Volume 35 No 2 **Spring 2025**

Quarterly Newsletter

ION®
INSTITUTE OF NAVIGATION

MPLS, MN
AUTONOMOUS SNOWPLOW COMPETITION 2025

Dunwoody College of Technology Hosts
15th Annual Autonomous Snowplow Competition

The 15th Annual Autonomous Snowplow Competition was held on January 17-18, 2025, at the Dunwoody College campus in Minneapolis, MN, with improvements from teams and organizers alike. The competition was hosted by Dunwoody College of Technology with the support of the Institute of Navigation's (ION) Satellite Division and the ION's North Star Section. Despite the bitter January cold,

continued on page 7

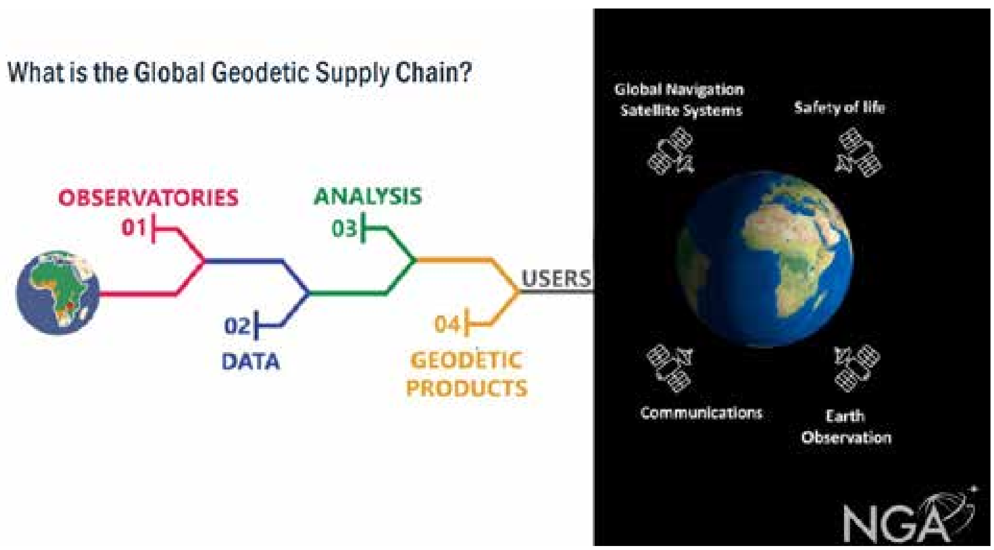
THE INVISIBLE FOUNDATION CRUMBLING

GPS Relies on a Fragile Global System

Kevin Dennehy

Modern society relies on GPS and other global navigation satellite systems (GNSS) to make lives better, whether that be to pinpoint a location with a smartphone app, seamless navigation that guides delivery trucks, and precision timing that serves financial markets.

Yet all of these uses rely on a critical yet largely invisible system: the global geodetic supply chain (GGSC). This intricate network of aging and underfunded ground observatories, data centers, and scientific expertise is facing a crisis that threatens GNSS, one industry expert warned at the recent ION International Technical Meeting (ITM).



The GGSC is a chain of ground observatories, data centers, products, scientific expertise, and users.
NGA

"We depend upon GPS," said Dr. J.N. "Nikki" Markiel, Senior GEOINT Authority for Geomatics Source Directorate, National Geospatial-Intelligence Agency (NGA), in a keynote address at ITM/PTTI on January 28. "That's not the topic of my conversation today. Instead, I'm going to shift the focus to a question rarely asked: What does GPS depend upon?"

continued on page 4

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

PRESIDENT'S COLUMN | DR. GARY MCGRAW

Succession

At the conclusion of ION's International Technical Meeting (ITM)/Precise Time and Time Interval (PTTI) Systems and Applications Meetings, the newly elected slate of ION Council members took office. I was grateful to accept the ION's presidential gavel from outgoing president Dr. Sherman Lo. I thank Dr. Lo for his leadership the past two years, and look forward to building on his initiatives.

Outgoing President, Dr. Sherman Lo, presents ION's presidential gavel to Incoming President, Dr. Gary McGraw, at the end of ITM/PTTI on January 30, 2025, in Long Beach, CA.

Goals: Membership, Publications, Collaboration and Advocacy

I want to continue to build on the growth of the last two years in attracting and retaining members, with an emphasis on individuals early in their careers. The retirement of "baby boomers" is not only an overall demographic challenge for membership, but also for organizational leadership and institutional memory. To foster the next generation of PNT leaders, ION strives to engage regularly and purposefully with those early in their careers and retain student members as they transition into their professional careers from academia. We plan to build on current student outreach programs, continue our evolving social media efforts, and encourage ION meeting organizers to include "fresh faces" in our meeting programs. More generally, I want to continue to build on ION's reputation as a pluralistic and welcoming organization that values the participation of all our members.

I have been involved with *NAVIGATION, Journal of the Institute of Navigation* for many years, first as a reviewer and then as an associate editor. *NAVIGATION* is one of the premier indexed, peer-reviewed technical journals focused on PNT. Our open access platform has expanded its reach for our authors and audience. We want to continue to provide *NAVIGATION* with all of the resources at our disposal to make it the top academic journal in our field. To aid in this objective, ION is searching for a full-time Managing Editor to become a member of the ION's National Office staff (see the advertisement located on page 30 of this newsletter). Please circulate this advertisement to those in your professional network, as we are anxious to fill this role with the right professional.

I also want us to develop, and begin executing, a strategy for collaborating with other organizations to advocate for PNT. PNT services are threatened on multiple fronts. Widespread and frequent jamming and spoofing are rising to a level that it is even being reported by the general media. But other issues are not receiving the same level of attention. Many of the scientific enterprises that form the basis for PNT performance and resilience, such as geodetic reference systems and space weather monitoring, are suffering from lack of investment in infrastructure and people. So, while there is a need to address the PNT infrastructure needs of various application areas, we also must consider the problems more broadly. While ION does not participate in partisan politics or lobbying, ION does want to ensure that user communities, policymakers, and the public, are provided with the expertise our organization offers. ION is the place where technologists, the commercial community, government/military, and academia all come together to learn from each other and collaborate. ION is where our voices can be strengthened and joined as a technical community. Over the next months, it is my goal for us to determine specific objectives, and identify organizations with which to collaborate to promote awareness of PNT needs. I am hopeful that this process will be rewarding for our members and provide them with information that can benefit their organizations as we work to protect the technologies our society depends on.

ION Council Convened January

The ION Council met in person on

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

ITM/PTTI 2025 Student Event, sponsored by QuNav, Long Beach, CA

January 27, 2025 prior to the ITM/PTTI meeting, with some members joining virtually. Outgoing president Dr. Sherman Lo reported on several actions that had been taken by the ION Executive Committee in the preceding months. The most notable among these actions were transfers from the ION's Operating Fund to the ION's Reserve Fund, the formal approval of the New England Section Bylaws, and a change to the Satellite Division's Student Paper Competition. Council approved ION's prior fiscal year's audit report and next year's National Office budget. Additionally, Council was advised of meeting locations and dates for ION GNSS+ 2028-2031 and plans for the celebration of 2025 International GNSS Day on October 23.

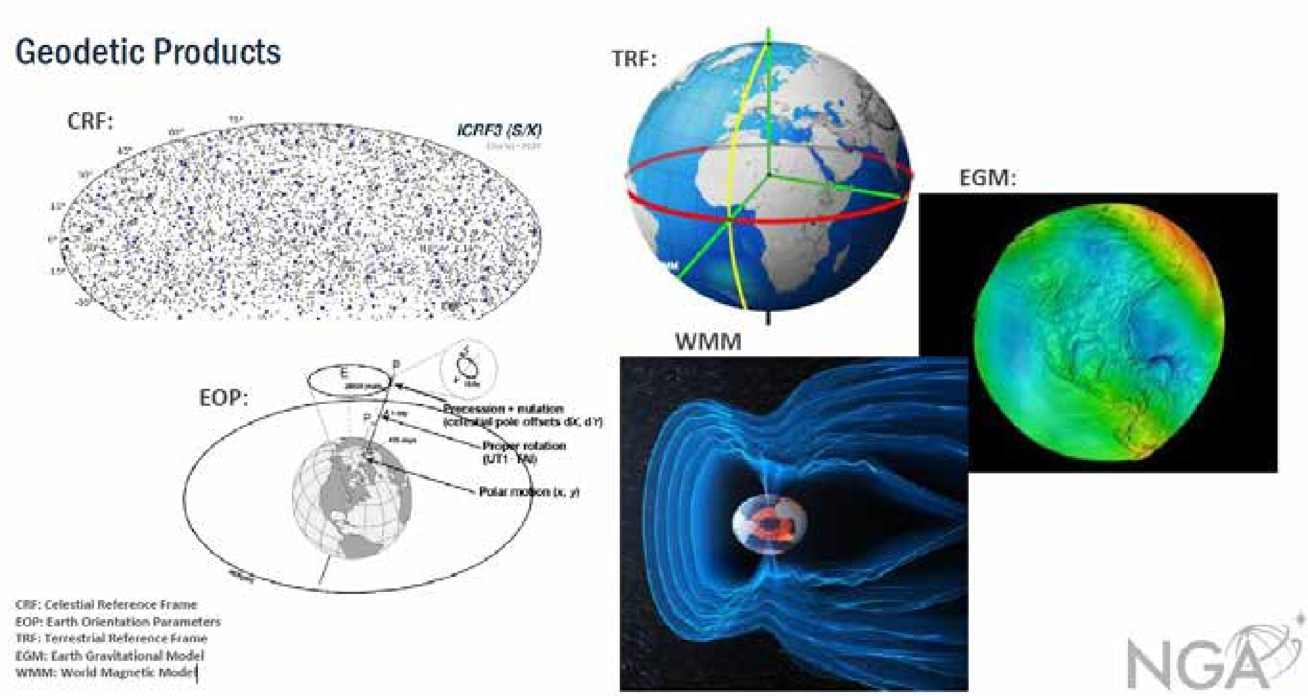
Minutes from the January Council meeting, with supporting information, are available for viewing at ion.org.

ION Convening at IEEE/ION PLANS this Spring

I look forward to greeting you at the IEEE/ION PLANS meeting, being held fully in-person, April 29-May 1, 2025, in Salt Lake City, Utah. The technical program will feature tracks on inertial sensing and technology, GNSS, integrated and opportunistic navigation, and applications of localization technologies. It is sure to be a full and exciting program – see you there!

Gary A. McGraw

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



Geodetic Products that provide crucial information about the Earth and satellites
NGA

continued from page 1

The answer is the global geodetic supply chain, Markiel said. As part of this supply chain, geodetic products are essential for the operation of satellites, including those used for GPS. These products that include Celestial Reference Frame, Earth Orientation Parameters, Terrestrial Reference Frame, Earth Gravitational Model, World Magnetic, and others provide crucial information about the Earth and the satellites themselves.

"The satellites that provide vital defense and civilian applications are relying on constant updates about their place in space, their satellite orbit information and the Earth's place in space, its shape, its orientation, its coordinate reference frame and its gravity field," a speaker at a recent industry event explained. "These are collectively known as geodetic products. Satellites need these new geodetic products uploaded to them constantly because the Earth and satellites are always moving. The Earth does not stay still. It breathes, it spins, and it wobbles."

The ground observatories, operated by scientists worldwide, constantly monitor the Earth's movement and the orbits of satellites, which are essential to the supply chain. "These include national and international timing systems stations for gravity and magnetic monitoring, and most critically, one of the things that I'm going to be focusing on is very long baseline interferometry, as well as the systems for satellite laser ranging," Markiel said.

In the data centers, specialists perform quality checks on the raw data collected by the observatories and make it available to the global geodetic analysis community. As for the analysis centers, along with correlation centers and individual analysts, they translate the raw data into the geodetic products that are essential for satellite operations.

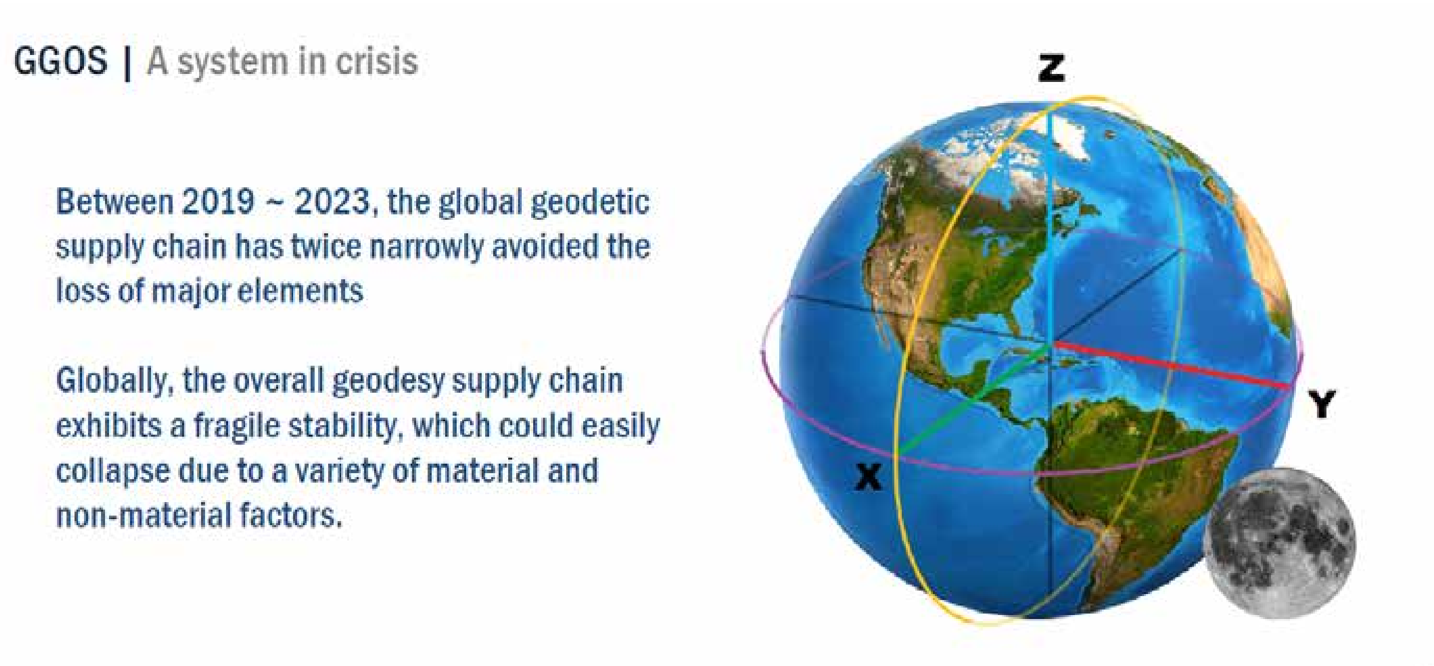
Markiel emphasized that maintaining the global geodetic supply chain is a worldwide endeavor, with no single country capable of providing all the necessary observations and analyses. "It is a global supply chain because no single country can fulfill all the requirements of accurately and reliably observing and analyzing the Earth in the satellites to measure those constant changes with frequency and the level of precision required to produce the geodetic products that satellites and users demand," she said.

Markiel cited a seminal 2001 Volpe National Transportation Systems Center report that highlighted the increased reliance on GPS and the growing vulnerability of the nation's infrastructure. Although more than 20 years old, the report called for a need for backup and complementary positioning, navigation, and timing (PNT) systems to mitigate the risks of GPS disruption.

"Over the intervening years there's been a very long litany of reports and presentations and studies and tests that have provided a very nearly continuous drip cautionary, sometimes even dire, warnings about the impacts to society and infrastructure systems of GPS, or more generally speaking, what if [GNSS] were to become degraded or denied?" Markiel said.

A System in Crisis

The lack of attention on the worldwide geodetic supply chain was directly responsible for two major crisis points,



A federal government shutdown and VBI sites in the Southern Hemisphere were two critical crisis points.
NGA

Markiel said. One was during the 2019 federal shutdown, when the United States came within eight days of losing all of its global geodetic supply chain systems. This would have resulted in a 100 percent reliance on foreign data to maintain critical national infrastructure sectors, Markiel said.

The other crisis occurred in the fall of 2022, when the world came within six weeks of losing every operational Very Long Baseline Interferometry (VBI) site in the Southern Hemisphere, Markiel said. This was due to a combination of factors, including aging equipment, lack of spare parts, and the discontinuation of academic programs.

"Some of them were undergoing upgrades, some of them finally ran out of parts to cannibalize. The station in Tasmania, I can say with their permission, had a failed main bearing and had been down for over a year," Markiel said.

In particular, aging infrastructure is a problem Markiel says needs to be addressed as soon as possible. "I would be willing to bet even money that I have stood on top of more mountain tops, [with] more of those VBI antennas and peered into more control boxes filled with obsolete 1970s electronics than anyone in this room," she said. "Some of those systems are decades old, built in the 1960s, to support the original Apollo moon landing and then they were transferred over to a variety of academic institutions. Let that sink in for a moment."

Markiel reported to have seen antennas rust and fall apart in the field and atomic clocks that are decades old. "I can assure you that if those clocks die tonight, in all likelihood a university does not have a half-a-million dollars to go buy a brand new [one]. Even if they did, the lead time is 40 months, so we would lose that station for almost three-and-a-half years," she said.

Markiel said she wanted to educate—and scare—ION ITM attendees about the realities of problems facing the global geodetic supply chain. "I make no apologies for that because the reality is that we have some very significant challenges and we need your help to get them addressed," she said.

Possible Solutions

To avert a potential collapse of the system that underpins everything from financial markets to emergency services, a multi-pronged strategy is needed, Markiel said. These include strengthening international agreements, developing clear governance mechanisms, and establishing formal mandates for the operation and maintenance of the geodetic infrastructure.

One critical area is government involvement as the current system, which relies on academic institutions and international collaboration, lacks the formal structure needed to ensure its long-term stability, Markiel said. "The analogy of building a beautiful building on foundations of sand is an apt analogy of our current global system," she said. "We agreed that we must ensure that a celestial reference frame, a terrestrial reference frame, Earth orientation and satellite orbit products have to be produced."

Another major challenge is a dwindling pool of skilled professionals. "We are running out of the very people and the expertise that know how to keep these systems running, process the data and make the geodetic products that are absolutely essential," Markiel said.

Markiel recommended increased

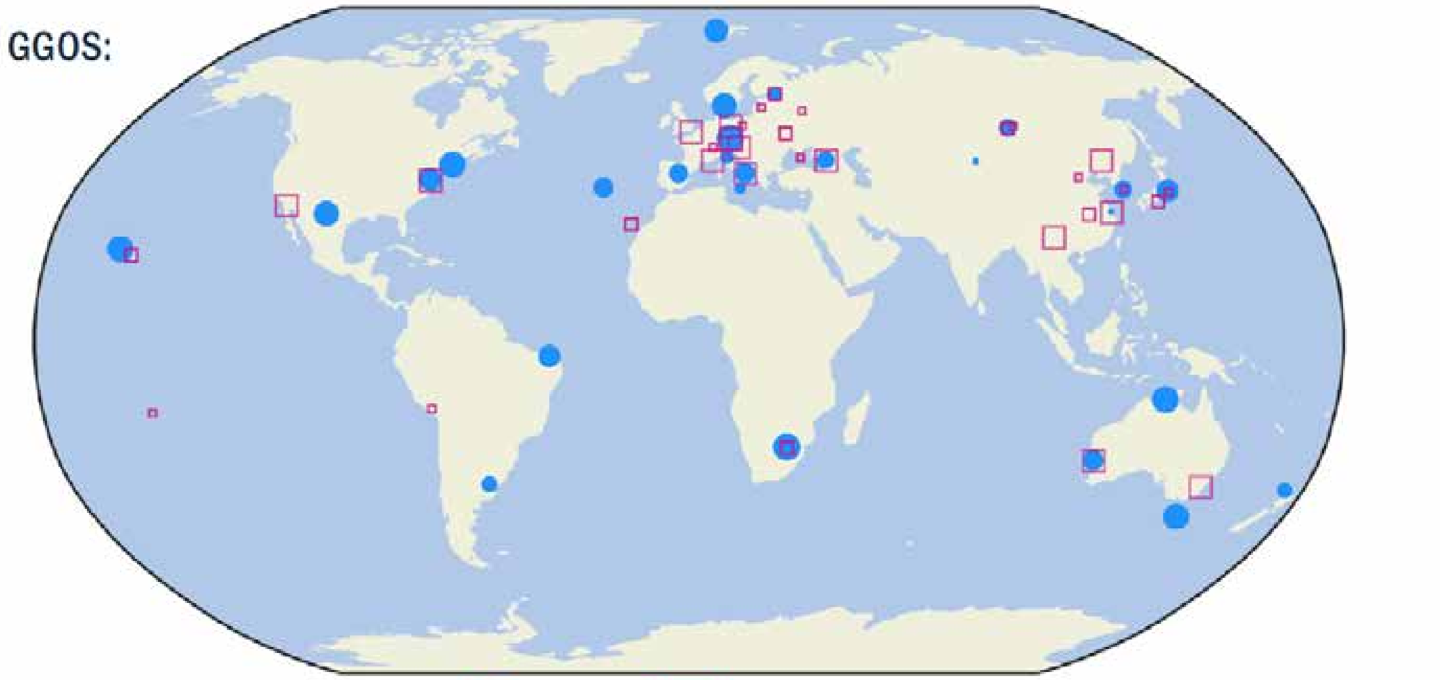


Figure: *Locations of ground-based VLBI stations; and SLR stations. The size of the circles and squares are roughly proportional to how much data each station provides to the global geodesy supply chain. The data is from 2023-2024.*

Graphic Courtesy of the UN-GGCE

investment in geodetic education and training programs to attract and retain talent. "We're also looking at a number of different programs to draw workers without college degrees into geodesy," she said. "Do you necessarily have to have a four-year degree to come work?"

Raising public awareness is also crucial because, despite its critical importance, the geodetic supply chain remains largely unknown to the public and policymakers. "It is exceedingly clear that the awareness of modern geodesy is low in critical industries, even in the science communities and in the public at large," Markiel said. "We need your help to formulate that consistent, clear, and simple messaging to raise the profile among students, among decision-makers, and among the public."

Markiel said that this messaging will help to develop business cases to attract investment and private sector involvement.

Finally, securing adequate financial resources is essential to the system's long-term sustainability that includes maintenance and modernization of existing infrastructure, as well as development of new technologies. "We need to stabilize what we have," Markiel said. "We need the funding to have dedicated observatories, data centers, analysis centers and standards development for what we have today."

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.

Dr. J.N. "Nikki" Markiel, National Geospatial-Intelligence Agency, presenting on Global Geodetic Observation Systems – Global Challenges to a Shared Resource, to an ION audience in Long Beach, California, January 28, 2025.

continued from page 1

fans gathered at Dunwoody to watch the events, and more watched the livestream on YouTube from their homes.

The overall competition events proceeded similar to previous years. The Preliminary Design Reviews were conducted via video conference in late 2024, and in-person events began on Friday, January 17, 2025. On that Friday, volunteers worked to set up the competition snowfields, while teams underwent Final Qualification Reviews and Safety Inspections. On Friday evening, the teams presented their poster presentations where sponsors and judges discussed each team's vehicles and their navigation strategies. The main competition event took place on Saturday, when the teams put their autonomous snowplows to the test in both morning and afternoon runs, followed by an awards ceremony at the end of the day.

Eleven teams initially applied for this year's competition. However, the team from the University of Wisconsin-Madison had to withdraw early as they were unable to complete their vehicle on time. Two other teams, those from Lake Area Technical College and the University of Ottawa who had originally participated in the Preliminary Design Reviews, had to drop out the week of the event due to electronic component failures that they were unable to repair in time. That left eight teams from six different universities, traveling from across the Midwestern United States and Canada to compete. Teams came from around the Twin Cities Metro, Ohio, North Dakota, Iowa, and Quebec. Team members from the Université Laval in Quebec drove 22 hours to the Twin Cities, though their software team members traveled by air. This year's competition also welcomed a new team from North Dakota State College of Science (NDSCS). While their team encountered technical issues and was only able to complete one run in the afternoon, completing a run in their first attempt is an achievement in itself, and we hope to see them return next year.

The Challenge

The competition itself followed the familiar format of plowing a T-shaped course, a setup designed to simulate real-life conditions where autonomous snowplows would start in a garage and navigate driveways and sidewalks. Similar to last year, stationary obstacles were placed throughout the course for teams to avoid. Past competitions included dynamic moving obstacles, which may become an option again for future competitions, especially considering this year's marked progress in obstacle avoidance by many teams. Snow depth also stayed the same as in past years, though there is consideration of making the snow deeper in future events. The shape of the course may also change in coming years.

A continued theme for this year's competition was *Precise Navigation and Coordination,* with a higher penalty imposed than in previous years for hitting obstacles. Teams were encouraged to improve their obstacle avoidance mechanisms and techniques, and most vehicles did an impressive job of maneuvering around these to remove all the snow without incurring additional penalties. The biggest success this year was the significant improvement in navigation, with teams demonstrating much more reliable and precise control of their vehicles. To aid maneuverability, the outer boundaries of the snowfield—marking the navigation zone where teams can safely reposition around the course—were expanded by one meter on one side. Another highlight of this year's event was that all teams successfully implemented their emergency kill switches, showing significant progress in overall vehicle safety.

Plowing Strategies and Solutions

Teams employed a range of strategies to navigate the course and clear snow. Lidar-based simultaneous localization and mapping (SLAM), used by Case Western, Iowa State, North Dakota State University (NDSU), and Université Laval, relied on lidar-based laser scanning to detect obstacles and build a real-time navigation map. While false detections

continued from page 1

from snowfall can be an issue, the lack of natural snow this year helped mitigate that problem. Lidar proved to be one of the most effective solutions. Another navigation approach was GPS real-time kinematic (RTK), used by Iowa State and NDSCS. This system enhances GPS accuracy through ground-based reference stations using the free over-the-air RTK signals available through the MNCORS Network available in Minnesota, though cold temperatures and signal loss in poor weather can pose challenges. Some teams, including NDSU and Dunwoody Ice Hawk supplemented their positioning with AprilTags—QR code-like markers optically imaged for precise localization. This method depends on clear visibility with no shadows or uneven lighting on the AprilTags. However, with no snow falling and bright skies this year, obscured tags were not a major concern at this event for these teams. Meanwhile, machine vision, used by Dunwoody Ice Hawk and Université Laval, allowed for real-time obstacle detection. However, lighting inconsistencies and glare from the snow along the path introduced slight challenges to these teams.

Other teams relied on alternative tracking methods. Dunwoody Snow Devil used magnetic strips laid around the snow path, which provided reliable navigation in controlled environments but can be thrown off by shifting snow or uneven terrain. Dunwoody Road Salt utilized ultrasonic beacons by MarvelMind, a localized GPS-like system that can be precise in ideal conditions but struggles in extreme cold and wind. Artificial intelligence played a key role in improving navigation and obstacle avoidance for several teams this year. Case Western's OTTO, Dunwoody's Ice Hawk, and Université Laval's WEASEL implemented AI-augmented sensor fusion techniques, integrating multiple data sources such as lidar, cameras, and GPS to improve real-time decision-making. These AI systems helped refine path planning, obstacle detection, and route optimization. For OTTO, AI-assisted unscented Kalman filtering

(UKF) was used to process sensor inputs and enhance localization accuracy, helping the vehicle maintain consistent performance throughout the course.

Dunwoody Ice

Hawk utilized computer vision algorithms combined with ultrasonic sensors, allowing the snowplow to detect obstacles and autonomously adjust its course. Université Laval integrated AI-based costmap generation to increase the cost of portions of the path around lidar-identified objects such as the post and adjust the path to minimize the cost, allowing their vehicle to dynamically update its plowing trajectory based on objects and environmental changes. While AI introduced challenges such as increased processing latency and the need for extensive tuning, these enhancements ultimately contributed to improved navigation and obstacle avoidance performance throughout the competition.

Plowing strategies varied as well in this year's competition. Most teams used fixed-angle plow blades, a simple and reliable choice that struggles with uneven terrain. Case Western Reserve University's OTTO and NDSU's HyFlex opted for adjustable and articulating plows, which allowed for better snow clearance but introduced more mechanical complexity and potential failure points. NDSU continued to utilize their unique articulating vehicle for turn motion, which has continued to improve over the years and performed quite well this year.

New This Year

New to this year's competition was a requirement that teams demonstrate multiple ways to transport their vehicles without trying to manually lift the heavy vehicles. This rule was implemented to prevent back injuries and is an important consideration for commercialization, as consumers would need to transport their vehicles safely back to a garage for charging if its battery were to run out.

Another key change was a higher level of rigor in how teams demonstrated their ability to control speed, both in their software and physically in the hardware, ensuring compliance with maximum speed regulations.

The competition was held not without its difficulties. Freezing temperatures presented a major challenge, with the weather on Saturday morning hovering around 7°F but feeling like -9°F with wind chill; and temperatures only proceeded downward with wind increasing throughout the day. The cold also affected the vehicles, with batteries draining much faster than expected. A mechanical failure added to the challenge when Dunwoody's Bobcat's frontend loader, which was being used to haul snow for the competition, suffered a hydraulic hose burst from the cold, spilling hydraulic fluid across the parking lot. This forced volunteers to manually shovel much of the snow from the event during clean-up. Another difficulty was the limited snowfall. It took most of the preceding week for Dunwoody personnel to produce enough snow for the competition, but when the temperature warmed above freezing by Thursday, snow production had to be halted. There was concern that there would not be enough snow to complete the event, but in the end, organizers had just enough to work with.

FINAL STANDINGS 2025

1st Place	**Case Western Reserve University** "OTTO" $3,000 (1st Place)
2nd Place	**Dunwoody College of Technology** "Ice Hawks" $2,500 (2nd Place)
3rd Place	**Université Laval** "WEASEL" $2,000 (3rd Place) +$500 (Dr. Nattu Award for best sportspersonship and competition spirit)
4th Place	**Dunwoody College of Technology** "Road Salt" $1,500
5th Place	**Dunwoody College of Technology** "Snow Devil " $1,000
6th Place	**North Dakota State University** "HyFlex" $500 (Best Poster)
7th Place	**Iowa State University "Sno Clone"**
8th Place	**North Dakota State College of Science**

Success Stories

The annual Autonomous Snowplow Competition is a valuable opportunity for students to refine their skills and push the boundaries of autonomous technology. This year, that impact was especially clear with the fixed display at the event of a remote-controlled snow removal robot from Nivoso, a company founded by a local using the autonomous snowplow technology that founder Max Minakov developed in school. Minakov's company now sells and rents remotely-operated and autonomous snowplows commercially, with a focus on keeping vulnerable populations safe in winter, particularly in places like nursing homes and assisted living facilities, where snow and ice pose serious hazards and residents may not be able to clear it themselves. His work is a testament to how this competition serves as a launchpad for engineers to develop meaningful, life-improving innovations.

Dr. Suneel Sheikh, CEO of ASTER Labs, Inc., has served as the event Marshal for the past 15 years and has seen many teams develop and grow as they implement key engineering principles in their snowplow designs and operation. He most enjoys seeing the students' enthusiasm for the competition, "watching them struggle through their challenges while questioning the rules and requirements. How does the vehicle match the requirements? How will we achieve the goals? How do we win? They are learning those engineering principles that are important for their careers." Looking ahead, the Autonomous Snowplow Competition Committee hopes to continue expanding the competition and making it accessible to more teams from a wide range of backgrounds and locations, possibly even a new virtual global format. Every year they report witnessing how students grow as engineers, problem-solvers, and innovators.

6th grade Minakov

Minakov with Nivoso's autonomous snowplow today.

Nivoso began as a sixth-grade science fair project when Max Minakov, frustrated with shoveling snow for his outdoor maintenance business, Gopher Boys, built a remote-controlled snowplow. What started as a personal solution grew into a broader vision during his time at the University of Minnesota, where he recognized the challenges snow removal companies face in keeping sidewalks safe and accessible. Competing in competitions at the University of Minnesota and St. Thomas further fueled his ambition to develop a commercial outdoor maintenance robot. Today, Nivoso is transforming the industry with autonomous technology designed for efficiency and reliability.
Nivoso.com

Congratulations ION 2024 Annual Award Recipients

PER ENGE EARLY ACHIEVEMENT AWARD
Given in memory of Prof. Per Enge, a brilliant engineer and teacher, who used his cheerfulness and enthusiasm to inspire others through education, advising and mentorship. This award recognizes an individual early in their career.

Dr. Jason N. Gross

For the development and demonstration of resilient navigation system algorithms and methods in degraded GNSS environments

SUPERIOR ACHIEVEMENT AWARD
For outstanding accomplishments as a practicing navigator

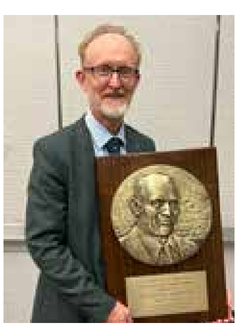
Captain Sarah Victoria Rowley

For outstanding innovation, leadership, and instructional ability in the development of fundamental skills of position, navigation, and timing for future United States Air Force aviators

DR. SAMUEL M. BURKA AWARD
To recognize outstanding achievement in the preparation of a paper advancing the art and science of positioning, navigation, and timing

Dr. Clark Taylor and Dr. Jason N. Gross

For their tutorial paper published in the Fall 2024 issue of *NAVIGATION: Journal of the Institute of Navigation*: Factor Graphs for Navigation Applications: A Tutorial



CAPTAIN P.V.H. WEEMS AWARD
For continuing contributions to the art and science of navigation

Dr. Andrew Dempster

For fundamental contributions to GNSS receiver architectures and signal processing; and interference detection, characterization, and mitigation

TYCHO BRAHE AWARD
To recognize outstanding contributions to the science of space navigation, guidance and control

Cheryl J. Gramling

For numerous outstanding contributions to the science of spacecraft navigation, ensuring the safety of life of crewed and robotic space missions, past and future

NORMAN P. HAYS AWARD
In recognition of outstanding encouragement, inspiration, and support contributing to the advancement of navigation

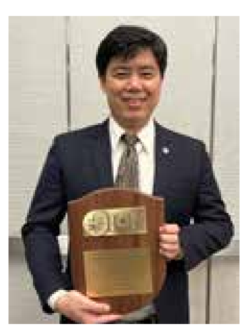
Dr. Didier Flament

For significant leadership in the early definition, development, qualification, and continued evolution of the European GNSS, particularly the European Geostationary Navigation Overlay Service (EGNOS)

COL. THOMAS L. THURLOW AWARD
In recognition of outstanding contributions to the science of navigation

Dr. José Ángel Ávila Rodríguez

For substantial contributions to the field of navigation, including Galileo's signal design, leadership in Galileo modernization, and efforts to foster international collaboration and education



DISTINGUISHED SERVICE AWARD
For extraordinary service to the Institute of Navigation

Dr. Sherman Lo

For extraordinary service to the Institute of Navigation

ION's 2025 Fellows

The Fellows designation recognizes the distinguished contribution of ION members to the advancement of the technology, management, practice, and teaching of the art and science of navigation, and/or for lifetime contributions to the Institute.

Dr. Jeffrey Hebert

For contributions to the advancement of navigation warfare and defense related positioning, navigation, and timing technologies

Dr. Michael Meurer

For sustained and visionary leadership and technical contributions advancing secure, high-integrity, and resilient PNT

Dr. Thomas Powell

For outstanding contributions to the GPS Enterprise, its military and civilian users, and promotion of GNSS and international cooperation

ION® INSTITUTE OF NAVIGATION

CALL FOR NOMINATIONS

The Johannes Kepler Award

Nominations Due: June 30

Presentation of the Johannes Kepler award takes place at the Satellite Division's Annual ION GNSS+ in September. The purpose of the Kepler Award is to honor an individual for sustained and significant contributions to the development of satellite navigation. All members of the ION are eligible for nomination. A special nominating committee determines the winner of the award, which is presented only when deemed appropriate.

ION members are encouraged to submit nominations for deserving individuals. For complete nomination instructions/to submit a nomination, go to ion.org/awards, and click on "Kepler" in the left hand menu. Nominations must be received by June 30.

For a complete list of previous winners, visit ion.org/awards/kepleraward.cfm.

Dr. John Raquet, 2024 Kepler Award winner; for significant technical contributions to GPS/GNSS integrated navigation systems; sustained leadership in the DoD and international community; and for the education of navigation professionals.

ITM/PTTI 2025 CONVENED IN LONG BEACH, CALIFORNIA

ION hosted 325 in-person attendees, from 22 nations, in Long Beach, California at the end of January at ION's combined International Technical Meeting (ITM) and Precise Time and Time Interval (PTTI) Systems and Applications Meeting, held January 27-30, 2025; an additional 26 persons participated virtually. In addition to the 146 technical presentations, 20 organizations displayed their products and services in the exhibit hall.

PTTI organized a full day of pre-conference tutorials on clocks, the role of time laboratories in the realization of reference timescales, White Rabbit, and low-noise digital electronics for time and frequency metrology. The plenary session's keynote addresses addressed GNSS dependence on geodetic parameters and products and the risk that the global geodesy supply chain may soon be in crisis; with a second address sharing the first images of black holes with the Event Horizon Telescope (EHT) and the extraordinary opportunities for black hole research that will be enabled through advances in the coming decade of precision timing. Both of the ITM/PTTI keynotes are hosted on the ION's YouTube channel.

Next year's ITM/PTTI is scheduled for January 26-29, 2026 at the Hyatt Regency Orange County in Anaheim, California.

ITM/PTTI 2025 Program Committee: Dr. Giancarlo Cerretto, PTTI Tutorials Chair; Dr. Josef Vojtech, PTTI Program Chair; Dr. Sherman Lo, ION President; Dr. Andrew Neish, ITM Program Chair; and Dr. Sabrina Ugazio, ITM General Chair

As part of the ITM/PTTI Student Social, students illustrated PNT terms while playing an ION version of "Pictionary" and networking. Thanks to QuNav for sponsoring the event.

ION THANKS THE FOLLOWING ITM/PTTI 2025 EXHIBITORS AND SPONSORS

746th Test Squadron
Brandywine Communications
CAST Navigation, LLC
Frequency Electronics, Inc.
GuideTech, Inc.
LKD Aerospace
Masterclock, Inc.
Menlo Systems
Microchip Technology Inc.
ORCA Technologies
Oscilloquartz
Pendulum Instruments, Inc.
PikTime Systems
Precise Time and Frequency, LLC
SiTime
SpectraDynamics
Stable Laser Systems
TimeTech GmbH
Vector Atomic, Inc.
Vescent

Media Partners
GPS World
Inside GNSS

Special Recognition for Support of ITM/PTTI Student Event/Social

QuNav.com

GMV's Real-time and Receiver Agnostic Jamming and Spoofing Detection and Mitigation

Wahyudin Syam, Nabeel Khan, Michael Turner, Luis Enrique Aguado, Ben Wales, Lisa Guerriero, Baris Toz, Inchara Lakshminarayan, Tom Stacey, Maria Ivanovici, and Terri Richardson

Motivated by the need for resilient GNSS operation in vulnerable environments facing jamming and spoofing threats, and driven by the desire to develop a receiver-agnostic and flexible signal cleaner that can be integrated into existing infrastructure, GMV, within the context of the ESA NAVISP-EL1-064 project, has developed jamming and spoofing detection and mitigation techniques utilizing artificial intelligence (AI) and advanced signal processing methods.

The development has resulted in a block-box system capable of receiving GNSS signals, detecting and mitigating jammed and spoofed signals, and then re-transmitting the mitigated (clean) signal to any downstream GNSS receivers. Figure 1 shows a schematic view of this block-box system.

In Figure 1, the block-box system comprises a GNSS antenna, the block-box unit itself, and a downstream COTS receiver. The block-box unit incorporates a radio-frequency front-end to receive and transmit signals, as well as a high-performance personal computer (PC) to process the jammed/spoofed signals and generate the mitigated (cleaned) signal.

Notably, the block-box system is designed for flexibility, allowing for seamless integration between a GNSS antenna and a receiver without requiring any modifications to the receiver's existing infrastructure.

The jamming detection and mitigation module consists of two submodules: (a) an interference detection and characterization module; and (b) an interference mitigation module. The interference detection/characterization module, as shown in

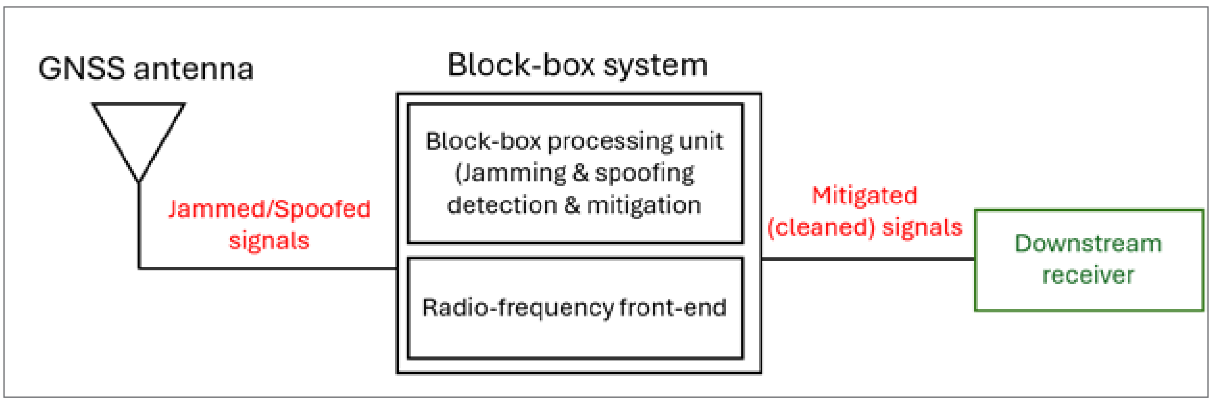


Figure 1: Schematic view of the block-box system

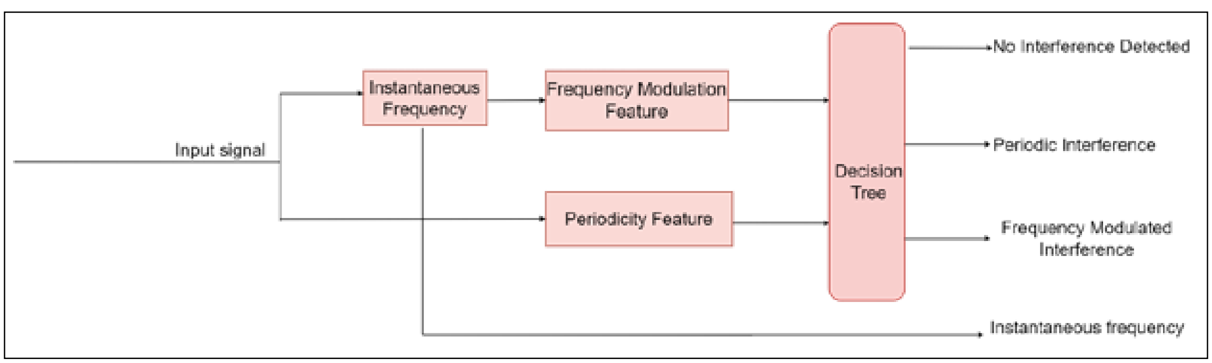


Figure 2: Interference characterization module

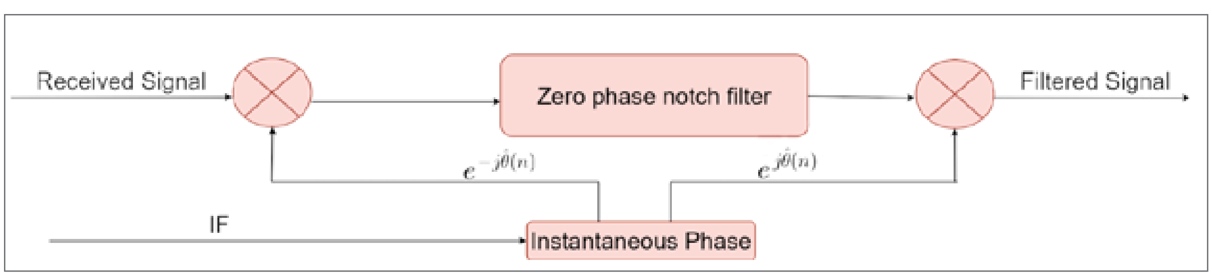


Figure 3: Frequency modulated interference mitigation

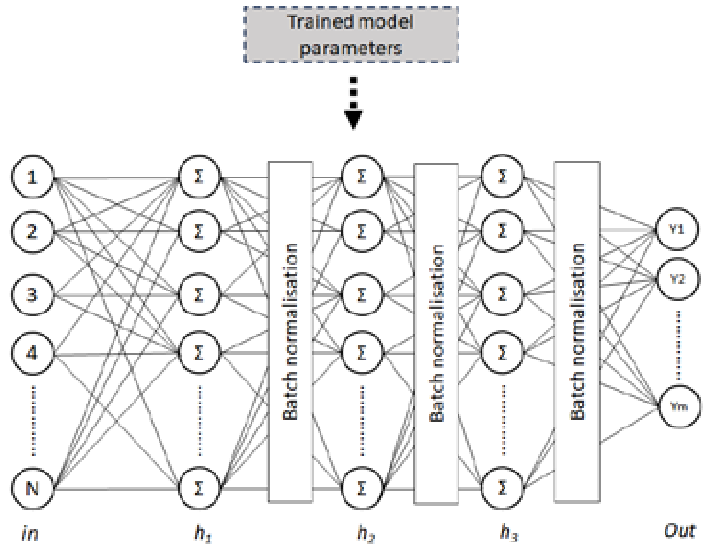


Figure 4: The architecture of the DNN model for spoofing detection

Figure 2, determines the presence or absence of interference within a given signal segment. If interference is detected, it is further classified as either chirp/frequency modulated interference or periodic interference (e.g., CDMA). This characterization and detection of interference is achieved using a decision tree classifier that employs features extracted from frequency modulation detection and periodicity detection. The frequency modulation feature is extracted based on the instantaneous frequency estimate obtained through a novel variant of an adaptive notch filter capable of tracking fast time-varying chirps. Periodicity detection is performed using a feature extracted from the frequency domain.

For chirp/frequency modulated interference, the mitigation is performed through zero-phase notch filter, as illustrated in Figure 3. The zero-phase filter does not suffer from non-linear phase distortions that is observed in commonly employed adaptive notch filters. To mitigate periodic interferences such as CDMA attacks, the mitigation strategy involves saturating the high-energy bins in the frequency domain followed by an inverse transformation.

For spoofing detection and mitigation, the focus is on GPS L1 signals. For detection, a fully connected deep neural network (DNN) model was selected following a trade-off analysis among support vector machines (SVM), convolutional neural networks (CNNs), and DNNs based on accuracy, model size, and data requirements for training. Figure 4 illustrates the developed DNN model, which comprises five layers: two input/output layers and three hidden layers.

The input to the DNN consists of 50 calculated features extracted from the correlator outputs of GPS L1 signals. These features include slope-based ratios, simple ratios, sum ratios, difference ratios, and residuals of correlation functions, calculated from the I and Q signal correlator outputs. The correlation process utilizes 15 taps: seven taps for both late and early chips, and one tap for the prompt chip. This tap selection represents a trade-off between computational load and chip resolution.

The model has a total of 8418 parameters. Testing results demonstrate a detection accuracy of 99.2% with a false alarm rate of 0.009. However, when evaluated on authentic signals with heavy multipath impairments, the detection rate degrades to 0.015.

An efficient spoofing mitigation algorithm has been developed specifically targeting aligned spoofing attacks, where a receiver initially tracks an authentic signal before encountering a spoofer. This algorithm calculates the second gradient

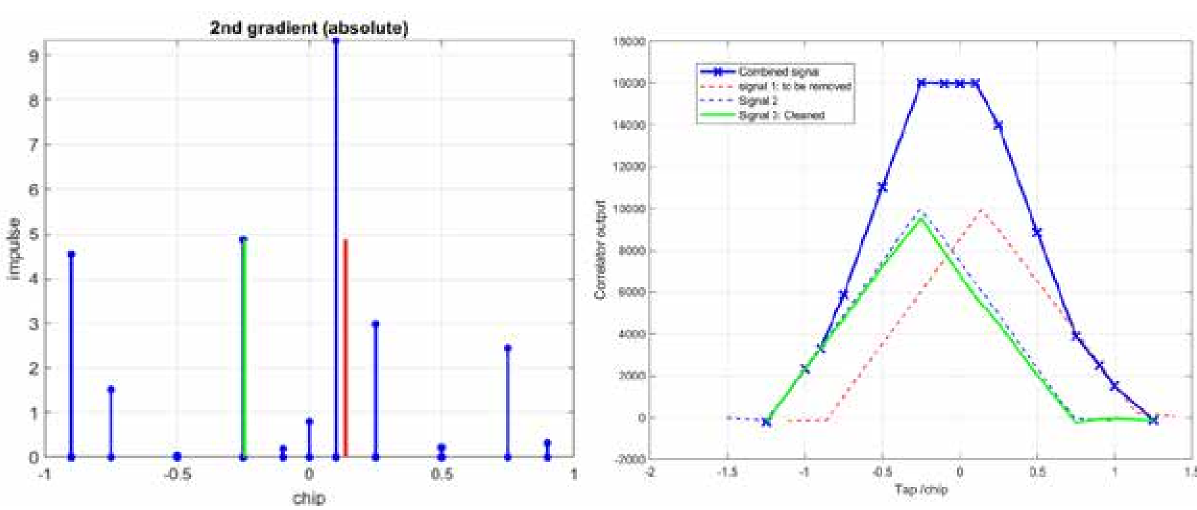


Figure 5: (left) the calculated second-gradient impulse; and (right) the results (in green) of the mitigated signal

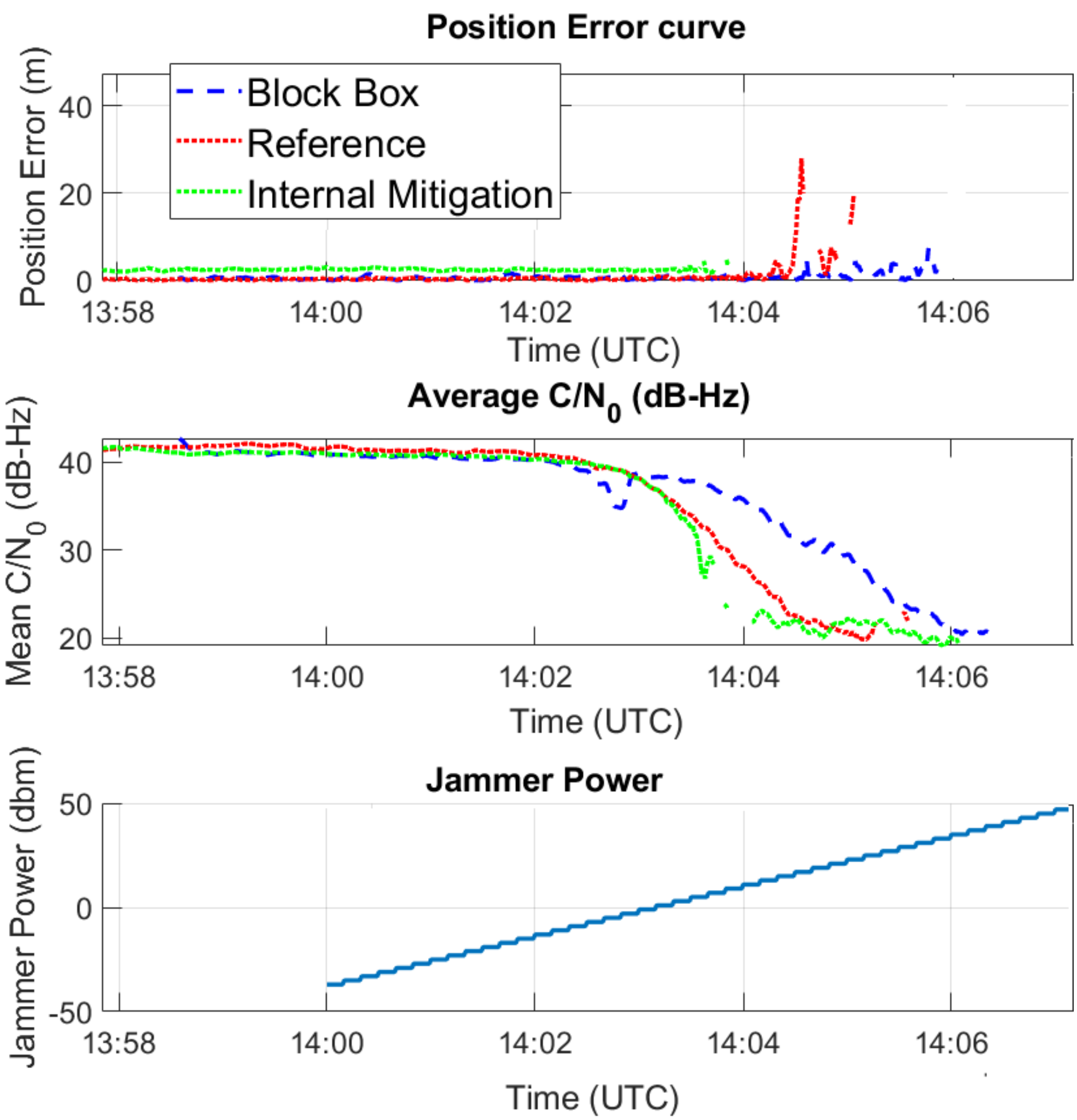


Figure 6: Performance comparison between Block-Box and reference receiver in terms of position error and average C/N_0

of the calculated correlator of the GPS L1 signal. Figure 5 illustrates an example of the calculated second-gradient impulse and an example of the mitigated spoofed signal in the correlator output domain.

By analyzing the calculated second gradient (Figure 5 left), the authentic and spoofer signals can be identified based on the two largest gradient impulses. The final estimated second-gradient impulse is obtained by a weighted average of the three impulses: the estimated tap location and its immediate left and right neighbours.

Using these impulses, the spoofer's power (assumed to have higher power than its authentic counterpart) and phase are estimated. Subsequently, a negative replica of the spoofer signal is generated and subtracted from the original signal (containing both the spoofer and authentic signals), as shown in Figure 5 right. This subtraction process effectively removes the spoofer signal, isolating the authentic signal component.

The interference mitigation performance of the block-box system was evaluated in the ESA lab using signals recorded during a jamming test campaign conducted in 2024. A CDMA-type ramp-up/ramp-down jammer signal was superimposed on GNSS signals and then replayed through a Spirent system. The jammer power was gradually increased from -37 dBm to 47 dBm in 2 dBm steps. Interference mitigation was performed in real-time using the block-box system. In this experiment, we also compared the mitigation performance of the block-box system with that of the internal mitigation capabilities of a state-of-the-art reference receiver.

The impact of interference mitigation in terms of extraction of position error and

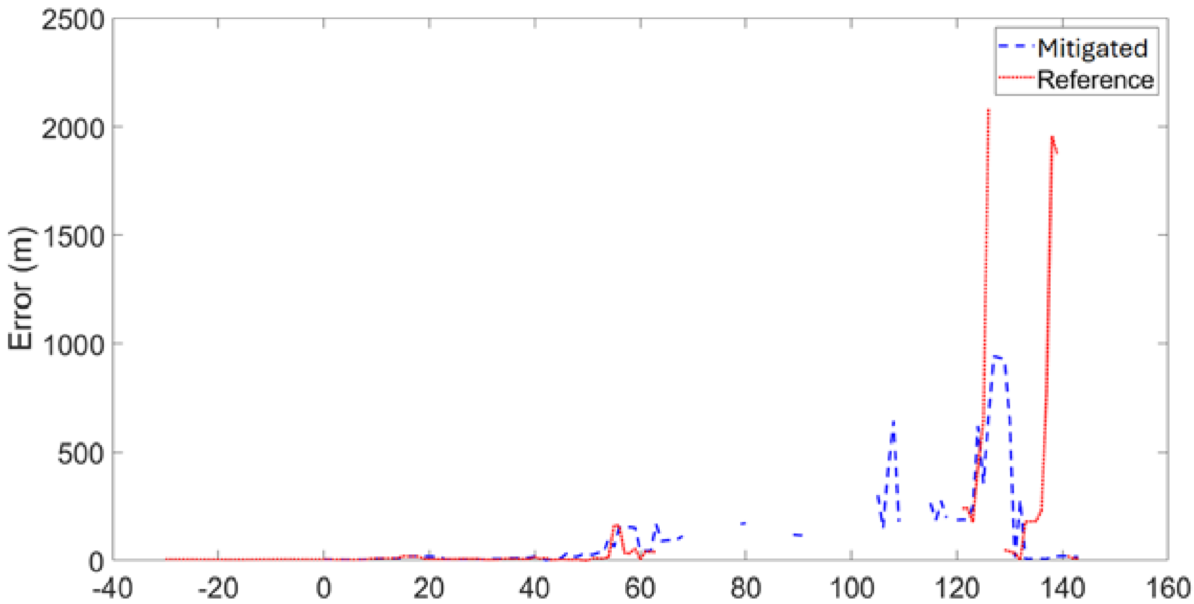


Figure 7: Error comparison on a static receiver position error between non-mitigated (reference) signal in red and mitigated signal in blue

average C/N_0 is illustrated in Figure 6.

It was observed that the block-box system exhibited higher C/N_0 values and lower position errors compared to the reference receiver, both with and without its internal mitigation enabled. The superior performance of the block-box system can be attributed to its ability to mitigate both chirp and CDMA attacks, whereas most commercial receivers primarily rely on notched filters to address chirp interference.

The spoofing mitigation algorithm was tested using the TEXBAT ds3 dataset. This dataset contains spoofed GPS L1 signals, where a static receiver initially tracks an authentic signal before encountering a spoofer (with a power 1.3 dB higher than the authentic signal), resulting in a significant shift in the static location for approximately 50 seconds. Figure 7 illustrates the results of the spoofing mitigation.

As shown in Figure 7, the block-box spoofing mitigation algorithm can effectively reduce static position error by up to 70%, and also improves position availability. The results from both jamming and spoofing mitigation evaluations demonstrate the potential benefits of the block-box system in providing clean signals to a wide range of receiver types.

Current applications for the block-box system include securing GNSS stations that require continuous, jamming- and spoofing-free GNSS signal recordings to provide publicly accessible data, as well as safeguarding receivers for critical assets. Since the current block-box system primarily relies on software implementation, a non-portable high-performance PC serves as the processing unit. In the future, the block-box system could be implemented in silicon, such as through FPGA or ASIC technology, enabling a more compact and portable solution suitable for a wider range of applications, including those involving dynamic environments and moving assets.

Throughout the development of the block-box system, the benefits of collaborating with ESA have been significant. These benefits include technical discussions, brainstorming sessions, valuable suggestions during development stages, access to ESA-provided data for interference characterization, the opportunity to utilize different GNSS receivers for testing purposes, access to the ESA-ESTEC facility, and the ability to leverage real-world data collected in field tests to identify and address system shortcomings.

Acknowledgements

This work was funded by the European Space Agency (ESA) NAVISP programme under the activity NAVISP-EL1-064: "Block-box for an optimised GNSS spectrum monitoring network using artificial intelligence". We also acknowledge the support of the ESA Technical Officer Luciano Musumeci for his contributions throughout the project. The view expressed in this article can in no way be taken to reflect the official opinion of the European Space Agency.

Contact

Wahyudin Syam - wahyudin.syam@gmv.com

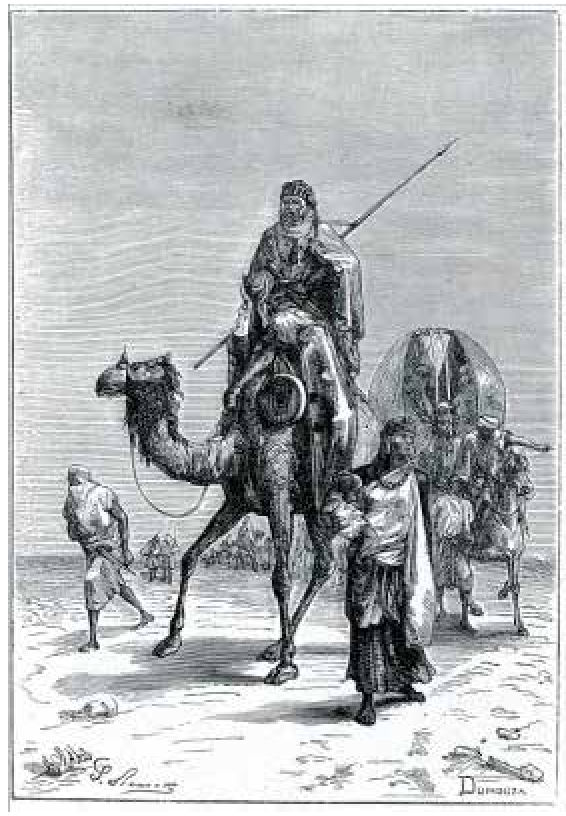
Jews in Medieval Navigation

Marvin B. May

Jews have been called the "people of the book". Originally this referred to the fact that the Jewish religion is rooted in its founding document, the Hebrew Bible or Torah. But in pre-Exploration Age medieval Europe, generally defined as from 1000 to 1400 CE, Jews might have been referred to as the "people of the map". Whether it be a book or a map, written documents were the rare artifacts that could be created and retained under the circumstances of frequent persecution and expulsion that Jews were subjected to. Unlike most of Europe, where Jews were at best, tolerated, but often subjugated, in the Iberian Peninsula and nearby island chains, they were accepted and often appreciated for their unique expertise. While under often-changing Muslim and Christian rulership, Iberian Jews, referred to as Sephardim, leveraged their itinerant history, to be important expeditors for commerce. Indeed, travel, trading, and various forms of brokering were burgeoning aspects of medieval life, as routes between the Iberian Peninsula, north Africa, Italy, Egypt, Levantine, Palestine, Turkey, and even India became heavily utilized. Jews often served as translators, intermediaries, and arbitrators between Christian and Muslim merchants. The forced mobility of Jewry led to cross-cultural interchanges that served as a catalyst for the development of improved cartographic techniques.

Binyamin MiTudela's "Book of Travels"

An early contributor was Binyamin MiTudela (b1130-d1173) who was born to a religious Sephardic family in the town of Tudela, now in Spain. Since this was at the height of the Crusades, it was a perilous time for anyone to make a pilgrimage, especially a Jew. Binyamin wanted to explore all the Jewish communities along the way and to create a detailed map showing the route one should take and where a Jew could find safe refuge on his journey. His travels took him to France and the Italian Peninsula, then to Greece and across what is today Turkey to the Near East, then to Persia, back around the Arabian Peninsula, to Egypt, and returning to Iberia by way of North Africa. A lover of history and geography, he also wished to leave a record of what the world looked like in the 12th century. Binyamin recorded all that he saw in his "Book of Travels". Today, the book is among the most important historical documents for scholars of the Middle Ages and the Renaissance, as well as of Jewish and Muslim history. A great deal of what we know about that era, including the daily lives of simple people, comes from his book. Some believe that it was this book that may have inspired another, more famous, adventurer about a century later: Marco Polo.

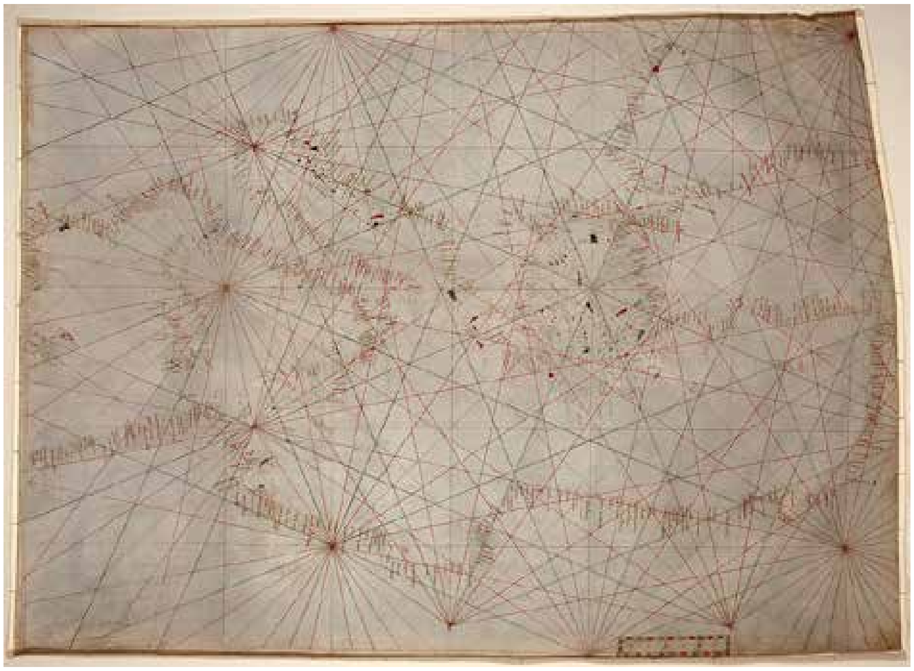


Binyamin MiTudela in the Sahara in the 12th century, engraving by Dumouza, 19th century
Wikipedia Commons

Portolan Charts

The island of Majorca (about 110 nautical miles southeast of the present coastal Spanish city of Barcelona), the largest of the Balearic Islands in the western Mediterranean, was in the crosshairs of the vibrant medieval maritime traffic lanes. It had a long history of seafaring, Jewish merchants, astronomers, and cartographers during the 12th to 15th centuries. Majorcan cosmographers and cartographers experimented with and developed their own cartographic techniques. According to some scholars, the Majorcans were responsible for the invention of the portolan chart. The portolan was a realistic, detailed nautical chart, gridded by compass lines, that could be used to deduce exact sailing directions between any two points.

Portolan charts, which appeared rather suddenly after 1300, constitute a sharp departure from all earlier maps. Unlike the circular *mappa mundi* of Christian academic tradition, the portolan was oriented toward the north, and focused on a realistic depiction of geographic distances with a degree of accuracy that is excellent, even by modern standards. Historians speculate that the portolan was constructed from the first-hand information of mariners and merchants, possibly assisted by astronomers, and was



A portolan nautical chart of the Mediterranean Sea, second quarter of the 14th century. The oldest original cartographic artifact in the Library of Congress.
Wikipedia Commons

geared for navigational use, particularly the plotting by compass of navigational routes. The Majorcans developed their own distinctive style or "school" of portolan cartography, which can be distinguished from the "Italian school". Both Italian and Majorcan portolan charts focus on the same geographic area, which is sometimes called the "Normal Portolan": the Mediterranean Sea, the Black Sea, and the Atlantic Ocean coast up to the environs of Flanders.

Catalan Charts

The Majorcan style, which came to be known as Catalan charts, is known for its elaborate and decorative designs including not only coastal outlines but also inland topography, cities, cultural icons, and even mythical creatures. The most famous Majorcan cartographer was Abraham Cresques, (~b.1350-d.~1400), known as "Cresques the Jew". He was appointed as a Master of Maps and Compasses by John of Aragon. The map Cresques produced (along with his son Jehuda) was known as the Catalan Atlas and is the single most important and detailed map of the medieval period. It illustrates numerous religious references as well as a synthesis of medieval *mappae mundi* (Jerusalem located close to the center) and the travel literature of the time, notably Marco Polo's book of travels. Mecca was denoted as the town where the shrine of Mohammed the Prophet of the Saracens lies. The Catalan Atlas has a note by Mecca indicating that people from every land come here on pilgrimages.

There is a large body of evidence that documents the major contributions that Jewry made to navigation and the related sciences of cartography and astronomy during the 11th to 15th centuries, leading up to the Age of Exploration. Recently, that body of evidence is pointing towards the strong possibility that Christopher Columbus, himself an accomplished astronomer and navigator, was of Sephardic Jewish descent, but this merits a separate article.

Marvin B. May is an ION Fellow and Professor Emeritus. His email is marvin.may@mayvenengineering.com.

A part of the Majorcan map called "Catalan Atlas". Copy of the 1375 original, made in 1959, Library of Congress, Geography and Map Division
Wikipedia Commons

Defense Matters

Positioning, Navigation, and Timing; Cybersecurity; and Spectrum Management

(Planning Mission Success in Modern Warfare)

Doug Taggart
President
Overlook Systems Technologies, Inc. and ION Fellow
with

Jules McNeff
VP Strategy and Programs

Prologue

As I draft this column in mid-February, our country's federal workforce is experiencing significant shake-ups, impacting both federal employees and federal contractors. The ongoing cuts and workforce reductions initiated by the Department of Government Efficiency (DOGE) raise questions about what the future holds. While the full impact remains unclear, here is a collection of quotes, attributed to Peter Drucker[1], that may be apropos to the uncertainty of what lies ahead.

"The only thing we know about the future is that it will be different."

"Trying to predict the future is like trying to drive down a country road at night with no lights while looking out the back window."

"There is nothing quite so useless as doing with great efficiency, something that should not be done at all."

"Efficiency is doing the thing right. Effectiveness is doing the right thing"

"The best way to predict the future is to create it."

Now to the business at hand – Defense Matters Positioning, Navigation, and Timing, Cybersecurity, and Spectrum Management (Planning Mission Success in Modern Warfare).

Maximizing Mission Success: A Critical Approach to Integrated PNT, Cybersecurity, and Spectrum Management

As military systems grow increasingly reliant on integrated technologies, the convergence of three critical areas—positioning, navigation, and timing (PNT), cybersecurity, and spectrum management—becomes paramount for mission success. To maximize the probability of success, these interconnected domains must not be considered in isolation, but seamlessly integrated as they are foundational to operational effectiveness.

This integral relationship was graphically depicted by the Department of Defense in its *Strategy for the DoD PNT Enterprise,* released to the public in 2019. An introductory figure titled "Electronic Foundations of Joint Warfighting" shows Communications (Spectrum), Computers (Cyber), and PNT as the three foundations of the DoD Information Technology (IT) and Cyber Enterprise. Precise PNT from GPS is shown as the catalyst that, since the early 2000's, has enabled warfighters to bridge the notional Command and Control (C2) divide between Reactive Operations, where information latency hinders C2 execution, to Coincident Operations where continuous Situation Awareness with precise position and time enables real-time C2 execution.

The strategy enjoins the entire DoD to adopt a holistic view toward implementation of these foundational elements within the military forces and notes that, while GPS will remain the cornerstone PNT capability for the department, complementary PNT sources must also be employed for flexibility and resilience in integrated PNT applications.

The Imperative of NAVWAR Compliance

This foundational guidance is codified by DoD policy in DoD Instruction 4650.08 (Positioning, Navigation, and Timing (PNT) and Navigation Warfare (NAVWAR) Policy). This policy document states, ***"DoD will use NAVWAR to ensure DoD use of and prevent adversary use of PNT information through coordinated employment of space, cyberspace, and electromagnetic spectrum operations."*** It requires that all DoD systems be equipped to operate in hostile NAVWAR environments and emphasizes that NAVWAR compliance is a non-negotiable requirement in the acquisition of PNT User Equipment (UE).

It mandates that a NAVWAR Compliant PNT system ***"…continues to provide trusted***

1 Peter Drucker (1909 to 2005) was regarded as the founder of modern management.

PNT information over the time period required by a specific mission at the level of accuracy required by the mission in the expected physical, electromagnetic, and cyber environment."

NAVWAR compliance is the bedrock for ensuring operational reliability and resilience, positioning the U.S. military for success in the face of adversary threats that are designed to exploit vulnerabilities in the PNT domain.

Addressing the Interconnected Challenges

The military's ability to operate in contested environments demands more than just a functional PNT system. It requires a comprehensive approach that integrates PNT, cybersecurity, and spectrum management.

Three key principles of PNT—accuracy, availability, and integrity—are essential benchmarks for evaluating system effectiveness. However, a fully resilient PNT system extends beyond these principles. A resilient PNT system must proactively detect and mitigate interference, identify spoofing attempts, and disregard corrupted data from compromised sources. Beyond the military environment, these capabilities are also foundational to civilian applications, ensuring the safety and security of critical infrastructure, such as power grids, transportation operations, and communication networks, all of which are equally vulnerable to PNT disruptions.

Cybersecurity: The Backbone of Mission Success

In the realm of cybersecurity, a similar set of principles, the CIA Triad—Confidentiality, Integrity, and Availability—serves as a guideline. This model underpins the strategies designed to protect critical systems from both malicious attacks and accidental breaches.

In the context of PNT, which is simultaneously an enabler and a product of computer operations, cybersecurity must be integrated at every level of process monitoring, authentication, and control. Any compromise of mission data or command authority can lead directly to mission failure. Therefore, robust cybersecurity measures are not an optional enhancement but a critical element that ensures the reliability and security of PNT systems, as well as the integrity among the multiple cyber networks supporting military operations.

The Role of Spectrum Integrity

Similarly, protection of the electromagnetic spectrum is no less critical. While the terminology around spectrum management lacks the specificity of PNT or cybersecurity, the radio spectrum plays a fundamental role in supporting both communication and PNT systems.

As adversaries increasingly exploit vulnerabilities in the spectrum—through tactics like frequency jamming or spoofing—military systems become more vulnerable and susceptible to disruption.

Spectrum integrity ensures the reliability of all electronic operations, and its protection is crucial for maintaining interoperability, especially in joint or coalition environments.

To secure mission success, the spectrum must be vigilantly monitored, with mechanisms in place to detect, characterize, attribute, and neutralize interference, whether deliberate or accidental, that could degrade system performance.

> ***"DoD will use NAVWAR to ensure DoD use of and prevent adversary use of PNT information through coordinated employment of space, cyberspace, and electromagnetic spectrum operations."***
> It mandates that a NAVWAR Compliant PNT system ***"…continues to provide trusted PNT information over the time period required by a specific mission at the level of accuracy required by the mission in the expected physical, electromagnetic, and cyber environment."***
> DoD Instruction 4650.08

Conclusion: Integration is Mandatory

As military operations become ever more dependent on integrated technologies, the ability to consolidate and securely manage the PNT, cyber, and spectrum elements of Information Technology-enabled systems is paramount for mission success.

Achieving NAVWAR Compliance in the acquisition of PNT UE is critical as PNT is a vital enabler in the operations of communications (spectrum management) and computer (cybersecure) systems. Resilience, proactive interference mitigation, and seamless integration across these domains will dictate operational effectiveness and the ability to adapt in the face of evolving threats.

The future success of military operations hinges on the ability to secure these interconnected domains, ultimately providing and maintaining a decisive edge on the battlefield.

Our government leaders have pondered this situation without substantive action for far too long, and we are at the precipice of being late in fielding fully resilient PNT capabilities for both military and civil critical infrastructure applications. Our adversaries are not sitting idly by but, as press reports indicate, are increasing their investments in resilient PNT capabilities, space and terrestrial.

The time for the U.S. to act is now—our future national security and economic prosperity demand nothing less.

ION's JOURNAL NAVIGATION Spotlight

ION's Associate Editor's TOP Picks from 2024

ION's 2024 Burka Award Winner

Factor Graphs for Navigation Applications: A Tutorial
Taylor, C., & Gross, J. (2024). Factor graphs for navigation applications: A tutorial. *NAVIGATION,* 71(3). https://doi.org/10.33012/navi.653

Optimal INS Monitor for GNSS Spoofer Tracking Error Detection
Kujur, B., Khanafseh, S., & Pervan, B. (2024). Optimal INS monitor for GNSS spoofer tracking error detection. *NAVIGATION,* 71(1). https://doi.org/10.33012/navi.629

Geodetic Altitude from Barometer and Weather Data for GNSS Integrity Monitoring in Aviation
Simonetti, M., & García Crespillo, O. (2024). Geodetic altitude from barometer and weather data for GNSS integrity monitoring in aviation. *NAVIGATION,* 71(2). https://doi.org/10.33012/navi.637

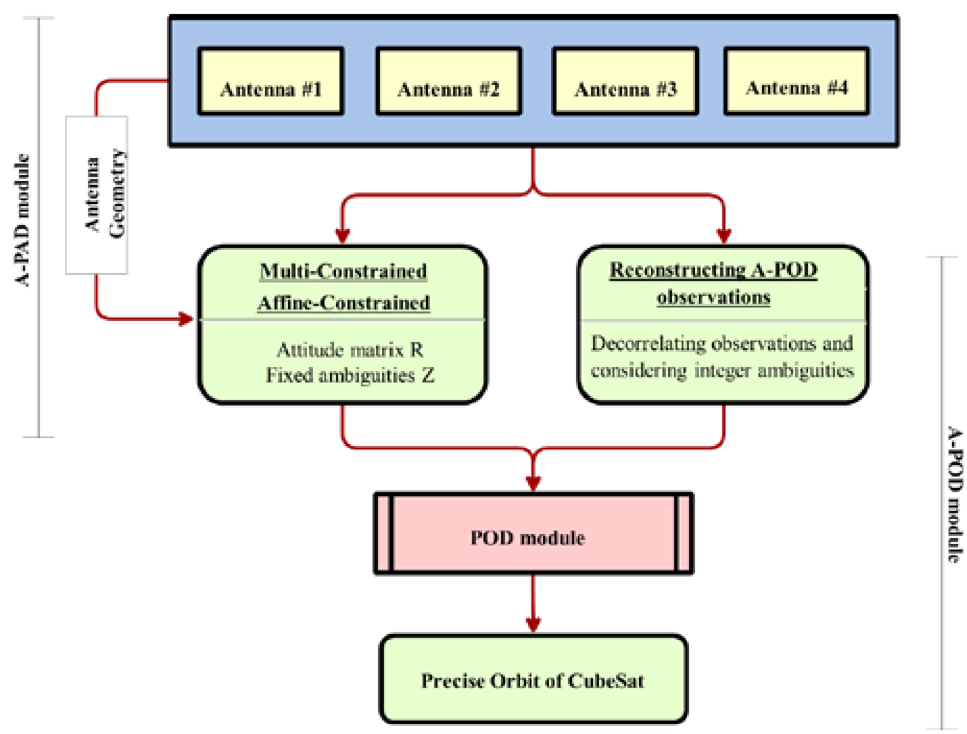
Formulation and Characterization of One-Way Radiometric Tracking with the Iris Radio Using a Chip-Scale Atomic Clock
Ely, T., Towfic, Z., & Sorensen, D. (2024). Formulation and characterization of one-way radiometric tracking with the Iris radio using a chip-scale atomic clock. *NAVIGATION,* 71(1). https://doi.org/10.33012/navi.633

Array-Aided Precise Orbit and Attitude Determination of CubeSats using GNSS

Amir Allahvirdi-Zadeh and Ahmed El-Mowafy

Our approach transforms how CubeSats determine their position and orientation in space. Our array-aided precise orbit and attitude determination (A-POAD) model offers a cost-effective alternative to expensive sensors like star trackers. By using an array of GNSS antennas, we have created a solution that achieves high precision while keeping costs down – a crucial factor for CubeSat missions. This approach simultaneously improves both orbital accuracy and attitude determination, achieving a three-dimensional accuracy of 4.1 cm compared to 11.8 cm with traditional single-antenna solutions. This precision is especially valuable for CubeSats with limited power and low-quality sensors, making it ideal for real-time applications including forthcoming LEO-PNT systems.

We conducted comprehensive testing using a simulated four-antenna array on a 12U CubeSat, based on actual GNSS observations from an operational Spire CubeSat. Our experiments evaluated both dual-frequency and single-frequency scenarios to ensure the model's robustness under different conditions. We achieved significantly improved orbital accuracy and produced smoother observation residuals with an RMS of just 6 mm, half of what is possible with conventional methods. These results demonstrate that low-cost CubeSats can achieve the high precision needed for LEO-PNT systems, increasing access to space-based navigation systems by making them more



economically viable.

While no CubeSat is currently equipped with multiple GNSS antennas, we implemented our algorithms in LeoPod software and validated them through extensive simulations. This preparatory work lays the foundation for future practical implementations as the CubeSat industry evolves.

Exciting applications for this technology include LEO-PNT systems where simultaneous precise orbit and attitude determination is essential; and formation flying scenarios where multiple small satellites operate in proximity, and enable cost-effective deployment of large LEO constellations for navigation and timing services. Beyond navigation, this system could enhance applications requiring precise pointing operations and integrate with existing GNSS systems to provide enhanced navigation capabilities. As the space industry continues to evolve toward smaller, more cost-effective satellites, this method provides a pathway to maintain high precision while reducing costs.

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

Allahvirdi-Zadeh, A., & El-Mowafy, A. (2024). Array-aided precise orbit and attitude determination of CubeSats using GNSS. *NAVIGATION,* 71(3). https://doi.org/10.33012/navi.651

Distributed Nonlinear Least-Squares Solver for Practical Network Determination

Josef Krška and Václav Navrátil

We describe several modifications of algorithms for infrastructure nodes (anchors) position determination without the need for specialized equipment and team of operators.

The knowledge of precise anchor position is critical for tag (user equipment) localization. The position is determined in a distributed fashion, where anchors first measure distances to other anchors in their range (e.g., with two-way ranging in case of ultra-wide band devices). Then, the anchors cooperatively find their own positions with distributed multilateration. The uniqueness lies in the approach to the problem and the reduction of resource requirements and complexity of the distributed algorithms. The problem is formulated as a non-linear least squares (NLSQ) problem and is solved with a distributed consensus sub gradient (CSG) method. Originally, with CSG the anchors estimate positions of every anchor within the network, which is memory consuming, especially for vast anchor networks. One of the proposed modifications reduces the dimension of the problem by limiting the position determination of each anchor only to its neighborhood; i.e., the anchors with direct line of sight. Second modification aims to speed up algorithm convergence through CSG's step-size coefficient adjustment. Several approaches of step-size search are investigated in the paper. An example of cost function development is in Figure 1, where the original CSG is the slowest in finding the minimal cost. It can be seen that by limiting the position estimation (N-CSG), and incorporating step-size coefficient search (N-CSG BLS and TBLS), the convergence can be sped up (convergence at around 200 iterations instead of 500+).

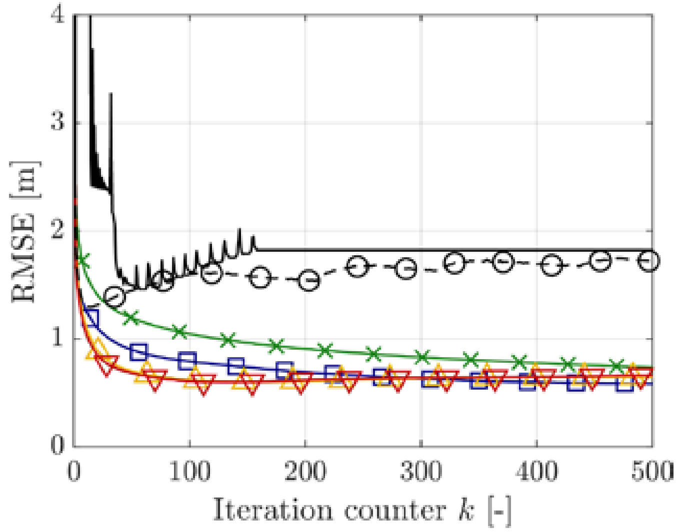


FIGURE 1: Cost function value development of current solution given by a solver over iterations. Black solid line is reference global Levenberg-Marquardt (LM) solver, solid green line with crosses is Consensus Subgradient (CSG), solid blue line with squares is modified CSG with reduced computation complexity (N-CSG), solid yellow line with up-triangle is N-CSG with Backtracking Line Search (BLS) used for step-size coefficient search, solid red line with down-triangle is N-CSG with Two-Way BLS, and dashed black line with circles is N-CSG with LM-like step-size coefficient computation.

In case of UWB anchors, the survey of the network does not require any specialized equipment since the anchors perform all the measurements on their own using TWR. The anchors also do not have to be interconnected via a wired connection to exchange data, as the UWB channel can be utilized for data transfer. Moreover, no central computer is required as the anchors do the calculations themselves.

We installed 25 anchors within a floor of an office building (approx. 27 m by 12 m), and their positions were surveyed with a total station to get the ground truth. The anchors measured distances to other anchors in their respective range. The measurement graph is in Figure 2. The anchors network spanned over several rooms. The measurements were affected by authentic measurement noise and errors emerging from multipath propagation, signal fading, etc. The computations were done in post-processing, in order to provide identical measurement inputs to all the evaluated algorithms. The distributed solver achieved mean estimation error of 50 cm and interestingly, it outperformed the reference centralized solution (estimation error of 1.26 m). The results indicate that the distributed algorithm can be used for automatic position determination of the anchors enabling, for instance, rapid setup and initialization of ad hoc networks for positioning or in case of emergencies.

Currently, the proposed method is being studied, developed, and incorporated into UWB devices. The findings of the paper are helpful and serve as a basis for the ongoing development. The methodology can be used for ad hoc networks, for tampering detection in existing UWB networks, or for quick expansion of an existing network. A new anchor added to an existing network can determine its position with the help of other anchors. After successful position determination it becomes a functional part of the localization network infrastructure. The algorithms provide means for rapid deployment of complete ad hoc localization networks.

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

Krška, J., & Navrátil, V. (2024). Distributed nonlinear least-squares solver for practical network determination. *NAVIGATION,* 71(3). https://doi.org/10.33012/navi.658

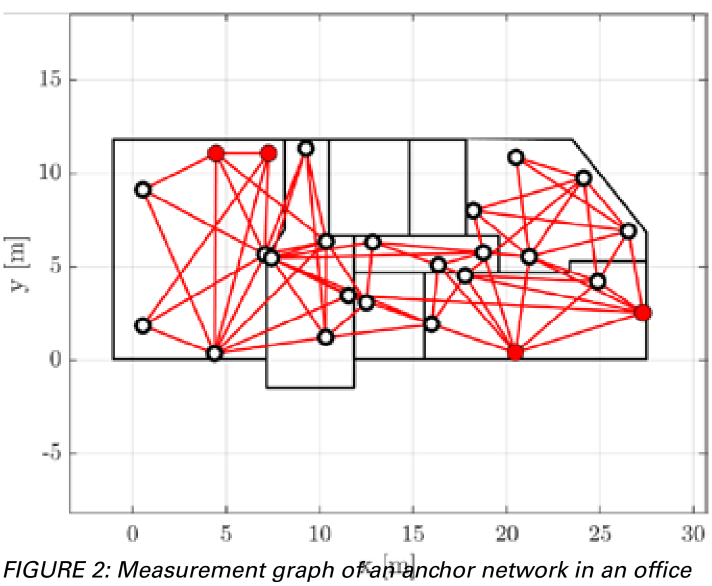


FIGURE 2: Measurement graph of an anchor network in an office building floor. Black circles are anchors, red circles are anchors with known and fixed positions, anchor pairs with measured distance are connected with red solid lines, and black solid lines are walls.

Synthesized Binary Offset Carrier Modulation for Interoperable GNSS L1 Band Signals

Dhaval J. Upadhyay, Vijay S. Bhadouria, Parimal J. Majithiya, and Subhash C. Bera

Many global navigation satellite system (GNSS) service providers plan to provide interoperable open civilian service in the L1 frequency band (1575.42 MHz). Hence, service providers have defined multiplexed binary offset carrier (MBOC) modulation for the L1 frequency band interoperable open civilian service. The prime goal in designing an interoperable open civilian signal in the L1 frequency band is to design a navigation signal that satisfies the power spectral density (PSD) requirement of MBOC(6, 1, 1/11) modulation, which contains BOC(1,1) and BOC(6,1) components with power sharing of 10/11 and 1/11, respectively. GNSS service providers have implemented various methods for implementing MBOC modulation, such as time-multiplexed BOC (TMBOC), composite BOC (CBOC), and quadrature multiplexed BOC (QMBOC) to meet the MBOC PSD criteria. The TMBOC implementation method combines the BOC(1,1) and BOC(6,1) components in a time-multiplexing manner. The CBOC implementation method combines the BOC(1,1) and BOC(6,1) components in a baseband level with desired amplitude factors. The QMBOC implementation method combines BOC(1,1) and BOC(6,1) components in a quadrature multiplexing manner with desired amplitude factors. CBOC does not provide flexibility in allocating the power sharing of data and pilot signals because of the cross-product terms between the BOC(1,1) and BOC(6,1) components of the data and pilot signals in the autocorrelation of these signals. Allocating equal power to the CBOC data and pilot signals removes these cross-product terms in the autocorrelation of the CBOC signal. TMBOC and QMBOC provide flexibility in allocating power-sharing between data and pilot signals. Typically, these MBOC modulation signals are multiplexed onboard a satellite with another open civilian service, public regulated services, and restricted service signals in order to generate a constant-envelope modulus composite signal. A constant-envelope modulus composite signal enables the operation of an onboard high-power amplifier in a saturation region, providing maximum efficiency. However, all of these MBOC implementation methods are based on non-constant-envelope modulus signals when GNSS satellites transmit only the L1 frequency band interoperable open civilian service signal, corresponding to standalone transmission of the MBOC-modulated signal.

Synthesized Binary Offset Carrier Modulation (SBOC): *a method to generate constant envelope combining three signals in a non-linear manner while meeting MBOC PSD criteria.*

This paper presents a constant-envelope modulation scheme, based on a SBOC, for GNSS that combines three signals in

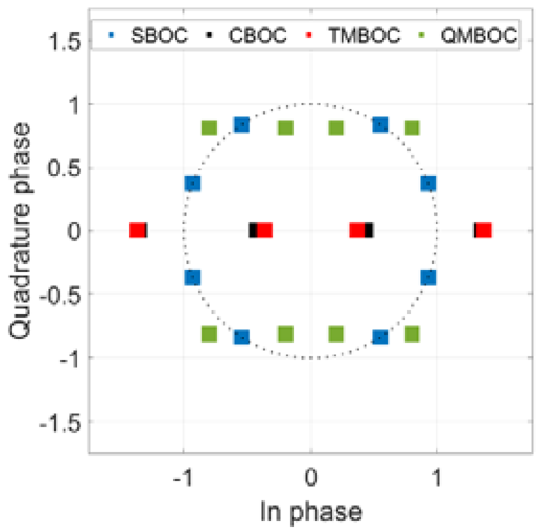


Figure 1: The constellation diagram of SBOC signal

a nonlinear manner with unequal amplitudes. The proposed SBOC modulation meets the MBOC(6,1,1/11) PSD criteria used in the L1 frequency band open civilian service interoperable signals for GNSS. This SBOC modulation also provides flexibility in selection of power-sharing ratio between the data and pilot signals. The proposed SBOC modulation also enables the GNSS service provider to transmit a standalone open civilian service signal from a satellite while operating an onboard high-power amplifier in a saturation region, achieving maximum efficiency. This approach provides better performance than various MBOC(6, 1, 1⁄11) modulations for narrowband receivers. Comparison of constellation diagram of SBOC with other MBOC modulation signals is shown in Figure 1.

SBOC Performance: *an optimized performance for BOC(1,1) unmatched receivers (low cost receivers).*

We optimize the power-sharing of BOC(1,1) and BOC(6,1) components of data and pilot signals of a SBOC composite signal to achieve optimum performance for BOC(1,1) unmatched receivers. The major performance metric of navigation signal designs is the root mean square (RMS) bandwidth. The RMS bandwidth quantifies the power content of the signal over the frequencies across its bandwidth. Figure 2 shows a comparison of the RMS bandwidth of the SBOC pilot signal with various MBOC pilot signals. The SBOC pilot signal performs better than various MBOC pilot signals for a BOC(1,1) unmatched receiver because less power is allocated in the BOC(6,1) component of the pilot signal compared to other MBOC implementations.

SBOC Utilization: *SBOC modulation scheme adopted in second generation Navigation with Indian Constellation (NavIC) Satellites.*

Second-generation NavIC satellite payload incorporates SBOC modulation scheme in L1 band open civilian service signal. NVS-01 satellite transmits SBOC modulated open civilian service signal in L1 band. In the future, SBOC signal may be multiplexed with other service signals generating constant envelope signal to provide new services to the users.

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

Upadhyay, D. J., Bhadouria, V. S., Majithiya, P. J., & Bera, S. C. (2024). Synthesized binary offset carrier modulation for interoperable GNSS L1 band signals. *NAVIGATION, 71*(2). https://doi.org/10.33012/navi.640

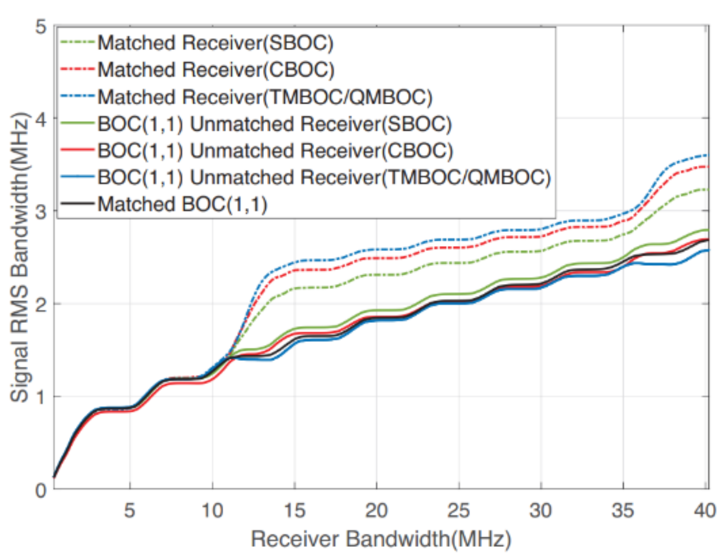
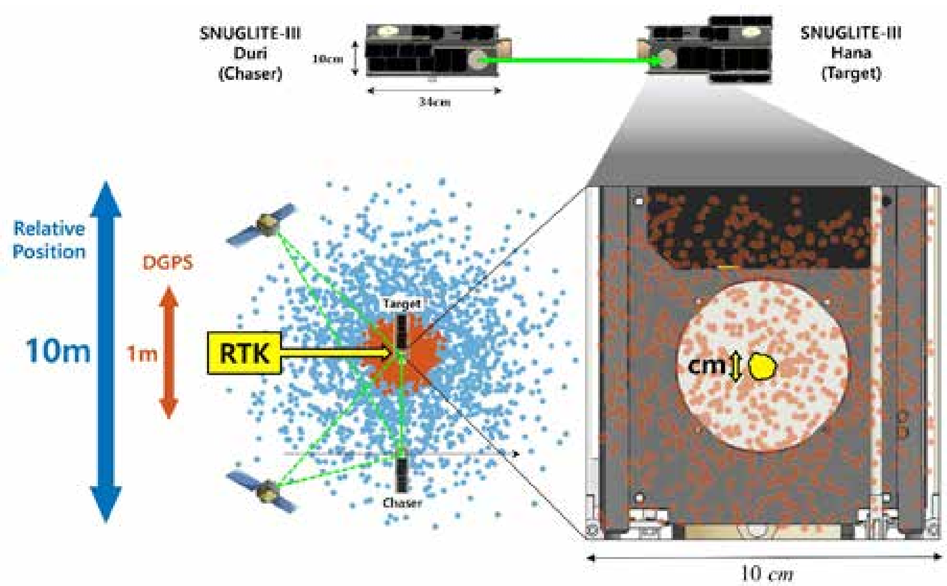


Figure 2: RMS bandwidth of the SBOC pilot signal

Highly Efficient Real-Time Kinematic-Based Precise Relative Navigation for Autonomous CubeSat Rendezvous CubeSat

Hanjoon Shim and Changdon Kee

This study aims to extend the use of real-time kinematic (RTK) relative navigation beyond terrestrial applications to low Earth orbit (LEO). It leverages single-frequency, single-reference station RTK, originally developed for ground-based systems, to enable centimeter-level relative navigation using only commercial GPS receivers on CubeSats. Despite the inherent limitations of CubeSat hardware—such as low-power processors, patch antennas, and restricted data transmission rates—the proposed algorithm successfully achieves precise relative positioning. The methodology is validated through both software-based orbital simulations and ground-based hardware experiments using actual CubeSat GPS receivers and antennas. Additionally, this technology is set for real-world demonstration aboard the SNUGLITE-III CubeSat, scheduled for launch in November 2025, marking a milestone in deploying efficient and cost-effective RTK navigation in space.



Conceptual illustration of RTK-based precise relative navigation for SNUGLITE-III CubeSat. The diagram compares DGPS and RTK accuracy in LEO, highlighting the centimeter-level precision achieved using GPS-only navigation.

To validate the proposed algorithm, we conducted both software LEO-based simulations and hardware experiments on ground. A software GPS simulator was used to model CubeSat formation flying, confirming that our RTK-based approach achieves centimeter-level accuracy in LEO while maintaining rapid ambiguity resolution. The ground-based experiment further validated the algorithm using real GPS receivers and patch antennas under open-sky conditions, demonstrating its robustness despite hardware limitations.

These results are significant for the positioning, navigation, and timing (PNT) community, as they prove that real-time centimeter-level navigation can be achieved in space without high-end hardware such as dual-frequency GPS receivers or atomic clocks. This technology has far-reaching implications, from enabling cost-effective CubeSat formation flying and docking to supporting next-generation satellite constellations for Earth observation, space debris tracking, and future autonomous space operations.

Traditionally, high-precision relative navigation in LEO relied on post-processed solutions or multi-GNSS, dual-frequency systems with complex filtering techniques. Our approach, however, demonstrates that centimeter-level accuracy can be achieved in real-time using single-frequency GPS and RTK techniques.

By incorporating double-difference ambiguity resolution without Kalman filtering, our method enables real-time relative positioning with minimal computational overhead, making it ideal for CubeSats and small satellite constellations. Unlike terrestrial RTK, where atmospheric effects such as tropospheric delay must be mitigated, the LEO environment inherently reduces error sources, allowing RTK to function effectively in space. The methodology is already integrated into the SNUGLITE-III CubeSat mission, which will serve as a flight demonstration of real-time GPS-based formation flying.

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

Shim, H., & Kee, C. (2024). Highly efficient real-time kinematic-based precise relative navigation for autonomous rendezvous CubeSat. *NAVIGATION,* 71(3). https://doi.org/10.33012/navi.661

Efficient Signal Quality Monitoring of GNSS Signals Disturbed by Evil Waveforms

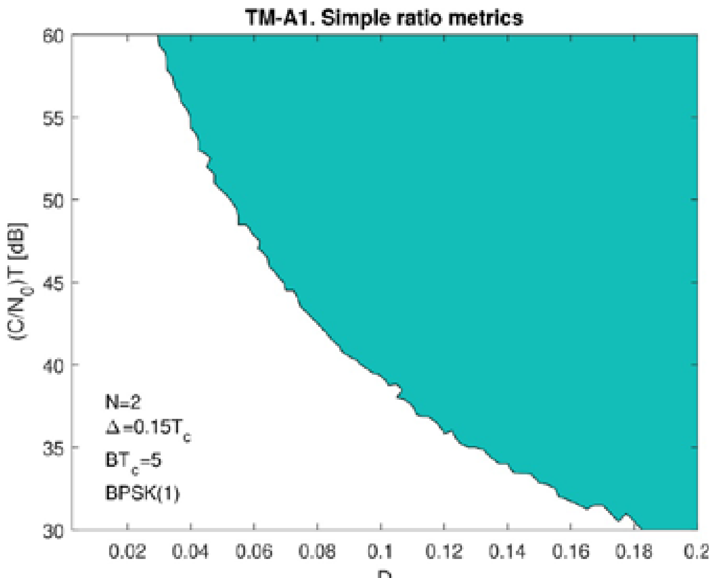
Fernando D. Nunes and Fernando M. G. Sousa

Evil waveforms (EWF) are anomalies in the signals transmitted by global navigation satellite system (GNSS) satellites, provoked by electric malfunctions aboard. Although the occurrence of those events is very rare, they can significantly degrade the accuracy of the receiver's position, velocity, and time. Therefore, the receivers should include algorithms to detect and mitigate the EWFs' effect.

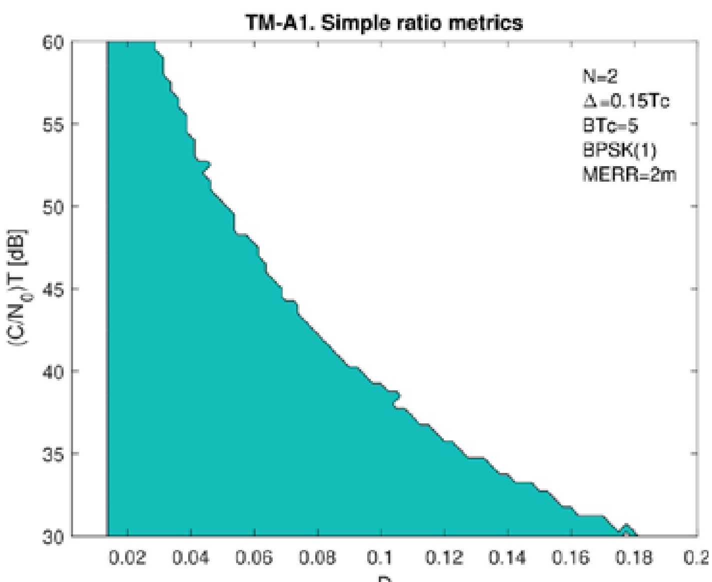
As EWF anomalies distort the autocorrelation function of the received signals, a bank of correlators is often used. By comparing the relative magnitudes of the different correlators it is possible to detect different types of EWF events. To assess the performance of the algorithms we should use EWF degraded signals, but due to the rarity and random nature of the events, this strategy is, in most cases, entirely impractical.

In this paper we propose an alternative semi-analytic approach whereby the EWF component of each correlator is calculated and a random Gaussian component is added, representing the thermal noise. This approach leads, in general, to a very small computational burden, being particularly suited for commercial GNSS signal simulators.

Three types of EWFs are usually considered in the literature: threat models TM-A, TM-B, and TM-C, which are associated with digital, analog, and digital plus analog distortion, respectively. Cross-correlation functions of the received signal disturbed by EWF distortion are derived for the three models, with expressions being obtained for BPSK, BOCs and CBOC pilot modulations. In the case of TM-A, closed-form expressions are offered in terms of the sine integral function.



Detectability region



Hazard region

Signal quality monitoring (SQM) techniques have been developed to detect distortions in GNSS caused by multipath or spoofing attacks and may also be employed for detecting EWF distortion. The following detection events may occur: false alarm (distortion is detected without being present), and missing detection (distortion is not detected although being present). The performance of an EWF detector may be measured in terms of the probability of missing detection (P_{md}) for a pre-defined probability of false alarm (P_{fa0}). As a result, we define the region of detectability for a given value of P_{fa0}, as the parameter set S for which P_{md} is smaller than a certain pre-selected probability of missing detection (P_{md0}). In general, the larger the region of detectability, the better the SQM technique will be. Associated with the region of detectability we may also determine the hazard region, which is the parameter set corresponding to the absence of detection of an existing EWF anomaly, but excluding the parameter subset that affects the pseudoranges, less than a certain threshold called MERR (maximum-allowable error in range).

The darker parts of the figures represent detectability and hazard regions for TM-A1 with BPSK(1) and normalized baseband bandwidth BT_C=5 (T_C is the chip duration). The set S includes parameters D (TM-A1 lead/lag in T_C units) and $(C/N_0)T$ (T is the correlation duration). A bank of $2N$+1=5 correlators with spacing $\Delta = 0.15T_C$ was employed and pre-selected probabilities were adjusted to $P_{fa0} = 10^{-4}$ and $P_{md0} = 10^{-3}$.

For the full article and accompanying data and figures, please see: Nunes, F. D., & Sousa, F. M. G. (2024). Efficient signal quality monitoring of GNSS signals disturbed by evil waveforms. *NAVIGATION,* 71(4). https://doi.org/10.33012/navi.668

High-Precision Time Transfer and Relative Orbital Determination Among LEO Satellites in Real-Time

K. Wang

This technology moves the phase common view (PCV) technology from the ground to space. It enables high-precision relative positioning and time transfer between LEO satellites of a few hundred kilometers without needing high-precision GNSS products.

Using real data from GRACE follow-on satellites, and three different types of real-time GNSS products, results showed that the PCV method can deliver a relative clock precision below 0.2 ns, and a relative orbital user range error of about 5 cm, even when using the broadcast ephemeris, whereas all three other methods encountered sharp degradations in their results when using degraded real-time GNSS products. This implies that with the observations of only a few key LEO satellites downlinked and with their precise orbits and clocks determined, POD and precise clock determination can be achieved for other LEO satellites in the constellation through the proposed method. No precise GNSS products are needed; only the observations need to be transferred between the satellites through inter-satellite links. This relieves the pressure for data downlinking, especially when the ground stations are limited and when other tasks need to occupy the downlinking channels.

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

Wang, K., Sun, B., El-Mowafy, A., & Yang, X. (2024). High-precision time transfer and relative orbital determination among LEO satellites in real-time. *NAVIGATION,* 71(3). https://doi.org/10.33012/navi.659

The Business of GNSS

Kevin Dennehy

Since our last update, **Hexagon** has signed an agreement to acquire Belgium-based ION member **Septentrio** for an undisclosed figure. While it hasn't said if there will be personnel consolidation or layoffs, Hexagon did say Septentrio, which employs 150 people worldwide, will be rolled into its Autonomous Solutions division.

Hexagon said it would merge Septentrio's GNSS platform with its larger positioning technology portfolio of sensor fusion, anti-jamming systems, correction services, and perception technologies. The focus will be on emerging autonomous systems adoption and other, the company said. These markets include robotics, UAVs, and defense applications.

In a mammoth $1 billion cloud infrastructure deal, ION member **HERE Technologies** and Amazon Web Services plan to support AI-powered live streaming map and location services for multiple markets. The agreement, which runs for 10 years, was announced at CES in January.

While it is unclear how the big dollars will be divided, HERE Technologies CEO Mike Nefkens said the deal allows both companies to combine expertise to help automakers quickly get software-defined vehicles, electric and autonomous cars to market.

The company also introduced its HERE WeGo Pro to enable customizable mapping truck navigation for commercial fleet operators. HERE WeGo Pro offers optimized, multi-stop routing with road restrictions and real-time traffic conditions, the company said.

HERE WeGo Pro enables customizable mapping truck navigation for commercial fleet operators.
HERE Technologies

In other company news, Thalwill, Switzerland-based **u-blox** said that it will phase out its cellular business to focus on its location division. The company said the focus on its location business will help it expand opportunities in GNSS, short-range IoT connectivity, autonomous vehicles, industrial and tracking markets.

u-blox updates module for rail applications
u-blox

The company hinted that there may be layoffs in its 200-employee cellular IoT business. While the division made about $30 million in the first half of 2024, it also had nearly $17 million in losses during the same time.

The Swiss company has updated its ZED-F9R for the rail applications. The ZED-F9R-04B module, with an integrated IMU features sensor fusion implementation.

In another big transaction, **Trimble** announced the completion of Platform Science's acquisition of its global transportation telematics business units. The deal, announced in September 2024, adds to Platform Science's growing Virtual Vehicle platform.

Trimble, which will acquire a 32.5 percent stake in Platform Science, said it is focusing on its Connect and Scale strategy.

In other business news:

ION member **L3Harris Technologies** has received a contract from the U.S. Space Force's Space Systems Command to design concepts for Phase 0 of the Resilient Global Positioning System (R-GPS) program.

ION member **Topcon Positioning Systems** has announced the launch of the HiPer XR, its latest GNSS receiver for surveying, mapping, and construction applications. The receiver is designed for construction professionals, surveyors, GIS professionals, archeologists, engineering firms, and others, the company said.

Topcon's HiPer XR GNSS receiver for surveying, mapping, and construction applications
Topcon Positioning Systems

ION member **VIAVI Solutions** has launched EdgeGM 7000, an Edge Grandmaster Clock that is part of the company's SecurePNT portfolio. EdgeGM 7000 offers up to 25G Precision Time Protocol (PTP) and multi-orbit SecureTime altGNSS for PNT services.

Kevin Dennehy has been writing about GNSS for more than 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.

GNSS Program Updates
News from Systems Around the World
Kevin Dennehy

NavIC

While India successfully launched a replacement satellite on January 29 for its Indian Regional Navigation Satellite System, or NavIC (Navigation with Indian Constellation), it got stuck in geosynchronous transfer orbit (GTO) after thrusters on board were not able to fire.

The Indian Space Research Organization (ISRO) said that while it has communication with the satellite, and all other systems are functioning, the failure of an oxidizer valve precludes the Liquid Apogee Motor, or LAM, from firing. The satellite cannot reach geostationary orbit – where it was to provide navigation services across India.

One of five planned replacement satellites, NVS-02 represented the country's ambitious plan to offer positioning services that hopes to be more accurate than GPS.

The launch, which was ISRO's 100th, offered a satellite that is heavier with a longer life expectancy. The satellites also carry an India-developed atomic clock.

The anticipated launch, and subsequent technical issues, dampen the fact that such companies as Apple and Qualcomm announced that their equipment and models work with NavIC.

QZSS

Japan launched its Michibiki 6 satellite, also known as the Quasi-Zenith Satellite System (QZSS) QZS-6, on February 2 from Tanegashima Space Center. The 1,900-kilogram satellite was aboard the Mitsubishi Heavy Industries (MHI) H3 flagship rocket.

Launch of Michibiki 6, Quasi-Zenith Satellite System (QZS-6) aboard H3 Launch Vehicle
JAXA

The first Michibiki satellite, for the proposed four-satellite QZSS system, was launched in 2010. However, recent reports have indicated that the Japanese government wants to launch an 11-satellite navigation system by the late 2030s.

Galileo

Arianespace signed a contract with the European Commission and the European Union Agency for the Space Program (EUSPA) to deploy the first two second-generation Galileo navigation satellites.

Three other launches (L14, L15, and L16) are scheduled aboard an Ariane 6 rocket. Each will carry two satellites to complete the first-generation Galileo navigation system.

In other Galileo news, the European Space Agency has started a large migration of the navigation constellation's control centers. Five European companies will lead the modernization efforts: Thales Alenia Space, ION member GMV, Telespazio Belgium, Thales SIX, and Indra. GMV is also working on the design, development, deployment, commissioning support and maintenance of Galileo's new iteration of a High Accuracy Data Generator (HADG). The contact is part of a Phase 2 of Galileo High Accuracy Service.

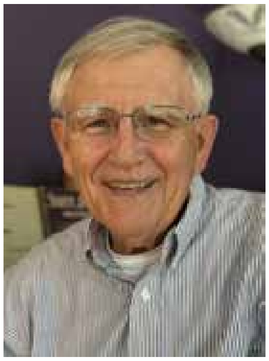
Artist rendering of NavIC satellite navigation satellite. NVS-02 was successfully launched, but stuck in orbit.
ISRO

GPS

To bring the GPS constellation to 31 active space vehicles, the U.S. Space Force has transferred Satellite Control Authority of the GPS III Space Vehicle 07 to the 2nd Navigation Warfare Squadron on January 8. The satellite, launched in December 2024, and nicknamed "Sally Ride," is set healthy and available to global users as of January 22, the Space Force said.

Industry observers are cautiously optimistic that the beleaguered GPS Next-Generation Operational Control System, or OCX, ground system may be on the road to completion. In published reports, the U.S. Air Force acting head of space acquisition said that the ground system has made it successfully through 97 percent of required testing—and may be ready by fall 2025.

ION News and Notes



Dr. Alan Evans, 82, passed away peacefully on January 5, 2025, in his home, surrounded by loved ones. During his career at Naval Surface Warfare Center Dahlgren Division (NSWCDD), Dr. Evans was the Principal Investigator for many R&D projects sponsored by the Department of Defense, the Office of Naval Research (ONR) and the National Geospatial-Intelligence Agency (NGA). His career in navigation has spanned over 30 years and he has contributed to both military and civilian applications. He worked additional years for the Penn State University Applied Research Laboratory after his retirement from federal service.

Together with other NSWC personnel, Dr. Evans demonstrated the very first basic use of the GPS phase measurements to achieve high accuracy position changes. The Stanford Telecommunications receiver, capable of one-measurement-per-minute, single satellite tracking, was used to obtain centimeter-level accurate position changes as the satellites moved across the sky. Dr. Evans was also credited with advancements to network-assisted GPS that substantially improved real-time accuracy and supported additional GPS anti-jam signal processing important to military applications.

Dr. Evans was a prolific author and conference presenter and won many academic awards including the Defense Mapping Agency Research and Development Award in 1989, the Navy Superior Civilian Service Award in 2007, and was awarded ION Fellow in 2013.

NSF Engineering Research Visioning Alliance (ERVA) Seeking Input on Space R&D and Engineering

ION is an affiliated organization of the Engineering Research Visioning Alliance (ERVA), an NSF-funded partnership that identifies future engineering research directions.

ERVA is currenting seeking input on a potential visioning event on space R&D. If you have an idea to refine this theme and how engineering, and specifically PNT in space, could play a role, please reach out at info@ervacommunity.org.

Ways you could possibly assist with this topic would include:

Agenda development: Support the development of an agenda that will result in actionable recommendations.

Participant recruitment: Identify subject matter experts from relevant sectors (academia, industry, government, and nonprofits)

Facilitation: Provide qualified subject matter experts to lead discussions, guide event flow, and optimize the experience and results.

Report development and writing: Support the creation of a report that reflects the current research and development environment and shares actionable recommendations that can be evaluated by government funding agencies for adoption

If you are interested in space research and development, you are encouraged to get involved!

– WANTED –

ION is Hiring a Managing Editor at the ION National Office in Manassas, VA

Reporting directly to the Executive Director, the Managing Editor for the Institute of Navigation (ION) will oversee all editorial responsibilities at ION including the following: The entire operation of *NAVIGATION, Journal of the Institute of Navigation.* Coordinates and manage the *NAVIGATION* webinar program. Works with ION's marketing manager to ensure *NAVIGATION* marketing campaigns across social media channels. Creates content for, produce, and edit, the ION's quarterly membership newsletter. Compiles reports about journal statistics. Maintains and track publication budget. Technical editing of other program content as assigned.

Job Requirements: PhD or MS degree in engineering, physical sciences, or applied mathematics. Excellent editing and technical writing skills. Familiarity with APA style guide is a plus. Knowledge of Adobe Acrobat and Microsoft Office; knowledge of LaTeX highly desirable. Knowledge of manuscript tracking software, such as ScholarOne. Ability to multitask and work independently. 1-2 years professional work experience preferred with internships considered. Must be a U.S. citizen.

For compensation, location, and application information, please see the ION's Job Board at: https://www.ion.org/job-board.cfm?jid=1730

Calendar of Upcoming Events

APRIL 2025

28-MAY 1: IEEE/ION Position, Location, and Navigation Symposium (PLANS) 2025, Salt Lake Marriott Downtown City Creek, Salt Lake City, Utah
ion.org

MAY 2025

21-23: European Navigation Conference (ENC), Wrocław, Poland
enc-series.org/2025

JUNE 2025

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

JULY 2025

14-25: ESA Summer School, Greece
www.esa-jrc-summerschool.org

AUGUST 2025

11-13: SmallSat, Small Satellite Conference, Salt Lake City, Utah
Visit ION in the exhibit hall!
smallsat.org

SEPTEMBER 2025

8-12: ION GNSS+ 2025, Hilton Baltimore Inner Harbor, Baltimore, Maryland
ion.org

JANUARY 2026

26-29: ION International Technical Meeting (ITM) & ION Precise Time and Time Interval (PTTI) Meeting 2026, Hyatt Regency Orange County, Anaheim, California
ion.org

APRIL 2026

13-16: ION Pacific PNT Meeting, Hilton Waikiki Beach, Honolulu, Oahu, Hawaii
ion.org

ION
INSTITUTE OF NAVIGATION

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

Nonprofit Org.
U.S. Postage
PAID
Permit No. 425
Southern, MD