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EDITORIAL

Navigator Notes

Editorial Highlights from the Editor-in-Chief

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Welcome to the Fall 2022 issue of *NAVIGATION*. In this issue, we again feature articles on a wide range of topics including the instrumentation group delays of BeiDou satellites, the gain patterns of GPS satellite antennas, time transfer for a lunar navigation system, and several articles on detecting jamming or spoofing of GNSS signals and navigating in environments where signals are denied.

We are proud to announce that our journal impact factor (JIF) for 2021 is 2.472. This represents a 19% increase in the JIF over the previous year and a whopping 340% increase since 2014. Note that the increase is independent of *NAVIGATION* moving to full open access (OA) as that didn't happen until the beginning of 2022. Rather, the increase in the number of cited articles was likely due to more OA articles being published in the past two years, and increased promotion of *NAVIGATION* articles through social media, video abstracts, and webinars. Of course, we also maintained the high-quality level of articles appearing in the journal thanks to our talented authors and the dedicated team of reviewers and associate editors.

ION will continue to promote the research of journal authors through compulsory video abstracts hosted on the ION website. The latest video abstracts are documented below. ION also engages with the PNT community, through its webinar series, to highlight current topics of interest to the community. The most recent webinars are 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 text delivery.

Video for "Positioning and Velocity Performance Levels for a Lunar Lander Using a Dedicated Lunar Communication and Navigation System"
By Antoine Grenier, Pietro Giordano, Lorenzo Bucci, Alexander Cropp, Paolo Zoccarato, Richard Swinden, and Javier Ventura-Traveset
(https://www.ion.org/publications/abstract.cfm?articleID=102953)

Abstract: The interest in Moon exploration has grown substantially in the last few years, appointing the Moon as the first step toward deep space exploration. However, the current state-of-the-art approach for lunar landing does not always reach the required performance levels. This contribution presents a potential implementation of a dedicated lunar communication and navigation service (LCNS) and the performance levels achievable by a representative lunar lander mission that uses the LCNS. The expected positioning precision during the final descent and at the landing site is demonstrated here with a variance-covariance analysis starting from reasonable assumptions about the capabilities of a potential dedicated LCNS system. The performance in positioning and navigation achievable during a generic moon-landing phase significantly outperforms existing ground-based baseline solutions, enabling the stringent requirements from the International Space Exploration Coordination Group (ISECG) to be met.

Article Citation: Grenier, A., Giordano, P., Bucci, L., Cropp, A., Zoccarato, P., Swinden, R., & Ventura-Traveset, J. (2022). Positioning and velocity performance levels for a lunar lander using a dedicated lunar communication and navigation system. *NAVIGATION*, *69*(2). https://www.doi.org/10.33012/navi.513

Video for "Impact of GNSS-Band Radio Interference on Operational Avionics"
By Okuary Osechas, Friederike Fohlmeister, Thomas Dautermann, and Michael Felux
(https://www.ion.org/publications/abstract.cfm?articleID=102954)

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

Video for "A Robust Detection and Optimization Approach for Delayed Measurements in UWB Particle-Filter-Based Indoor Positioning"
By Ning Zhou, Lawrence Lau, Ruibin Bai, and Terry Moore
(https://www.ion.org/publications/abstract.cfm?articleID=102955)

Abstract: Ultrawideband (UWB) technology has received considerable attention in indoor positioning because of its high ranging accuracy. However, UWB range measurements can be contaminated by the delayed signals resulting from obstruction and reflection in difficult indoor environments. These signals introduce delays to range measurements and degrade positioning accuracy if they are not resolved properly. In order to mitigate the effects of delayed range measurements

on positioning and achieve a high-accuracy position estimation, this paper proposes a robust particle-filter-based indoor positioning algorithm. In the proposed algorithm, an outlier detection method is proposed for delayed measurement identification, and a constrained particle sampling method is proposed to optimize the distribution of the predicted particles. The proposed algorithm is assessed rigorously through testing. The test results show that the proposed algorithm can effectively identify delayed range measurements, mitigate their effects on position estimation, and improve positioning accuracy.

Article Citation: Zhou, N., Lau, L., Bai, R., & Moore, T. (2022). A robust detection and optimization approach for delayed measurements in UWB particle-filter based indoor positioning. *NAVIGATION*, *69*(2). https://doi.org/10.33012/navi.514

Video for "Multi-Epoch 3D-Mapping-Aided Positioning using Bayesian Filtering Techniques"
By Qiming Zhong and Paul D. Groves
(https://www.ion.org/publications/abstract.cfm?articleID=102956)

Abstract: The performance of different filtering algorithms combined with 3D-mapping-aided (3DMA) techniques is investigated in this paper. Several single- and multi-epoch filtering algorithms were implemented and then tested on static pedestrian navigation data collected in the City of London using a u-blox EVK M8T GNSS receiver and vehicle navigation data collected in Canary Wharf, London, by a trial van with a Racelogic Labsat 3 GNSS front-end. The results show that filtering has a greater impact on mobile positioning than static positioning, while 3DMA GNSS brings more significant improvements to positioning accuracy in denser environments than in more open areas. Thus, multi-epoch 3DMA GNSS filtering should bring the maximum benefit to mobile positioning in dense environments. In vehicle tests at Canary Wharf, 3DMA GNSS filtering reduced the RMS horizontal position error by approximately 68% and 57% compared to the single-epoch 3DMA GNSS and filtered conventional GNSS, respectively.

Article Citation: Zhong, Q., & Groves, P. D. (2022). Multi-epoch 3D-mapping-aided positioning using Bayesian filtering techniques. *NAVIGATION*, *69*(2). https://doi.org/10.33012/navi.515

Video for "Integrity of Visual Navigation—Developments, Challenges, and Prospects"
By Chen Zhu, Michael Meurer, and Christoph Günther
(https://www.ion.org/publications/abstract.cfm?articleID=102957)

Abstract: Camera-based visual navigation has great potential for various applications, especially in satellite-signal-degenerated environments. However, the lack of integrity protection has constrained its utilization in safety-critical applications. Integrity characterizes the quality of the information that a navigation system delivers. Integrity frameworks have been developed over decades for satellite navigation, and continue to play an essential role in safety-critical applications like civil aviation. Nevertheless, there are several challenges to quantify the risks associated with visual navigation. Over the last few years, several approaches to tackle these challenges have been investigated. These developments are the first steps toward a reliable visual positioning framework with integrity monitoring capabilities. In this paper, we review the current status, particular challenges, and development

trends in visual positioning integrity monitoring. In addition, we propose a preliminary framework so that the future developments on visual navigation integrity can benefit from a systematic approach.

Article Citation: Zhu, C., Meurer, M., & Günther, C. (2022). Integrity of visual navigation—Developments, challenges, and prospects. *NAVIGATION*, *69*(2). https://doi.org/10.33012/navi.518

Video for "High-Accuracy Static Baseline Estimation using NavIC L5 Observables"
By A. Althaf and H.B. Hablani
(https://www.ion.org/publications/abstract.cfm?articleID=102958)

Abstract: The estimation of static baselines using NavIC L5 double-differenced (DD) pseudoranges and carrier phases is investigated. We estimate the baseline with increasing accuracy by using the DD pseudoranges, smoothing the DD pseudoranges with the DD carrier phases, fixing the ambiguities in DD carrier phases, and imposing height-constraints on ambiguity and baseline estimates. Using the DD pseudoranges in estimating a 6-m baseline, the 3D root-mean-square error (RMSE) is 1.71 m. By incorporating the DD carrier-phase measurements and fixing its ambiguities, we achieved a 3D steady-state accuracy of 3 cm and convergence time of 23 minutes for a 350-m baseline in the secondary service area of NavIC. Further performance gains were achieved using a height-constrained solution in which 3D steady-state accuracy and convergence time was improved to 1 cm and 8 minutes, respectively.

Article Citation: Althaf, A., & Hablani, H. (2022). High-accuracy static baseline estimation using NavIC L5 observables. *NAVIGATION, 69*(2). https://doi.org/10.33012/navi.517

Video for "Mapping Bit to Symbol Unpredictability with Application to Galileo Open Service Navigation Message Authentication"
By Cillian O'Driscoll and Ignacio Fernández-Hernández
(https://www.ion.org/publications/abstract.cfm?articleID=102959)

Abstract: This paper investigates the distribution of unpredictable symbols in the open service navigation message authentication (OSNMA) scheme, which introduces cryptographic elements into the Galileo I/NAV message. Prior work has described the forward estimation attack (FEA; Curran & O'Driscoll, 2016), that takes advantage of the forward error correction (FEC) employed by the Galileo E1 OS to ensure that a spoofed receiver correctly decodes the I/NAV message, even if it has been generated with errors in some symbols. In order to defend against such an attack, the receiver can re-encode the navigation message into symbols and compare the symbol error rates for those symbols that are predictable and those that are not. In order to perform this, it is first necessary to know which symbols are unpredictable. This paper presents in detail how this can be achieved, including the impact of the cyclic redundancy check (CRC) on symbol unpredictability.

Article Citation: O'Driscoll, C., & Fernández-Hernández, I. (2022). Mapping bit to symbol unpredictability with application to Galileo open service navigation message authentication. *NAVIGATION, 69*(2). https://doi.org/10.33012/navi.519

Video for "Gravity Modeling in GNSS-Aided Inertial Navigation System Safety Certification"
By Timothy Needham and Michael Braasch
(https://www.ion.org/publications/abstract.cfm?articleID=102960)

Abstract: Safety certification of GNSS-aided inertial navigation systems (INS) in civil aircraft requires thorough testing to ensure proper operation, even in worst-case conditions. One error that must be considered is that of gravity compensation on accelerometer measurements. Prior to the work described in this paper, no stochastic models existed with the Gaussian bounding of the tails required to ensure integrity performance. This paper describes a method to determine efficient stochastic models of the error of current high-order gravity models such as EGM2008. The stochastic and high-order models are combined to achieve a high-fidelity model suitable for use in testing systems designed for low-approach operations such as RNP-AR. This paper also describes a method to determine efficient stochastic models for low-order gravity models such as the WGS-84 ellipsoidal model. Such models may be used in testing systems designed for operations with less stringent lateral requirements.

Article Citation: Needham, T., & Braasch, M. (2022). Gravity modeling in GNSS-aided inertial navigation system safety certification. *NAVIGATION, 69*(2). https://doi.org/10.33012/navi.520

Video for "Tracking Digital FM OFDM Signals for the Determination of Navigation Observables"
By Mark L. Psiaki and Brian D. Slosman
(https://www.ion.org/publications/abstract.cfm?articleID=102961)

Abstract: Methods are developed to acquire and track orthogonal frequency division multiplexing (OFDM) digital FM radio signals. These methods are being developed with the goal of using FM signals' pseudorange and accumulated delta-range observables to navigate. Delay lock loop and phase lock loop discriminator outputs are computed by solving an optimal fitting problem in the frequency domain for each OFDM symbol. Single-differencing of the signals' observables between a roving user receiver and a reference station receiver can remove transmitter clock drift effects. Wideband data collected in Roanoke, Virginia, and in Charlotte, North Carolina, have been processed offline and used to study these signals' suitability for navigation. Single-differenced pseudorange measurement and bias errors relative to a base station can be on the order of 100 m, but single-differenced accumulated delta-range precision can be better than 0.1 m. A system that uses accumulated delta range may be able to yield 5-m level positioning accuracy if multipath effects can be compensated for. The present study represents an initial effort toward the goal of achieving this level of accuracy. Only pseudorange-based navigation is tested here, however, and its observed errors are on the order of 500 m.

Article Citation: Psiaki, M. L., & Slosman, B. D. (2022). Tracking digital FM OFDM signals for the determination of navigation observables. *NAVIGATION, 69*(2). https://doi.org/10.33012/navi.521

Video for "Comparison of Autonomous Orbit Determination for Satellite Pairs in Lunar Halo and Distant Retrograde Orbits"
By Zhao-Yang Gao and Xi-Yun Hou
(https://www.ion.org/publications/abstract.cfm?articleID=102962)

Abstract: A comprehensive study on the autonomous orbit determination (AOD) performance of satellite pairs in halo orbits and distant retrograde orbits (DROs) is carried out. A factor called dynamic and geometric dilution of precision (DAGDOP) is proposed to simultaneously incorporate influences from the dynamics and geometry of satellite pairs. Based on the DAGDOP, the effect of different observation arcs on the AOD accuracy is investigated. Next, the AOD accuracy of three different types of satellite pairs—halo+halo, DRO+DRO, and halo+DRO—is systematically analyzed. The hybrid halo+DRO type shows the best overall accuracy. Finally, the AOD performance of the hybrid type is verified in a realistic model. Our studies find that the average AOD accuracy of the halo orbit is about 170 meters, and that of the DRO is about 190 meters. The relative time synchronization error of two satellites is less than 30 nanoseconds.

Article Citation: Gao, Z.-Y., & Hou, X.-Y. (2022). Comparison of autonomous orbit determination for satellite pairs in lunar halo and distant retrograde orbits. *NAVIGATION, 69*(2). https://doi.org/10.33012/navi.522

Video for "TrackMe—A Hybrid Radio-Optical System for Assets Localization in Industry 4.0 Plants"
By Kamil Staniec, Michał Kowal, Sławomir Kubal, and Piotr Piotrowski
(https://www.ion.org/publications/abstract.cfm?articleID=102963)

Abstract: Precise localization is considered one of the most salient features of Industry 4.0 manufacturing facilities. For this reason, multiple solutions have already been proposed. The method presented in this paper entails the use of double-band radio and optical technologies for near-real-time location tracking and remote reporting, with a final tracking accuracy of 0.5 meters. To preserve low-energy operations, the system infrastructure part is deployed on passive radio-frequency identification (RFID) tags, whereas the part installed on tracked assets implements energy-saving mechanisms. The system was deployed in an automotive production plant which allowed us to draw practical remarks on such aspects as the separation of onboard Ultra High Frequency (UHF) antennas; proper electromagnetic isolation of radio modules to prevent signal blocking; the placement and mechanical securing of RFID tags on the floor; as well as how to implement procedures to decrease the duty cycle, allowing for a trade-off between system sensitivity and energetic efficiency.

Article Citation: Staniec, K., Kowal, M., Kubal, S., & Piotrowski, P. (2022). TrackMe—A hybrid radio-optical system for assets localization in Industry 4.0 plants. *NAVIGATION, 69*(2). https://doi.org/10.33012/navi.524

Video for "INS Stochastic Noise Impact on Circular Error Probability of Ballistic Missiles"
By Salem Abd El-Hakem Hegazy, Ahmed M. Kamel, Ibrahim Ismail Arafa, and Yehia Z. Elhalwagy
(https://www.ion.org/publications/abstract.cfm?articleID=102965)

Abstract: A circular error probability (CEP) metric in ballistic missile science is an experimental indicator of the accuracy of a missile system. There are a lot of error sources that cause a ballistic missile to deviate from its ideal trajectory, and that causes a deviation from required CEP. This work discusses the problems of dispersion of ballistic missiles due to inertial navigation system (INS) errors. INS

deterministic errors are usually calibrated and compensated using some proper techniques. However, INS stochastic errors can be modeled and analyzed. In this study, a chosen missile is thoroughly analyzed using the six degrees-of-freedom missile flight trajectory simulator. A Monte Carlo simulation is used to generate a large number of flight trajectories to inspect the effect of INS stochastic noise on missile CEP. Moreover, a strategy for selecting an adequate sensor according to mission requirements and its corresponding sensor errors is introduced.

Article Citation: Hegazy, S., Kamel, A., Arafa, I., & Elhalwagy, Y. (2022). INS stochastic noise impact on circular error probability of ballistic missiles. *NAVIGATION, 69*(2). https://doi.org/10.33012/navi.523

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.

August 4, 2022 Webinar: Mapping Bit to Symbol Unpredictability with Application to Galileo Open Service Navigation Message Authentication
By Cillian O'Driscoll and Ignacio Fernández-Hernández
(https://www.ion.org/publications/webinar-odriscoll.cfm)

Abstract: This paper investigates the distribution of unpredictable symbols in the open service navigation message authentication (OSNMA) scheme, which introduces cryptographic elements into the Galileo I/NAV message. Prior work has described the forward estimation attack (FEA; Curran & O'Driscoll, 2016), that takes advantage of the forward error correction (FEC) employed by the Galileo E1 OS to ensure that a spoofed receiver correctly decodes the I/NAV message, even if it has been generated with errors in some symbols. In order to defend against this and other attacks, the receiver can re-encode the navigation message into symbols and compare the symbol error rates for those symbols that are predictable and those that are not. In order to perform this, it is first necessary to know which symbols are unpredictable. This paper presents in detail how this can be achieved, including the impact of the cyclic redundancy check (CRC) on symbol unpredictability. The webinar will also present how unpredictable symbol verification can be integrated in a receiver to protect against spoofing, and the level of protection achieved.

Article Citation: O'Driscoll, C., & Fernández-Hernández, Ignacio (2022). Mapping bit to symbol unpredictability with application to Galileo open service navigation message authentication. *NAVIGATION, 69*(2). https://doi.org/10.33012/navi.519

July 13, 2022 Webinar: National Strategy for Ocean Mapping: Exploring and Characterizing the United States Exclusive Economic Zone and the Global Seabed 2030 Initiative—Goals, Progress and Challenges
By Meredith Westington and Briana Welton Hillstrom
(https://www.ion.org/publications/webinar-noaa.cfm)

Background: Knowledge of the depth, shape, and composition of the seafloor has far-reaching benefits, including safer navigation, hazard mitigation for coastal resilience, preservation of marine habitats and heritage, and a deeper understanding

of natural resources for sustainable ocean economies. The 2020 National Strategy for Ocean Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone (NOMEC) and the Seabed 2030 initiative both make comprehensive ocean mapping a priority for the coming decade. These are drivers of innovation to increase survey efficiency, foster cooperation, and encourage the open sharing of data. During this webinar, the presenters will introduce the U.S. and international mapping goals, strategies for reaching those goals, current state of progress within U.S. waters, and challenges.

June 16, 2022 Webinar: WAAS and the Ionosphere—A Historical Perspective: Monitoring Storms
By Lawrence Sparks
(https://www.ion.org/publications/webinar-sparks.cfm)

Abstract: Satellite-based augmentation systems ensure the accuracy and integrity of aircraft position estimates derived from radio signals broadcast by the Global Navigation Satellite System. The United States' Wide Area Augmentation System (WAAS) protects users of the Global Positioning System from threats generated by ionospheric disturbances. The means by which WAAS mitigates these threats depends upon their magnitude. This paper addresses: a) how WAAS monitors the level of ionospheric perturbation over North America; b) how various availability and integrity concerns have influenced the implementation of WAAS's extreme and moderate ionospheric storm detectors; c) how the algorithms governing these implementations have evolved since WAAS's commissioning in 2003; and d) how the largest ionospheric storms of the past two solar cycles can be ranked according to their impact on WAAS. A subsequent companion paper will address the evolution of the WAAS methodology for protecting users from the adverse influence of more moderate ionospheric disturbances.

Article Citation: Sparks, L., Altshuler, E., Pandya, N., Blanch, J., & Walter, T. (2022). WAAS and the ionosphere—a historical perspective: Monitoring storms. *NAVIGATION, 69*(1). https://doi.org/10.33012/navi.503

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