Received: 16 August 2021 | Accepted: 18 August 2021

DOI: 10.1002/navi.447

EDITORIAL

WILEY ION

Navigator Notes

Editorial Highlights from the Editor-in-Chief

Welcome to the Fall 2021 issue of *NAVIGATION*. In this issue, we feature articles on a wide range of topics from R-Mode, a proposed new maritime PNT backup system, to new algorithms for improving GNSS integrity in a variety of applications, to positioning using the Doppler shift of signals from a constellation of low-Earth-orbiting satellites. It is articles like these, from authors around the globe reporting on their frontline research and benefitting from our dedicated group of associate editors and reviewers, that have made *NAVIGATION* a leading journal for the PNT community. In fact, I am proud to announce that *NAVIGATION* has recorded its sixth consecutive year of growth of its journal impact factor and is now 2.1! Authors can further promote their research through video abstracts hosted on the ION website. The latest ones 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, including one on the U.S. Government Accountability Office's report on defense navigation capabilities, are 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 "GNSS spoofing detection through spatial processing"

By Fabian Rothmaier, Yu-Hsuan Chen, Sherman Lo, and Todd Walter

(https://www.ion.org/publications/abstract.cfm?articleID=102906)

Abstract: In this paper, we present an algorithmic framework for signal-geometry-based approaches of GNSS spoofing detection. We formulate a simple vs. simple hypothesis test independent of nuisance parameters that results in significantly reduced missed detection probability compared to prior approaches. It is highly tractable such that it can be computed online by the receiver. We employ a hypothesis iteration framework that finds spoofed subsets of satellites efficiently and accounts for the presence of weak multipath, for a provable decision behavior in safety-of-life applications. We support the theoretical derivations by showing results on previously published simulated and on-air data sets. We validate the measurement model and show robustness to multipath with flight data from a Dual Polarization Antenna (DPA) mounted on a C12 aircraft. Finally, we show the algorithm's benefit on data recorded during a government-sponsored live spoofing event.

Article Citation: Rothmaier, F, Chen, Y-H, Lo, S, Walter, T. GNSS spoofing detection through spatial processing. *NAVIGATION*. 2021; 68(2): 243–258. https://doi.org/10.1002/navi.420

Video for "Overbounding the effect of uncertain Gauss-Markov noise in Kalman filtering"

By Steve Langel, Omar García Crespillo, and Mathieu Joerger

(https://www.ion.org/publications/abstract.cfm?articleID=102907)

Abstract: Prior work established a model for uncertain Gauss-Markov (GM) noise that is guaranteed to produce a Kalman filter (KF) covariance matrix that overbounds the estimate error distribution. The derivation was conducted for the continuous-time KF when the GM time constants are only known to reside within specified intervals. This paper first provides a more accessible derivation of the continuous-time result and determines the minimum initial variance of the model. This leads to a new, nonstationary model for uncertain GM noise that we prove yields an overbounding estimate error covariance matrix for both sampled-data and discrete-time systems. The new model is evaluated using covariance analysis for a one-dimensional estimation problem and for an example application in Advanced Receiver Autonomous Integrity Monitoring (ARAIM).

Article Citation: Langel, S, García Crespillo, O, Joerger, M. Overbounding the effect of uncertain Gauss-Markov noise in Kalman filtering. *NAVIGATION*. 2021; 68(2): 259–276. https://doi.org/10.1002/navi.419

Video for "Factor graph optimization for GNSS/INS integration: A comparison with the extended Kalman filter"

By Weisong Wen, Tim Pfeifer, Xiwei Bai, and Li-Ta Hsu (https://www.ion.org/publications/abstract.cfm?articleID=102910)

Abstract: Factor graph optimization (FGO) recently has attracted attention as an alternative to the extended Kalman filter (EKF) for GNSS-INS integration. This study evaluates both loosely and tightly coupled integrations of GNSS code pseudorange and INS measurements for real-time positioning, using both conventional EKF and FGO with a dataset collected in an urban canyon in Hong Kong. The FGO strength is analyzed by degenerating the FGO-based estimator into an "EKF-like estimator." In addition, the effects of window size on FGO performance are evaluated by considering both the GNSS pseudorange error models and environmental conditions. We conclude that the conventional FGO outperforms the EKF because of the following two factors: (1) FGO uses multiple iterations during the estimation to achieve a robust estimation; and (2) FGO better explores the time correlation between the measurements and states, based on a batch of historical data, when the measurements do not follow the Gaussian noise assumption.

Article Citation: Wen, W, Pfeifer, T, Bai, X, Hsu, L-T. Factor graph optimization for GNSS/INS integration: A comparison with the extended Kalman filter. *NAVIGATION*. 2021; 68(2): 315–331. https://doi.org/10.1002/navi.421

Video for "Performance assessment of GNSS diffraction models in urban areas"

By Fabian Rothmaier, Yu-By Guohao Zhang, and Li-Ta Hsu (https://www.ion.org/publications/abstract.cfm?articleID=102912)

Abstract: The GNSS performance is significantly degraded in urban canyons because of the signal interferences caused by buildings. Besides the multipath and non-line-of-sight (NLOS) receptions, the diffraction effect frequently occurs in urban canyons, which will severely attenuate the signal strength when the satellite line-of-sight (LOS) transmitting path is close to the building edge. It is essential to evaluate the performance of current diffraction models for GNSS before applying mitigation. The detailed steps of applying the knife-edge model and the uniform geometrical theory of diffraction (UTD) model on GNSS are given, including the C/N0 and pseudorange simulation of the diffracted signal. The performances of both models are assessed using real data from two typical urban scenarios. The result shows the UTD can adequately model the GNSS diffraction effect even in a complicated urban area. Compared with the knife-edge model, the UTD achieves better modeling accuracy, whereas it requires higher computational loads.

Article Citation: Zhang, G, Hsu, L-T. Performance assessment of GNSS diffraction models in urban areas. *NAVIGATION*. 2021; 68(2): 369–389. https://doi.org/10.1002/navi.417

Video for "Ionospheric spatial decorrelation assessment for GBAS daytime operations in Brazil"

By Hyeyeon Chang, Moonseok Yoon, Sam Pullen, Leonardo Marini-Pereira, and Jiyun Lee (https://www.ion.org/publications/abstract.cfm?articleID=102913)

Abstract: Extensive ionospheric studies were conducted to support the initial phase of system design approval for the existing SLS-4000 GBAS installed at Antonio Carlos Jobim International Airport (formerly Galeão International Airport) (GIG) in Rio de Janeiro, Brazil. This paper focuses on determining the broadcast value of the standard deviation of vertical ionospheric gradients (or σ_{vig}) that is required to bound ionospheric spatial gradients in Brazil under nominal conditions during daytime hours. The time-step method is useful for gaining sufficient samples at distances less than the physical separation distance of ground stations and was utilized to estimate ionospheric spatial gradients. A new method called "geometric similarity" was developed to estimate ionospheric temporal gradients and evaluate the temporal effect added to the bounding σ_{vig} values. As a result, a σ_{vig} of 13 mm/km, including a temporal gradient contribution of approximately 2 mm/km, is conservative enough to bound ionospheric spatial decorrelation for daytime GBAS operations in Brazil.

Article Citation: Chang, H, Yoon, M, Pullen, S, Marini-Pereira, L, Lee, J. Ionospheric spatial decorrelation assessment for GBAS daytime operations in Brazil. *NAVIGATION*. 2021; 68(2): 391–404. https://doi.org/10.1002/navi.418

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 17, 2021 Webinar: Overbounding the effect of uncertain Gauss-Markov noise in Kalman filtering

By Steve Langel

(https://www.ion.org/publications/webinar-langel.cfm)

Background: Prior work established a model for uncertain Gauss-Markov (GM) noise that is guaranteed to produce a Kalman filter (KF) covariance matrix that overbounds the estimate error distribution. The derivation was conducted for the continuous-time KF when the GM time constants are only known to reside within specified intervals. This paper first provides a more accessible derivation of the continuous-time result and determines the minimum initial variance of the model. This leads to a new, nonstationary model for uncertain GM noise that we prove yields an overbounding estimate error covariance matrix for both sampled-data and discrete-time systems. The new model is evaluated using covariance analysis for a one-dimensional estimation problem and for an example application in Advanced Receiver Autonomous Integrity Monitoring (ARAIM).

Article Citation: Langel, S, García Crespillo, O, Joerger, M. Overbounding the effect of uncertain Gauss-Markov noise in Kalman filtering. *NAVIGATION*. 2021; 68(2): 259–276. https://doi.org/10.1002/navi.419

July 23, 2021 Webinar: GNSS Spoofing Detection through Spatial Processing

By Fabian Rothmaier

(https://www.ion.org/publications/webinar-rothmaier.cfm)

Background: In this webinar, we present an algorithmic framework for signal-geometry-based approaches of GNSS spoofing detection. We formulate a simple vs. simple hypothesis test independent of nuisance parameters that results in significantly reduced missed detection probability compared to prior approaches. It is highly tractable such that it can be computed online by the receiver. We employ a hypothesis iteration framework that finds spoofed subsets of satellites efficiently and accounts for the presence of weak multipath, for a provable decision behavior in safety-of-life applications. We support the theoretical derivations by showing results on previously published simulated and on-air data sets. We validate the measurement model and show robustness to multipath with flight data from a Dual Polarization Antenna (DPA) mounted on a C12 aircraft. Finally, we show the algorithm's benefit on data recorded during a government-sponsored live spoofing event.

Article Citation: Rothmaier, F, Chen, Y-H, Lo, S, Walter, T. GNSS spoofing detection through spatial processing. *NAVIGATION*. 2021; 68(2): 243–258. https://doi.org/10.1002/navi.420

June 28, 2021 Webinar: Factor Graph Optimization for GNSS/INS Integration: A Comparison with the Extended Kalman Filter

By Dr. Li-Ta Hsu

(https://www.ion.org/publications/webinar-hsu.cfm)

Abstract: Factor graph optimization (FGO) recently has attracted attention as an alternative to the extended Kalman filter (EKF) for GNSS-INS integration. This study evaluates both loosely and tightly coupled integrations of GNSS code pseudorange and INS measurements for real-time positioning, using both conventional EKF and FGO with a dataset collected in an urban canyon in Hong Kong. The FGO strength is analyzed by degenerating the FGO-based estimator into an "EKF-like estimator." In addition, the effects of window size on FGO performance are evaluated by considering both the GNSS pseudorange error models and environmental conditions. We conclude that the conventional FGO outperforms the EKF because of the following two factors: (1) FGO uses multiple iterations during the estimation to achieve a robust estimation; and (2) FGO better explores the time correlation between the measurements and states, based on a batch of historical data, when the measurements do not follow the Gaussian noise assumption.

Article Citation: Wen, W, Pfeifer, T, Bai, X, Hsu, L-T. Factor graph optimization for GNSS/INS integration: A comparison with the extended Kalman filter. *NAVIGATION*. 2021; 68(2): 315– 331. https://doi.org/10.1002/navi.421

June 15, 2021 Webinar: GAO Report, "Defense Navigation Capabilities"

By Chi Mai and Jenn Beddor, US GAO

(https://www.ion.org/publications/webinar-GAOreport.cfm)

Background: Join the Institute of Navigation (ION) and the Resilient Navigation and Timing Foundation for a complimentary webinar featuring the recently published GAO Report "Defense Navigation Capabilities." On May

10, 2021, the Government Accountability Office (GAO) released its report "Defense Navigation Capabilities: DOD is Developing Positioning, Navigation, and Timing Technologies to Complement GPS." Among the report's recommendations were that the Department of Defense consider using resilient technologies as the cornerstone of its PNT efforts going forward, instead of its current plan to build its plans around GPS. The webinar features two of the principal authors of the report who will discuss their findings.

Dr. Richard B. Langley