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EDITORIAL

WILEY ION

Navigator Notes

Editorial Highlights from the Editor-in-Chief

Welcome to the Summer 2021 issue of *NAVIGATION*. We present the latest research articles (papers) that have successfully completed the thorough review process managed by our associate editors and their expert reviewers. Once again, the topics span the broad range of PNT research from GNSS spoofing detection, to real-time navigation of low Earth orbit satellites, to the development of the BeiDou satellite-based augmentation system. Here in "Navigator Notes," we highlight the latest video abstracts of articles published in the journal. Of particular note is the video abstract for the article on ION's GNSS software-defined radio (SDR) metadata standard, which was published in the Spring 2021 issue of the journal. We also list the most recent ION webinars, which continue to draw large audiences. The webinar on navigating NASA's Perseverance Rover to Mars was particularly popular.

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 "ION GNSS software-defined radio metadata standard"

By Sanjeev Gunawardena, Thomas Pany, and James Curran

(https://www.ion.org/publications/abstract.cfm?articleID=102892)

Abstract: The past several years have seen a proliferation of software-defined radio (SDR) data collection systems and processing platforms designed for or applicable to satellite navigation (satnav) applications. These systems necessarily produce datasets in a wide range of different formats. To correctly interpret this SDR data, essential information such as the packed sample format and sampling rate is needed. Communicating this metadata between creators and users has historically been an ad-hoc, cumbersome, and error-prone process. To address this issue, the satnav SDR community developed a metadata standard and normative software library to automate this process, thus simplifying the exchange of datasets and promoting the interoperability of satnav SDR systems. The standard was ratified and formally accepted as an Institute of Navigation Standard in January 2020. This article describes the ION GNSS SDR metadata standard and associated open-source software project. All content associated with the standard is available on sdr.ion.org.

Article Citation: Gunawardena, S, Pany, T, & Curran, J. ION GNSS software-defined radio metadata standard. *NAVIGATION*. 2021; 68: 11–20. https://doi.org/10.1002/navi.407

Video for "Design of a parallelized direct position estimation-based GNSS receiver"

By Matthew Peretic and Grace X. Gao

(https://www.ion.org/publications/abstract.cfm?articleID=102893)

Abstract: Theoretical results conclude that direct position estimation (DPE)-based Global Navigation Satellite System (GNSS) receivers can achieve more robust localization than their conventional two-step counterparts. However, compared to conventional approaches, there is a much smaller body of work for DPE, and DPE receiver implementations are highly experimental. This work surveys DPE techniques from the literature and presents a software-defined parallelized DPE-based receiver prototype built on popular DPE techniques. The parallelized receiver software, along with a companion sequential implementation, is made available to the community as an open source. The GPU usage of the parallelized DPE-based receiver is profiled and compared to the companion sequential implementation and another sequential implementation presented in the literature. Through the literature survey, discussion of the open-source receiver software, and the performance evaluation of the receiver, resultant insights for design decisions are presented.

Article Citation: Peretic, M & Gao, GX. Design of a parallelized direct position estimation-based GNSS receiver. *NAVIGATION*. 2021; 68: 21–39. https://doi.org/10.1002/navi.402

Video for "Using dual-polarization GPS antenna with optimized adaptive neuro-fuzzy inference system to improve single point positioning accuracy in urban canyons"

By Rui Sun, Linxia Fu, Guanyu Wang, Qi Cheng, Li-Ta Hsu, and Washington Yotto Ochieng

(https://www.ion.org/publications/abstract.cfm?articleID=102894)

Abstract: This paper builds on the machine learning research to propose two new algorithms based on optimizing the Adaptive Neuro Fuzzy Inference System (ANFIS) with a dual-polarization antenna to predict pseudorange errors by considering multiple variables including the right-hand circular polarized (RHCP) signal strength, signal strength difference between the left-hand circular polarized (LHCP) and RHCP outputs, satellites' elevation angle, and pseudorange residuals. The final antenna position is calculated following the application of the predicted pseudorange errors to correct for the effects of non-line-of-sight (NLOS) and multipath signal reception. The results show that the proposed algorithm results in a 30% improvement in the root mean square error (RMSE) in the 2D (horizontal) component for static applications when the training and testing data are collected at the same location. This corresponds to 13% to 20% when the testing data is from locations away from that of the training dataset.

Article Citation: Sun, R, Fu, L, Wang, G, Cheng, Q, Hsu, L-T, & Ochieng, WY. Using dual-polarization GPS antenna with optimized adaptive neuro-fuzzy inference system to improve single point positioning accuracy in urban canyons. *NAVIGATION*. 2021; 68: 41–60. https://doi.org/10.1002/navi.408

Video for "Multi-slices navigation approach for unknown 3D environments using micro aerial vehicles"

By H. A. Mohamed, A. M. Moussa, N. El-Sheimy, and M. M. Elhabiby

(https://www.ion.org/publications/abstract.cfm?articleID=102895)

Abstract: Due to the small size of micro aerial vehicles, they are well suited for various indoor applications, especially search/rescue operations. Most of these operations are performed in unknown 3D environments. Real-time map construction and vehicle's localization are essential tasks. Various approaches provide solutions for 3D-map representation. However, these approaches require expensive embedded systems to afford high-processing memory/computational costs. Because of its exposure to risks, the MAV should be equipped with a low-cost navigation system. The principal aim of map construction herein is to facilitate the navigation task. Thus, constructing a massive 3D map is not required. Consequently, this paper proposes an efficient real-time 3D SLAM. The proposed method avoids the 3D-map representation of each region of the trajectory. Alternatively, it divides the environment along the trajectory into several 2D maps with a single 2D map in every region at the height of the MAV, as well as a transient region between each of the two constructed maps to enable connecting neighboring maps.

Article Citation: Mohamed, HA, Moussa, AM, El-Sheimy, N, & Elhabiby, MM. Multi-slices navigation approach for unknown 3D environments using micro aerial vehicles. *NAVIGATION*. 2021; 68: 61–73. https://doi.org/10.1002/navi.403

Video for "GNSS interference mitigation: A measurement and position domain assessment"

By Daniele Borio and Ciro Gioia

(https://www.ion.org/publications/abstract.cfm?articleID=102897)

Abstract: Modern Global Navigation Satellite System (GNSS) receivers have to withstand significant levels of interference in order to operate under harsh conditions, such as in the presence of jamming and of other Radio Frequency (RF) threats. A possibility is to implement pre-correlation interference mitigation techniques that operate directly on the samples provided by the receiver front-end. This paper provides an assessment of five interference mitigation techniques at the measurement and position level. The analysis focuses on the Adaptive Notch Filter (ANF) and on four Robust Interference Mitigation (RIM) techniques. Several data collections were performed in the presence of jamming, and the data collected were used for the analysis that shows that RIM techniques do not introduce biases at both the measurement and position level. While the ANF delays pseudorange measurements, the biases introduced are predominantly common to all the observations with a negligible impact on a Single Point Positioning (SPP) solution.

Article Citation: Borio, D & Gioia, C. GNSS interference mitigation: A measurement and position domain assessment. *NAVIGATION*. 2021; 68: 93–114. https://doi.org/10.1002/navi.391

Video for "Network-based ionospheric gradient monitoring to support GBAS"

By Maria Caamano, José Miguel Juan, Michael Felux, Daniel Gerbeth, Guillermo González-Casado, and Jaume Sanz

(https://www.ion.org/publications/abstract.cfm?articleID=102899)

Abstract: Large ionospheric gradients acting between a Ground Based Augmentation System (GBAS) reference station and an aircraft on approach could lead to hazardous position errors if undetected. Current GBAS stations provide solutions against this threat that rely on the use of "worst-case" conservative threat models, which could limit the availability of the system. This paper presents a methodology capable of detecting ionospheric gradients in real time and estimating the actual threat model parameters based on a network of dual-frequency and multi-constellation GNSS monitoring stations. First, we evaluate the performance of our algorithm with synthetic gradients that are simulated over the nominal measurements recorded by a reference network in Alaska. Afterwards, we also assess it with one real ionospheric gradient measured by the same network. Results with both simulated gradients and a real gradient show the potential to support GBAS by detecting and estimating these gradients instead of always using "worst-case" models.

Article Citation: Caamano, M, Juan, JM, Felux, M, Gerbeth, D, González-Casado, G, & Sanz, J. Network-based ionospheric gradient monitoring to support GBAS. *NAVIGATION*. 2021; 68: 135–156. https://doi.org/10.1002/navi.411

Video for "Characterizing BDS signal-in-space performance from integrity perspective"

By Shizhuang Wang, Yawei Zhai, and Xingqun Zhan (https://www.ion.org/publications/abstract.cfm?articleID=102900)

Abstract: The full deployment of China's BeiDou navigation satellite system (BDS) was finalized in June 2020. To support safety-critical applications, the system must provide assured signal-in-space (SIS) performance. As one of the key steps forward for BDS, this paper characterizes the SIS range errors (SISREs) for both the regional (BDS-2) and the global (BDS-3) systems from the integrity perspective. Following the safety standards in aviation, a data-driven SISRE evaluation scheme is presented in this work. This scheme evaluates the overbounding user range accuracy (URA) and the prior fault probability to respectively capture the nominal and anomalous SIS behaviors. By processing the 4.5-year ephemerides starting from 2016 for BDS-2 and the recent 1.5-year data from 2019 for BDS-3, we preliminarily provide an overall picture of the BDS SIS characteristics and reveal the significant performance variation among different satellites.

Article Citation: Wang, S, Zhai, Y, & Zhan, X. Characterizing BDS signal-in-space performance from integrity perspective. *NAVIGATION*. 2021; 68: 157–183. https://doi.org/10.1002/navi.409

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.

May 27, 2021 Webinar: Hurricane Hunters: Navigating a plane through a hurricane

By Lt. Cmdr. Brian Richards (https://www.ion.org/publications/webinar-hurricane.cfm)

Background: Every year beginning June 1, two Lockheed WP-3D Orion aircraft and a crew from the National Oceanic and Atmospheric Administration's (NOAA's) Aircraft Operations Center deploy as "Hurricane Hunters," flying directly into violent hurricanes to perform aerial weather reconnaissance, which helps forecasters make accurate predictions on hurricane strength, direction, and any threats to land and life. But what is it like to fly these missions? What navigation tools and instruments are used? How do weather conditions impact these flights? Presenter Lt. Cmdr. Brian Richards is a WP-3D Orion navigator and training section chief for NOAA's Aircraft Operations Center.

May 11, 2021 Webinar: Multi-slices navigation approach for unknown 3D environments using micro aerial vehicles

By Dr. Haytham Mohamed (https://www.ion.org/publications/webinar-Mohamed.cfm)

Abstract: Due to the small size of micro aerial vehicles, they are well suited for various indoor applications, especially search/rescue operations. Most of these operations are performed in unknown 3D environments. Real-time map construction and vehicle's localization are essential tasks. Various approaches provide solutions for 3D-map representation. However, these approaches require expensive embedded systems to afford high-processing memory/computational costs. Because of its exposure to risks, the MAV should be equipped with a low-cost navigation system. The principal aim of map construction herein is to facilitate the navigation task. Thus, constructing a massive 3D map is not required. Consequently, this paper proposes an efficient real-time 3D SLAM. The proposed method avoids the 3D-map representation of each region of the trajectory. Alternatively, it divides the environment along the trajectory into several 2D maps with a single 2D map in every region at the height of the MAV, as well as a transient region between each of the two constructed maps to enable connecting neighboring maps.

(https://www.ion.org/publications/abstract.cfm?articleID=102895)

Article Citation: Mohamed, HA, Moussa, AM, El-Sheimy, N, & Elhabiby, MM. Multi-slices navigation approach for unknown 3D environments using micro aerial vehicles. *NAVIGATION*. 2021; 68: 61–73. https://doi.org/10.1002/navi.403

April 20, 2021 Webinar: GNSS interference mitigation: A measurement and position domain assessment

By Dr. Daniele Borio and Dr. Ciro Gioia

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

Abstract: Modern Global Navigation Satellite System (GNSS) receivers have to withstand significant levels of interference in order to operate under harsh conditions, such as in the presence of jamming and of other Radio Frequency (RF) threats. A possibility is to implement pre-correlation interference mitigation techniques that operate directly on the samples provided by the receiver front-end. This paper provides an assessment of five interference mitigation techniques at the measurement and position level. The analysis focuses on the Adaptive Notch Filter (ANF) and on four Robust Interference Mitigation (RIM) techniques. Several data collections were performed in the presence of jamming, and the data collected were used for the analysis that shows that RIM techniques do not introduce biases at both the measurement and position level. While the ANF delays pseudorange measurements, the biases introduced are predominantly common to all the observations with a negligible impact on a Single Point Positioning (SPP) solution.

(https://www.ion.org/publications/abstract.cfm?articleID=102897)

Article Citation: Borio, D & Gioia, C. GNSS interference mitigation: A measurement and position domain assessment. *NAVIGATION*. 2021; 68: 93–114. https://doi.org/10.1002/navi.391

March 23, 2021 Webinar: Navigation of the Mars 2020 Perseverance Rover from Earth to Jezero Crater

By Dr. Gerhard Kruizinga

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

Background: In humanity's most sophisticated and historic mission ever, NASA's Mars 2020 Perseverance Rover Mission, Journey to the Red Planet, began on July 30, 2020, with the launch of the Atlas V rocket from Cape Canaveral Air Force Station in Florida. Nearly seven months later, Perseverance landed safely in the Jezero Crater.

The precision landing required very high precision inter-planetary navigation and accommodation of entry guidance target requirements, planetary protection requirements and propellant allocation for trajectory correction maneuvers. The main navigation objective was to predict the trajectory accuracy at atmospheric entry, such that the Entry Descent and Landing system requirements were satisfied for a safe landing. This presentation discussed the planning to meet all navigation requirements and the actual navigation performance during cruise and landing.

Presenter Dr. Gerhard Kruizinga has worked as a navigation engineer on Earth science missions, missions to the Moon, missions to Mars and a mission to Pluto and beyond. He was Mars 2020 Navigation Team Chief, NASA Jet Propulsion Laboratory.

February 18, 2021 Webinar: Effect of GPS III weighted voting on P(Y) receiver processing performance

By Dr. Karl Kovach

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

Abstract: Signal generation in the GPS III satellites employs weighted voting to combine the baseband P(Y) signal with both components of the baseband L1C signal on the in-phase part of the L1 carrier. Weighted voting employs majority voting with pseudorandom time multiplexing of pure signals, producing a constant-envelope real-valued combination of the three bi-phase inputs with different useful received powers. Weighted voting introduces jitter into receivers' correlation functions, adding to jitter from noise and interference. This paper quantifies the effect of weighted voting on receiver input signal-to-noise ratio (SNR), then predicts the effect of weighted voting on carrier tracking by conventional, codeless, and semi-codeless P(Y) receivers. Analysis and computer simulation results are supplemented by receiver measurements, providing conclusive evidence that degradation by weighted voting is evident only at high SNR, having an insignificant effect on receiver performance.

(https://www.ion.org/publications/abstract.cfm?articleID=102879)

Article Citation: Allen, DW, Arredondo, A, Barnes, DR, Betz, JW, Cerruti, AP, Davidson, B, Kovach, KL, & Utter, A. Effect of GPS III weighted voting on P(Y) receiver processing performance. *NAVIGATION*. 2020; 67: 675–689. https://doi.org/10.1002/navi.394

Dr. Richard B. Langley