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EDITORIAL

Navigator Notes

Editorial Highlights from the Editor-in-Chief

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Welcome to the Fall 2024 issue of *NAVIGATION*. We have some big news to report. *NAVIGATION*'s Journal Impact Factor (JIF) has jumped to 3.1 in the latest (2023) report from Clarivate! This is the highest it has ever been and, furthermore, the journal is now in the top 10 of all aerospace engineering journals. As most of you know, a journal's JIF is based on the number of times its recently published articles are cited by other articles. It indicates the relative importance of a journal within its field. A journal with a higher impact factor is generally viewed as publishing more significant and timely research. The increase in our JIF is down to the dedication of our expert associate editors and reviewers, the hard-working ION headquarters staff, and to the authors who choose to submit their manuscripts to *NAVIGATION*, whether they are graduate students just starting out in their careers or seasoned professionals with many published articles. Thanks to all of you for making *NAVIGATION* such a well-respected journal.

As part of the celebration of the increase in our impact factor, I would like to recognize the following paper from 2021 that received the most citations in 2023:

> Wen W., Pfeifer T., Bai X., & Hsu L.-T. (2021). Factor graph optimization for GNSS/INS integration: A comparison with the extended Kalman filter. *NAVIGATION*, *68*(2). https://doi.org/10.1002/navi.421

I would also like to specifically acknowledge the efforts of all the stalwart associate editors, both present and past, who have contributed to *NAVIGATION* and made it an outstanding vehicle for positioning, navigation, and timing academic publication.

In this issue, we continue to publish a variety of articles across the whole spectrum of positioning, navigation, and timing. We have articles on CubeSat navigation and attitude determination, the security of GNSS positioning and navigation, estimating accelerometer errors, and the use of factor graphs in positioning and navigation (including a tutorial on the subject) among others.

ION promotes the research of journal authors in a variety of ways including 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.

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 "Geodetic Altitude from Barometer and Weather Data for GNSS Integrity Monitoring in Aviation"
By Maximilian Simonetti and Omar García Crespillo (https://navi.ion.org/content/71/2/navi.637/tab-supplemental)

Abstract: Vertical navigation is crucial for safe aircraft separation and has been traditionally based on the pressure altitude provided by barometric altimeters. New aviation operations require robust determination of geodetic altitude and are expected to primarily rely on a global navigation satellite system (GNSS). Because deviations between pressure and geodetic altitudes can reach hundreds of meters, an altitude harmonization is needed to use barometers in combination with GNSS. In this paper, we first present a methodology to compute an accurate geodetic altitude from barometer and external weather data. Secondly, we derive error and threat models of this geodetic altitude. Finally, we employ these models within a GNSS integrity monitoring algorithm augmented with the derived altitude. We assess our methodologies against flight test measurements and availability simulations of localizer performance with vertical guidance operations. These analyses illustrate the potential benefits of employing barometers as augmentation or stand-alone systems for geodetic altitude navigation.

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

Video for "GPS Spoofing-Resilient Filtering Using Self-Contained Sensors and Chimera Signal Enhancement"
By Tara Mina, Ashwin Kanhere, Akshay Shetty, and Grace Gao (https://navi.ion.org/content/71/2/navi.636/tab-supplemental)

Abstract: To protect civilian Global Positioning System (GPS) users from spoofing, the Air Force Research Lab has developed the chips-message robust authentication (Chimera) signal enhancement for the GPS L1C signal. With Chimera, standalone receivers that only have access to the GPS signal will be able to authenticate their received measurements once every 3 min, whereas users with access to an out-of-band source will be able to perform authentication once every 1.5 or 6 s. However, moving receivers typically rely on much faster real-time GPS update rates of 1–20 Hz. In this work, we design a spoofing-resilient filter framework that provides continuous and secure state estimation between Chimera authentication times. By leveraging self-contained sensors on-board the vehicle, such as an inertial measurement unit or wheel encoder, as well as the periodic Chimera authentication, our proposed filter determines how much to rely on the received unauthenticated GPS measurements for state estimation. In this respect, our filter relies more extensively on GPS measurements in order to improve real-time navigation performance and reduce localization errors when GPS signals are authentic, while successfully mitigating spoofing-induced errors during an experienced attack. We experimentally validate our proposed spoofing-resilient filter in a simulated test

environment for a ground vehicle model with access to the 3-min Chimera channel, under various simulated spoofing attack scenarios. To the best of the authors' knowledge, this is the first adaptive filter proposed for Chimera that continuously leverages real-time GPS measurements in a spoofing-resilient manner.

Article Citation: Mina, T., Kanhere, A., Shetty, A., & Gao, G. (2024). GPS spoofing-resilient filtering using self-contained sensors and Chimera signal enhancement. *NAVIGATION, 71*(2). https://doi.org/10.33012/navi.636

Video for "Synthesized Binary Offset Carrier Modulation for Interoperable GNSS L1 Band Signals"
By Dhaval J. Upadhyay, Vijay S. Bhadouria, Parimal J. Majithiya, and Subhash C. Bera (https://navi.ion.org/content/71/2/navi.640/tab-supplemental)

Abstract: This paper presents a constant-envelope modulation scheme, based on a synthesized binary offset carrier (SBOC), for a global navigation satellite system (GNSS) that combines three signals in a nonlinear fashion with unequal amplitudes. The proposed SBOC modulation meets the power spectral density criteria of multiplexed binary offset carrier (MBOC) modulation used in the L1 frequency band (1575.42 MHz) open civilian service interoperable signals for GNSS. This SBOC modulation also allows for the selection of an arbitrary power-sharing ratio between the data and pilot signals. This approach provides better performance than various MBOC(6, 1, 1/11) modulations for narrowband receivers.

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

Video for "Enhancing Navigation Accuracy in a Geostationary Orbit by Utilizing a Regional Navigation Satellite System"
By Yu Nakajima and Toru Yamamoto (https://navi.ion.org/content/71/2/navi.641/tab-supplemental)

Abstract: This paper presents an innovative approach aimed at enhancing satellite position determination accuracy within a geostationary equatorial orbit (GEO) by integrating a regional navigation satellite system (RNSS) with a global navigation satellite system (GNSS). In a GEO, incoming GNSS signals are typically constrained to a specific direction on the other side of the Earth, resulting in a significant dilution of precision (DOP) and, consequently, a significant radial error. By incorporating an RNSS, signals from more diverse directions are available, improving observability and enhancing navigation precision. Taking the quasi-zenith satellite system (QZSS) as a representative RNSS, this paper demonstrates the feasibility of receiving signals from GEO satellites across a substantial range. Link budget analyses were conducted using the precise side-lobe patterns of the QZSS, revealing that QZSS signals can be consistently observed across most arcs in a GEO. Two comprehensive simulations were conducted: a point solution and an extended Kalman filter-based orbit determination. The results affirm the anticipated improvement in navigation precision indicated by the DOP analysis. It is essential to note that whereas RNSS signals can be received from any longitude in a GEO, enhanced navigation precision relies on the distance from the satellite to the RNSS. Considering the availability of multiple RNSS options, the concept presented in this research can be adapted to any longitude within a GEO, thereby promoting stable, high-precision navigation.

Article Citation: Nakajima, Y., & Yamamoto, T. (2024). Enhancing navigation accuracy in a geostationary orbit by utilizing a regional navigation satellite system. *NAVIGATION, 71*(2). https://doi.org/10.33012/navi.641

Video for "Improved Time-Step Method for Bounding Nominal Spatial and Temporal Ionospheric Gradients for Ground-Based Augmentation Systems in Hong Kong"
By Wang Li and Yiping Jiang (https://navi.ion.org/content/71/2/navi.642/tab-supplemental)

Abstract: A ground-based augmentation system (GBAS) is a critical component in civil aviation that augments the Global Positioning System (GPS) in providing precision approach and landing capabilities with guaranteed accuracy and integrity. The GBAS ground facility broadcasts a parameter known as σ_{vig} to the aircraft, which is used to compute vertical protection levels for evaluating navigation integrity. σ_{vig} represents the standard deviation of the vertical ionospheric gradients, which bounds the spatial gradients under nominal conditions. Although the time-step method has been widely utilized to estimate ionospheric spatial gradients, this strategy suffers from temporal effects. In this paper, an improved time-step method is developed for separating temporal gradients from spatial gradients using observation data collected from the Hong Kong Satellite Positioning Reference Station Network. We investigated two parameters: σ_{tg}, which bounds the standard deviation of temporal gradients, and σ_{vig}. The results show that a constant value of 5.5 mm/km can serve as an upper bound for all σ_{tg} values. However, the results of σ_{vig} vary seasonally, with maximum and minimum values occurring at the equinoxes and summer, respectively. To reflect this seasonality, quadratic polynomial expressions, given as functions of the day of the year, were derived to provide an upper bound for all σ_{vig} values.

Article Citation: Li, W., & Jiang, Y. (2024). Improved time-step method for bounding nominal spatial and temporal ionospheric gradients for ground-based augmentation systems in Hong Kong. *NAVIGATION, 71*(2). https://doi.org/10.33012/navi.642

Video for "Digital Twin-Enabled Characterization of GNSS Multipath in Challenging Reference Stations Using a Dual-Polarized Probe"
By Ernest Ofosu Addo, Wahid Elmarissi, and Stefano Caizzone (https://navi.ion.org/content/71/2/navi.644/tab-supplemental)

Abstract: Reference stations constitute important elements within the global navigation satellite system (GNSS) infrastructure, as they provide valuable measurements for performance monitoring. For high-quality measurements from such stations, local error sources should be properly characterized and compensated for or minimized. Multipath remains a major contributor to these errors. In severe occurrences, multipath can cause critical errors in sensitive systems such as those utilized for code-dependent applications. This paper discusses a method for GNSS multipath characterization in challenging installation scenarios, based on a dual-polarization antenna and its integration in a hybrid measurement–simulation framework. A dedicated dual-polarized probe, which houses both an effective geodetic antenna and a multipath-susceptible antenna, was designed, manufactured, and assessed. The dual-sensing nature of the probe allows auxiliary information to be acquired about multipath generated by nearby objects and can be used to

infer a plausible range of expected multipath-induced code error at a GNSS sensor station. In addition, a ray-tracing method is discussed, in which antenna measurements are integrated into digital-twin simulations of installations for characterizing multipath conditions. Finally, this study demonstrates that by combining the DPA with digital-twin simulations, it is possible to predict multipath error bounds at an installation in advance. This combined technique presents a flexible tool that is useful for planning system performance with respect to multipath, site layout/selection, and even optimal receiving antenna placement at a given installation. The proposed simulative method is validated through field experiments, and tests with commercial geodetic-grade antennas are presented to confirm the capability of this method to predict their performance ranges.

Article Citation: Addo, E. O., Elmarissi, W., & Caizzone, S. (2024). Digital twin-enabled characterization of GNSS multipath in challenging reference stations using a dual-polarized probe. *NAVIGATION, 71*(2). https://doi.org/10.33012/navi.644

Video for "Real-Time Precise Point Positioning Method Considering Broadcast Ephemeris Discontinuities"
By Quanrun Cheng, Junping Chen, Yize Zhang, and Chao Yu (https://navi.ion.org/content/71/2/navi.643/tab-supplemental)

Abstract: With advancements in the broadcast ephemeris accuracy of global navigation satellite systems (GNSSs), precise point positioning based on broadcast ephemeris (BE-PPP) is gradually showing promising prospects. However, the periodic updates of GNSS ephemeris result in discontinuities in the satellite orbit and clock offset during handovers. These discontinuities can significantly impact positioning accuracy. In this study, we calculate the combined ephemeris discontinuities, which indicate a linear combination of satellite radial orbit and clock discontinuities. We then compensate for the combined ephemeris discontinuities in the subsequent satellite clocks prior to positioning. For BeiDou Navigation Satellite System 3 (BDS-3) and the Global Positioning System (GPS), the three-dimensional (3D) position accuracy in kinematic mode is improved by 30–50 cm, reaching 33.9 cm. For GPS/Galileo/BDS-3 triple-constellation kinematic solutions, the accuracy reaches 23.2 cm. In static mode, the 3D position accuracy is 14.6 cm for BDS-3-only positioning and 15.1 cm for GPS. For GPS/Galileo/BDS-3 triple-constellation static BE-PPP solutions, the 3D position accuracy improves to 8 cm.

Article Citation: Cheng, Q., Chen, J., Zhang, Y., & Yu, C. (2024). Real-Time precise point positioning method considering broadcast ephemeris discontinuities. *NAVIGATION, 71*(2). https://doi.org/10.33012/navi.643

Video for "Adaptive Multiple-Model Kalman Filter for GNSS Carrier Phase and Frequency Estimation Through Wideband Interference"
By Wengxiang Zhao, Samer Khanafseh, and Boris Pervan (https://navi.ion.org/content/71/2/navi.646/tab-supplemental)

Abstract: Interference events, both intentional and unintentional, are significant threats to global navigation satellite system (GNSS) service continuity. In the presence of interference, it can be difficult for GNSS receivers to maintain continuous tracking of carrier phase and frequency. To address this issue, in place of a traditional phase-locked loop (PLL), we develop and validate a new estimation-based

approach to allow GNSS receivers to correctly estimate carrier phase and frequency under conditions of low carrier-to-noise power. An adaptive Kalman filter forms the core of the estimator, with a multiple model algorithm to account for discrete navigation data bit transitions. The performance of the estimator in the presence of wideband interference is validated through simulation and experiment, showing performance markedly superior to that of a PLL.

Article Citation: Zhao, W., Khanafseh, S., & Pervan, B. (2024). Adaptive multiple-model Kalman filter for GNSS carrier phase and frequency estimation through wideband interference. *NAVIGATION*, 71(2). https://doi.org/10.33012/navi.646

Video for "Can Numerical Simulations of Equatorial Plasma Bubble Plume Structures be Simplified for Operational and Practical Usage?"
By Rezy Pradipta, Charles S. Carrano, Keith M. Groves, and Patricia H. Doherty (https://navi.ion.org/content/71/2/navi.645/tab-supplemental)

Abstract: We argue the merits of having a simplified method to simulate equatorial plasma bubble (EPB) plume structures for practical usage. The capability to realistically model EPB plume structures in simulations would be advantageous when assessing the severity of ionospheric threats. Such advantages would arise because a realistic model of EPB plume structures could allow nonstationary scintillation signals to be simulated. Although EPB plume structures can be modeled via first-principle physics-based models, these models tend to be computationally demanding. High-performance computing facilities might be able to offer some remedy, but serious handicaps would remain for those without access to such advanced facilities. We investigated multiple options that utilize the diffusion-limited aggregation (DLA) fractal process to generate bifurcating structures that resemble typical EPB plume structures. We combined the DLA algorithm with the International Reference Ionosphere model to simulate EPBs in three dimensions. Initial tests of this modeling approach indicate promising results.

Article Citation: Pradipta, R., Carrano, C. S., Groves, K. M., & Doherty, P. H. (2024). Can numerical simulations of equatorial plasma bubble plume structures be simplified for operational and practical usage? *NAVIGATION, 71*(2). https://doi.org/10.33012/navi.645

Video for "ICET Online Accuracy Characterization for Geometry-Based Laser Scan Matching"
By Matthew McDermott and Jason Rife (https://navi.ion.org/content/71/2/navi.647/tab-supplemental)

Abstract: Distribution-to-distribution point cloud registration algorithms are fast and interpretable and perform well in unstructured environments. Unfortunately, existing strategies for predicting the solution error for these methods are overly optimistic, particularly in regions containing large or extended physical objects. In this paper, we introduce the iterative closest ellipsoidal transform (ICET), a novel three-dimensional (3D) lidar scan-matching algorithm that re-envisions the normal distributions transform (NDT) in order to provide robust accuracy prediction from first principles. Like NDT, ICET subdivides a lidar scan into voxels in order to analyze complex scenes by considering many smaller local point distributions; however, ICET assesses the voxel distribution to distinguish random noise from

deterministic structure. ICET then uses a weighted least-squares formulation to incorporate this noise/structure distinction while computing a localization solution and predicting the solution-error covariance. To demonstrate the reasonableness of our accuracy predictions, we verify 3D ICET in three lidar tests involving real-world automotive data, high-fidelity simulated trajectories, and simulated corner-case scenes. For each test, ICET consistently performs scan matching with sub-centimeter accuracy. With this level of accuracy, combined with the fact that the algorithm is fully interpretable, this algorithm is well suited for safety-critical transportation applications. Code is available at https://github.com/mcdermatt/ICET.

Article Citation: McDermott, M., & Rife, J. (2024). ICET online accuracy characterization for geometry-based laser scan matching. *NAVIGATION, 71*(2). https://doi.org/10.33012/navi.647

Video for "Implementation and Accuracy of Doppler Navigation with LEO Satellites"
By Ariel Baron, Pini Gurfil, and Hector Rotstein (https://navi.ion.org/content/71/2/navi.649/tab-supplemental)

Abstract: Utilizing broadband low Earth orbit satellite signals in an opportunistic manner for navigation is becoming increasingly popular. This paper deals with a particularly useful approach for navigation based on satellite signals of opportunity, which uses carrier Doppler-shift observables. We provide analytically derived and simplified formulas for the Jacobian involved in the numerical computation of the navigation solution and derive a global navigation satellite system-like dilution-of-precision metric that can be used to assess accuracy. A numerical study provides preliminary computational results.

Article Citation: Baron, A., Gurfil, P., & Rotstein, H. (2024). Implementation and accuracy of Doppler navigation with LEO satellites. *NAVIGATION, 71*(2). https://doi.org/10.33012/navi.649

Video for "Assessment of Cryptographic Approaches for Quantum-Resistant Galileo OSNMA"
By Javier Junquera-Sánchez, Carlos Hernando-Ramiro, Oscar Gamallo-Palomares, and José-Antonio Gómez-Sánchez (https://navi.ion.org/content/71/2/navi.648/tab-supplemental)

Abstract: As time goes on, quantum computing has become more of a reality, bringing several cybersecurity challenges. Modern cryptography is based on the computational complexity of specific mathematical problems; however, as new quantum-based computers are developed, classical methods might not be sufficient to secure communications. In this paper, we analyze the state of the Galileo open service navigation message authentication (OSNMA) to overcome these new threats. This analysis and its assessment have been performed using OSNMA documentation, where we have reviewed the available post-quantum cryptography (PQC) algorithms competing in the National Institute of Standards and Technology standardization process and assessed the possibility of OSNMA implementation in the Galileo service. The main barrier to adopting PQC approaches is the size of both the signature and the key. This analysis shows that OSNMA is not yet capable of facing quantum threats and that significant changes are required. This work

concludes by assessing different transitory countermeasures that can be implemented to sustain the system's integrity in the short term.

Article Citation: Junquera-Sánchez, J., Hernando-Ramiro, C., Gamallo-Palomares, O., & Gómez-Sánchez, J.-A. (2024). Assessment of cryptographic approaches for quantum-resistant Galileo OSNMA. *NAVIGATION, 71*(2). https://doi.org/10.33012/navi.648

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.

June 26, 2024 Webinar: Implementation and Accuracy of Doppler Navigation with LEO Satellites (https://www.ion.org/publications/webinar-baron.cfm)
By: Ariel Baron

Abstract: Utilizing broadband low Earth orbit satellite signals in an opportunistic manner for navigation is becoming increasingly popular. This paper deals with a particularly useful approach for navigation based on satellite signals of opportunity, which uses carrier Doppler-shift observables. We provide analytically derived and simplified formulas for the Jacobian involved in the numerical computation of the navigation solution and derive a global navigation satellite system-like dilution-of-precision metric that can be used to assess accuracy. A numerical study provides preliminary computational results.

Article Citation: Baron, A., Gurfil, P., & Rotstein, H. (2024). Implementation and accuracy of Doppler navigation with LEO satellites. *NAVIGATION, 71*(2). https://doi.org/10.33012/navi.649

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