



**SATELLITE DIVISION
SPONSORSHIP**

ION's Outreach in Africa

The ION Satellite Division was a co-sponsor of the 2023 Eastern Africa Capacity Building Workshop on Space Weather and Low-latitude Ionosphere held in Malindi, Kenya, October 3-12, 2023. The workshop is a continuation of the Africa GNSS Outreach effort initiated and co-organized by former ION president Patricia Doherty and the International Center for Theoretical Physics in Trieste, Italy, since 2009.

This year's workshop had a total of 51 participants from Austria, Asia, Canada, Cote d'Ivoire, France, Italy, Kenya, Nigeria, South Africa, Spain, and USA. Among them, 27 students were from Africa. Other attendees included faculty, researchers, government agencies from Kenya and other African countries, and international instructors.

Over 30 lectures on topics ranging from introduction to GNSS to big GNSS data for ionosphere monitoring were presented at the workshop. The workshop also included multiple sessions of hands-



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INTERNATIONAL SPACE PRIORITY

Lunar PNT

Kevin Dennehy



The European Space Agency is supporting several lunar PNT initiatives.
ESA

Because the Moon is now an international space exploration priority, with 80 national space agencies and dozens of private companies involved, accurate positioning, navigation, and timing (PNT) are essential for safe lunar landings, precise maneuvering, and successful navigation on its surface.

Heading to the Moon is a big opportunity for the industry as 28 national space agencies have signed the Artemis Accords to cooperate in the exploration and use of the Moon. In addition, NASA said that the International Space Exploration Coordination Group, comprised of 27 space agencies, has identified at least 14 Moon missions—and seeks increased levels of accuracy for precision landing.

The European Space Agency (ESA) says future Moon exploration activity is even greater, with more than 250 missions planned on its surface, or in orbit, over the next 10 years. ESA says there are key market drivers such as science and technology development, asset transportation, and pre-human robotic

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Celebrating 50 Years of GPS

In recognition of the indispensable role that global navigation satellite systems (GNSS) play in shaping the modern world, and the fundamental GPS frequency that forms the foundation for all GNSS, the Institute of Navigation (ION) proudly proclaimed the establishment of "International GNSS Day" on the 23rd of October annually.

This date, written as "10/23" in U.S. date format, captures the frequency of 10.23 MHz, the original heartbeat of all GPS satellites, signals, and receivers. This frequency was later adopted by all other GNSS service providers, serving as the basis of L-band signals for over 100 navigation satellites today.

As a day of celebration, International GNSS Day serves to highlight the global impact of satellite navigation in diverse sectors, including transportation, agriculture, aviation, surveying, and beyond. It provides a platform to recognize the collaborative efforts of nations, organizations, and individuals in advancing GNSS technology. ION pays special tribute to the developers of GPS, celebrating 50 years since its inception this year.

Dr. Joanna Hinks, Air Force Research Lab (AFRL), is credited for the proposal – extending the logical tradition of International Pi Day to a day dedicated to the marvels of GNSS. The ION plans to celebrate and publicize October 23rd on an annual basis going forward and encourage professionals, enthusiasts, and the public alike to commemorate this day.

Interview with Dr. Bradford Parkinson

On December 5, in Houston, Texas, the Resilient Navigation and Timing Foundation hosted a gala to celebrate the 50th anniversary of GPS. During the event, held in conjunction with the National PNT Advisory Board meeting, Matteo Luccio, editor-in-chief of GPS World, interviewed Dr. Bradford Par-



Dr. Bradford Parkinson, The Father of GPS, and Matteo Luccio, editor GPS World
D. Goward

kinson about the early days of GPS, its development, and his thoughts about the future. Here are two excerpts from the interview:

Question: How does GPS today differ from the design that came out of the Lonely Halls meeting 50 years ago this past September?

Parkinson: Well, I'm very proud of what happened because, to my knowledge, there is no fundamental difference. Basically, that fundamental design has held up. ... As a matter of fact, I still have one of the old Trimble handhelds, it's called an EnsignGPS. It was one of those little devices that got shipped to the Iraq War. The other day, I pulled it out, bat-

teries were kind of crummy, I got those squared away and went out, sure enough and navigated. I probably hadn't pulled it out in at least 20 years. The point of the story is that evidently it still works.

Question: What do you consider the most significant impact of GPS on society?

Parkinson: Well, the most significant impact is also probably the most perilous: kids today just take it for granted. They know where they are.

To view the full interview, see: <https://www.gpsworld.com/celebrating-50-years-of-gps-an-evening-with-the-father-of-gps/>

I invite you to read other GPS origin stories where champions of GPS share

Dana Goward, president of the Resilient Navigation and Timing Foundation, hosts a 50th anniversary interview with Dr. Bradford Parkinson on the history of GPS at the PNT Advisory Board Meeting, December, 2023.
RNT Foundation





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.

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Tim Murphy, Dr. Bradford Parkinson, and Thad Allen at December's PNT Advisory Board Meeting, Houston, Texas
F. van Diggelen

navigation, and timing technology and applications where policy and technical leaders from all Pacific Rim nations, and the USA, meet to discuss policy updates, receive program status updates, and exchange technical information. Special sessions have been organized on BeiDou, COSMIC/

beginnings, breakthroughs, and what is next in the December issue of GPS World magazine.

Invitation to Join Me at Pacific PNT in Waikiki, Honolulu, Hawaii (April 2024)

As this year's program chair, I am particularly excited to announce that ION's biennial Pacific PNT conference's technical program is now online and registration is open. This will be the first year we have been able to hold this conference fully in-person since 2019. We are excited to host this highly collaborative technical conference that emphasizes the global cooperative development of positioning,

FORMOSAT and QZSS. See ion.org/pnt for more information.

Looking forward to greeting everyone in this year's ION Hawaiian shirt. ✨



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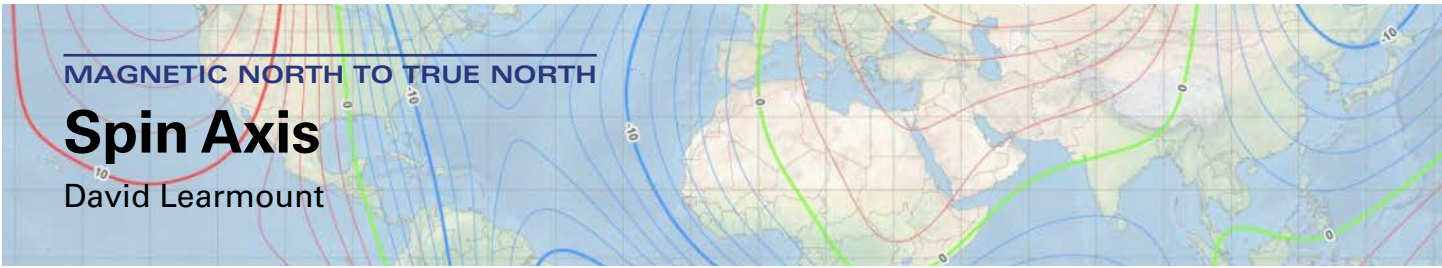
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NOAA NCEI

It may seem unlikely that in 2023 some full-time aviation professionals still do not know that the global industry is preparing to change its navigational heading reference from Magnetic North to True North (Mag2True). However, the reality is that there may be many people employed by airlines, airports, air navigation service providers, and even some at national civil aviation authorities unaware of impending changes.

Magnetic North, aviation's traditional heading reference, has always been shifting but, for reasons unknown, the shift has accelerated in the last three decades. The industry has long coped with the navigational anomalies that arise from measurable variations in the Earth's magnetic field, but having to cope with this uncertainty has now become an expensive distraction. This is ironic considering that modern navigation technologies already enable an alternative – using True North as the heading and azimuth reference eliminates the problems, the inaccuracies, and the associated ongoing costs of this constantly shifting reference.

Canada's air navigation service provider (ANSP), Nav Canada, is the world's expert in coping with navigation difficulties resulting from massive local variations between Magnetic and True North. This is because the geographical location of Magnetic North has traditionally been in its far north domestic territory, but this has recently changed, with the magnetic pole now lying in the eastern hemisphere. Rates of change may now become more of a European problem, and Mag/True variation can change significantly when aviators are operating in the vicinity of the geographic magnetic north pole.

The maximum possible value of the variation between the two norths – 180deg – occurs on the line between the geographic surface positions of Magnetic

North and True North: anywhere on that line, an aircraft's magnetic compass will show north as south, and vice versa. For these reasons, Canada divides its domestic airspace into two sectors: northern domestic airspace (NDA) and southern domestic airspace (SDA). In the NDA the heading reference is True North, and the ANSP and all ground-based navigational aids and performance-based navigation procedures, along with charts and airports, reflect this fact. Meanwhile in Canada's SDA, where changes in Mag/True variation are less pronounced, the heading reference used is Magnetic.

Canada's aviators cope by a variety of means according to their aircraft's equipment. The crews of aircraft with the latest avionics, including the latest triplex inertial reference units (IRU) as well as GPS, have no problems. Pilots flying classics have to be familiar with the techniques of flying in an area where variation can change considerably on a single leg, especially flying across lines of longitude rather than along them. But this can be done, even with old equipment, and traditional navigation skills prevail.

Because of their experience in managing airspace encompassing huge differences between Magnetic and True North, Nav Canada leads the multinational Attitude and Heading Reference Transition Action Group (AHRTAG), which has been engaged for more than three years in a detailed study of the Mag2True transition and all its implications, technical, and operational. AHRTAG is an International Association of Institutes of Navigation (IAIN) specialist working group, and the progress of its work is being monitored by the International Civil Aviation Organization (ICAO) and aviation authorities around the world. Indeed, with AHRTAG taking on the research role, ICAO's specialist resources

like the Air Navigation Commission (ANC) are freed to oversee the proposals and processes.

Nav Canada has its own True North Sub-Working Group, and it has produced a Concept of Operations (ConOps) for transitioning the whole of Canadian airspace onto True North as employed in its NDA. This ConOps is, effectively, a blueprint for the methodology that the rest of the world could adopt during transition to True North. Nav Canada has used the year 2030 in the ConOps as a target, because it needs a proposed transition date for costing purposes.

The ConOps rationale for the change to True North: "After the 1980s, as aircraft systems became more tightly integrated and digital systems developed, minor magnetic variation errors have become more than a mere distraction, driving a mismatch between the various navigation systems." Whatever risks might be involved in transitioning to True, the growing risks just described by Nav Canada's ConOps will outweigh them.

Dai Whittingham, a member of AHRTAG and chair of the UK Flight Safety Committee, observed that failure to transition would be to ignore the definition of the duty to ensure flight safety adopted by the UK Civil Aviation Authority (CAA). The CAA says organizations have a duty to make aviation "as safe as reasonably practicable." Whittingham points out that, by staying with the Magnetic heading reference, "We are accepting errors that we can easily eliminate."

There are still voices expressing reluctance, but they are becoming fewer, and they are mostly posing questions to bodies like AHRTAG about how to overcome anticipated transition problems and costs.

Factors to be considered in the event of

the Mag2True transition include aircraft equipage, airport signage, ground navigation beacon orientation, ANSP/ATC procedures, meteorological reporting, and aviation information service (AIS) updating.

Changes, where necessary, may often be adopted in advance, or a switch-over prepared beforehand. Nav Canada, which has carried out airborne trials of options for transitioning to True, makes this observation: “In its simplest form, changing from Magnetic to True could be done in many aircraft avionics systems by setting the magnetic variation or declination to ‘0’. Since all procedures and systems have been built by original equipment manufacturers (OEM) to a stable common reference (TRUE NORTH) and then converted to Magnetic for end use, setting the correction to ‘0’ will set the reference to TRUE. Databases for navigation now using standard 424-23 have recognized this concept since the publication of ARINC 424-20 many years ago.”

Susan Cheng of Boeing paints a picture of the potential for data mismatches that exists within all modern commercial air transport category aircraft when they use the Magnetic heading reference for navigation. As the Nav Canada ConOps paper has already stated, there is a potential for “mismatch between the various navigation systems.” Cheng, who is a flight deck crew operations engineer at Boeing, points out that the main sources of potential mismatch are the magnetic variation (MagVar) tables that are part of both the inertial reference system (IRS) and the flight management computer system (FMCS). There is a need for the operator to update the MagVar tables regularly in both these complex interacting systems, so if they are updated late; not at all; or if one table is updated and the other is not, the outputs can differ, confusing the auto-flight systems. Also, other pilot tools like synthetic vision systems can be affected by mismatches. Nav Canada reports that it has investigated several operational incidents caused by just such inputs, and fortunately they

have not led to accidents yet.

Operators of older aircraft with less sophisticated navigation systems clearly worry about the Mag2True transition challenge, but rather than threatening to veto it they have appealed for time and consultation to work out how best to cope. No one is demanding that they, nor the major airlines, give up their standby magnetic compasses. But organizations like General Aviation Manufacturers’ Association (GAMA) and Aircraft Owners and Pilots’ Association (AOPA) warn against forcing GA pilots, while flying, to read their standby compass, apply the local magnetic variation, and set their gyro-driven directional indicators (DI) to True. The potential for error, they argue, is high. Both are also nervous about GA aircraft fitted with horizontal situation indicators (HSI) slaved to flux valves that provide Magnetic headings. Their concern is the expense of fitting converters to make the HSI read True. Indeed, like other organizations, GAMA and AOPA say they would want to see a proper ConOps from ICAO for transition well before the Mag2True transition phase, to enable the industry to prepare. Meanwhile there are also those who accuse detractors of exaggerating the problems, and of ignoring input from global navigation satellite systems (GNSS), widely used by all sectors of GA.

ICAO has, meanwhile, conducted a survey to measure the support for a Mag2True change. ICAO reported that it received a robust response from more than half the contracting states. Among these respondents, which ICAO confirms came from regulators and all sectors of industry, less than 10% were resolutely opposed to it. Those most in favor included ANSPs and flight procedure designers. Air operators provided varied levels of support, but less than 15% opposed change. Interestingly, the particularly high reported level of appreciation of “foreseen benefits” and “additional foreseen benefits” appeared to be at odds with the level of nervousness about managing the transition.

ICAO also confirmed that many air operators report already operating True North procedures in remote and oceanic airspace,

and in polar regions.

Given this chance to voice their concerns to ICAO, the industry’s two most important demands were for a clear transition plan supported by regulation and guidance, and for the transition to be well-coordinated across states, stakeholders, and the military. In terms of timescale for implementation, most respondents said five to ten years to prepare is acceptable.

Right now, a set of four objectives to prepare for transition have been raised: 1) development of a global ConOps; 2) development of strategies for implementing True North; 3) analyzing the potential safety risks and identifying mitigations; and finally, 4) identifying the ICAO Air Navigation Commission Panels that will be impacted and propose tasks accordingly.

Nav Canada’s own ConOps argues that the move to True is unquestionably beneficial, indeed essential, for aviation’s future: “The case for converting to True as the datum for aviation instructions, procedures, and surveillance is clear, and the only problems would be those of practically implementing it. While it would be a large-scale undertaking, it would also be a one-off operation which, once completed, would be final, unlike the present situation, which is also costly and constantly with us, requiring resources to manage it.”

Chair of the AHRTAG, Nav Canada’s Anthony MacKay, sums up the group’s conclusion: “The risks of change are known and manageable. The transition will require careful planning and implementation, most likely through ICAO. To remain on Magnetic continues to allow a latent threat to safety to reside within our aviation safety system.” ✨

David Learmont is an aviation consultant and journalist. His aviation blog can be found at <http://davidlearmount.wordpress.com>.

Evolutionary Milestones in Lunar PNT



Lunar PNT milestones
NASA

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exploration that are potentially worth more than \$100 billion.

The number of missions could increase to around 400 thanks to the recent discovery of ice waters on the Lunar South Pole—and since the Moon presents a natural gateway to other planets—starting with Mars, said Dr. Cosimo Stallo, head of E2E Navigation Systems Design Unit, Engineering of Domain of Observation and Navigation Italy, Thales Alenia Space (TAS). “Lunar PNT represents one of the most relevant ambitions of the GNSS industry in next few years,” he said.

For three years, ESA has been working with private industry on the Moonlight initiative that is conducting an analysis of planned lunar missions and developing solutions, both technical and business, to provide telecommunication and navigation services for the Moon.

“Thales Alenia Space has been deeply involved since the beginning of ESA’s Moonlight initiative, and is covering a

primary role in the Lunar Navigation—End to End navigation system, Navigation Lunar Space Segment (LSS) and EGS (Earth Ground Segment) Navigation Mission Segment,” Stallo said.

ESA’s Lunar Communications and Navigation Services (LCNS) Phase A/B1, part of Moonlight with Telespazio as prime contractor, has attempted to create a financially sustainable infrastructure to provide LCNS, Stallo said. “TAS has been part of the core team, participating in the definition and design of the entire system—both navigation and communication—as well as the Lunar Space Segment and Moon Surface Segment,” he said.

ESA’s Lunar Pathfinder carries a navigation payload consisting of a GPS-Galileo high-sensitivity receiver and a high gain antenna, furnished by ESA, and a laser retro-reflector array provided by NASA, said James Miller, NASA Deputy Director Policy & Strategic Communications, Space Communications and Navigation (SCaN), Space Operations Mission Direc-

torate (SOMD).

“The [NASA Laser Retroreflector Array] was delivered and tested in November 2022. It will enable combined radiometric and optical laser measurements for geodesy and will help tie the Earth and lunar reference frames, which will in turn further improve navigation throughout cislunar space,” Miller said.

In March 2023, Firefly Aerospace was selected to launch both Blue Ghost Mission-2 lunar landers and ESA’s Lunar Pathfinder in 2026.

In another major launch, NASA and the Italian Space Agency’s (ASI) Lunar GNSS Receiver Experiment (LuGRE) payload consists of a high-sensitivity GNSS receiver, a high-gain L-band patch antenna, a low-noise amplifier, and an RF filter. The receiver will track GPS L1 C/A and L5, and Galileo E1 and E5a signals and will return pseudorange, carrier phase, and Doppler measurements to the ground, said Joel J.K. Parker, NASA Goodard Space Flight Center Flight Dynamics Engineer.

“LuGRE is on track for a mid-2024 launch on Firefly’s Blue Ghost Mission 1. We look forward to a great mission and for the chance to demonstrate the first GNSS-based PNT solutions around the Moon and on the lunar surface,” Parker said.

LuGRE was chosen by the NASA Commercial Lunar Payload Services (CLPS) program as one of ten NASA-funded payloads on its Task Order 19D, which was awarded to Firefly Aerospace in 2021, the agency said. It was delivered to the contractor in February 2023 and is part of 10 payloads on Blue Ghost Mission-1. “Experiments such as LuGRE and the Lunar Pathfinder In-Orbit Navigation Demo are intended to validate that the use of GPS plus Galileo signals will provide the performance levels we anticipate,” Miller said. Implementing space navigation has been a high-level job at NASA as the agency sponsored the National Space-based PNT

port human spaceflight in cislunar space, Miller said.

Interoperability is a Concern

Because so many international space agencies, private companies and contractors are working on lunar PNT, it is critical for the new technologies to be interoperable, compatible and available to all, said Cheryl Gramling, associate chief for technology, NASA’s Mission Engineering and Systems Analysis Division.

“The intent is for the lunar PNT capabilities to be interoperable. To that end, NASA, ESA, and JAXA [Japan Aerospace Exploration Agency] are developing the LunaNet Interoperability Specifications,” she said.

Gramling said that this cooperation is in alignment with the White House Office of Science and Technology Policy’s National Cislunar Science and Technology Strategy.

Volume One.’ The SUSG is now working on a third edition, which will expand the SSV beyond GEO and into cislunar and lunar space,” he said.

Companies such as Redwire have been selected by the Defense Advanced Research Projects Agency (DARPA) to conduct research and develop technologies as part of its 10-Year Lunar Architecture (LunA-10) study. Redwire’s contribution for the LunA-10 study will be focused on approaches for providing services to lunar assets from cislunar space, including high-speed communications and PNT.

Not everyone believes that Lunar PNT is ready to go—at least for now—and may be used as part of another larger space system. “Lunar PNT is certainly interesting from a technical perspective, but until such time that there are users, I think it will remain a laboratory curiosity,” said GNSS expert Logan Scott. “If

it ever gets deployed, my expectation is that it will be part of a communication system and not something that does solely PNT.”

Overall, the biggest story in the GNSS industry in 2023 was the 50th anniversary of GPS being approved as part of our national infrastructure,



LunaNet navigation services will provide autonomous navigation at the Moon.
NASA

Advisory Board meeting in December 2023, which was chaired by retired U.S. Coast Guard Admiral Thad Allen. While lunar PNT was not the focus of the meeting, it was brought up as an important initiative, Miller said.

Another NASA briefing was given to Vanessa Wyche, director, Johnson Space Center, to discuss the use of GPS to sup-

Miller said the International Committee on GNSS (ICG) Space User Subgroup (SUSG) has been working on developing an Interoperable GNSS Space Service Volume, which currently covers the volume of space between 3,000 and 36,000 kilometers. “This work is summarized in the ICG publication, ‘The Interoperable GNSS Space Service

which led to the eventual development of space-based PNT, including current lunar missions, Miller said. “In my view, without the dedication and persistence of people like Dr. Bradford Parkinson, we would probably be nowhere where we are today in terms of space-based PNT,” he said. 🌟



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on experiments that work with low cost GNSS receivers and ionosphere TEC and scintillation data processing. As in past years, ION supported ION members to serve as technical workshop instructors.

One highlight of the workshop was the

women’s dinner, a special event started by Patricia Doherty and sponsored by ION, where all female participants of the event gather for an evening of social interactions and career advising and mentoring. This year’s event was particularly significant as we had a record number of 14 female students and five female instruc-

tors. As was in the past, the women’s dinner and other onsite interactions have led to long lasting collaborations among all international participants.

The next African Outreach program is scheduled to take place in October 2024 at the Center for Theoretical Physics in Trieste, Italy. 🌟

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2024

ABSTRACTS DUE MARCH 1 **ion.org/gnss**

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2024 T-SHIRT

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Design should work on a white t-shirt

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*Designs must be submitted by ION members.

THE RULES

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

QUESTIONS?

Email: blathrop@ion.org

THE JUDGING

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

SCAN FOR MORE INFO



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

The Business of GNSS

Kevin Dennehy

While not entirely a business story, the biggest news since our last column is Ligado's \$39 billion lawsuit against the U.S. government. The company says the government blocked its plans to use assigned spectrum in "a multiyear misinformation and disparagement campaign."

Ligado's President and CEO Doug Smith said that the Federal Communications Commission, in a 2020 decision, granted the company exclusive authority over the use and licensing of the spectrum, which operates near that of GPS.

ION member HERE Technologies came out as the top provider in Omdia's 2023 Location Platform Index. The index evaluates major digital mapping and location technology vendors including HERE, Google, TomTom, Mapbox, Esri, Apple and Microsoft.

In other HERE news, the company appointed industry veteran Mike Nefkens as CEO. Nefkens has executive experience in IoT, automotive, cloud services and other technologies for several international corporations.

ION member u-blox has launched its "Focus-Innovate-Execute" strategy that will increase focus on its highly differenti-



GMV provides positioning technology for BMW Group.
GMV

ated positioning business by "substantially shifting research and development teams" to those market areas. The Swiss company said it will discontinue future cellular chipset development.

ION member GMV has been chosen by BMW Group to provide positioning technology for automated driving. GMV's positioning solution has two components – an onboard Positioning Engine software and a GNSS Corrections Service providing the vehicles with corrections to the Broadcast GNSS Ephemeris, the company said. GMV of-

fers its precise positioning solution, GMV GSharp, for automotive applications that provides accuracy, safe and reliable positioning information (position, velocity, and heading), the company said.

ION member BAE Systems said its Digital GPS Anti-jam Receiver (DIGAR) has been selected to continue to the next phase of the Phase 4 Enhancements (P4E) capability program on the Eurofighter Typhoon aircraft. The company says DIGAR will boost the protection of the aircraft from GPS signal jamming, spoofing, and radio frequency (RF) interference.

The fighter will also receive BAE Systems' new GEMVII-6 airborne digital GPS receiver, the company said. Work on DIGAR and GEMVII takes place in BAE Systems' facility in Cedar Rapids, Iowa.

Skydio has partnered with ION member Trimble to offer autonomous drone products in critical infrastructure industries for surveying, mapping and inspections. The partnership is in the development stage, but will include Skydio's drones with Trimble GNSS receivers and software. Skydio's flagship X10 drone, with an RTK GPS attachment, will be



HERE integrates Live Map with BMW's 7 Series' Personal Pilot.
HERE Technologies



BAE Systems selected to enhance GPS technology on Eurofighter Typhoon.
BAE Systems

210-S and VN-310-S, to expand the company's tactical series of GNSS-aided Inertial Navigation Systems (INS).

NextNav, an ION member, has announced the appointment of Mariam Sorond as its CEO. ✦

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

fully compatible with Trimble's GNSS receivers, the companies say.

Other Business News:

ION member Hexagon's Autonomy & Positioning division and Munhwa Broadcasting Corp. (MBC) have agreed to bring the TerraStar-X Enterprise Correction Service to South Korea. MBC, which offers real-time kinematic (RTK) positioning across South Korea, offers atmospheric data that enhances the redundancy of Hexagon's precise point

positioning (PPP) network.

ION member Topcon Positioning Systems has joined Septentrio's Agnostic Corrections Partner Program. The program enables the use of Septentrio receivers with high-accuracy services for integrators.

ION member VectorNav Technologies has launched the VN-



Skydio's X10 drone will be compatible with Trimble's GNSS receivers.
Skydio

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2024

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Northern Kentucky Convention Center
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Marvin B. May

ION Historian Challenges Artificial Intelligence Apps

In the Fall 2011 ION Newsletter, the ION Historian challenged the readership with a navigation quiz. The quiz consisted of 20 multiple choice questions. The questions all related to navigation history and most of them could be answered by an astute reader who perused the previous 60 ION Historian newsletter articles. Only one reader correctly answered all 20 questions. Now may be a good time for the present reader to access the Fall 2011 Historian ION Newsletter article in the ION archives and (re)test your knowledge.

In this article, I challenge the ChatGPT and Bing Apps to the same navigation quiz. I summarize below a few of the more interesting responses. Note that the questions were not posed to the AI apps as multiple choice, but as direct questions. The numbers below are keyed to the original quiz questions.

3. *In what year was TRANSIT, the first operational satellite navigation system, installed on Polaris submarines?*

ChatGPT: "TRANSIT, the first operational satellite navigation system, was installed on Polaris submarines in the year 1960."

Bing: "Therefore, the first operational satellite navigation system was installed on Polaris submarines in 1964."

Historian: Bing is correct. The first TRANSIT satellites were launched in 1960 but were not used on Polaris submarines until 1963-4.

4. *What ship was used by the United States Navy from 1960-1980 to test navigation systems for strategic submarines?*

ChatGPT: "The ship used by the United States Navy from 1960 to 1980 to test navigation systems for strategic submarines was the USS

Observation Island (EAG-154)."

Bing: "I still couldn't find any information on a specific surface ship that was used by the Strategic submarine communication community to test navigation equipment from 1960 to 1980."

Historian: Neither AI app answered correctly. Per Historian newsletter article (Summer 2000) the correct answer is USS Compass Island.

6. *What is a figure-8 type pattern that can be used to determine position at sea without the use of GPS, computers, calculators, nautical almanacs, batteries, or even the Internet?*

ChatGPT: "Another possible way to determine your position at sea without GPS is to use figure eight which is based on the geometry theorem that the angle subtended by any arc at the center of the circle is twice the angle subtended at the circumference. By measuring the horizontal angles between three identified shore objects using a sextant, you can draw arcs on a chart and find the intersection point as your position."

Bing: "An analemma is a diagram that shows the position of the sun in the sky as seen from a fixed location on Earth at the same mean solar time throughout the year. The diagram looks like a figure eight and can be used to determine the equation of time and the declination of the sun for any given date."

Historian: Bing gave the correct answer (Analemma) plus good supplemental information. Not sure how ChatGPT came up with figure eight.

7. *Who is the author of the book "Inventing Accuracy," which delves into the*

history of the dominant technology of missile guidance: inertial "black box" navigation?

ChatGPT: "I'm sorry, but as of my knowledge cutoff in September 2021, there is no book titled "Inventing Accuracy" specifically focusing on the history of missile guidance and inertial "black box" navigation. It's possible that the book was published after my knowledge cutoff or that it is a less well-known or specialized publication."

Bing: "The author of the book "Inventing Accuracy," which delves into the history of the dominant technology of missile guidance – inertial "black box" navigation, is Donald MacKenzie. He is a professor of sociology at the University of Edinburgh and has written several books on the social aspects of science and technology."

Historian: Bing is correct. ChatGPT has some updating to do.

10. *Who was credited with inventing the ship's gyrocompass after winning a court patent case over American Elmer Sperry?*

ChatGPT: "The person credited with inventing the ship's gyrocompass and winning a court patent case over American Elmer Sperry was German engineer Hermann Anschütz-Kaempfe. Hermann Anschütz-Kaempfe developed the gyrocompass in the late 19th and early 20th centuries. His invention revolutionized navigation at sea by providing an accurate and reliable method for determining true north based on the Earth's rotation. Anschütz-Kaempfe's gyrocompass was initially challenged by Elmer Sperry, an American inventor who had also been working on similar technology."

However, Anschütz-Kaempfe ultimately prevailed in the court patent case, establishing his claim as the inventor of the gyrocompass.”

Bing: “The first patent for a working model of gyrocompass was awarded to Marinus Gerardus van den Bos in 1885. However, his design was not practical for use on naval ships, so the first usable design was provided by German inventor Hermann Anschütz-Kaempfe in 1906. He was credited with inventing the ship’s gyrocompass after winning a court patent case over American Elmer Sperry, who also developed gyroscopic compasses and stabilizers.”

Historian: Both AI apps gave wonderful answers. I learned about Gerardus van den Bos from Bing.

12. Who was the University of Illinois professor who researched the electrostatically suspended gyroscope which still is used in high accuracy inertial systems?

Chat GPT: “The University of Illinois professor who researched the electrostatically suspended gyroscope in the early 1950s was Dr. Charles F. Draper. Draper’s work on the electrostatically suspended gyroscope laid the foundation for the development of high accuracy inertial navigation systems, which are still used today.”

Bing: “I can tell you that he was Professor Arnold Nordsieck. He proposed the development of a gyroscope constructed with two axes that utilized two spherical metal rotors constructed from beryllium that would be supported by an electromagnetic field inside a vacuum chamber. He worked with his colleague Howard Knoebel to develop the first prototype of the electrostatically suspended gyroscope in 1957. This device was later used in high accuracy inertial navigation systems for submarines and spacecraft.”

Historian: As far as I can research, Dr. Draper did not work at the University of Illinois, nor did he develop the Electrostatically Suspended Gyroscope, although it was a reasonable fabrication by ChatGPT. Bing was right on, also giving credit to Howard Knoebel, who I had not heard of prior.

17. Who was an expert in chronometers and pioneered methods of determining longitude using telegraphy?

ChatGPT: “The individual you are referring to is Charles V. H. Dudley. Charles V. H. Dudley was an American inventor and scientist who made significant contributions to the fields of chronometry and telegraphy in relation to determining longitude.”

Bing: “According to my web search, one of the experts in chronometers and longitude using telegraphy was John Harrison, a self-educated English carpenter and clockmaker who invented the marine chronometer, a device for solving the problem of calculating longitude while at sea.”

Historian: The answer I was looking for was Charles Wilkes (see ION Newsletter, Fall 2002). I had never heard of Charles V. H. Dudley, ChatGPT’s response. Bing’s response failed to realize

that telegraphy did not exist in John Harrison’s lifetime.

20. Where did the Navy build a precise inertial sensor testing laboratory in 1963?

ChatGPT: “In 1963, the United States Navy built an inertial test facility at the Naval Air Development Center (NADC) located in Warminster, Pennsylvania. The facility was specifically constructed to conduct inertial navigation system testing and evaluation. The Naval Air Development Center (NADC) was a research and development facility operated by the U.S. Navy, primarily focused on aviation-related technologies. The inertial test facility at NADC was designed to support the development and assessment of inertial navigation systems, which provide accurate position, orientation, and velocity information without relying on external references such as landmarks or GPS. It’s worth noting that the Naval Air Development Center (NADC) in Warminster, Pennsylvania, was closed in 1996 as part of the Base Realignment and Closure (BRAC) process. However, during its operational years, it played a crucial role in advancing naval aviation and related technologies.”

Bing: “The facility was designed to measure the radar scattering of various objects and vehicles, and to test the performance of inertial navigation systems. The facility comprises two complementary sites, Main site and RATSCAT Advanced Measurement System (RAMS), which use different radar frequencies and tracking methods.”

Historian: From personal experience the ChatGPT gave the answer I was seeking. I could not validate the Bing research pertaining to an inertial test facility that the Navy ostensibly built in New Mexico in 1963.

Overall, the AI apps are amazing at mining, combining, extrapolating, and sometimes spinning a fabrication based on Internet entries, which were initially created by humans; but the AI apps lack humanity’s attributes of judgment, compassion, and humor. ✨

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Defense Matters

The UK Government's National PNT Initiative

Imitation—the Sincerest Form of Flattery—Time will Tell

In October the United Kingdom (UK) Government's Science Minister released a strategy for ensuring the continuity of PNT services in the UK.

The strategy embodies a ten-point plan which includes the establishment of a National PNT Office, a National Timing Centre (NTC), the development of back-up plans in the event of a GNSS disruption, and other initiatives to include the establishment of a terrestrial timing network and precision clock research to enhance critical infrastructure PNT resilience.

The UK Strategy

The noted UK critical national infrastructure sectors to be addressed are finance, defense, transportation, telecommunications, and emergency services.

In announcing the strategy, the Science Minister's statement noted that "Enhancing our PNT resilience and long-term capabilities is key to both Critical National Infrastructure, our economic security and resilience and strategic high growth sectors like space, future telecoms, quantum and cyber security."

The ten elements of the strategy are:

1. Establish a National PNT Office in the Department of Science, Innovation and Technology, with responsibility for PNT policy, coordination and delivery.
2. Retain and update a cross-government PNT Crisis Plan to be activated if GNSS-provided PNT is lost.
3. Develop a proposal for a National Timing Center (NTC) to provide resilient, terrestrial, sovereign and high-quality timing for the UK's National Physical Laboratory time scale.
4. Develop a proposal for a distinct Ministry of Defence Time that would use the National Timing Center's timing to support the defense sector.
5. Develop a proposal for a resilient, terrestrial and sovereign Enhanced Long-Range Navigation (eLORAN) system.
6. For infrastructure resilience, roll out resilient GNSS receiver chips, develop holdover clocks and consider options for legislation on critical national infrastructure sectors to require minimum-resilient PNT.
7. Develop a proposal for a UK Satellite-Based Augmentation System (SBAS) to replace the use of the European Geostationary Navigation Overlay Service.
8. Explore options for Centers for Doctoral Training

in timing and PNT, and review PNT skills, education and training for long-term sovereign PNT capability.

9. Develop a PNT growth policy, including R&D program, standards and testing, to drive innovation for PNT-based productivity.
10. Develop next-generation PNT by deploying existing R&D funding into a UK Quantum Navigator and investigate possible options for a sovereign UK regional satellite system.

What follows is a top-tier review of the UK strategy as it compares and contrasts to the US approach, with closing thoughts on the way ahead.

At first glance, there appears to be a great deal of similarity between the US and UK's respective national approaches to strengthening PNT resilience. However, in the UK's case it now has a specific plan in place, and though it may be too early to predict how much of the desired resiliency will ultimately be funded and achieved, the US to date has mostly been focused on admiring the problem.

The UK strategy includes the establishment of a National PNT Office, much like the US National Coordination Office (NCO) for Space-based PNT.

Although the UK strategy states that the office will be responsible for policy, coordination and delivery, it is not specifically clear if it means the delivery of policy or the delivery of desired capabilities. This is similar to the US NCO, which is responsible for coordinating among PNT policy federal agencies but has no direct management or resourcing authority.

Concurrent with release of the strategy, John Pottle, the director of the Royal Institute of Navigation (RIN), optimistically opined in the RIN blog that, "The ownership provided by the National PNT Office will provide policy and delivery oversight, and co-ordination across all stakeholders. As well as improving national preparedness, the PNT framework



Doug Taggart
President
Overlook
Systems
Technologies, Inc.

has potential to help further strengthen the UK's thought leadership and innovation in robust and resilient PNT."

The tone of the strategy, earmarked by passive phrases such as: "develop a proposal for", found in #3, #4, #5, and #7; "retain and update", point #2; "consider options, explore options", #6 and #8, respectively; and "develop ... policy", #9; conveys that the authority to actually execute will be handled by some other unstated government sectors, which one must assume will have the budgetary authority to acquire the funding and ultimately execute the necessary collection of contracts.

In fact, in announcing the plan, the Science Minister stated, "For those actions that require additional spending commitments, the newly established National PNT Office...will work with other Government Departments over the coming months to develop business cases for this extra resource for consideration at the next Spending Round."

On a more optimistic front, the language of #10, "deploying existing R&D funding" does indicate evidence of direct funding to address issues of resiliency but the concluding phrase, "investigate possible options for a sovereign UK regional satellite system" leaves the impression that this was an agenda-driven outcome of a quid-pro-quo component of finally getting the strategy released, e.g., *we'll give you the R&D piece, but a sovereign UK space component must be part of the plan.*

A focus on space-based solutions is also an underlying component of the US "space-based" PNT activity specifically stated in the charter of the US National Space-based Executive Committee. This space-based emphasis has proven to be counterproductive when it comes to dealing with the establishment of a terrestrial backup to GPS, an on-going challenge that has been problematic following the closing of the US domestic Loran-C program in 2010. Since closure of domestic Loran, any attempts to rekindle interest within or by the US Space-based Executive Committee has been sidestepped by

citing that the office's charter is uniquely focused on "space-based" activities.

In that regard, and unlike in the US, it is encouraging to note that #5 in the UK plan specifically addresses an intention to make use of eLORAN technology, which is widely acknowledged as a viable backup for PNT capabilities.

Another encouraging element within the UK's strategy is the identification of a National Timing Center to provide "resilient, terrestrial, sovereign and high-quality timing" to the UK's underlying time-scale. Additionally, the NTC would provide a time source for a separate Ministry of Defence (MOD) Time, serving the UK military. As a dedicated focus for time management, it would propose to be a resilient timing source for the UK's National Physical Laboratory (NPL), a public corporation owned by the Department for Science, Innovation and Technology, and the source of official UK time contributing to global coordinated time calculation by the International Bureau of Weights and Measures (BIPM) in France.

Similarly, here in the US, timing responsibilities are borne by the US Naval Observatory (USNO), official time source for the US military and for GPS, and the US National Institute of Standards and Technology (NIST), both of which contribute a significant portion of timing services used in BIPM time calculations.


The UK plan also recognizes the need to educate and train the next generations of PNT scientists and engineers, a significant problem in the US with which the government has just begun to recognize and grapple. A significant decrease in the number and quality of educational programs noted as science, technology, engineering, and mathematics (STEM), and specifically in the areas of geophysical and geodetic science, means that the scientific and technology underpinnings which make GPS possible are eroding quickly as those who are skilled in those areas retire.

The UK plan is silent on opportunities to solicit and incorporate any public

outreach activity while US civil PNT outreach activity is very focused on public awareness and support to include the NCO's www.gps.gov website and the National Space-based PNT Advisory Board sponsored by NASA and operated under the authority of the Federal Advisory Committee Act.

As noted above, both the US and the UK coordinating activities are not granted direct budgeting authorities; those are retained within separate government departments. However, it should be noted that in making the announcement of the UK plan, the Science Minister included reference to a total of about £30 million being allocated to NTC development and to quantum PNT initiatives. That may be a significant start.

Referring back to the subtitle of this piece, we will have to wait awhile to learn in the end who is imitating whom. Since the advent of GPS, the US has been a global PNT leader, and the US clearly acknowledges the importance of PNT for national security and critical infrastructure purposes. However, talk is cheap; actions are what counts, and the US has become complacent in some areas, most notably in a persistent inability over more than a decade in achieving the goal of providing a resilient source of basic positioning and timing to backup GPS.

With its release of a strategic plan for national PNT services, and initial funding for its NTC vision, the UK has taken a major step forward in PNT leadership. It remains to be seen whether the US will continue to lead as well. 

Ambiguity-Fixing in Frequency-Varying Carrier Phase Measurements: Global Navigation Satellite System and Terrestrial Examples

A. Khodabandeh and P.J.G. Teunissen

The ultra-precise GNSS carrier phase measurements serve as key data in PNT. Although they can be made with a precision of the order of millimeters, each of these measurements is accompanied by an unknown offset. To exploit the carrier phase measurements in a PNT estimation platform, the corresponding offsets must be eliminated, or resolved, during the estimation process. The offsets consist of arbitrary cycle counts, called integer-cycle ambiguities, and fractional biases caused by each of the transmitter and receiver clocks.

As most navigation satellite systems employ the code division multiple access (CDMA) scheme to broadcast carrier phase signals on identical frequencies, the fractional bias of each transmitter (receiver) is equally sensed by the involved receivers (transmitters). As a consequence, the fractional biases can be simply eliminated through two successive differences of the carrier phase measurements: 1) between-receiver difference, and 2) between-transmitter difference. The resulting offsets would then only contain 'double-differenced' integer ambiguities which can, in turn, be resolved via integer ambiguity resolution (IAR) methods like LAMBDA, thereby essentially constructing ultra-precise pseudoranges from the carrier phase

signals to enable high-precision PNT.

Up to now, the rigorous applicability of IAR methods is confined to GNSS CDMA signals. However, there are several other radio-frequency measuring systems such as GLONASS, low Earth orbiting (LEO) communication satellites, or cellular long-term evolution (LTE) transmitters, which do not necessarily employ the CDMA scheme. For such systems having frequency-varying carrier phase signals, the transmitter and receiver fractional biases cannot be simply eliminated by the double-differencing combinations. This is because the receivers experience each

fractional bias proportional to its carrier frequency. This paper presents the theory and algorithmic tools that can identify the required integer-estimable combinations of non-CDMA carrier phase measurements, eliminating their associated fractional biases, thereby extending the applicability of IAR to non-CDMA measuring systems.

Just as with the classical GNSS ionosphere-free combinations that eliminate the effect of the first-order ionospheric refraction from GNSS signals, one can also identify combinations that can remove the fractional biases from the

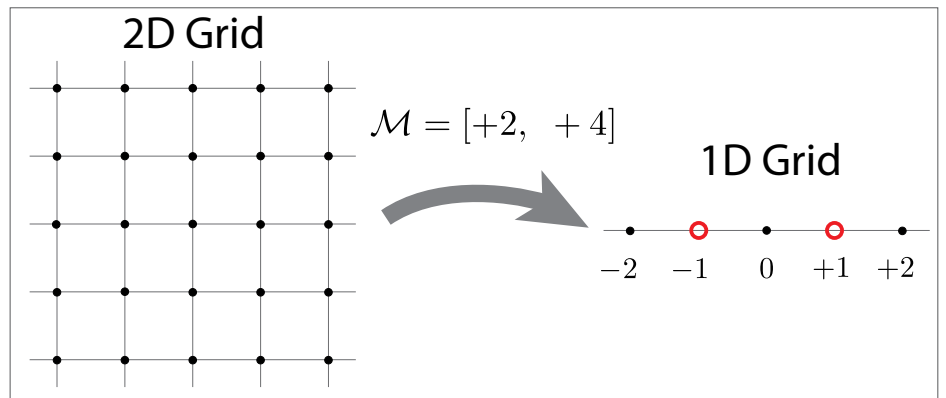


Figure 1. An inadmissible mapping 'M' from a 2D integer grid to its 1D counterpart. Despite being formed by the integer coefficients '2' and '4', the mapping 'M' fails to map integer vectors to the odd numbers, i.e., the red hollow dots.

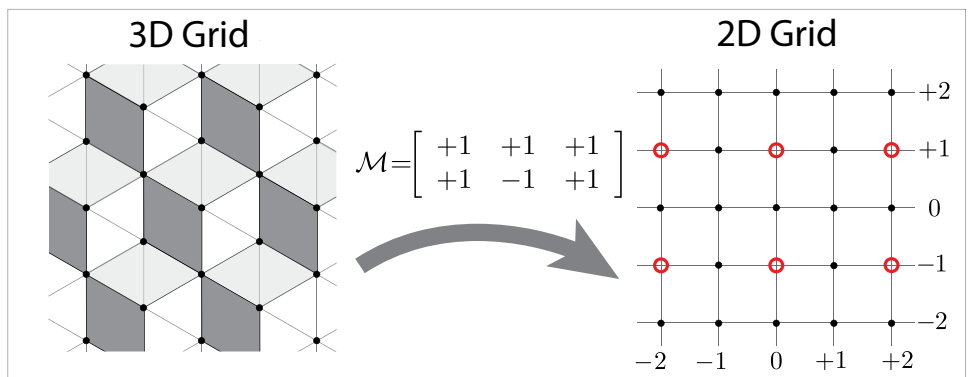


Figure 2. An inadmissible mapping 'M' from a 3D integer grid to its 2D counterpart. Despite being formed by the integer coefficients '+1' and '-1', the mapping 'M' fails to map 3D integer vectors to the 2D integer vectors (red hollow dots) whose first and second entries are even and odd numbers, respectively.

non-CDMA phase measurements. Unlike the ionosphere-free combinations, such combinations must be integer to preserve the integer-property of the phase ambiguities. Otherwise, the underlying IAR method is input by combinations that do not represent integer-valued quantities, failing to correctly resolve ambiguities, thereby deteriorating the corresponding carrier phase-based PNT solutions.

One may then be inclined to think that the coefficients of such combinations can be simply scaled up to become integer values. This paper illustrates that such integer coefficients still need to satisfy an important additional condition to deliver admissible inputs to IAR. For instance, consider Figure 1 in which the mapping ‘M’, with even numbers 2 and 4, maps two-dimensional (2D) integer vectors to their 1D combinations. Despite having integer entries, the mapping ‘M’ fails to map integer vectors to odd numbers (the red hollow dots in Figure 1). This implies that if an odd number is integer estimated by the IAR method, one in fact is computing an inadmissible ambiguity solution, since no integer ambiguities in the original 2D integer grid correspond to it. The so-computed solution would be physically impossible and thus wrong. Another example of an inadmissible mapping ‘M’, but now from a 3D grid, is shown in Figure 2. This mapping, with its integer coefficients ‘+1’ and ‘-1’, fails to deliver 2D integer vectors whose first and second entries are even and odd numbers, respectively.

Figure 3 compares two inadmissible integer mappings with an admissible one. As shown, there is no 3D integer vector $[z_1, z_2, z_3]$ that can be mapped by the two inadmissible mappings (in red) to the 2D integer vector $[1,1]$. However, the admissible mapping (in green) maps a subset of 3D integer vectors $[a-1, 3a-1, 7a-1]$ to the 2D integer vector $[1,1]$, where the scalar a is an arbitrary integer number.

Finding mappings with admissible integer coefficients becomes more involved when the dimension of the phase ambiguity vector increases, which in the

$$\begin{aligned}
 \mathcal{M}: \begin{bmatrix} -7 & 0 & 1 \\ 2 & 4 & -2 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} &\neq \begin{bmatrix} 1 \\ 1 \end{bmatrix} \\
 \mathcal{M}: \begin{bmatrix} 3 & 6 & -3 \\ 3 & -1 & 0 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} &\neq \begin{bmatrix} 1 \\ 1 \end{bmatrix} \\
 \mathcal{M}: \begin{bmatrix} 0 & -7 & 3 \\ -1 & -2 & 1 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} &= \begin{bmatrix} 1 \\ 1 \end{bmatrix} \rightarrow \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} = \begin{bmatrix} a-1 \\ 3a-1 \\ 7a-2 \end{bmatrix}
 \end{aligned}$$

Figure 3. Admissible (in green) versus inadmissible mappings (in red). There is no 3D integer vector $[z_1, z_2, z_3]$ that can be mapped by the two inadmissible mappings to the 2D integer vector $[1,1]$. However, the admissible mapping maps a subset of 3D integer vectors $[a-1, 3a-1, 7a-1]$ to the 2D integer vector $[1,1]$. The scalar a is an arbitrary integer number.

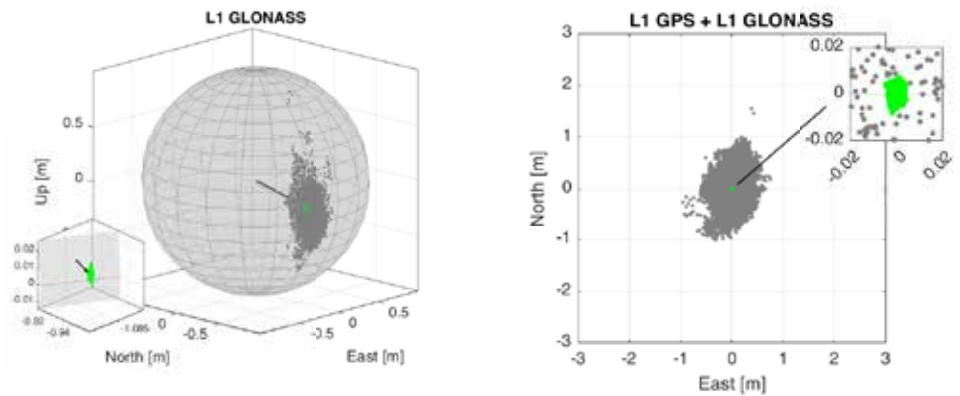


Figure 4. High-precision positioning solutions via GLONASS phase measurements. Left: single-frequency, GLONASS-only instantaneous direction-finding visualized by unit-sphere scatterplots. Right: single-frequency, GPS+GLONASS instantaneous positioning visualized by east-north scatterplots. The solutions are shown in grey (before IAR), in green (correctly fixed after IAR) and red dots (incorrectly fixed after IAR).

case of GNSS can become very large indeed. This paper introduces the required integer-estimability conditions, with corresponding algorithms, to automatically generate proper ambiguity mappings ‘M’, thus guaranteeing that only admissible IAR solutions are computed. This enables PNT users to directly apply the existing body of IAR knowledge to also measure systems that have frequency-varying carrier phase signals.

The paper shares the MATLAB source-code of the algorithm that produces admissible integer-estimable combinations. Several studies have employed the algorithm and show the performance of integer-estimability theory at work, particularly for high-precision PNT ap-

plications via the GLONASS Frequency Division Multiple Access (FDMA) carrier phase measurements. As an example, Figure 4 highlights the two orders of magnitude precision-improvement in the GLONASS-derived positioning solutions that are realized by successful IAR using integer-estimability theory.

Through its IAR-relaxation of signal frequency allocation among transmitters, the integer estimability theory provides new opportunities and applications for interferometric measuring systems. In the realm of PNT for instance, it enables the extension of standard GNSS IAR-methods, like LAMBDA, to non-conventional carrier phase signals of opportunity, e.g., such as those of LEO communication sat-

ellites and/or terrestrial LTE transmitters.

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

Khodabandeh, A., & Teunissen, P. J. G. (2023) Ambiguity-fixing in frequency-varying carrier phase measurements: GNSS and terrestrial examples. NAVIGATION, 70(2). <https://doi.org/10.33012/navi.580>

3D Vision Aided GNSS Real-Time Kinematic Positioning for Autonomous Systems in Urban Canyons

Weisong Wen, Xiwei Bai, and Li-Ta Hsu

The global navigation satellite system (GNSS) real-time kinematic (RTK) can provide centimeter-level positioning accuracy in open areas. However, its performance is significantly degraded in urban areas, due to the multipath and non-line-of-sight (NLOS) receptions caused by the signal reflections from the tall buildings. Moreover, the tall buildings block most of the satellites leading to degraded satellite geometry. To tackle these challenges, this paper developed a unique solution, the 3D vision-aided GNSS RTK positioning (3DVA GNSS RTK). In particular, the sky-pointing camera is employed to detect the NLOS satellites. The “virtual satellite” generated from the visual landmark is employed to improve the satellite geometry. As a result, the performance of the GNSS RTK is significantly improved with the help of the proposed method.

Experimental scenarios: To verify the effectiveness of the proposed method, two experiments were conducted in urban canyons (Figure 2) in Hong Kong. The top-left and bottom-left figures present the scenario of the evaluated urban canyons. Both urban scenarios contain static buildings, trees, and dynamic objects such as double-decker buses, which can cause potential GNSS NLOS receptions. To see how the proposed method works in scenarios with different levels of urbanization, we first experimented with a typical urban canyon in Hong Kong (urban

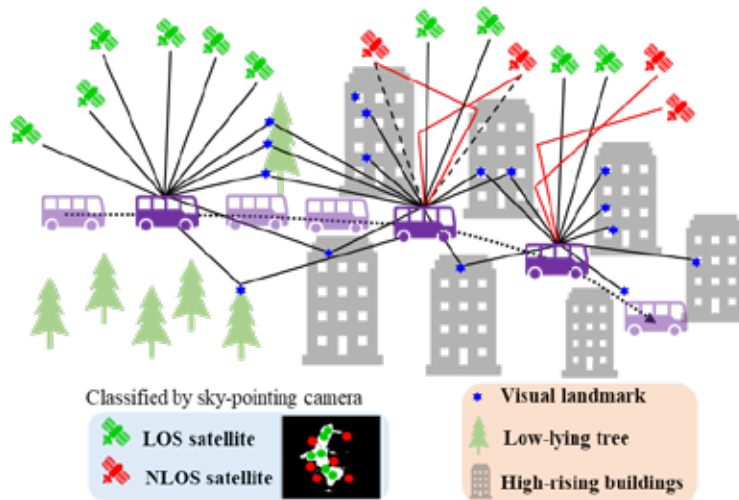


FIGURE 1. Demonstration of the strong complementarity between the low-lying visual landmarks and the healthy but high-elevation satellite measurements



FIGURE 2. Demonstration of the experimental vehicle and the evaluated urban canyons 1 and 2

canyon 1 in Figure 2-(a)). Subsequently, the other experiment was conducted in a more urbanized scenario (urban canyon 2 in Figure 2-(b)) with denser and taller building structures, which is more challenging for GNSS-RTK positioning.

Results and evaluation: In the experiment of urban canyon 1, the positioning error decreased from 1.83 meters using the conventional method to 0.84 meters using the proposed method. In the experiment of urban canyon 2, the positioning error decreased from 2.68



Applying the developed technology to autonomous driving vehicle testing.

meters using the conventional method to 1.37 meters using the proposed method. The positioning improvement shows the effectiveness of the proposed method.

The developed technology provides a new solution for the low-cost positioning service in complex urban areas. We are currently proposing to apply the developed technology to the unmanned aerial vehicle (UAV) industry. We are also currently applying the developed 3D vision-aided GNSS RTK positioning method to the testing of autonomous driving vehicles on the university campus.

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

Wen, W., Bai, X., & Hsu, L. (2023). 3D Vision aided GNSS real-time kinematic positioning for autonomous systems in urban canyons. NAVIGATION, 70(3). <https://doi.org/10.33012/navi.590>

Decimeter Positioning in an Urban Environment Through a Scalable Optical-Wireless Network

Christian Tiberius, Gerard Janssen, Jeroen Koelemeij, Erik Dierikx, Cherif Diouf, and Han Dun

This paper presents a terrestrial radio PNT system to complement GNSS in challenging built-up areas. The two innovative key-features are first, dissemination of a time and frequency reference over a fiber-optic Gigabit Ethernet network; and

second, the use of wideband radio signals to allow for accurate ranging by the mobile receiver. Using a fiber-optic network, a single atomic clock can drive the entire transmitter-infrastructure, rather than having to equip each transmitter with an atomic clock. The transmitters are synchronized to a common reference time scale at 0.5 ns level, or better. Wideband radio signals are used to overcome, to a large extent, the effects of multipath abundantly present in built-up areas. With the prototype system

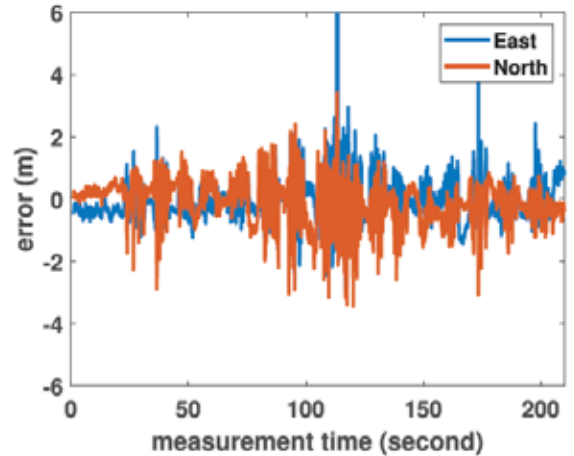


FIGURE 2. Horizontal positioning performance: at left, using 20 MHz of bandwidth, and at right, using 160 MHz of bandwidth; at a carrier frequency of 3.96 GHz (note that the range of the vertical axis in the two graphs differs by a factor of 10).



FIGURE 1. Setup of the experiment with the prototype system at The Green Village on the TU Delft campus. Several of the transmitter antennas are shown in this photograph (in red ellipses), and the receiver antenna is mounted on the roof of the car. Automated optical land-surveying equipment provided the ground-truth trajectory of the car on this local street.

a horizontal position accuracy of 0.1 m (rms) has been demonstrated in tests, with a mobile receiver, carried out on the TU Delft campus.

Though in the prototype initially 160 MHz of bandwidth was (entirely) used for ranging, soon the idea was born to use instead a virtual wideband signal, meaning

that only some small, frequency related, bands, each of for instance 10 MHz, are used, and these can be dispersed over a wide frequency range (e.g., 1 GHz). Ranging still enjoys – to a large extent – the high time resolution offered by the virtual wide bandwidth, yet at little spectral cost. The radio signals used in the prototype hint on integration in 5G mobile telecommunication networks.

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

Tiberius, C., Janssen, G., Koelemeij, J., Dierikx, E., Diouf, C., & Dun, H. (2023). Decimeter positioning in an urban environment through a scalable optical-wireless network. NAVIGATION, 70(3). <https://doi.org/10.33012/navi.589>



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GNSS Program Updates News from Systems Around the World

Kevin Dennehy

Galileo

Space X to Launch Four Galileo Satellites

SpaceX has signed a deal to launch as many as four Galileo navigation satellites into orbit in 2024. The satellites, through a \$192 million contract, will be launched onboard the SpaceX Falcon 9 rockets from the United States, according to published reports.

It's been a tough road for Galileo as Europe ended its relationships with Russia, which was to launch its satellites, when it invaded Ukraine in February 2022. Another option, the Ariane 5, was retired—and the Ariane 6 has been delayed.

“We had a couple of launches planned for mid-2022—and were ready to launch [onboard Russian Soyuz launch vehicles]. Then the war in Ukraine started,”

said Eric Chatre, European Commission head of Galileo Second Generation Project Office, at an ION conference.

An interesting point is that SpaceX will be launching satellites with classified payloads from a non-U.S. entity, according to published reports.

NavIC

ION member Qualcomm Technologies has announced its support for the recently launched L1 signals of India's Navigation and Indian Constellation (NavIC) in select chipset platforms. The company, which is working with the Indian Space Research Organization (ISRO), said the collaboration will accelerate the adoption of NavIC and enhance geolocation capabilities for use in mobile, automotive and IoT applications.

Qualcomm will offer a solution based

on its Location Suite, which supports as many as seven satellite constellations concurrently. These include all of NavIC's L1 and L5 signals for location, faster time-to-first fix position acquisition and location-based services, the company said.

Qualcomm said that additional support for the NavIC L1 signals will be available in select chipset platforms starting in the second half of 2024. However, the company said that commercial devices supporting NavIC L1 signals won't be available until the first half of 2025. India said it may make it mandatory for all 5G phones sold in the country to support NavIC by January 2025.

GLONASS

A Soyuz rocket launched the fifth satellite in Russia's GLONASS-K series on October. 9, 2023, from the Plesetsk

Cosmodrome, according to published reports. The satellite reached orbit successfully and received the designation Cosmos-2559, according to RussianSpaceWeb.com. Published reports indicate that the country launched a GLONASS-K2 satellite on board a Soyuz-2 rocket on August 7, 2023. The previous launch, in November 2022, saw a



A SpaceX Falcon 9 taking off in September 2023.
SpaceX

GLONASS-M satellite launched, which was the 61st and final GLONASS-M spacecraft.

BeiDou

China has launched two BeiDou Navigation Satellite System (BDS) satellites into medium-Earth orbit (MEO) in December. A Long March 3B rocket launched the navigation satellites from the Xichang Satellite Launch Center.

In other BDS news, the satellite system has been recognized by the International Civil Aviation Organization (ICAO) as a civil aviation standard, according to the country's Civil Aviation Administration. The agency said that the latest revised version of Annex 10 to the International Civil Aviation Convention is now effective, making BDS included in ICAO's standards.

GPS

The U.S. Space Force celebrated the 30th anniversary of the Global Positioning System (GPS) at Schriever Space Force Base on December 9, 2023. The GPS constellation first reached initial operating



Qualcomm to support NavIC's L1 signals with new products.
ISRO

capability (IOC) on December 8, 1993.

The 2nd Space Operations Squadron at Schriever has been providing support for the system for more than three decades, according to Lt. Gen. Stephen Whiting, Space Operations Command commander.

In other constellation news, space acquisition czar Frank Calvells said he expects the long-delayed Next-Genera-

tion Operational Control System (OCX) to be operational by June or July 2024, according to published reports. 🌟

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



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MEMBER NEWS



Schuyler "Clark" Wardrip, a founding organizer of the Precise Time and Time Interval (PTTI) Systems and Applications Meeting, passed away on August 13, 2023. Clark worked as an electrical engineer at the U.S. Naval Research Laboratory and NASA Goddard Space Flight Center where his area of expertise was precision atomic frequency standards development and time transfer systems. In 1969, he collaborated with the U.S. Naval Observatory to organize the first PTTI conference held at the Observatory. Clark authored more than 30 papers and technical reports, chaired the PTTI Executive Committee, established and chaired the PTTI Advisory Board, and received the 2003 Distinguished PTTI Service Award.



Sheila Faulkner, retired U.S. Department of State Foreign Service Officer and U.S. Naval Observatory Time Service Department Office Manager and scientific conference meeting planner, passed away June 6, 2023. Sheila served as the Precise Time and Time Interval (PTTI) Systems and Ap-

plications Meeting Executive Committee Chair, and meeting planner from 1985 to 1996, and after retirement continued as the PTTI meeting planner until 2012. In 1985, Sheila was instrumental in relocating the PTTI meeting from government facilities (NASA Goddard, NRL and USNO) to hotel conference centers in the Washington, D.C. area and California. Sheila is well remembered by the entire timing community as a creative and collaborative partner in the PTTI meeting's success.

SECTION NEWS

The New England Section of the Institute of Navigation held a meeting on June 28, 2023, at Draper where Ryan Cassel of The MITRE Corporation spoke on Quantum vs. Classical Complementary PNT. The presentation provided a summary of various complementary PNT techniques, identified where quantum technologies are likely to fit within the broader complementary PNT ecosystem, and encouraged a holistic consideration of quantum and classical technologies to support robust and resilient PNT. The presentation was followed by constructive questions and dialogue. The section hopes to host their next meeting soon.

The North Star Section is excited to announce that preparations for the 14th Autonomous Snowplow Competition are



ION Fellow, Prof. Terry Moore was recognized by HRH The Princess Royal with the Order of the British Empire for "Services to Satellite Navigation." Pictured with wife, Ingrid Moore, at Windsor Castle, October 3, 2023.

well underway. The event will be held January 19-20, 2024, on the campus of Dunwoody College of Technology in Minneapolis, Minnesota. This fun-filled competition challenges university and college students, to design, build and operate a fully autonomous snowplow to remove snow from a designated path.

Minnesotans love snow and the beautiful winter landscapes are enjoyed in our

Prof. Sunil Bisnath of York University (pictured center of photo in dark blue NAVIGATION jacket) with members of his lab and students celebrating ION GNSS+ Student Competition winner, Ding Yi (to right of Bisnath holding framed certificate), and recent ION webinar speakers Yi and Shihan Yang (sporting the NAVIGATION jackets).

Pictured: Benjamin Adu (MSc), Soroush Sasani (PhD), Jiahuan Hu (PhD), Pragati Basnet (MSc), Narin Gavilikilane (PhD), Sunil Bisnath (Prof), Ding Yi (PhD), Shihan Yang (PhD), Anurag Raghuvanshi (postdoc), Sogand Talebi (MSc), Sandesh Mishra (MSc), Caitlyn Hayden (BSc)



Calendar of Upcoming Events

MARCH 2024

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

Contact: Munich Satellite Navigation Summit
<https://www.munich-satellite-navigation-summit.org/>

APRIL 2024

16-18: ION Pacific PNT, Hilton Waikiki Beach, Honolulu, Oahu, Hawaii

Contact: ION
[ion.org](https://www.ion.org)

MAY 2024

22-24: European Navigation Conference (ENC), ESA ESTEC, Noordwijk, The Netherlands

Contact: <http://enc-series.org/2024>
[ion.org](https://www.ion.org)

JUNE 2024

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

Contact: ION
[ion.org](https://www.ion.org)

SEPTEMBER 2024

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

Contact: ION
[ion.org](https://www.ion.org)

OCTOBER 2024

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

Contact: IAIN
<https://www.iainav.org>

JANUARY 2025

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

Contact: ION
[ion.org](https://www.ion.org)

state. This annual event encourages students and others to utilize the state of the art in navigation and control technologies as they create and activate remarkably inventive snowplows, capable of amazing functions. Our ION Section also has a very good time doing it!

The competition will be using the same

T-shaped field as last year, to simulate a path coming out of a garage, down a driveway, and a 1-meter-wide sidewalk to plow. This path includes a challenging initial turn, with several tricky obstacles to avoid. Precise navigation remains the ultimate focus, and teams have used unique sensors with much success in past

and present competitions.

Eight teams have completed their preliminary design reviews and are ready to compete in January. We hope to have some serious fluffy white stuff by then in Minneapolis. "Let's Plow!" ❄️

Smartphone Decimeter Challenge



Google, the Institute of Navigation's Satellite Division, and Kaggle are sponsoring the 3rd Smartphone Decimeter Challenge at ION GNSS+.

The competition began September 12, 2023, and will end May 23, 2024. Over 150 new traces containing raw GNSS measurements, sensor data,

and precise ground truth will be publicly available. Participation in the competition is open to everyone. Participants are encouraged to submit an abstract to the session titled "Smartphone Decimeter Challenge" which will take place at ION GNSS+ 2024.

Competition Description:

Teams develop high precision GNSS positioning using a pool of GNSS & IMU datasets collected from smartphones, accompanied by high accuracy ground truth. They compete to achieve the best location accuracy with the datasets provided. To be eligible for

prizes, competitors must provide a technical paper, register for the ION GNSS+ 2024 conference and present their paper. Authors must submit a completed manuscript in proper form by June 30, 2024. See g.co/gnssstools for details.

The top three teams receive:

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

Additional Information

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



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