawaii, the university's Polynesian Cultural Center, and Kuleana Coral Restoration. For nearly ten years, using GPS and other technology, the professors have worked on environmental projects in what the natives call Mauka to Makai—or from the mountains to the ocean.

Western development of the Hawaiian Islands has created many environmental and cultural challenges, said Dr. Richard Gill, a BYU professor who employs remote sensing, ecoinformatics and sensor instrumentation to assess the human impacts on coastal and marine ecosystems.

"With the Europeans' arrival, not only was the environment adversely changed, but there was a concerted effort to eliminate the culture by making it illegal to speak the na-

continued on page 12

The Institute of Navigation
8551 Rixlew Lane, Suite 360
Manassas, Virginia 20109

PRESIDENT'S COLUMN | DR. SHERMAN LO

ION's JNC Smashes Record - AGAIN!

The ION's Military Division hosted 1,248 U.S. Department of Defense (DOD) and Department of Homeland Security (DHS) professionals in Covington, Kentucky (June 3-6, 2024) for the largest U.S. military positioning, navigation, and timing (PNT) conference of the year with joint service and government participation. This represents a 7.5% growth from the previous year, and sets a new record for the conference.

2024 Expands the Technical Program

The JNC's expanded technical program focused on robust, resilient, assured PNT for warfighters and homeland defense. There was special interest this year in space-related sessions and sessions related to situational awareness. Another technical highlight of the 2024 event was the return of the SECRET session, hosted by Dr. Clark Taylor of the Air Force Institute of Technology, with security services provided by Barbara Frantom of the Air Force Research Laboratory, with content curated by chairs Dr. Keith McDonald, The MITRE Corporation, and Amanda Humphrey, JNWC. It was reported that attendees benefited from current and relevant technical information that could only be presented at the SECRET level; they were also surprised by the morning police escort that accompanied the shuttle buses from Covington, KY to Dayton, OH to ensure the morning session began on time.

The conference's two plenary sessions were highly attended, with keynotes provided by Anthony C. Smith, Principal Director for the Deputy Chief Information Officer for Command, Control, & Communications, Office of the Secretary of Defense; and Dr. John H. Burke, Office of the Under Secretary of Defense for Research and Engineering, who spoke on resilient PNT with quantum applications.

Dr. Greg Reynolds, JNC Program Chair; Anthony C. Smith, OSD Plenary Speaker; Dr. John Burke, OSD Plenary Speaker; and Dr. Thomas Powell, ION Military Division Chair

JNC's second plenary was the popular warfighter panel, chaired by Sean Memmen and Amanda Humphrey. During this interactive panel, a discussion was hosted between the audience and the panel of warfighters with recent operational experience. The warfighters shared their experiences in such a way to assist the equipment developers and policy-makers on how they can better formulate military PNT systems for practical in-theater operations.

The exhibit hall also set records with 71 exhibitors (22% growth from 2023). Exhibitors experienced lively discussions throughout the event.

Attendance Demographics:

• Industry	49%
• Government	21%
• Military	25%
Air Force	42%
Army	21%
Space Force	19%
Coast Guard	2%
Navy	16%
OSD	1%
• Academia	5%

Amanda Humphrey, panel co-chair; Maj Jordan Moss, USAF; Maj John Lira, USAF; QMCM Aurora Robles, USN; LT Christine McCulla, USCG; SMSgt Joshua Griffin, USSF; LT Brandon Vitton, USN, and Sean Memmen, panel co-chair

Acknowledgements

Most importantly, ION would like to acknowledge all the meeting's organizers, sponsors, chairs, and authors that contributed to the community; with special recognition for AFRL and AFIT that made it possible to hold the event in a secure environment; and the Military Division's leadership and liaisons that organized the conference (see page 4 for more information).

Next Year's JNC … and ION GNSS+ this September

Mark your calendars for next year's ION JNC 2025 that will be held June 2-5, 2025, again at the Northern Kentucky Convention Center. And of course, I look forward to seeing many of you this September at ION GNSS+ 2024, September 16-20, in Baltimore!

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

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.

· · · · How to Reach the ION® · · · ·

Telephone: 703-366-2723
Facsimile: 703-366-2724

Website: ion.org
E-mail: membership@ion.org

The ION® National Office
8551 Rixlew Lane, Suite 360
Manassas, VA 20109

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 JNC Recap

ION Acknowledges Our Volunteers:

JNC's Military Division Organizers

Back Row: John Langer, Military Division Immediate Past Chair; Dr. Jacob Campbell, Government Liaison; Brian Louie, Government Liaison; Amanada Humphrey, Government Liaison; Dr. Keith McDonald, Military Division Vice Chair; Jan Anszperger, Liaison; Joe Schnecker, Government Liaison; Paul Olson, Government Liaison; Dr. Steven Lewis, Liaison; Dr. Thomas Powell, Military Division Chair. Front Row: Dr. J.P. Laine, Liaison; Elliott Kaplan, Liaison; Dr. Madeleine Naudeau, Government Liaison; Dr. Greg Reynolds, Government Liaison and JNC 2024 Program Chair; Dr. David Wolfe, Government Liaison; Chad Pinkleman, Government Liaison. Not Pictured: Greg Panas, Government Liaison; John Del Colliano, Government Liaison; and Aaron Nascimento, Government Liaison.

JNC organizers waiting for their shuttle bus assignments: David Wolfe, Brian Louie, Steven Lewis, Joe Schnecker, and Greg Panas.

At the conclusion of JNC 2024, in-coming Military Division Chair, Dr. Keith McDonald, presented the out-going Military Division Chair, Dr. Thomas Powell with a plaque of appreciation for his three years of service as Chair. Dr. Powell will continue to serve on the Military Division's Executive Committee for an additional three years as Immediate Past Chair.

Military Division Chair, Dr. Thomas Powell, presents JNC 2024 Program Chair, Dr. Greg Reynolds, with a certificate of appreciation.

THANK YOU TO OUR SPONSORS

JNC Conference Patrons

emcore | BAE SYSTEMS | SAFRAN Federal Systems

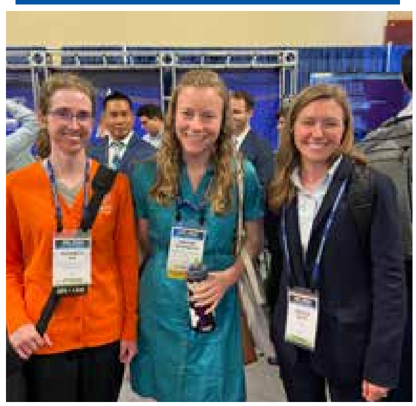
JNC Conference Benefactor

GPSS Operations Enabled | Inside GNSS | Hexagon | NovAtel | Antcom | L3Harris Fast. Forward. | General Dynamics Mission Systems | Lockheed Martin | VectorNav

JNC Media Partners

GPS World | Inside GNSS | Aerospace & Defence Review

Action in the JNC Exhibit Hall



JNC 2024 Exhibitors:

746th Test Squadron
Acutronic USA Inc.
Advanced Navigation
Aevex
Air Force Research Laboratory
Anello Photonics
Applied Research Laboratories–UT Austin
Autonomy & Navigation Technology Center at AFIT
BAE Systems
Brandywine Communications
CAST Navigation, LLC
Chelton Limited
Collins Aerospace
Continental Electronics Corporation
EMCORE Corporation
Enertia Microsystems, Inc.
Epson America, Inc.
Exail Defense Systems Inc.
Fibernetics LLC
FIBERPRO, Inc.
Fizoptika Malta
Frequency Electronics, Inc.
General Dynamics Mission Systems – GPS Source
Gladiator Technologies, LLC
GPS Networking Inc.
Hexagon/NovAtel/Antcom
Honeywell Aerospace Technologies
Ideal Aerosmith
Inertial Labs
Inside GNSS
Institute of Navigation
Integrated Solutions for Systems
Kearfott Corporation
L3Harris
LinQuest
Mayflower Communications Company
Microchip Technology Inc.
NAL Research
Naval Information Warfare Center Pacific
NAVSYS Corporation
NavtechGPS
Northrop Grumman
NTA. Inc.
oneNav
Oscilloquartz
OxTS
PNI Sensor
Psionic LLC
Safran Federal Systems
SandboxAQ
Septentrio
Silicon Microgravity Ltd.
SiTime
Spirent Federal Systems
Technology Advancement Group (TAG)
TRX Systems
Tualcom Elektronik A.S.
UHU Technologies LLC
US Army C5ISR Center
VectorNav Technologies
VIAVI Solutions
Xona Space Systems

CARNATIONS

Center for Assured & Resilient Navigation in Advanced Transportation Systems

A U.S. Department of Transportation University Transportation Center

Resilient PNT for Advanced Transportation Systems

Boris Pervan and Mathieu Joerger

Center Vision and Objectives

The Center for Assured and Resilient Navigation in Advanced Transportation Systems (CARNATIONS) is a new U.S. Department of Transportation (USDOT) Tier-1 University Transportation Center (UTC) confronting cyber-physical risks affecting Positioning, Navigation, and Timing (PNT). The Center is explicitly focused on Resilient PNT (R-PNT) and relevant vehicle-to-everything (V2X) communications for all modes of surface transportation.

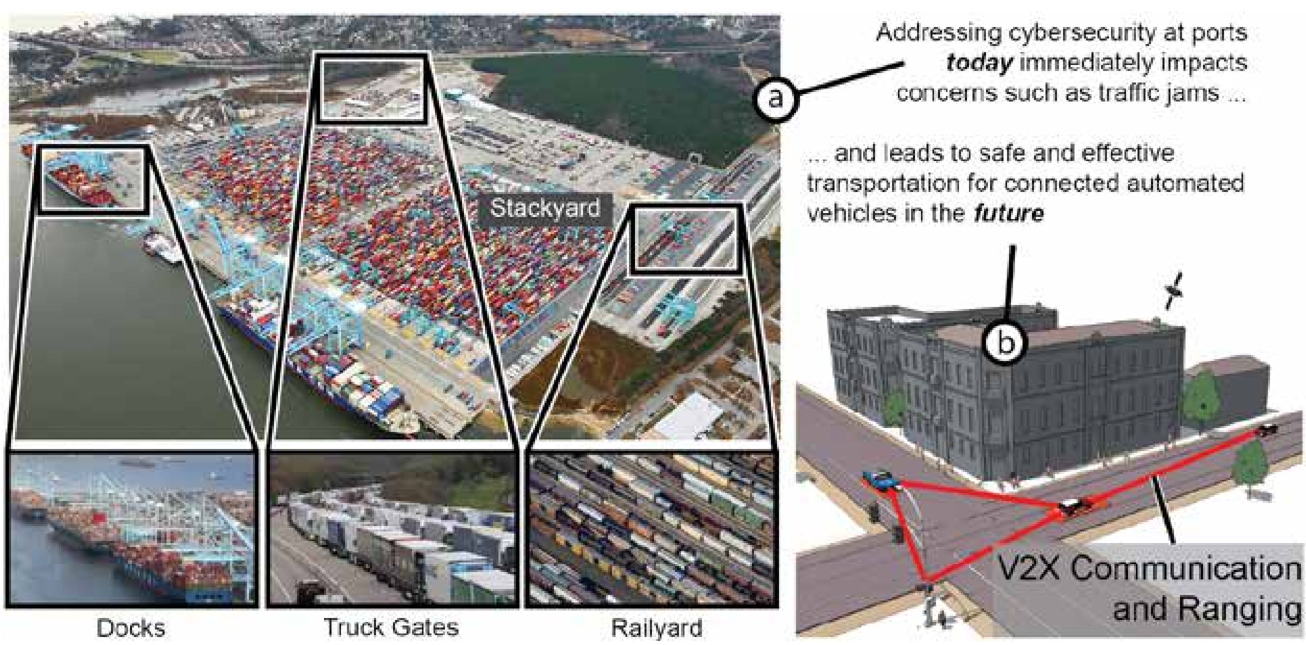
R-PNT is at a crucial juncture for transportation. Transportation systems have become heavily reliant upon PNT, and the number of occurrences of PNT interference is rising. Jamming and spoofing have caused major disturbances at civilian ports and airports. Interference events can instigate delays and traffic jams on roadways, railways, and waterways, and create dangerous situations for all modes of transport. CARNATIONS is designed to enable the fundamental transformations to infrastructure and technology that will make the U.S. surface transportation systems resilient to existing and impending interference and cyber threats, including those affecting future automated systems.

Today's growing threat of PNT and V2X interference must be addressed. Only then will it be possible to create opportunities for tomorrow's transformation towards a safer, more energy-efficient and cost-effective transportation system. CARNATIONS pursues this goal while also providing support for underserved communities through outreach and education, and restoring trust in government through evidence-based policy-making by developing standards and best practices that promote the responsible use of PNT in transportation.

CARNATIONS' primary ***research*** goals are to develop technologies to toughen, augment, and protect transportation PNT against cyber-physical disruption and manipulation. The Center provides resources for ***transferring these emerging technologies*** to public agencies and industry through partnerships, dissemination, and leadership in standardization bodies. CARNATIONS also runs a ***multi-university curriculum*** to help prepare current and future transportation professionals to tackle R-PNT challenges in transportation.

Center Initiatives

Research: The CARNATIONS research vision is founded on three research pillars for multi-modal surface transportation: ***(1) Toughen PNT*** through advanced global navigation satellite systems



(GNSS) receiver and antenna technology; ***(2) Augment PNT*** with non-GNSS sensors (e.g., inertial navigation systems (INS), odometry, vision, LiDAR) and signals from multiple GNSS providers, communication satellites, and terrestrial RF including V2X; and ***(3) Protect PNT*** through RFI detection, tracking, and mitigation by leveraging V2X connectivity, community information, and crowdsourcing.

Education and Workforce Development: Resilient PNT systems and technologies are not traditional areas of expertise in transportation professions; however, they have rapidly emerged as critical to the design of future transportation systems. CARNATIONS offers a unique concentration program training future talent to support R-PNT for transportation. The Center especially values outreach to first-generation college students, female, and underrepresented minorities (URM). CARNATIONS' Engineering Research Toolkit (ERT) is a framework organizing inter-university URM student exchanges and hands-on R-PNT research with experienced faculty mentors from all CARNATIONS institutions.

Technology Transfer: CARNATIONS' five institutions have long-established records of R-PNT solutions adopted by industry, public agencies, and other transportation practitioners. Coordination and standardization with stakeholders are key to the development of consensus technology that is accepted worldwide. CARNATIONS researchers lead and contribute heavily to numerous international PNT committees for all modes of transportation.

Research and Management Team

Our research team is composed of experts in R-PNT for transportation at key locations in the transcontinental supply chain: Boris Pervan, Samer Khanafseh, Matt Spenko (Illinois Tech); Mathieu Joerger, Laura Freeman, Mark Psiaki, Hesham Rakha, Walid Saad (Virginia Tech); Moussa Ayyash (Chicago State); Jay Farrell and Matt Barth (UC Riverside); Todd Walter, Juan Blanch, Sherman Lo, Sam Pullen (Stanford).

Members of the CARNATIONS Advisory Board, government and industry partners keep the Center's research timely and topical and play an active role in the Center's management. Frequent contributors include: Karen Van Dyke and James Aviles (USDOT); Hadi Wassaf and Andrew Hansen (DOT Volpe); Charles Schue and Erik Johannessen (UrsaNav); Michael O'Connor (Satelles); John Raquet (IS4S); Chris Hegarty and Steve Langel (MITRE); Tim Weisenberger (SAE); John Janeski and Steven Lewis (Aerospace); Jeremy Bennington and Chris Coromelas (Spirent); Boubeker Belabbas (Bosch), and many others.

If you would like to join this effort, please contact the CARNATIONS Program Manager Aashish Narang (anarang2@iit.edu).

Global Earth Observation Decentralized Network

GEODNET

Mike Horton, David Chen, Yudan Yi, Xiaohua Wen, and James Doebbler

GEODNET is a decentralized protocol for an international "Internet" of GNSS reference stations. Leveraging the decentralized approach described in this article, GEODNET aims to become the world's largest Real-Time Kinematic (RTK) station network. The idea of using blockchain and web3 technologies to scale a global publicly-accessible Continuously Operating Reference Network (CORS) was first described at ION GNSS+ in September 2021. Since the award-winning presentation at ION GNSS+, the GEODNET network has grown continuously. As of today, 6966 stations have been added to GEODNET; over 5764 stations are operating stably; and over 150 new stations are joining the network weekly. On the usage side, more than 20 commercial entities are using data streams from the GEODNET network supporting applications ranging from smart lawnmowers to surveying.

Before describing the technical architecture of the GEODNET, it is useful to define a few blockchain oriented terms that may not readily resonate with the positioning and navigation community.

Blockchain: an advanced database that stores data in blocks that are linked together in a chain. The database is maintained by a peer-to-peer network, and a public blockchain such as used in GEODNET provides full transparency to the history of transactions.

Decentralized: Refers to collective ownership and collective management method where the individual ownership is not linked directly to a central entity, and the management is distributed across many participants. Within blockchains there is also an emphasis on transparency and efficiency. Public blockchains are decentralized.

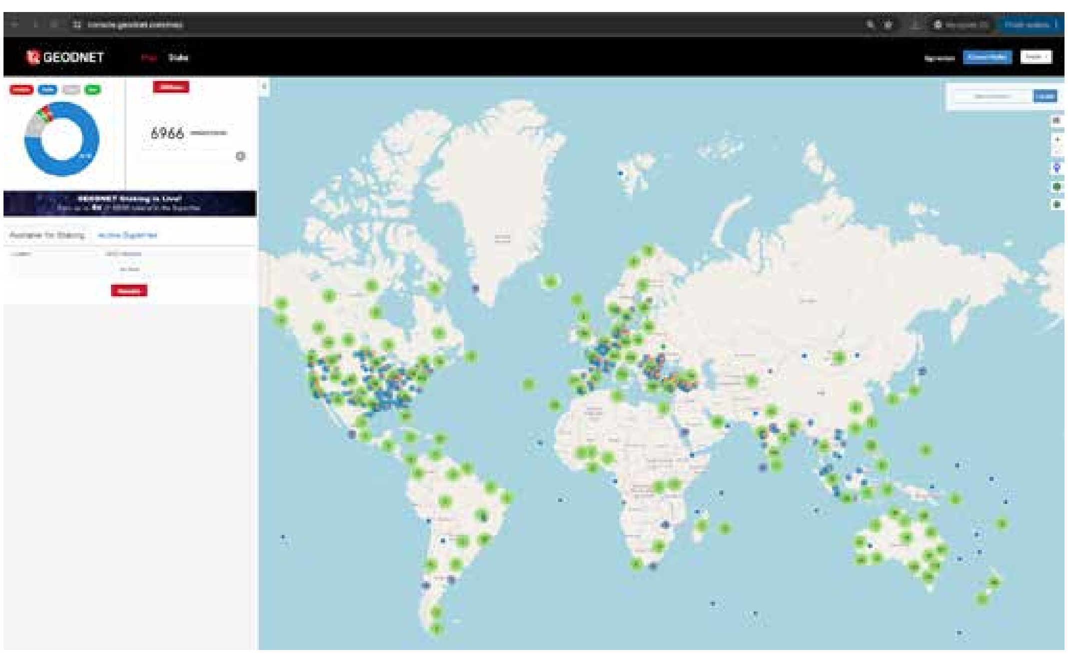
Protocol: A set of rules describing how data is stored, transmitted, and validated across the network, ensuring the data's security, consistency, and reliability

Token: Refers to a digital asset created on top of a blockchain. A token is used to exchange value between parties participating in the network. In the case of GEODNET, the underlying blockchain is Polygon, a Layer 2 Ethereum scaling chain.

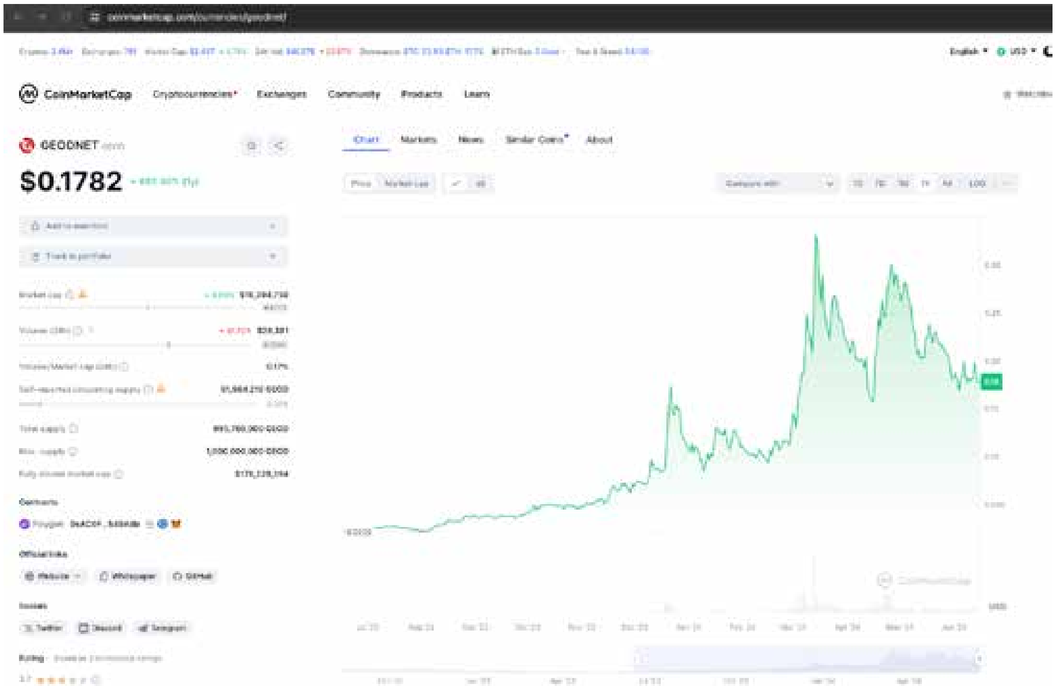
The establishment of an "Internet" of GNSS reference station data faces several key challenges including (1) the high-cost of station deployment, (2) the management of a large global network with significant data storage requirements, and (3) the need to guarantee data quality to all users of the network. To overcome these challenges, a robust decentralized blockchain protocol is the key innovation as compared to previously developed CORS networks. How the GEODNET protocol addresses each of these three key challenges is described next.

The ideal spacing of stations for optimal RTK positioning performance and ionospheric observation is less than twenty kilometers. Dividing the land surface of the Earth, excluding Antarctica, into hexes with approximately twenty-kilometer edge length, yields over 100,000 individual locations. GNSS reference stations require specialized equipment, valuable roof-top real-estate, and high-reliability Internet connectivity. Therefore, the cost to build and manage such a large-scale network is measured in billions of dollars. GEODNET has developed an impartial, automated financial incentive system that encourages deployment of GNSS reference stations in response to market needs. Station contributors are awarded in GEODNET's native token, GEOD, which is redeemable to local fiat (e.g., USD) currency using a combination of decentralized and centralized token exchanges such as Quickswap and Coinbase.

The management of a large network of stations is complex and requires significant computation resources as well as operational maintenance. When the network is both decentralized and supported with financial incentives, there are risks of bad actors and network attacks. The full GEODNET paper describes in detail a method for decentralized network validation utilizing satellite signal characteristics, the satellite Ephemeris, and a cryptographic chip internal to each receiver. GEODNET seeks to only reward and incentivize the deployment of real reference stations, in real locations, collecting



GEODNET Reference Station Network (https://console.geodnet.com/map)



GEOD Token on coinmarketcap.com

real high-quality data. With validated data in hand, the network can (1) store data for use in post-processing applications (RINEX), (2) continually position each station to millimeter accuracy using Precise Point Positioning (PPP) techniques, and (3) perform automated alerts to station of any performance issues.

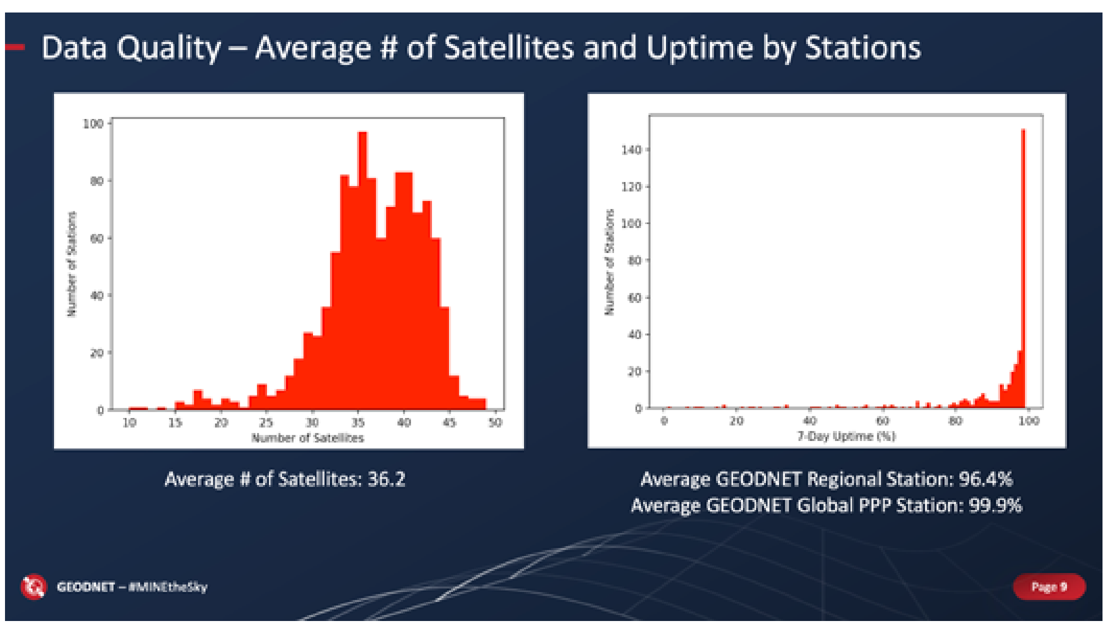
The users of GEODNET data products must trust the data to be accurate and valid despite the individual station data not being centrally deployed or controlled. The protocol must continuously remove poor quality data, and token rewards should be aligned to good performance. The performance of the network was reported on in the ION GNSS+ 2022 meeting. The results showed that the average station had 96.4% on-line reliability and tracked an average of 36.3 unique satellite vehicles.

Customer requirements are typically 99.9% reliability, so redundancy is required. To encourage redundancy, GEODNET hex sizes are set to 10km edge lengths to provide a full set of rewards for multiple stations within the 20km target spacing. Station hosts are incentivized via performance-driven GEOD token rewards to maintain excellent signal quality, avoid multipath sources, control positional stability, and maintain online time.

The major deployed applications utilizing the GEODNET network today include Agriculture, Survey, Drones, and Robotics. By providing fully modernized data sets from an ever-growing number of online stations, GEODNET is improving GNSS station coverage in many regions of the world. The GEODNET Foundation also seeks active collaboration with other groups to promote station deployments and high-precision positioning applications. One example is GEODNET's collaboration with Geoscience Australia. In the ION GNSS+ 2022 meeting, results of clock and orbit determination were presented based on processing of GEODNET station data with GINAN, an open-source tool maintained by Geoscience Australia.

In the coming years, GEODNET seeks to grow to 100,000 deployed stations which will be more than ten times the size of any other GNSS reference network. The use of high-precision GNSS in consumer applications is a fast-emerging trend that can benefit greatly from the large, dense and affordable "Internet" of GNSS reference stations.

For more information, and a recent scholarly article published in the ION's journal, with accompanying data and figures, please see:
Horton, M., Chen, D., Yi, Y., Wen, X., & Doebbler, J. (2023). GEODNET—Global Earth observation decentralized network. *NAVIGATION,* 70(4). https://doi.org/10.33012/navi.605

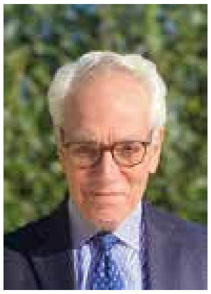


GEODNET Station Reliability Data Presented at ION GNSS+ 2022

The following address was delivered to the U.S. Space-Based Positioning, Navigation and Timing National Advisory Board on April 24, 2024, in Colorado Springs, Colorado.

A Call to Acknowledge and Step-Up:

PNT Governance for a Changed World



Jeffrey N. Shane

The Problem

Despite the widely acknowledged, pivotal importance of state-of-the-art PNT technology to America's economy and national security, the structure and governance of our PNT program no longer seems adequately responsive to today's challenges.

An Increasingly Challenging Environment

It is a changed world. One obvious way in which it has changed is in the number of stories we see in the news about jamming and spoofing. Another way is the way in which PNT is being used as an element in what we call "great power competition." Let's briefly explore these challenges.

Vulnerability an Increasing Concern

It's happening routinely in conflict zones, but we experience anomalies too often everywhere, even domestically. We know there are ways to toughen PNT; the National Space-Based Positioning, Navigation, and Timing Advisory Board has been addressing these for some time, but we aren't seeing the requisite urgency from governmental and regulatory leadership attached to addressing that need.

PNT: A Critical Enabler in Great Power Competition

We all love to think of GPS as the gold standard when it comes to space-based PNT. And without question, it certainly is. But maybe it's just 18K gold while some other systems are looking like 24K. There are capabilities that other GNSSs have that GPS doesn't. One of those GNSSs is China's BeiDou system. We know that China is aggressively marketing BeiDou in competition with GPS, using its system as a way to establish greater influence, and even dependence, particularly among developing economies. It's become a feature of China's Belt and Road Initiative, and is merely the latest episode in China's long history of seeking to gain influence in the developing world through investment and other assistance. I think it's a mistake to characterize all this activity as inherently sinister; after all, the U.S. wrote the book on the use of foreign assistance in order to cement relationships and alliances.

What we should probably treat as more worrisome is that China appears to be way ahead of us in developing a multiplicity of domestic PNT systems. Dana Goward and the RNT Foundation have been documenting this phenomenon for some time. What it means, simply, is that in the event of a conflict–however unlikely we hope it is–our single source of PNT could be disabled but China's multi-PNT capability would continue to function. That's a position we don't want to be in, but that we have been very slow to address.

> For many years, GPS was the acknowledged leader in space-based PNT. Today, however, U.S. leadership is beginning to erode in terms of services, performance, global adoption, and strategic benefit. If unchecked, this decline will have serious consequences for the U.S.

Time for a PNT Governance "Reset"

What all of this tells us is that there's a governance problem. But let me be very clear about something: In no way is our concern about governance meant to imply criticism of the people who built GPS, who operate it, who continue to maintain and improve it over time, and who continue to encourage the development of complementary PNT technologies. On the contrary, we salute them. What they have accomplished, what they accomplish every day, is nothing short of a miracle. It's an over-used cliché, I'm sure, but of course the system itself is a miracle. And let's never forget that GPS was America's gift to the world–possibly the greatest gift that any nation has ever given to the world. It remains powerful evidence of American ingenuity and leadership.

Unfortunately, what may be *most* miraculous about what the professionals involved in the GPS system do every day is that they do it without the quality of support that both they and the American people deserve. We think that's because the governance framework, which was designed 20 years ago and enshrined in a National Security Presidential Directive (NSPD-39)[1], a framework that made sense at the time, is no longer responding sufficiently to the strategic, geopolitical, and even the spectrum allocation challenges that America faces today. It's not about a lack or competence; it's about a lack of emphasis and urgency. It's time for a change.

What's Needed?

We need a new and more contemporary policy declaration–one that acknowledges the importance of PNT as an element in America's critical infrastructure, as well as its role in ensuring America's standing in the world. And we also need a revised approach to governance – one that ideally vests genuine decision-making authority in a single, properly empowered entity, one that has clear authority to address the shortfalls on a more timely basis and advocate for the funding that's necessary – both at OMB and before Congress.

This is, of course, a very big ask. But

1 NSPD-39 was superseded by SPD-7 in 2021, but no change was made to the governance framework.

we shouldn't treat it as beyond reach. Think about it: The fact that GPS may be lagging behind some of the capabilities we see emerging in other GNSS's should be treated as an opportunity to demonstrate the kind of leadership we have so often seen in our government. To use another shop-worn cliché, it's a wake-up call. Whenever the U.S. has perceived itself as behind in some strategically important way, we have stepped it up, usually with positive results. Launching an updated, contemporary PNT policy should be seen as nothing less than the stuff of legacy.

WHAT's NEEDED:

1. A high-level policy declaring America's PNT capability is both an element of the country's critical infrastructure and an important factor in the country's standing in the emerging great power competition.
2. PNT decision-making needs a formally centralized, fully empowered focus of responsibility capable of:
   a. addressing today's challenges more urgently, including the accuracy, resilience, and geopolitical importance of America's PNT assets; and
   b. advocating more effectively the funding necessary to accelerate future developments in keeping with current challenges.

Maybe it needs its own brand. We accelerated the modernization of our air traffic control system with a program we called "NextGen." We reformed the way international air travel works with a program called "Open Skies." And Hollywood now knows all about a program called the "Manhattan Project." What should we call this initiative to elevate PNT as an element of America's critical infrastructure? We have kicked around "GPS+" but I wonder if that diminishes the importance of terrestrial PNT. Maybe we should have a naming contest, but not until there's something to attach a name to.

Of course we need to be realistic. It's a very tough budget environment in Washington these days. Our national debt is famously $34 trillion; the budget deficit for 2024 is $1.6 trillion. Congress is not in a generous mood. But in the context of numbers like that, the resources necessary to support a PNT policy better tailored to today's needs should be treated as relatively small potatoes. It's hard to imagine leveraging money spent more effectively than by accelerating PNT development. Where there's a will – provided it's at a sufficiently high level – there's a way.

Role of the PNTAB?

Okay, you say, so we advocate a change in policy and a change in the governance structure. What should the U.S. National Space-Based Positioning, Navigation and Timing Advisory Board do then? Just wait for it to happen?

Of course not. We keep doing what our charter tells us to do. If our proposal for changes in policy and governance are accepted, we will find that there's a far more receptive audience for the informed, practical, actionable recommendations that come out of our meetings. And even if our overarching proposal isn't accepted, there's at least a chance that it will trigger some useful conversations within government. Maybe there are other ways to skin the cat. Even if that's all we get, it should encourage more attention to our recommendations – provided, again, that they are practical and actionable and provided we communicate them effectively.

Jeffrey N. Shane, member of the U.S. National Space-Based Positioning, Navigation, and Timing Advisory Board, is the former general counsel for the International Air Transport Association (IATA) and continues to represent IATA on IATA's Advisory Board. Mr. Shane held three Presidential appointments, including Under Secretary of Transportation for Policy between 2003 and 2008. In addition to other senior positions at the U.S. Department of Transportation, he was Deputy Assistant Secretary of State for Transportation Affairs for four years, where he served as chief U.S. aviation negotiator. Recognized for his role in establishing an Open Skies aviation policy for the United States, Mr. Shane was also a principal architect of USDOT's approach to international aviation alliances and antitrust immunity. He was an early champion of the "NextGen" transformation of the U.S. air traffic control system, the acceleration of GPS modernization, and other technology initiatives to enhance the safety, security, and efficiency of aviation and other modes of transportation.

continued from page 1

tive language, engage in hula or surfing," Gill said at ION's Pacific PNT conference in April.

In addition, massive erosion came with Westernization of agriculture in the islands, Gill said. "First came sugarcane fields, then the large pineapple plantations. Then livestock ranching took place," he said. "With this development came massive erosion. The iron-rich soil from the mountains sometimes moves out into the reef. In the 20th century, red mangrove from the Caribbean was imported in an attempt to capture some of the sediment."

In 2019 and 2021, uncrewed aerial vehicles were used to map and establish ground control points to assess the environmental damage, Gill said. "We aligned the images and made [low vegetation] classifications to bare Earth. We made digital surface models in both years," he said.

The overall native Hawaiian practice of biocultural resource management is called Ahupua'a, which leads to sustainability for life, Gill said. "[As part of Ahupua'a], water continues down coastal areas. These streams are unique in how they affect the marine systems," Gill said.

Saving Molokai Reef a Priority

Saving the coral reefs surrounding the Hawaiian island of Molokai has been one of the main goals of the project, said Dr. Joshua Mangelson, an assistant professor at BYU, who specializes in field robotic navigation, localization, perception, and mapping.

"The fringing reef, which is the largest in the United States, is still used for subsistence fishing and is an important resource. Right now, sedimentation is running down and destroying the reef," he said. "Older people talked about how the water used to be perfectly clear, but now it is muddy."

Mangelson said the first thing the project did was to determine what was happening and how it was happening. "We realized that collecting manual samples was hard—and doing it at scale was very hard, particularly with a limited time. "We initially used an autonomous surface vehicle, with RTK GPS and sensors [in November 2021]," he said. "It was a 3D model, but not underwater, with GPS at the surface and camera data below the surface."

As part of the environment efforts, using Gill's BYU biology laboratory, an autonomous surface vehicle was developed to monitor the reefs. The system, from Clearpath Robotics, is a Heron Robot outfitted with GPS for navigation and geotagging of data. It also has two forward-looking infrared cameras and a water sensor.

The ASV collected samples and created a geotagged 3D map of the coral reef that lets researchers identify individual coral reefs. The map also allows researchers to track the levels of reef degradation to allow future mitigation.

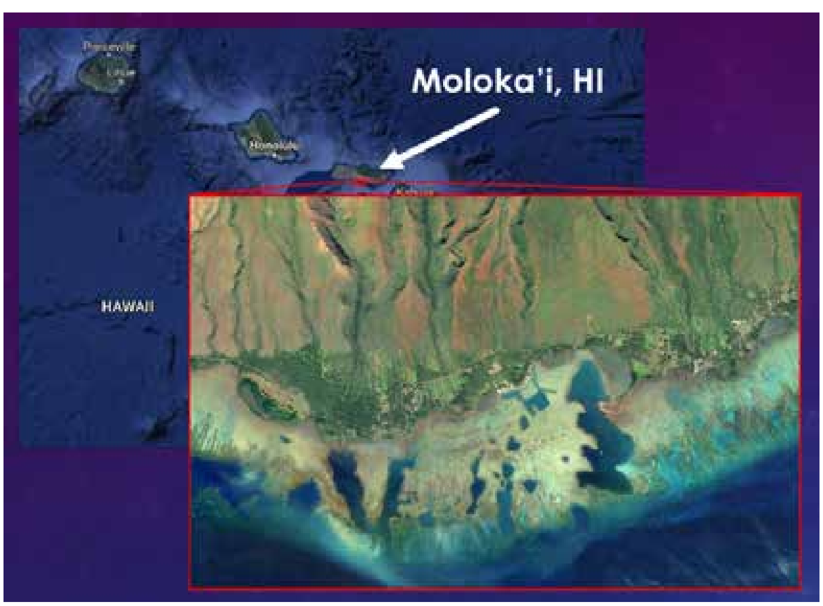
"A map gives you the location of landmarks with a camera or other sensors and range-bearing measurements. However, we don't have a prior map, we need to find landmarks to determine where you are—it's a chicken and egg problem," Mangelson said. "[Some of the most important principles include] where you are, where you are going, and what is around you. As we get measurements, dead reckoning, your uncertainty grows."

"At five sites off the Molokai coast, areas 30 meters by 50 meters were monitored, with full stereo reconstruction of the sites", Mangelson said. This included zooming in to assess the size of the coral heads in the 3D model. "The 3D model assessed something called rugosity, which measures the complexity of [coral] corners and angles. Some are turned in to sand and rubble and will be just flat," he said.

"Overall, BYU partner Kuleana Coral Restoration is replanting to keep the ecosystem healthy. [To assist], we are using underwater vehicles and surface cameras equipped with stereo cameras," Mangelson said. "We hope to build a time series on a 3D model later in the year, in Oahu and Molokai, to see the difference in complexity of [coral] corners and angles. Some are turned into sand and rubble and will be just flat," he said.

Autonomous underwater vehicle navigation comes with challenges inherent with GPS-denied areas. "After six inches of water, we lose [GPS]. We also often don't see areas underwater because of the particulates," Mangelson said.

"Besides GPS availability, some of the underwater vehicle challenges include high turbidity and low light, highly constrained communications, minimal if any prior maps and, frankly, outside common human experience. The roots of under-



Molokai's large coral reefs were examined by the BYU team.
Brigham Young University

Traditional native navigation and wayfinding relied on the stars.
Brigham Young University

water navigation algorithms used today are found in the indigenous principles used centuries ago," Mangelson said. BYU is working with Mark Ellis, of the Pacific Voyaging Society and Polynesian Cultural Center, on native navigation projects.

Native Navigation Making a Comeback

Some of the centuries-old native navigation techniques are consistent with modern robotic navigation and location techniques. These include location heading estimates through current evaluation and the direction of the swells. Another is velocity estimation—where the wave crest is monitored from a vessel's bow to stern.

Native Hawaiians have been using navigation and wayfinding techniques that have been proven over the centuries—and are being relearned by a new generation, Gill said. NHPI navigators use dead reckoning, which needs a heading translation or velocity measurement of some kind, he said.

"[Native mariners] tracked heading currents. They build stick charts where islands were—and the stick charts with shells represent current islands," Gill said. "When you can detect a current, you know a heading relative to an island. [Ocean] swells can be assessed near sundown to measure their angle. They also made a time estimate to determine how quickly they were moving."

Latitude observations come through star declination and zenith, Gill said. "If a star is at your zenith, its declination is equal to your latitude," Gill said. "Unfortunately, determining zenith can be hard at sea. Finding the zenith is easy to know on dry land. However, a rocking boat is more difficult."

BYU grad student Easton Potokar explains how an aquatic drone works.
Matt Mitchell

In addition to traditional celestial navigation, NHPI navigators also identified birds, who lived close to land, to determine how far they were away from shore, Gill said. "These bird species could live as far as 100 kilometers—or as close to 30 kilometers from land. They could monitor the direction of the birds and what time they would land," he said.

BYU's autonomous underwater vehicle.
Brigham Young University

Cloud formations, created by island mountains, were also used by early native sailors. "They also used cloud formations that form over the tops of mountains and even their reflections that showed shadows of islands; wind patterns as they hit mountains, Gill said."

Some of the renewed interest in traditional navigation and wayfinding arose out of expeditions from other Pacific islands to Hawaii in the 1970s and 1980s, Gill said. One was a 1987 to 1989 voyage from New Zealand to Hawaii.

Gill also sees the growing interest in navigation could interest younger Hawaiians to have a connection to not only cultural renewal, but [science, technology, engineering and mathematics] fields. "We're committed to connect young people with the principles of robotics and the Polynesian vision of voyaging and wayfinding," he said. "The insights we hope they get, as we do as scientists and engineers, are those immersive "aha" moments and realization that they can share with others."

BYU Continues Reef Monitoring With New Technology

In the future, BYU will continue to monitor the island's coral reefs, particularly with its more recent Oahu efforts. Future plans include a time-series of monitoring the restoration on the reef and ecology side. Other future studies include characterizing the fish community and reef health.

Ultimately, the university plans to field new monitoring technology on all of its Hawaii environmental projects. This includes artificial intelligence to enable high-level autonomous vehicle test capabilities.

continued from page 1

MHz, International GNSS Day commemorates our technological heritage and, inspired by Dr. Joanna Hinks' visionary proposal last year, recognizes the extraordinary contributions of GNSS technologies that have transformed the sectors of agriculture, aviation, transportation, surveying, and beyond.

Why we Celebrate

This annual celebration provides a unique opportunity to acknowledge the historical developments and collaborative efforts that have shaped the current landscape of satellite navigation, marking 51 years since the inception of GPS, while also driving momentum for future advancements in GNSS. It is a day for professionals, students, educators, and enthusiasts to engage deeply with the technology and history of GNSS, sharing the passion that drives our field.

Join the Celebration

We invite you to dive into the festivities by exploring our educational modules designed to inspire and inform the next generation of GNSS experts. You can find our educational resources on our website at ion.org/news/internationalgnssday.cfm. We suggest you celebrate by participating in workshops, lead discussions, or simply share your GNSS experiences, as every interaction helps to foster a broader understanding and appreciation of GNSS. Whether you are a seasoned professional or just beginning your career in PNT, International GNSS Day serves as a platform to connect with like-minded individuals and contribute to a global dialogue on the significance of GNSS.

Engage with us at ION GNSS+ 2024

This September, as part of our International GNSS Day celebrations at ION GNSS+ 2024, we are excited to offer a unique opportunity for attendees to engage directly with the broader PNT community. At our exhibit booth, we will be conducting mini-video interviews where attendees, as an incentive for sharing their insights, will receive an exclusive International GNSS Day t-shirt.

To qualify for this incentive, attendees must agree to be filmed while answering one or several of the following prompts, designed to explore various aspects of GNSS and its impact:

1. How are you planning to celebrate International GNSS Day?
2. What is your favorite memory related to GNSS?
3. What advice do you want to give to future PNT engineers/professionals?
4. What innovative GNSS application or innovation do you predict for the future?

By participating, you help us illuminate the diverse voices and experiences within our community, contributing to a richer narrative about the significance of GNSS in shaping our world.

Celebrate International GNSS Day with ION this October 23!

Celebrations from 2023's Inaugural International GNSS Day

Aerospace Engineers Commemorate GPS 50th Anniversary

Towards the end of last year, in commemoration of the 50th anniversary of the GPS and Aerospace's pioneering role in developing global navigation satellite system (GNSS) technology, Aerospace employees in El Segundo gathered on the STARS patio to observe and celebrate the inaugural International GNSS Day on October 23. Similar to Pi Day, whose March 14 observation date is based on the approximate value of pi, the 10.23 date for International GNSS Day was chosen to recognize the significance of 10.23 as a fundamental number upon which all GNSS signal frequencies and pseudorandom "spreading codes" are based.

Aerospace has played an instrumental role in advancing the concept and technology and continues to support these critical systems today.

More than 30 experts and fans of GPS gathered on the STARS patio for a reading of the official proclamation and the establishment of what are sure to be long-lasting International GNSS Day traditions. These included identifying the unique 1023-bit C/A Code PRN sequence printed onto the 10.23 Day cake, followed by several rounds of 10-2-3 trivia and Nav-War card games. As the driving force behind International GNSS Day - now recognized by professional societies, international forums, and trade publications - Karl Kovach had the honors of cutting the cake.

Senior VP of ETG Kevin Bell joins the festivities.

Upon joining the event, ETG Senior Vice President and GPS enthusiast Kevin Bell said, "Events like International GNSS Day on 10.23 are essential to bring our teams together and connect

Aerospace employees showing the GPS waveform while celebrating the inaugural International GNSS Day on October 23.

Karl Kovach reads the proclamation

them to the mission!"

The use of the term "chips" to describe the binary bits of GPS signals was celebrated by serving potato and corn chips. A fishbowl with 1,023 gold poker chips was displayed and gold chocolate coins were served in recognition of the binary sequences, known as Gold Codes for their inventor Robert Gold, that enable receivers to identify individual GPS satellite signals.

In addition to the El Segundo-based event, Aerospace's Colorado Springs contingent also got into the action. Located just a few miles from the GPS Master Control Station, Aerospace's Colorado Springs GPS enthusiasts held an event on the COS-1 patio similarly rife with chips - and guacamole, perhaps as a nod to their California co-workers.

International GNSS Day began a series of GPS-themed celebrations, including a formal event in Washington, D.C. in mid-November. These events culminated on December 17, on the day the GPS program was formally approved in 1973, which is the date recognized as the "birthday" of GPS.

Although inaugural events required some last-minute planning, Aerospace organizers had a vision for the festivities. Said Aerospace Tech Fellow Tom Powell, "This was not a random event. It was pseudo-random."

Len Jacobson

More "Firsts"

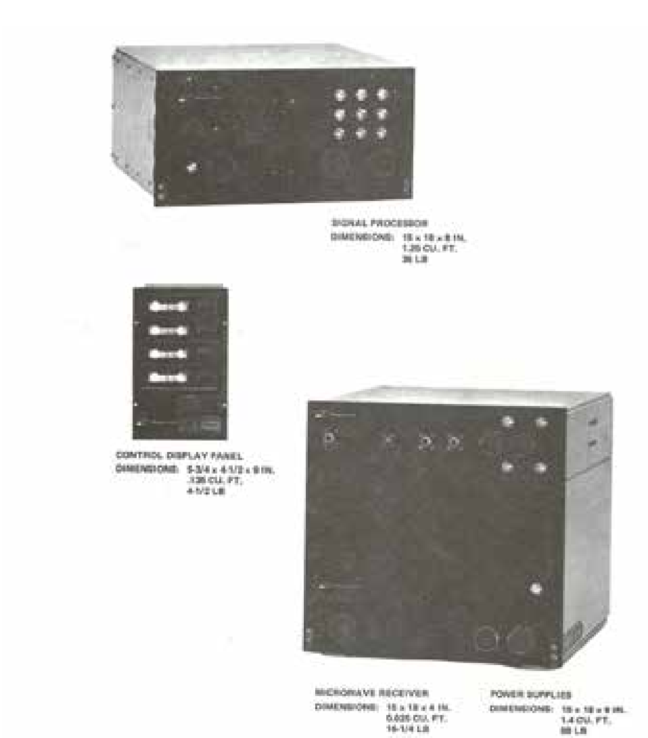
How GPS Began: A View from the Ground

Edited by ION Historian, Marvin B. May

I first encountered what would become GPS in 1968 in an afternoon meeting at the Hughes Aircraft Co. in El Segundo, California. Hughes was the leader in synchronous communications satellites and had built the Surveyor that landed on the moon. They, along with TRW, were studying satellite navigation concepts for the nearby USAF's Space and Missile Systems Office (SAMSO) in a project called 621B, first proposed by The Aerospace Corporation (El Segundo, California), SAMSO's technical adviser. The study analyzed various constellation configurations and signal modulations, including spread spectrum transmission, a type of signaling that was classified at that time. Hughes had a teammate in the study, the Magnavox Research Laboratory (MRL) of Torrance, California. MRL was probably the world's leader in direct sequence spread spectrum technology at that time, having provided modems for military communications. MRL was also a major purveyor of receivers for TRANSIT (the USN's navigation satellite system), the world's first global navigation satellite system. While most of the buildings where these feats were accomplished still stand, those company names have all been merged, acquired, or dissolved; and the people who performed the studies are either retired or deceased.

At the conclusion of the 621B studies, the USAF requested that Hughes and TRW do an experiment to determine how accurately the spread spectrum signal could be employed to measure the length of a half-mile of radio frequency cable. TRW took the contract, but Hughes didn't believe that 621B had a future. So, MRL volunteered to perform the experiment. The possibility that there could be a GPS got more serious afterwards with a program to demonstrate that such signals could be used to calculate a position. It was called the 621B Inverted Range Experiment to be run at Holloman Air Force Base, with Hazeltine Corporation and MRL (MX450 shown) receivers in an aircraft getting ranging signals from four ground stations transmitting to an antenna on the bottom of the aircraft. Grumman was the prime contractor, their first entry into GPS. Those tests provided the crucial data that enabled GPS development to begin. I still have the Executive Summary of the Final Report from those tests.

Armed with the 621B test data, the newly assigned Program Manager, Air Force Colonel Brad Parkinson, was able to get the Advanced Development Phase of



GPS under contract. Rockwell Corporation in Seal Beach was chosen to provide a small number of spacecrafts. General Dynamics Corporation in San Diego would provide the ground control system, and Magnavox would develop a suite of user equipment for various military platforms (see figure). There would be a high-dynamics set with a 4-channel receiver (called the X-set), a low dynamic set with a 2-channel receiver, the Y-set, a manpack and a single channel Z-set that only used the C/A, civil code configured to replace an aircraft's TACAN receiver. I believe the Z-set was the first civil GPS receiver, and was the first to be used in an actual military mission.

During Phase1, NATO joined the program and sent several officers to the Joint Program Office. Consequently, several NATO countries decided to either develop GPS user equipment, or purchase some for evaluation for their military needs. For the actual field-testing, the X-set, along with its ancillary equipment, was placed in an AIM-9 pod under an F-4 aircraft. The plane flew over the test area and when the GPS indicated it was at the optimum place to drop its load of five inert bombs, they were launched at a big orange X-target laid out on the desert floor at a known location. Most bombs fell within 30 feet of the target. On one test flight the ground crew was making the measurements between the big X and the bomb craters, but they only found four craters. It seems two of the bombs landed in the same place. When these results were briefed up the chain of command at the Pentagon, the briefer said the accuracy was equivalent to releasing the bomb over the White House and hitting the gazebo in the center of the Pentagon. One smart aleck in the audience piped up and said, "You're going the wrong way." These bomb drops were so accurate that they amazed the Department of Defense management briefed on the results and were key to the decision to proceed with further development of GPS.

During the test period that lasted over a year, there was a big demonstration planned for distinguished visitors from NATO. A huge open-air tent was set up atop a mesa and about 50 of us were able to witness bomb drops, fly-bys and Manpack demos. It was thrilling to see a C-140 approach from a distance and then fly 50-feet over our head. During Phase 1 testing, both the military, and most of the engineers, including myself, were surprised by a particular result. While we expected the military signal to provide fixes with horizontal position errors of about 10-meters, and the civilian signal to have errors of about five times larger than the military signal, we were consistently achieving results with the civil signal Z-set that were within only twice the error of the military signal. Clearly, this was too good of a capability to give away to potential adversaries who could use civilian receivers for nefarious applications. It would undermine the advantage afforded to the US and its Allies who would be using the military signal for positioning and navigation. So led by Captain Mel Birnbaum of the GPS Joint Program Office, a scheme was devised to distort the civilian signal in the satellite such that a civilian receiver could get no better than 100-meters accuracy 95% of the time. This scheme to degrade the accuracy available utilizing the civilian signal was to be known as selective availability. Magnavox also won a contract to space qualify the Manpack and have it installed on NASA's Landsat and on classified satellites. The receiver performed as expected and gained fame as the GPSPAC, the first GPS receiver in space.

In late 1979 a man in a trench coat who couldn't say what it was going to be used for borrowed the Z-set. He suggested I should call over to the JPO and they would verify the validity of the request. About a year later I found out what it was all about. The Z-set had two boxes, a receiver and a panel mounted control/display unit (CDU). Magnavox got the receiver back, but never got the CDU back. I learned later that the Z-set had been installed in one of the helicopters used in Operation Eagle Claw, the failed April 1980 raid to rescue hostages held at the U.S. Embassy in Iran. I guess the Special Forces were able to recover the Z-set receiver but not the CDU as the helicopters were all destroyed. I ran a coverage plot for the day of the raid over Iran and there were four satellites in view at that time. I also received a copy of an Iranian newspaper that had a big article on GPS in Farsi. I couldn't read it, and I don't think it mentioned the raid, but there was a diagram of the GPS constellation, so I know the Iranians were very aware of GPS. That mission may have been the very first operational military use of GPS.

Later that year a VELA reconnaissance satellite detected a "double flash" that was deemed by many to be evidence of an atmospheric nuclear explosion off South Africa in the South Indian Ocean. While many of the details are classified, there is quite a write up about it in Wikipedia. See: http://en.wikipedia.org/wiki/Vela_Incident

This came at a time when the GPS Program was in even greater budget trouble than normal. Then SECAF was trying to zero out the GPS budget and it looked very likely he would succeed. But along came a procurement for a Nuclear Detonation Detection System payload package to be placed on all future GPS satellites. I believe that saved the GPS program from a premature demise. I also suspect, as do many others, but cannot prove, that the "flash" was caused by an Israeli nuclear test. If so, perhaps one could conclude that Israel may have inadvertently saved the GPS program from extinction.

Len Jacobsen has been a technical, management, and business development consultant to GPS for the U.S. Government, and to the legal profession, for over 30 years, after a distinguished industrial career. He is a prolific author and noted media and legal expert on GPS.

Marvin B. May is a Professor Emeritus of navigation, ION Fellow, and ION Historian.

Defense Matters

New Thinking to Confront New PNT Challenges

"We Cannot Solve our Problems with the Same Thinking We Used When We Created Them"

The title of this Defense Matters article is a quote attributed to Albert Einstein. It was often times noted by the late Dr. Jim Schlesinger (February 15, 1929 – March 27, 2014) in his capacity as the chair of the National PNT Space-Based Advisory Board.

The subtitle, *New Thinking to Confront New PNT Challenges,* is apropos to the quote's emphasis to suggest a shift in mindset, to pursue a course departing from conventional thinking, and the need to adopt new perspectives to tackle the challenges being experienced for both civil and military aspects of how PNT systems are being pursued in the United States.

Modernizing GPS

The initiative to modernize GPS, dating back to the final few years of the last century, was founded on the premise that steadily pursuing a national policy for continuous GPS improvement would discourage foreign competition. That premise must now be reevaluated as the world has evolved over the last 25 years and GPS, along with broader U.S. PNT policy, needs to adapt. A change in thinking is needed.

Jamming and spoofing of GPS are being experienced daily in the ongoing conflicts in Ukraine, Syria, and Gaza. The impacts have diminished the military utility of GPS equipped weapons. Not surprisingly, the spill-over of jamming has impacted civil aviation resulting in canceled flights and diminished civil aviation operations around these areas of military operations.

With that said, there is a degree of benefit in the growing number of news stories as they raise awareness across a broader audience to the dangers of GPS dependencies, e.g., those in charge of critical infrastructure sectors. At the same time, and hand-in-hand with this growing awareness, those who are not surprised by the impacts will be asked what is being done to address the issue. A change in thinking is needed.

From a national security/military perspective, the implementation of the next-generation GPS Operational Control System (OCX) is delaying the space segment from taking full advantage of on-orbit M-Code signals. The current operational date for OCX is projected for the fall of 2025. Given the track record to date on OCX, further slips to the right should be anticipated. A change in thinking is needed.

OCX delays, combined with the launch of the next generation of GPS satellites (IIIF), are extending the date when the new L5 signal will be declared operational. Currently there are 17 on-orbit L5-equipped GPS satellites, with the current "launch for replenishment" strategy not delivering a 24-satellite L5-capable system until the 2028 time frame.

At a recent National Space-Based PNT Advisory Board meeting, a discussion took place on the benefit of transitioning the current on-orbit L5 signals to a "healthy" status. Then, the benefits of the spectrally separated, wider band L5 signals could be used by GPS receivers for improved interference protection capability when compared to single frequency L1 receiver operations. Taking this step now, ahead of the U.S. Space Force declaring the L5 service reaching full operational capability (FOC) with a 24-satellite constellation, would enable use of these nearly 30-year-old modernized GPS signals that have already been copied and made available by other GNSS like Galileo and BeiDou.

The GPS L5 signal was conceived as a "safety-of-life" signal for civil aviation needs, and meeting those stringent aviation requirements should still be factored into when it is integrated into aviation procedures. However, enabling early use of the on-orbit GPS signals for non-aviation applications requires a shift in mindset that can benefit and add resilience to a larger user community of PNT users that does not need to adhere to the strict rules developed by the Federal Aviation Administration and the International Civil Aviation

Doug Taggart
President
Overlook Systems Technologies, Inc.

Organization. A change in thinking is needed.

Governance of PNT

Other GNSS providers, and most notably China, have taken steps to implement alternatives to BeiDou to enhance national PNT resilience. A May 2024 report prepared by the China Aerospace Studies Institute, addressing future efforts to further integrate BeiDou services with 5G, mobile communications, big data and the internet, states that in 2025 "… the People's Republic of China (PRC) will begin building a low Earth orbit (LEO) augmentation to improve the speed, reliability, and accuracy of the signal." By 2035, the PRC plans for BeiDou to be "more ubiquitous, integrated, and intelligent" and capable of providing "core support" to the development of autonomous vehicles and new-generation communications. The intention is to create a system that can provide accuracies down to 2 millimeters globally. The PRC is also investigating other capabilities, such as quantum navigation, underwater navigation, and deep space navigation.

The U.S. approach to managing PNT has been struggling with no measurable steps taken to rekindle a terrestrial PNT backup. We need to rethink and redefine the current National Space-Based PNT Executive Committee to broaden its portfolio and take the long overdue step of changing its name to be more than just space-based PNT. A change in thinking is needed.

Beyond that simple name change, as challenging as it may be to conceive, a means to provide it with budgetary authorities is also needed. Again, a shift in mindset will be needed. See Defense Matters, "The UK Government's National PNT Initiative," Winter 2024.

Military Exclusivity

The concept of fielding GPS as a dual-use technology, providing both civil and national security attributes, served it well as it was being developed. But times have changed, and the exclusivity of the DoD having a closed system where the space segment, control segment, and military user equipment are 100% dedicated to serving the military users, has severely slowed progress on implementing enhancements.

Noting the vital role of satellite communications, the DoD is actively taking steps to contract with commercial satellite services to buttress its needs supporting a global fighting force. Similar steps might be taken to move beyond just military grade GPS for miliary purposes. Bringing other PNT sources into the mix will have the effect of "taking the bullseye" off of GPS.

The Space Force's FY24 budget includes efforts to procure and downstream deploy GPS-Lite capabilities that would provide a collection of GPS signals for military use. This approach, although taken to add complementary PNT services, will have an effect of keeping the bullseye on GPS while further complicating the control and user segments.

DoD Directive 4650.08, which provides PNT and NAVWAR Policy guidance to Military Departments, currently states that reliance "on civil, commercial, or foreign sources as the primary means of obtaining PNT information for combat, combat support, or combat service support operations is not authorized without a waiver in accordance with Joint Chiefs of Staff (CJCS) Instruction (CJCSI) 6130.01G. These systems may be utilized as complementary sources, subject to successful NAVWAR compliance determination."

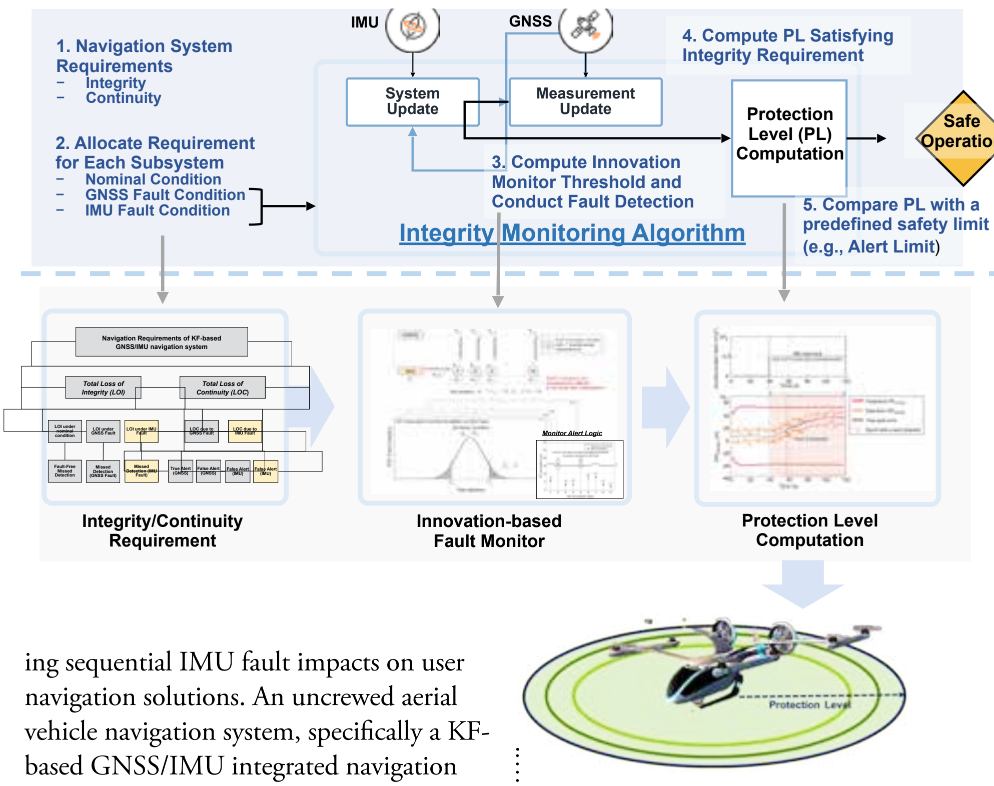
Meeting the conditions of successfully demonstrating NAVWAR compliance, when the bullseye of GPS jamming is set squarely on L1, is further exacerbated by M-Code equipment not being available, OCX not able to support M-Code capability, and M-code user equipment not available for the Services to procure or with funding for integration. A change in thinking is needed.

To embrace a fresh perspective and a revised understanding of the world today, we can benefit by changing not only our thinking of how PNT services are pursued in the U.S., but we must do it soon or we will find ourselves lost in not knowing where we are and being seriously challenged to find our way out.

ION's JOURNAL
NAVIGATION Spotlight
navi.ion.org

Navigation Safety Assurance of a KF-Based GNSS/IMU System: Protection Levels Against IMU Failure

Jinsil Lee, Minchan Kim, Dongchan Min, Sam Pullen, and Jiyun Lee



Addressing a key challenge in autonomous vehicle (AV) navigation: protecting against inertial measurement unit (IMU) sensor failures.

Imagine an urban air mobility vehicle flying over a city, its systems relying on a Kalman filter (KF)-based global navigation satellite system (GNSS)/IMU navigation system. What happens when faulty IMU measurements silently infiltrate the navigation system, causing errors over time and potentially leading to catastrophic consequences? While most KF-based GNSS/IMU navigation safety systems prioritize protection against GNSS faults, this research tackles the key challenge in autonomous vehicle navigation by unveiling the sequential impact of IMU faults on user estimates and offering a novel approach to ensure safety with protection levels against IMU faults. IMU measurements exhibit different fault propagation characteristics in user state error compared to GNSS, as they are applied in different steps—state prediction and measurement update, respectively. By addressing IMU vulnerabilities in addition to GNSS, this technology paves the way for a future of truly reliable autonomous navigation systems

This paper presents simulations that show the algorithm's effectiveness in detecting, quantifying, and mitigating sequential IMU fault impacts on user navigation solutions. An uncrewed aerial vehicle navigation system, specifically a KF-based GNSS/IMU integrated navigation system, is used for the simulation, and the proposed integrity and continuity algorithms, integrated with fault monitors, are incorporated into the navigation system. The simulation results successfully demonstrate that the two types of protection levels (PLs) bound the sequential impacts of IMU faults on the user error domain when introducing various types of IMU sensor faults, such as bias faults and ramp faults during simulated operations. Real-time PLs safely bound the errors introduced by faults, ensuring navigation safety during fault events. Predictive PLs proactively warn of potential integrity violations before they occur, enabling preventive measures. The simulations validate the theoretical framework of the algorithm and its practical applicability in ensuring navigation safety under IMU faults. The enhanced integrity and continuity of navigation solutions open up new possibilities for their utilization in various sectors.

While the methodology has recently been published and is not currently in use in the navigation market, its introduction to the academic and research community marks a significant step towards addressing crucial challenges in safety assurance against sequential IMU sensor failure (or any other sensor faults applied in the state prediction step) within a KF-based multi-sensor navigation system. It's important to note that as the required level of safety increases, confirming navigation safety against every potential sensor fault that can cause safety concerns becomes a demanding task. The methodology's potential benefit lies in its ability to provide quantitative measures for the safety of multi-sensor-based autonomous navigation systems, contributing to advancing

safety standards in navigation technology. As awareness and understanding of this methodology grow within industrial domains, we anticipate its adoption in addressing real-world demands, including providing guidance for navigation safety assessments for future mobility applications.

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

Lee, J., Kim, M., Min, D., Pullen, S. & Lee, J. (2023). Navigation safety assurance of a KF-based GNSS/IMU system: Protection levels against IMU failure. *NAVIGATION,* 70(4). https://doi.org/10.33012/navi.612

Privacy-Preserving Cooperative GNSS Positioning

Guillermo Hernandez, Gerald LaMountain, and Pau Closas

The architecture of collaborative position framework is an expanding research area within the GNSS and PNT communities aiming to increase their availability, position accuracy, and reliability. While these frameworks, such as a cooperative positioning approach, enhance these features, they introduce privacy concerns for collaborating users that make up the frameworks. Ideally, these frameworks would be constructed with trustworthy users who are authentic and do not misuse the sensitive information of their collaborators. However, this may not always be guaranteed, as malicious users may exist. Secondly, the risk of insecure communication links poses the threat of sensitive information being intercepted by unauthorized users, similar to external eavesdroppers attempting to infiltrate the framework with malicious intent.

	Eavesdropper privacy		n-th user privacy		
Scheme	$\hat{\boldsymbol{x}}^{(m)}$	$\mathrm{Cov}(\hat{\boldsymbol{x}}^{(m)})$	$\hat{\boldsymbol{x}}^{(m)}$	$\mathrm{Cov}(\hat{\boldsymbol{x}}^{(m)})$	**RT**
non-encryption	✓	✗	✓	✗	✓
regular encryption	✓	✓	✓	✗	✓
homomorphic encryption	✓	✓	✓	✓	✗

Table 1: Summary table of the information that can be potentially leaked from user m to either an eavesdropper agent or the -th user. The primary information regards either its position xˆ(m) or the associated position uncertainty Cov(xˆ(m)). A check denotes the quantity is kept private, while a cross refers otherwise. The table also shows the real-time readiness of each approach given their corresponding complexity.

These concerns have prompted research to mitigate privacy issues within these frameworks. Various methodologies objectively address the two main aspects of privacy, with common approaches utilizing non-encryption and encryption implementations. In Table 1, the limitation of each approach is identified. Consider the non-encryption approach, which takes into account the privacy of a user's position information against an eavesdropper and its collaborative user (n-th user). However, the position uncertainty information is not considered private for an eavesdropper and its collaborator. While these approaches focus on privacy from a single perspective, the research presented here adopts a simultaneous approach to address both aspects of privacy concerns.

The article discusses three different privacy-preserving schemes. The proposed privacy-preserving cooperative positioning solution utilizes the fully homomorphic encryption (FHE) methodologies, and it provides the same benefits of highly accurate positioning estimation results as the non-encrypted cooperative position solution, while guaranteeing the privacy characteristics given by the FHE. The proposed solution underwent a rigorous experiment to evaluate position accuracy and gain a better understanding of the fully homomorphic encryption parameters. This experiment involved two enabling GNSS receivers, specifically two Android phones, which were placed approximately 321.9 meters away from each other. Throughout the experiment, these devices remained stationary at their respective locations, and each observed their raw GNSS measurements and this was processed to obtain the pseudorange information.

Using the pseudorange data, a non-cooperative solution was implemented as an iterative least squares and weighted least squares algorithm to serve as a benchmark. A cooperative solution (CoPo) scheme was introduced to eliminate the ionospheric delay effect. The CoPo process was compared to the benchmark to ascertain an accuracy improvement over the noncooperative solution. Then, the fully homomorphic encryption scheme was integrated into the CoPo process to establish a privacy layer. This encrypted cooperative positioning scheme was also compared to the benchmark's accuracy results.

It is important to understand that there is a possibility of obtaining incorrect position results. The primary cause of an incorrect result is the introduction of noise into the encoded data during the encryption process, which is then converted to ciphertext. As the ciphertext undergoes a computational process, the initial noise from the encryption process increases. When this noise level surpasses a certain threshold, the ciphertext may become corrupted, leading to an incorrect decrypted value. As part of the experiment, a boundary metric was identified to successfully decrypt a ciphertext that underwent the cooperative position scheme.

Taking this into consideration, the results of the encrypted cooperative

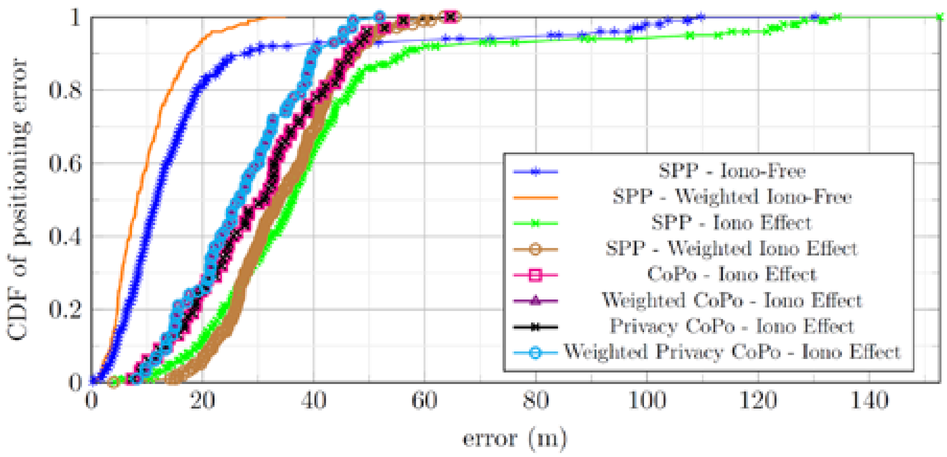


Figure 1: CDF of the positioning error using raw data collected from Android smartphones. The case study compared non-cooperative LS and WLS (ionosphere-free), non-cooperative LS and WLS, cooperative LS and WLS and the implementation of the homomorphic encryption onto the cooperative WLS and LS methods.

positioning scheme were then compared to the cooperative solution results. These results were similar when the fully homomorphic encryption parameters were within a certain boundary. If these parameters were outside of their specified boundary, the decryption process would not correctly decrypt the true values within the ciphertext. Fig. 1, provides the CDF of the position errors of each approach. Additionally, the results also indicated that certain parameter values would increase the computational cost. These findings introduced the constraint of establishing a privacy-concerning solution.

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

Hernandez, G., LaMountain, G., & Closas, P. (2023). Privacy-preserving cooperative GNSS positioning. *NAVIGATION,* 70(4). https://doi.org/10.33012/navi.625

RFI Mapped by Spaceborne GNSS-R Data

Clara Chew, T. Maximillian Roberts, and Steve Lowe

Our research shows that GNSS-Reflectometry observations, collected by low Earth orbit (LEO) satellites, can be used to approximate the location of terrestrial sources of GNSS radio frequency interference (RFI, i.e., jammers or spoofers). In contrast to previous studies that use similar LEO observations to geolocate sources of RFI, our method does not require advanced data processing or special data collections and can provide daily, global maps of the approximate locations of sources of RFI. However, unlike the aforementioned techniques, our method cannot precisely pinpoint these locations, though it can provide quick approximations that could inform where to task special data collections to more precisely geolocate the source.

We observed that regions of high noise in our satellite observations are associated with locations of known sources of GNSS RFI. We used the noise data to then map other possible locations of GNSS jammers or spoofers that were previously unmapped, and we associate the timing of the appearance or disappearance of GNSS RFI with notable conflicts. Our findings are important not only to aid in the geolocation of GNSS jammers or spoofers but also in the interpretation of GNSS data used for scientific applications, which can be negatively impacted by RFI and needs to be flagged as potentially contaminated.

In the near-term, our findings are helping inform how to improve flagging RFI in spaceborne GNSS-Reflectometry datasets. We hope at some point in the future to create a GNSS RFI data viewer such that anyone can view maps of RFI in near-real time without having to know how to process the data themselves.

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

Chew, C., Roberts, T. M., & Lowe, S. (2023). RFI mapped by spaceborne GNSS-R data. *NAVIGATION,* 70(4). https://doi.org/10.33012/navi.618

Evaluation of the Benefits of Zero Velocity Update in Decentralized Extended Kalman Filter-Based Cooperative Localization Algorithms for GNSS-Denied Multi-Robot Systems

Cagri Kilic, Eduardo Gutierrez, and Jason N. Gross

Our manuscript presents an approach to cooperative localization in multi-robot systems, particularly in environments where GNSS signals are denied or degraded. The method uses zero velocity update (ZU) in a decentralized extended Kalman filter (DEKF) framework. It fuses the sensor data from inertial measurement units (IMUs), ultra-wideband (UWB) sensors, and, optionally, visual/wheel odometry to enhance localization accuracy. The key innovation lies in applying ZU to one robot in the system, which significantly improves the localization of other robots in the group when they share state information pairwise, even if ZU is not used directly by all of them.

The experiments include testing our method in both a simulation environment and a real-world setting using small, wheeled ground robots. The real-world experiment involved three robots moving in an indoor environment equipped with inertial and ranging sensors, but no GPS and visual sensors for positioning purposes. In the mission scenario, one

continued on page 27

The Business of GNSS

Kevin Dennehy

In a big announcement since our last column, reacting to worldwide jamming incidents and other GPS interference, the U.S. Defense Department is asking $1.5 billion for positioning, navigation, and timing (PNT) resiliency programs as part of its fiscal year 2025 budget. The PNT chunk of the budget is part of an overall $33.7 billion request for space programs in fiscal year 2025.

Also, since our last column, there have been some big acquisitions: Keysight Technologies has announced its intention to acquire United Kingdom-based ION member **Spirent Communications,** which rolled out its PNT X simulation system during the quarter, for nearly $1.5 billion. Saying it wants to expand its reach as a global alternative PNT service, Iridium Communications has acquired **Satelles** for $115 million.

In the quarter's biggest contract, the **European Space Agency (ESA)** has awarded $253 million for three contracts that fund two satellite navigation missions. The navigation missions, Genesis and LEO-PNT, are part of ESA's FutureNAV program. As part of the LEO PNT portion, 78.4 million euros went to ION member **GMV Aerospace** and Defence, OHB System, and **Thales Alenia Space.**

Depiction of a future Genesis satellite.
ESA

Another significant business move occurred when ION member **NextNav** signed an agreement to acquire spectrum licenses covering an additional 4 MHz in the lower 900 MHz band for as much as $50 million. The company also filed a petition with the Federal Communications Commission to reconfigure the 900 MHz band for a terrestrial complement and backup to GPS.

Accelerating the deployment of a low Earth orbit (LEO) alternative to GPS, **Xona Space Systems** this week closed a $19 million Series A round of funding. Xona said it will begin beta operations of its PULSAR satellite service, which the company said "brings orders of magnitude improvements in accuracy, availability and security" over GPS.

u-blox anticipates $100 million from the robotic lawn mower market.
u-blox

Saying it has partnered with the majority of robotic lawn mower manufacturers, ION member **u-blox** anticipates more than $100 million in expected market segment revenue. The company said that the development of real-time kinematic (RTK) GNSS systems, capable of delivering centimeter-level accuracy, has significantly increased the performance of robotic lawn mowers.

Recent Product Launches

ION member **HERE Technologies** has partnered with Australian telematics provider Netstar to enhance asset management and navigation capabilities for commercial and heavy vehicles. The companies plan to leverage HERE's Location Services and Map Content for asset tracking.

CMC Electronics and ION member **Hexagon's Autonomy & Positioning division** have partnered on a GNSS platform for aviation. The companies said they will merge CMC's certification expertise with a Hexagon-NovAtel GNSS platform that aims to detect spoofing and jamming.

Saying the product launch comes as Russia is interfering with GPS technology throughout Europe, **oneNav** announced the launch of L5-direct, which is directly acquiring and tracking L5-band signals. Russian forces have been successful in using GPS blackout technology to thwart American-made drones on the Ukrainian battlefield, the company said.

Septentrio is partnering with several major drone solutions providers, including 3DR, Holybro, ARK Electronics and Systork, to prototype or integrate its mosaic GNSS receiver into UAVs.

Topcon Positioning Systems has announced strategic agreements with Bentley Systems and Worldsensing to integrate its GNSS technology into the companies' software and connectivity solutions. As part of its agreement with Bentley Systems, Topcon will provide access to its web-based GNSS processing engine for Bentley's iTwin IoT monitoring solution.

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

ION News and Notes

2024-'26 SATELLITE DIVISION NOMINATIONS & VOTING

The Satellite Division Nominating Committee, chaired by Dr. Chris Hegarty, has submitted the following nominations for Satellite Division Officers:

Chair:
Dr. Dorota Grejner-Brzezinska

Vice Chair:
Dr. José Ángel Ávila Rodríguez
Dr. Mohammed Khider

Secretary:
Dr. Juan Blanch
Dr. Okuary Osechas

Treasurer:
Dr. Seebany Datta-Barua
Dr. Yu (Joy) Jiao

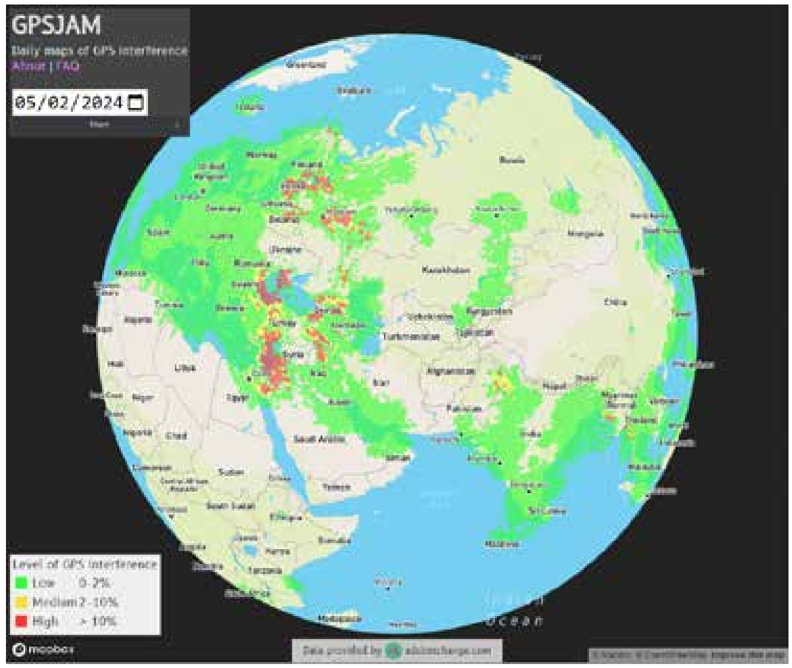
Pursuant to Article IV of the Institute of Navigation Satellite Division Bylaws, "Additional nominations may be made by petition signed by at least 25 members entitled to vote for the office for which the candidate is nominated." All additional nominees must fulfill nomination requirements as indicated in the ION Satellite Division Bylaws and the nomination must be received at the ION National Office by July 10, 2024.

Online voting for the ION Satellite Division Officers will be available after July 17. Completed ballots must be received at the ION office by August 5, 2024, in order to be counted.

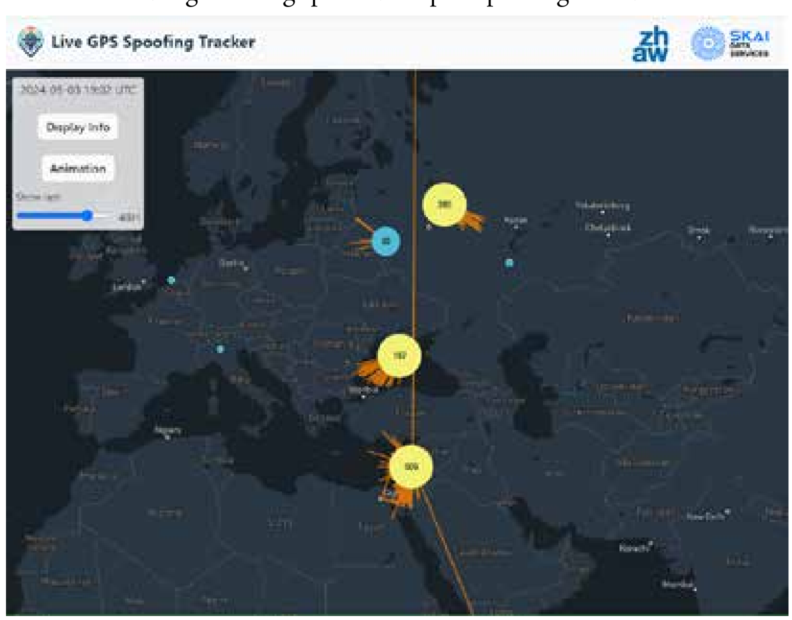
Election results will be announced during the International Technical Meeting of the ION Satellite Division being held September 16-20, 2024. The newly elected officers will take office on September 21, 2024, at the conclusion of the meeting and will serve for two years. Election results will be reported in the *ION Newsletter.*

Real-Time GPS Interference Websites Hosted by the RNT Foundation

GPSJam.org uses ADS-B information collected by the volunteer ADS-B Exchange to produce a daily depiction of low navigation integrity reports from aircraft worldwide over a 24-hour period. The site was created and is maintained by John Wiseman. https://gpsjam.org



A Live Spoofing Tracker was created and is maintained by the Zurich University of Applied Sciences. It uses ADS-B data from the Open Sky Network and shows spoofing activity in near-real time. It also has links to FlightRadar24 that provide information about the aircraft and flights being spoofed. https://spoofing.skai-data-services.com/



Both of these sites can also be found on the main page of ION's sister organization's website, the RNT Foundation at rntfnd.org.

Gary Hannum presents Frank Czopek with Syntony GNSS' recreation of a Galileo satellite from Legos during ION's ITM/PTTI 2024 in Long Beach, California.

Branden McNally (pictured left), of the ION's Dayton Section, presented 2Lt Sean Quiterio (pictured right) with an ION sponsored graduate student award at the Air Force Institute of Technology, for excellence in navigation research.

GNSS Program Updates

News from Systems Around the World

Kevin Dennehy

Space X Launches Galileo Satellites

Galileo

SpaceX launched two Galileo satellites into orbit on April 28 aboard a Falcon 9 rocket from the Kennedy Space Center in Florida. The launch, through a $200 million contract, was the first time Galileo satellites (GM25 and FM27) have been launched from the United States.

Two Galileo navigation satellites launched
Space X

Right after the launch, Arianespace said that its anticipated Ariane 6 rocket was selected by the European Commission and the European Union Agency for the Space Program (EUSPA) to launch Galileo satellites in 2026 and 2027.

Two more Galileo satellites will launch on a Falcon 9 later this year.

GPS

While panelists at the recent Space Foundation's Space Symposium acknowledged that China's BeiDou satellite navigation constellation has more satellites, including low-Earth orbit (LEO) augmentation systems, the collective feeling was…so what?

In a future of positioning, navigation, and timing (PNT) panel, moderator Todd Simon, of Geospatial Alpha, asked panelists to comment on whether BeiDou, with twice as many navigation satellites, three LEO PNT systems, and 10 times as many monitoring ground stations, is a threat to the United States and its allies.

"It's not about the numbers. You can pull the Chinese order of battle [to view] the number of ships, the number of soldiers, intelligence satellites and drones—they often have a greater number," said Cordell DeLaPena, program executive officer for military communications and PNT, Space Systems Command. "Our focus is not about numbers, it's about an approach that thickens our resistance between our coalition partners. China is on the other side of the world. We have to focus on maintaining a gold standard [GPS] in five critical areas. Anyone can put up numbers."

For its part, the U.S. Space Force's procurement entity, Space Systems Command, issued a request for information this year that asks the private sector to design a smaller, more affordable GPS satellite that can work with the current satnav infrastructure.

GLONASS

While Russia has placed six navigation satellites in orbit over the past four years, including two GLONASS-M and four GLONASS-K varieties, constellation age is concerning, according to published reports. The number of GLONASS satellites that have exceeded their warranted lifetime has reached 15 of 26 active satellites.

While little has been written about GLONASS since the Russian invasion of Ukraine, approximately 22 navigation satellites would need to be replaced by 2030 before their warranted lifetime expires.

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

Calendar of Upcoming Events

SEPTEMBER 2024

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

Contact: ION

ion.org

OCTOBER 2024

29-30: International Association of Institutes of Navigation (IAIN) 18th World Congress, Beijing, China

Contact: IAIN

https://www.iainav.org

JANUARY 2025

27-30: ION International Technical Meeting (ITM) & ION Precise Time and Time Interval (PTTI) Meeting 2025, Hyatt Regency Long Beach, Long Beach, California

Contact: ION

ion.org

APRIL 2025

27-30: IEEE/ION Position, Location, and Navigation Symposium (PLANS) 2025, Marriott Salt Lake Downtown City Creek, Salt Lake City, Utah

Contact: ION

ion.org

JUNE 2025

2-5: ION Joint Navigation Conference (JNC) 2025, Northern Kentucky Convention Center, Greater Cincinnati Ohio Area

Contact: ION

ion.org

continued from page 22

robot has reliable localization in the beginning of its traversal and performs autonomous ZU to keep its localization reliable. Conversely, two other robots were declared 'lost' due to their inaccurate position estimates, where no external aid was available for recovery. The robot performing ZU significantly reduced the positioning errors of the lost robots during relative updates between them and was able to recover their positioning estimates, enabling them to traverse in the environment. This finding is important for positioning, navigation, and timing (PNT) technologies as it provides a robust solution for accurate localization in challenging environments.

This method could have significant commercial and military applications. For example, in commercial sectors, it could be used for indoor navigation systems in warehouses, for inventory management by autonomous robots, and in retail spaces for stocking and logistics. In military applications, the method can be useful for reconnaissance missions in GNSS-denied environments, such as dense urban areas or underground facilities. It could also be used in autonomous convoy formation and coordination in challenging terrains, enhancing mission efficiency and safety. Additionally, this technology can be advantageous in space missions, providing reliable localization solutions for planetary robot fleets. The ability to accurately navigate and coordinate multiple robots in such environments would significantly enhance efficiency and safety. The societal impact is also significant, as this can be used in various applications, including search and rescue missions, environmental monitoring, and automated logistics in spaces where accurate and reliable robot localization is vital.

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

Kilic, C., Gutierrez, E., & Gross, J. N. (2023). Evaluation of the benefits of zero velocity update in decentralized extended Kalman filter-based cooperative localization algorithms for GNSS-denied multi-robot systems. *NAVIGATION,* 70(4). https://doi.org/10.33012/navi.608

INSTITUTE OF NAVIGATION

8551 Rixlew Lane, Suite 360
Manassas, VA 20109-3701