Received: 10 November 2022 | Revised: 10 November 2022 | Accepted: 11 November 2022

DOI: 10.33012/navi.551

EDITORIAL

Navigator Notes

Editorial Highlights from the Editor-in-Chief

Dr. Richard B. Langley
Editor of *NAVIGATION: Journal of the Institute of Navigation*
Email: lang@unb.ca

Welcome to the Winter 2022 issue of *NAVIGATION*. In this issue, we again feature articles on a wide range of topics including GNSS orbit and clock modeling, monitoring GNSS signals, characterizing the ionosphere and its effects on navigation, and improved GNSS positioning using a variety of tools.

ION continues to promote the research of journal authors through compulsory video abstracts hosted on the ION website. The latest video abstracts are documented below. You can find the video abstract for any recently published article under the article's supplemental menu item on the journal's website. ION also engages with the PNT community, through its webinar series, to highlight current topics of interest to the community. The most recent webinar is also documented below.

Remember, we have a dedicated website for our journal: https://navi.ion.org/. From the home page, you can find the current issue, early view articles to be compiled into the next issue, recent archived issues, and other information about the journal. The full archive of *NAVIGATION* is available on the ION website: https://www.ion.org/publications/browse.cfm.

VIDEO ABSTRACTS

Video Abstracts allow authors to present their research in their own words. This multimedia format communicates the background and context of authors' research in a quick and easy way, elevating research from simple print delivery.

Video for "Characterization and Performance Assessment of BeiDou-2 and BeiDou-3 Satellite Group Delays"
By Oliver Montenbruck, Peter Steigenberger, Ningbo Wang, and André Hauschild
(https://navi.ion.org/content/69/3/navi.526/tab-supplemental)

Abstract: Based on one year of data, a comprehensive assessment of broadcast group delays and differential code biases (DCBs) from network solutions is presented for all open BeiDou signals. Daily DCB estimates exhibit a precision of 0.1 ns, which also places a limit on long-term variations of the satellite group delays. On the other hand, the estimated DCBs show a notable dependence on the employed receivers, which causes inconsistencies at the few-nanosecond level between BeiDou-2 and BeiDou-3 satellites. Systematic satellite-specific offsets can likewise be identified in broadcast group delay values and clock offsets. These constitute the dominant contribution of the signal-in-space range error (SISRE) budget and are a limiting factor for single point positioning and timing. Use of the modernized B1C/B2a signals is therefore recommended instead of B1I/B3I. This offers a SISRE reduction from about 0.6 m to 0.45 m and also improves the consistency of precise clock and bias products derived from heterogeneous receiver networks.

Article Citation: Montenbruck, O., Steigenberger, P., Wang, N., & Hauschild, A. (2022). Characterization and performance assessment of BeiDou-2 and BeiDou-3 satellite group delays. *NAVIGATION, 69*(3). https://doi.org/10.33012/navi.526

Video for "AGPC-SLAM: Absolute Ground Plane Constrained 3D Lidar SLAM"
By Weisong Wen and Li-Ta Hsu
(https://navi.ion.org/content/69/3/navi.527/tab-supplemental)

Abstract: 3D lidar-based simultaneous localization and mapping (SLAM) is a well-recognized solution for mapping and localization applications. However, the typical 3D lidar sensor (e.g., Velodyne HDL-32E) only provides a very limited field of view vertically. As a result, the vertical accuracy of pose estimation suffers. This paper aims to alleviate this problem by detecting the absolute ground plane to constrain vertical pose estimation. Different from the conventional relative plane constraint, this paper employs the absolute plane distance to refine the position in the z-axis and the norm vector of the ground plane to constrain the attitude drift. Finally, relative positioning from lidar odometry, constraint from ground plane detection, and loop closure are integrated under a proposed factor graph-based 3D lidar SLAM framework (AGPC-SLAM). The effectiveness is verified using several data sets collected in Hong Kong.

Article Citation: Wen, W., & Hsu, L.-T. (2022). AGPC-SLAM: Absolute ground plane constrained 3D lidar SLAM. *NAVIGATION, 69*(3). https://doi.org/10.33012/navi.527

Video for "Modified CEMIC Scheme for Multiplexing Signals Over Single Frequency Band"
By Vijay Singh Bhadouria, Dhaval J. Upadhyay, Parimal J. Majithiya, and Subhash Chandra Bera
(https://navi.ion.org/content/69/3/navi.528/tab-supplemental)

Abstract: The paper presents a modified Constant Envelope Multiplexing with Intermodulation Construction (CEMIC) technique for multiplexing signals within a single frequency band. A constant envelope signal is necessary to operate a transponder at maximum efficiency. This paper proposes a novel scheme to incorporate backwards compatibility constraints into the cost function of the existing CEMIC scheme to minimize changes in the onboard navigation system and ground receivers. The proposed scheme maximizes multiplexing efficiency by optimizing signal power sharing as per system requirements. Simulation results indicate that the proposed scheme provides 0.1% to 13.7% better efficiency than the existing CEMIC scheme, depending upon the case severity. Furthermore, the power distribution and phasing of the individual intermodulation constituent signals are optimized to minimize intra-system and inter-system interference. As a result, the proposed scheme facilitates frequency coordination with GNSS service providers. The paper also discusses the hardware performance of the proposed scheme's composite signal.

Article Citation: Bhadouria, V.S., Upadhyay, D.J., Majithiya, P.J., & Bera, S.C. (2022) Modified CEMIC scheme for multiplexing signals over single frequency band. *NAVIGATION, 69*(3). https://doi.org/10.33012/navi.528

Video for "Precise Onboard Time Synchronization for LEO Satellites"
By Florian Kunzi and Oliver Montenbruck
(https://navi.ion.org/content/69/3/navi.531/tab-supplemental)

Abstract: Onboard time synchronization is an important requirement for a wide range of low Earth orbit (LEO) missions such as altimetry or communication services, and extends to future position, navigation, and timing (PNT) services in LEO. For GNSS-based time synchronization, continuous knowledge about the satellite's position is required and, eventually, the quality of the position solution defines the timing precision attainable through GNSS measurements. Previous research has shown that real-time GNSS orbit determination of LEO satellites can achieve decimeter-level accuracy. This paper characterizes the performance of GNSS-based real-time clock synchronization in LEO using the satellite Sentinel-6A as a real-world case study. The satellite's ultra-stable oscillator (USO) and triple-frequency GPS/Galileo receiver provide measurements for a navigation filter representative of real-time onboard processing. Continuous evaluation of actual flight data over 14 days shows that a 3D orbit root-mean-square (RMS) error of 11 cm and a 0.9-ns clock standard deviation can be achieved.

Article Citation: Kunzi, F., & Montenbruck, O. (2022). Precise onboard time synchronization for LEO satellites. *NAVIGATION, 69*(3). https://doi.org/10.33012/navi.531

Video for "The Role of Antennas on GNSS Pseudorange and Multipath Errors and Their Impact on DFMC Multipath Models for Avionics"
By Stefano Caizzone, Mihaela-Simona Circiu, Wahid Elmarissi, Christoph Enneking, Markus Rippl, and Matteo Sgammini
(https://navi.ion.org/content/69/3/navi.532/tab-supplemental)

Abstract: Current satellite navigation systems are providing more and more dual-frequency capabilities, enabling improved navigation accuracy and a reduction of residual errors (e.g., from ionosphere). Recently, the aviation community has started an effort to achieve new standardized Minimum Operational Performance Specifications (MOPS) for GNSS equipment in order to allow for the use of dual-frequency multi-constellation (DFMC) systems in the future, with clear benefits in terms of obtainable navigation performance. In such conditions, residual errors introduced by the user GNSS antenna become even more relevant and need to be properly identified and bounded, both in antenna specifications and in the models for aircraft multipath. The present work investigates this problem and shows the results of an activity aiming at new airborne multipath models for L1/E1 and L5/E5a frequency bands and for their ionospheric-free combination. The paper outlines a detailed investigation of the physical rationale of such errors.

Article Citation: Caizzone, S., Circiu, M.-S., Elmarissi, W., Enneking, C., Rippl, M., & Sgammini, M. (2022). The role of antennas on GNSS pseudorange and multipath errors and their impact on DFMC multipath models for avionics. *NAVIGATION, 69*(3). https://doi.org/10.33012/navi.532

Video for "GPS-Denied Navigation Aided by Synthetic Aperture Radar Using the Range-Doppler Algorithm"
By Colton Lindstrom, Randall Christensen, Jacob Gunther, and Scott Jenkins
(https://navi.ion.org/content/69/3/navi.533/tab-supplemental)

Abstract: The need to successfully navigate in the absence of GNSS has grown in recent years. In particular, light aircraft such as UAVs are growing in popularity for a variety of applications vulnerable to GPS denial. The research presented here develops a GPS-denied navigation scheme for light aircraft employing images formed from a synthetic aperture radar system. Past research has explored the utility of radar telemetry in GPS-denied systems. This research advances previous work by exploiting radar images to obtain range and cross-range position measurements. Images are formed using the Range-Doppler Algorithm, an efficient image formation algorithm ideal for the sometimes limited processing packages available to light aircraft. An inertial navigation and radar processing system is implemented using both real and simulated radar images to aid in estimating an aircraft's state in a GPS-denied environment. The results show that navigation in the absence of GPS using synthetic aperture radar is feasible with converging and bounded estimation errors.

Article Citation: Lindstrom, C., Christensen, R., Gunther, J., & Jenkins, S. (2022) GPS-denied navigation aided by synthetic aperture radar using the Range-Doppler Algorithm. *NAVIGATION, 69*(3). https://doi.org/10.33012/navi.533

Video for "Developing a Spoofer Error Envelope for Tracking GNSS Signals"
By Tobias Bamberg, Andriy Konovaltsev, and Michael Meurer
(https://navi.ion.org/content/69/3/navi.534/tab-supplemental)

Abstract: Global navigation satellite systems (GNSSs) are the most significant service for global positioning and timing. The high relevance and wide spread of these systems contrast with the risk for interference or even manipulations of GNSS signals. One specific threat is GNSS spoofing. A spoofer counterfeits satellite signals to mislead the receiver to an erring position/time estimation. The technological progress enabling affordable and easy-to-use spoofer hardware further increases the relevance of this threat. To maintain the integrity of the position/time information, it is mandatory to be able to assess the errors induced by spoofing. The paper at hand derives a bound of the code tracking bias in relevant spoofing scenarios extending the well-known Multipath Error Envelope. These new bounds can be used as a tool to estimate the position/time error, especially but not exclusively for receivers that are collateral damage of a spoofing attack.

Article Citation: Bamberg, T., Konovaltsev, A., & Meurer, M. (2022). Developing a Spoofer Error Envelope for tracking GNSS signals. *NAVIGATION, 69*(3). https://doi.org/10.33012/navi.534

Video for "Deterministic Heading-Independent Celestial Localization Measurement Model"
By Ilija Jovanovic and John Enright
(https://navi.ion.org/content/69/3/navi.529/tab-supplemental)

Abstract: Planetary rover navigation frequently relies on dead reckoning and external infrastructure such as orbiting satellites. Celestial navigation techniques

combine measurements of the Sun, stars, and gravity to provide autonomous absolute localization. This study examines the performance of digital star sextants (DSS)—a suite of sensors combining a star tracker and an inclinometer—on estimating position on the planetary surface. In particular, we discuss the estimation, calibration, and error analysis for an elevation-only measurement formulation that does not rely on ground-truth heading information. Field tests and Monte Carlo simulations provide validation of the proposed techniques. The real-world performance of the experimental system gives a mean single-orientation error of 296 m. The relative agreement between the predicted and observed error reveals a clear roadmap to help evaluate the impact of prospective sensor improvements on DSS performance.

Article Citation: Jovanovic, I., & Enright, J. (2022). Deterministic heading-independent celestial localization measurement model. *NAVIGATION, 69*(3). https://doi.org/10.33012/navi.529

Video for "Detecting GNSS Jamming and Spoofing on Android Devices"
By Nicholas Spens, Dong-Kyeong Lee, Filip Nedelkov, and Dennis Akos
(https://navi.ion.org/content/69/3/navi.537/tab-supplemental)

Abstract: Global navigation satellite system (GNSS) location engines on Android devices provide location and navigation utility to billions of people worldwide. However, these location engines currently have very limited protection from threats to their position, navigation, and time (PNT) solutions. External sources of radio frequency interference (RFI) can render PNT information unusable. Even worse, false signals or spoofing can provide a false PNT solution to Android devices. To mitigate this, four detection methods were developed and evaluated using native location parameters within Android: Comparing the GNSS and network locations, checking the Android mock location flag, comparing the GNSS and Android system times, and observing the automatic gain control (AGC) and carrier-to-noise density (C/N0) signal metrics. These methods provide a powerful means to significantly increase the robustness of the Android GNSS-based PNT solution and are implemented in the GNSSAlarm Android application to demonstrate real-time jamming and spoofing detection.

Article Citation: Spens, N., Lee, D.-K., Nedelkov, F., & Akos, D. (2022). Detecting GNSS jamming and spoofing on Android devices. *NAVIGATION, 69*(3). https://doi.org/10.33012/navi.537

Video for "Gain Pattern Reconstruction of GPS Satellite Antennas Using a Global Receiver Network"
By Gerardo Allende-Alba, Steffen Thoelert, and Stefano Caizzone
(https://navi.ion.org/content/69/3/navi.530/tab-supplemental)

Abstract: For GNSS signal power monitoring systems, the characterization of satellite antennas plays an important role. Recently, gain pattern reconstructions of Galileo satellite antennas have been obtained using single-station observations. However, due to the characteristics of GPS orbits, such an approach is less suitable for GPS satellite antennas. This study introduces a methodology for multi-station satellite antenna gain pattern reconstruction. To overcome the unavailability of receiver antenna gain patterns at the employed stations, a dedicated algorithm is introduced that uses an antenna at a base station to remotely characterize the antennas in network stations. Obtained reconstructions of L1 antenna gain patterns of selected GPS satellites show a consistency at the 0.3–0.4 dB level (95%) with data provided by the manufacturer and better than 0.3 dB (95%) with ground-based observations using a high-gain antenna. The introduced methodology may be employed in the establishment of permanent multi-constellation GNSS signal power monitoring systems.

Article Citation: Allende-Alba, G., Thoelert, S., & Caizzone, S. (2022). Gain pattern reconstruction of GPS satellite antennas using a global receiver network. *NAVIGATION, 69*(3). https://doi.org/10.33012/navi.530

Video for "Time Transfer From GPS for Designing a SmallSat-Based Lunar Navigation Satellite System"
By Sriramya Bhamidipati, Tara Mina, and Grace Gao
(https://navi.ion.org/content/69/3/navi.535/tab-supplemental)

Abstract: For the future lunar navigation satellite system (LNSS), a GPS-like constellation for the Moon, NASA has expressed interest in using a smallsat platform. However, many design decisions have yet to be finalized, including the orbit, constellation, and onboard clock. Furthermore, designing a dedicated smallsat-based LNSS limits the payload capacity, thus restricting the size, weight, and power (SWaP) of the onboard clock. We propose an LNSS design with time transfer from intermittently available GPS signals wherein we design a Kalman filter to estimate timing corrections for a low-SWaP clock. Additionally, we devise a lunar User Equivalent Range Error (UERE) metric to characterize the ranging accuracy of signals transmitted by an LNSS satellite. We further validate our time-transfer technique with simulations of an LNSS satellite in an elliptical lunar frozen orbit (ELFO) with an onboard chip scale atomic clock (CSAC) while analyzing the visibility effects of GPS, timing errors, and lunar UERE across ELFOs.

Article Citation: Bhamidipati, S., Mina, T., & Gao, G. (2022). Time transfer from GPS for designing a smallsat-based Lunar Navigation Satellite System. *NAVIGATION, 69*(3). https://doi.org/10.33012/navi.535

Video for "ONCLE (One Clock Ensemble) for Galileo's Next-Generation Robust Timing System"
By Qinghua Wang and Pascal Rochat
(https://navi.ion.org/content/69/3/navi.536/tab-supplemental)

Abstract: This paper presents the ONCLE (One Clock Ensemble) solution for the Galileo time and frequency reference system with advanced features in terms of robustness, performance, continuity, and simplicity. Each component clock is frequency-steered to the ensemble time, which itself creates an average of those steered clock outputs, while clock faults are detected and corrected in real time within an integrated system. The feasibility of algorithm and hardware approaches has been demonstrated on an elegant breadboard and verified by an extended test and validation campaign at the Engineering Model (EM) level, developed for the Galileo next-generation onboard timing system under European GNSS Evolutions Program. Based on the progress for space application and the heritage on the Galileo ground precise timing facility (PTF), we propose a robust solution for the upgrade of PTF for ground application aiming to provide a fully continuous and performance-improved timescale under automated operation. The capability is demonstrated by preliminary simulation results.

Article Citation: Wang, Q., & Rochat, P. (2022). ONCLE (One Clock Ensemble) for Galileo's next-generation robust timing system. *NAVIGATION, 69*(3). https://doi.org/10.33012/navi.536

WEBINARS

ION Webinars highlight timely and engaging articles published in *NAVIGATION* and other topics of interest to the PNT community in an interactive virtual presentation.

October 27, 2022 Webinar: Impact of GNSS-Band Radio Interference on Operational Avionics
By Michael Felux and Okuary Osechas
(https://www.ion.org/publications/webinar-osechas.cfm)

Abstract: GNSS outages due to intentional jamming affecting the airspace over the Eastern Mediterranean have received significant attention in recent years. In an effort to better understand the phenomenon and its impact on aviation hardware, DLR sent a data collection flight to the area. The flight was conducted in an Airbus 320, which allowed a study of the behavior of regular avionics and aviation-grade GNSS receivers under jamming conditions. Part of the experimental instrumentation included a high-definition radio-frequency recording device, which allows in-depth pre-correlation analysis of the radio spectrum around the main GPS and Galileo carrier frequencies. The results confirm that the observed outages likely stem from man-made radio interference. They also provide an in-situ opportunity to study the behavior of commercial avionics under GNSS interference conditions.

Article Citation: Osechas, O., Fohlmeister, F., Dautermann, T., & Felux, M. (2022). Impact of GNSS-band radio interference on operational avionics. *NAVIGATION, 69*(2). https://doi.org/10.33012/navi.516

How to cite this article: Langley, R. B. (2022). Navigator notes: Editorial highlights from the Editor-in-Chief. *NAVIGATION, 69*(4). https://doi.org/10.33012/navi.551