

# Navigator Notes

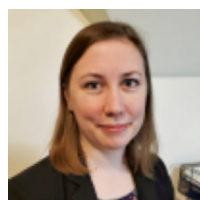
## Editorial Highlights from the Editor-in-Chief

Welcome to the Spring 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. The topics span the broad range of PNT research from GNSS interference mitigation to better positioning of low Earth orbit satellites. And we feature an article on ION's GNSS software-defined radio (SDR) metadata standard, which was adopted by the institute in January 2020. This standard will simplify the exchange of datasets between groups and promote the interoperability of satnav SDR systems. Here in "Navigator Notes," in addition to highlighting the latest video abstracts of articles published in the journal and the most recent ION webinars, we announce the ION 2020 Samuel M. Burka Award winners and the five most downloaded *NAVIGATION* articles in 2020.

### 2020 SAMUEL M. BURKA AWARD WINNERS

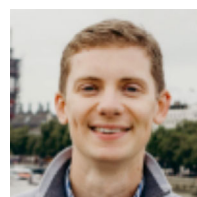
*The Samuel M. Burka Award, sponsored by The Institute of Navigation, recognizes outstanding achievement in the preparation of papers advancing the art and science of positioning, navigation, and timing. It is given in memory of Dr. Samuel M. Burka, a dedicated public servant, who devoted a long and distinguished career to the research and development of air navigation equipment and reviewing technical material for official publications.*

The award is presented to the following authors for their article "Characterization of On-orbit GPS Transmit Antenna Patterns for Space Users" published in the Spring 2020 issue of *NAVIGATION*:

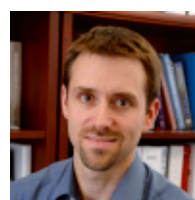


**Jennifer Ellen Donaldson** is an aerospace engineer in the Navigation and Mission Design Branch at NASA Goddard Space Flight Center, Greenbelt, Maryland,

where she is involved in numerous spacecraft navigation-related projects. Most recently, Ms. Donaldson served as an RF engineer for the Tracking and Data Relay Satellite (TDRS) project and is project manager of NASA's Next Generation Broadcast Service (NGBS) and the GPS Antenna Characterization Experiment (GPS ACE). She has contributed to the Navigator weak-signal tracking GPS receiver project and is active in GPS/GNSS policy initiatives to define and advance the GPS Space Service Volume (SSV).



**Joel J. K. Parker** is senior navigation analyst in the Navigation and Mission Design Branch at NASA Goddard Space Flight Center, where he contributes to projects in the fields of mission design, navigation, and space policy. Mr. Parker is the principal investigator for the Lunar GNSS Receiver Experiment CLPS payload and is a founding member of the GSFC Positioning, Navigation and Timing Policy team, where he is involved in national and international projects related to GPS, GNSS, and space-based PNT services. He leads NASA involvement in the development of the Interoperable GNSS Space Service Volume concept via the United Nations International Committee on GNSS. Mr. Parker received his BS and MS in aerospace engineering from Mississippi State University.



**Dr. Michael C. Moreau** has worked for NASA since 2001 and has been one of the leaders of NASA's OSIRIS-REx asteroid sample return mission since 2013, currently as deputy project manager. Prior to joining OREx, he contributed to space navigation activities as part of NASA Goddard's Satellite Servicing Capabilities project, NASA's Constellation Program, GPS III, and another large national defense satellite program. Dr. Moreau has degrees in mechanical engineering and

This is an open access article under the terms of the [Creative Commons Attribution](https://creativecommons.org/licenses/by/4.0/) License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

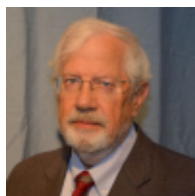
© 2021 The Authors. *NAVIGATION* published by Wiley Periodicals LLC on behalf of Institute of Navigation.

aerospace engineering from the Universities of Vermont and Colorado, respectively. His PhD research, which found application on a number of Earth orbiting satellites, focused on applications of GPS in high Earth orbits.



**Dr. Dolan E. Highsmith** is a senior project engineer at The Aerospace Corporation in the Systems Integration and Protection Department of the Civil Systems Group based in the Washington, DC

region. His current projects include the GPS Antenna Characterization Experiment (ACE) and OSIRIS-REx Flight Dynamics, and he recently took on the role of deputy chief engineer for the NASA Conjunction Assessment Risk Analysis (CARA) team at Goddard Space Flight Center. Dr. Highsmith received his BS in aerospace Engineering from the University of Virginia and MS and PhD from the University of Colorado, Boulder.



**Dr. Philip D. Martzen** is a senior engineering specialist at The Aerospace Corporation in the Navigation and Geopositioning Systems Department where he has worked since 1997. His work

experience includes orbit determination during early orbit operations, orbit estimation algorithms development, dynamical and measurement models development, and weak signal GPS batch mode receiver development. His previous work included gravity and geodetic error analysis at Geodynamics Corporation. He has 40 years of experience with Aerospace TRACE and its variants, which he currently maintains. Dr. Martzen received his PhD in physics from the University of California, Santa Barbara.

**Abstract:** The GPS Antenna Characterization Experiment (GPS ACE) has made extensive observations of GPS L1 signals received at geosynchronous (GEO) altitude with the objective of developing comprehensive models of the signal levels and signal performance in the GPS transmit antenna side lobes. The GPS ACE architecture has been in place collecting observations with extreme sensitivity for several years, enabling the accumulation of full azimuthal coverage of the GPS transmit gain patterns over time. Results discussed in this paper include the reconstructed transmit gain patterns with comparison with available pre-flight gain measurements from the GPS vehicle contractors. For GPS blocks with extensive ground measurements, the GPS ACE results show remarkable agreement. For blocks without extensive ground measurements, the GPS ACE results provide the only existing assessments of the full transmit gain patterns. The paper also includes results

of the pseudorange deviation analysis to assess systematic errors associated with GPS side-lobe signals. (<https://www.ion.org/publications/abstract.cfm?articleID=102863>)

**Article Citation:** Donaldson, JE, Parker, JJK, Moreau, MC, Highsmith, DE, Martzen, PD. Characterization of on-orbit GPS transmit antenna patterns for space users. *NAVIGATION*. 2020; 67: 411–438. <https://doi.org/10.1002/navi.361>

## THE FIVE MOST DOWNLOADED ARTICLES IN 2020

The Institute of Navigation announces 2020's most downloaded articles from *NAVIGATION*.

An Overview of the Effects of Out-of-Band Interference on GNSS Receivers

By Christopher J. Hegarty, Dan Bobyn, Joe Grabowski, and A.J. Van Dierendonck

(<https://www.ion.org/publications/abstract.cfm?articleID=102846>)

**Abstract:** This paper addresses the wide range of mechanisms through which out-of-band interference can disrupt the functioning of GNSS receivers. These mechanisms include saturation and desensitization of front-end low noise amplifiers, mixers, and other circuitry; reciprocal mixing effects that arise from the fact that receivers cannot generate a perfect tone to down-convert the desired signals; intermodulation products; aliasing of out-of-band emissions that remain after filtering into the receiver's passband; and the reception of in-band (to GNSS) emissions that are always present due to imperfections in the signal generation and filtering of the interfering system. These mechanisms are described in detail, and mitigation approaches for each are discussed.

**Article Citation:** Hegarty, CJ, Bobyn, D, Grabowski, J, Van Dierendonck, AJ. An overview of the effects of out-of-band interference on GNSS receivers. *NAVIGATION*. 2020; 67: 143–161. <https://doi.org/10.1002/navi.345>

MagSLAM: Aerial Simultaneous Localization and Mapping Using Earth's Magnetic Anomaly Field

By Taylor N. Lee and Aaron J. Canciani

(<https://www.ion.org/publications/abstract.cfm?articleID=102843>)

**Abstract:** Instances of spoofing and jamming of Global Navigation Satellite Systems (GNSSs) have emphasized the need for alternative navigation methods. Aerial navigation by magnetic map matching has been demonstrated as a

viable GNSS-alternative navigation technique. Flight test demonstrations have achieved accuracies of tens of meters over hour-long flights, but these flights required accurate magnetic maps, which are not always available. Magnetic map availability and resolution vary widely around the globe. Removing the dependency on prior survey maps extends the benefits of aerial magnetic navigation methods to small unmanned aerial systems (sUAS) at lower altitudes where magnetic maps are especially undersampled or unavailable. In this paper, a simultaneous localization and mapping (SLAM) algorithm known as FastSLAM was modified to use scalar magnetic measurements to constrain a drifting inertial navigation system (INS). The algorithm was then demonstrated on real magnetic navigation flight test data. Similar in performance to the map-based approach, MagSLAM achieved tens of meters accuracy in a 100-minute flight without the use of a prior magnetic map. Aerial SLAM using Earth's magnetic anomaly field provides a GNSS-alternative navigation method that is globally persistent, impervious to jamming or spoofing, stealthy, and locally accurate to tens of meters without the need for a magnetic map.

**Article Citation:** Lee, TN, Canciani, AJ. MagSLAM: Aerial simultaneous localization and mapping using Earth's magnetic anomaly field. *NAVIGATION*. 2020; 67: 95–107. <https://doi.org/10.1002/navi.352>

**GPS-Based Satellite Formation Flight Simulation and Applications to Ionospheric Remote Sensing**  
By YuXiang Peng, Wayne A. Scales, and Thom R. Edwards  
(<https://www.ion.org/publications/abstract.cfm?articleID=102838>)

**Abstract:** The Virginia Tech Formation Flying Testbed (VTFFTB), a GNSS-based hardware-in-the-loop (HIL) simulation testbed for spacecraft formation flight, is developed and applied to ionospheric remote sensing. The current VTFFTB consists of GNSS RF hardware signal simulators, multi-constellation multi-frequency GNSS receivers, a navigation and control system, an STK visualization system, and an ionospheric remote sensing system. GPS signals are emulated using GNSS simulator scenarios that include ionospheric phenomena. A formation of two spacecraft (“chief” and “deputy”) is considered. GNSS receiver data are used to produce space-based Total Electron Content (TEC) and scintillation measurements. A reference low Earth orbit (LEO) scenario is benchmarked with past simulation results to validate functionality. A LEO formation flying mission is designed to probe two Equatorial Spread F (ESF) scenarios with plasma bubbles. The results investigate the structure of ionospheric irregularities and demonstrate that the

GPS-based satellite formation is able to measure vertical electron density by differencing 1D GPS vertical TEC.

**Article Citation:** Peng, YX, Scales, WA, Edwards, TR. GPS-based satellite formation flight simulation and applications to ionospheric remote sensing. *NAVIGATION*. 2020; 67: 3–21. <https://doi.org/10.1002/navi.354>

**Flight Results of GPS-Based Attitude Determination for the Canadian CASSIOPE Satellite**  
By André Hauschild, Oliver Montenbruck, and Richard B. Langley  
(<https://www.ion.org/publications/abstract.cfm?articleID=102842>)

**Abstract:** The paper presents attitude determination results of the “GPS Attitude, Positioning and Profiling Experiment” (GAP) on board the CASSIOPE satellite using real flight data. The GAP payload consists of five minimally modified commercial-off-the-shelf NovAtel OEM4-G2L receivers that provide dual-frequency GPS measurements and allow for attitude and orbit determination of the satellite as well as electron density profiling. To the authors' knowledge, the CASSIOPE mission is the first space mission that provides dual-frequency observations for attitude determination. The data has been analyzed with a GPS attitude determination algorithm originally developed for the analysis of data from the “Flying Laptop” mission. The GPS-based solution for selected attitude maneuvers is compared to a reference orientation provided by the satellite's star sensors. Furthermore, an analysis of the typical time-to-first-fix (TTFF) for the attitude solution is provided. The advantage of dual-frequency ambiguity fixing compared to single-frequency is assessed.

**Article Citation:** Hauschild, A, Montenbruck, O, Langley, RB. Flight results of GPS-based attitude determination for the Canadian CASSIOPE satellite. *NAVIGATION*. 2020; 67: 83–93. <https://doi.org/10.1002/navi.348>

**A New Array Concept Using Spatially Distributed Sub-arrays for Unambiguous GNSS Interference Mitigation in Automotive Applications**  
By Marius Brachvogel, Michael Niestroj, Soeren Zorn, Michael Meurer, Syed N. Hasnain, Ralf Stephan, and Matthias A. Hein  
(<https://www.ion.org/publications/abstract.cfm?articleID=102839>)

**Abstract:** Radio frequency interference (RFI) poses a severe problem for conventional GNSS receivers. Even low powered RFI can block the reception of satellite signals and prevent a position determination. Antenna array

systems have been proven suitable to counteract RFI by incorporating spatial processing techniques. The large size of uniform rectangular arrays (URA) with half-wave antenna spacing impedes an installation in cars intended for the consumer mass market, where a hidden installation is a strict requirement by industry and customers. This paper introduces a new approach, where a conventional URA is split into distributed linear subarrays with the aim to reduce their footprint but to maintain the possibility of spatial processing. The achievable gain in robustness against RFI is evaluated. Drawbacks in terms of manifold ambiguities and their consequences for spatial processing techniques are also discussed. Furthermore, the accuracy of positioning results derived from a field test is put into context with a single antenna receiver.

**Article Citation:** Brachvogel, M, Niestroj, M, Zorn, S, Meurer, M, Hasnain, SN, Stephan, R, Hein, MA. A new array concept using spatially distributed subarrays for unambiguous GNSS interference mitigation in automotive applications. *NAVIGATION*. 2020; 67: 23–41. <https://doi.org/10.1002/navi.353>

## 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** “Effect of GPS III Weighted Voting on P(Y) Receiver Processing Performance”

By David William Allen, Alberto Arredondo, Daniel R. Barnes, John W. Betz, Alessandro P. Cerruti, Benjamin Davidson, Karl L. Kovach, and Alexander Utter  
(<https://www.ion.org/publications/abstract.cfm?articleID=102879>)

**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 biphasic 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 the receiver input signal-to-noise ratio (SNR) and then predicts the effect of weighted voting on carrier tracking by conven-

tional, codeless, and semicodeless 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.

**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>

### **Video for** “HEAD: smooth Estimation of wAlking Direction with a handheld device embedding inertial, GNSS, and magnetometer sensors”

By Johan Perul and Valerie Renaudin  
(<https://www.ion.org/publications/abstract.cfm?articleID=102881>)

**Abstract:** Pedestrian navigation with handheld sensors is still particularly complex. The pedestrian dead reckoning method is generally used, but the estimation of the walking direction remains problematic because the device's pointing direction does not always correspond to the walking direction. To overcome this difficulty, it is possible to use gait modeling-based approaches, but these methods suffer from sporadic erroneous estimates and their accumulation over time. The HEAD (smooth Estimation of wAlking Direction) filter uses WAISS and MAGYQ angular estimates as observations to correct the walking direction and to obtain more robust and smooth results. TDCP updates are applied to constrain the walking direction estimation error while pseudoranges directly update the position. HEAD is tested by 5 subjects over 21 indoor/outdoor acquisitions (between 720 m and 1.3 km). A 54% improvement is achieved thanks to the fusion in texting mode. The median obtained angular error is 5.5 degrees in texting mode and 12 degrees in pocket mode.

**Article Citation:** Perul, J, Renaudin, V. HEAD: smooth Estimation of wAlking Direction with a handheld device embedding inertial, GNSS, and magnetometer sensors. *NAVIGATION*. 2020; 67: 713–726. <https://doi.org/10.1002/navi.389>

### **Video for** “Novel Partial Correlation Method Algorithm for Acquisition of GNSS Tiered Signals”

By Jiří Svatoň, František Vejražka, Pavel Kubalík, Jan Schmidt, and Jaroslav Borecký  
(<https://www.ion.org/publications/abstract.cfm?articleID=102883>)

**Abstract:** This paper presents a new modified single block zero-padding (mSBZP) partial correlation method (PCM) parallel code search (PCS) algorithm for the effective acquisition of a weak GNSS-tiered signal using the coherent processing of its secondary code (SC) component. Two problems are discussed: acquisition of primary codes with a longer period using FFT blocks of limited length and the utilization of PCS in the presence of SC bit transition. The PCM and SC bit transition forms parasitic fragments in the cross-ambiguity function (CAF) to devalue signal detection performance. A novel analysis of this mechanism and its impact is presented. A novel mSBZP-PCM-PCS algorithm is proposed, which does not degrade the CAF. Then, the algorithm is combined with SC bit transition removal schema and sequential search to construct an estimator for weak-tiered signal acquisition. The performance of the method is demonstrated by analysis and computer simulation using Galileo E1C and GPS L1C-P signals.

**Article Citation:** Svatoň, J, Vejražka, F, Kubalík, P, Schmidt, J, Borecký, J. Novel partial correlation method algorithm for acquisition of GNSS tiered signals. *NAVIGATION*. 2020; 67: 745–762. <https://doi.org/10.1002/navi.390>

**Video for** “Improving the Calibration Process of Inertial Measurement Unit for Marine Applications”

By Hossein Rahimi and Amir Ali Nikkhah  
(<https://www.ion.org/publications/abstract.cfm?articleID=102884>)

**Abstract:** Marine navigation systems have very accurate sensors, such as 0.01 deg/hr gyro drift stability and 0.1 mg/year accelerometer bias stability. Common calibration methods and equipment do not meet the accuracy required. In this paper, a systematic method for calibration of an inertial measurement unit (IMU) for marine applications is proposed, which is not based on the accuracy of the calibration turn table and only requires one specific plate to determine the initial attitude of the IMU and functions independently of the turn table. The first contribution of this paper is to derive a model for systematic calibration of IMU that expresses the rotation matrix error and velocity as a linear function of the calibration parameters at any time. As the second contribution, this paper proposes a calibration algorithm with only using an initial, specific plate. Using the actual data, it was found that the proposed algorithm provides a good estimation of the parameters.

**Article Citation:** Rahimi, H, Nikkhah, AA. Improving the calibration process of inertial measurement unit for marine applications. *NAVIGATION*. 2020; 67: 763–774. <https://doi.org/10.1002/navi.400>

**Video for** “An Efficient Tuning Framework for Kalman Filter Parameter Optimization Using Design of Experiments and Genetic Algorithms”

By Alan Zhang and Mohamed Maher Atia  
(<https://www.ion.org/publications/abstract.cfm?articleID=102885>)

**Abstract:** The extended Kalman filter (EKF) is currently a dominant sensor fusion method for mobile devices, robotics, and autonomous vehicles. Its performance heavily depends on the selection of EKF parameters. Therefore, the optimal selection of parameters is a critical factor in EKF design and use. In this paper, a methodical and efficient method of EKF parameter tuning is presented. The tuning framework uses nominal parameters generated by Gauss Markov (GM) and Allan Variance (AV) methods that are tuned by Genetic Algorithms (GA) accelerated by Design of Experiments (DoE). This framework has been implemented in MATLAB and tested using simulations and real data under a tightly coupled EKF that fuses IMU and GNSS measurements of a self-driving car provided by the Blackberry QNX company. The results demonstrate that GA-tuned parameters increase accuracy substantially over nominally tuned parameters and that the DoE technique consistently improves the convergence behavior of the GA.

**Article Citation:** Zhang, A, Atia, MM. An efficient tuning framework for Kalman filter parameter optimization using design of experiments and genetic algorithms. *NAVIGATION*. 2020; 67: 775–793. <https://doi.org/10.1002/navi.399>

**Video for** “Sensitivity Analysis of Precision Inertial Sensor-based Navigation System (SAPIENS)”

By Rachit Bhatia and David Geller  
(<https://www.ion.org/publications/abstract.cfm?articleID=102886>)

**Abstract:** The future of deep space exploration depends upon technological advancement towards improving spacecraft's autonomy and versatility. This study aims to examine the feasibility of autonomous orbit determination using advanced accelerometer measurements. The objective of this research is to ascertain specific sensor requirements to meet pre-defined mission navigation error budgets. Traditional inertial navigation (dead reckoning and external aiding) is not considered. Instead, measurements from pairs of advanced, highly sensitive accelerometers (e.g., cold atom accelerometers) are used onboard to determine gravity field gradients, which are then correlated to onboard gravity maps and used to determine orbital information. Linear Covariance Theory helps to efficiently conduct an error budget

analysis of the system. This error budget analysis helps to determine the effect of specific error sources in the sensor measurements, thereby providing information to rank and compare relevant sensor parameters and determine an optimal sensor configuration for a given space mission. The procedure is repeated to evaluate different accelerometer configurations and sensor parameters.

**Article Citation:** Bhatia, R, Geller, D. Sensitivity Analysis of Precision Inertial Sensor-based Navigation System (SAPI-ENS). *NAVIGATION*. 2020; 67: 795–822. <https://doi.org/10.1002/navi.397>

**Video for** “A Collocation Framework to Retrieve Tropospheric Delays from a Combination of GNSS and InSAR”  
By Endrit Shehaj, Karina Wilgan, Othmar Frey, and Alain Geiger (<https://www.ion.org/publications/abstract.cfm?articleID=102887>)

**Abstract:** High spatio-temporal variability of atmospheric water vapor affects microwave signals of Global Navigation Satellite Systems (GNSS) and Interferometric Synthetic Aperture Radar (InSAR). A better knowledge of the distribution of water vapor improves both GNSS- and InSAR-derived data products. In this work, we present a collocation framework to combine and retrieve zenith and (relative) slant tropospheric delays. GNSS and InSAR meteorological products are combined aiming at a better retrieval of the atmospheric water vapor. We investigate the combination approach with synthetic and real data acquired in the Alpine region of Switzerland. Based on a closed-loop validation with simulated delays, a few mm accuracy is achieved for the GNSS-InSAR combination in terms of retrieved ZTDs. Furthermore, when real delays are collocated, the combination results are more congruent with InSAR computed products. This research is a contribution to improve the spatio-temporal mapping of tropospheric delays by combining GNSS-derived and InSAR-derived delays.

**Article Citation:** Shehaj, E, Wilgan, K, Frey, O, Geiger, A. A collocation framework to retrieve tropospheric delays from a combination of GNSS and InSAR. *NAVIGATION*. 2020; 67: 823–842. <https://doi.org/10.1002/navi.398>

## WEBINARS

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

**December 10, 2020 Webinar:** Automatic Detection of Ionospheric Scintillation-like GNSS Satellite Oscillator Anomaly Using a Machine-learning Algorithm

By Yunxiang (Leo) Liu and Y. Jade Morton

(<https://www.ion.org/publications/webinar-morton.cfm>)

**Abstract:** In this paper, we propose a machine-learning-based approach to automatically detect a satellite oscillator anomaly. A major challenge is to differentiate an oscillator anomaly from ionospheric scintillation. Although both scintillation and oscillator anomalies cause phase disturbances, their underlying physics are different and, therefore, show different carrier-frequency dependency. By using triple-frequency signals, distinct features are extracted from the disturbed signals and applied to the radial basis function (RBF) support vector machine (SVM) classifier to identify an oscillator anomaly. The results show that the proposed RBF SVM displays superior performance and outperforms several other classification methods. The proposed approach is applied to an extensive GNSS database to conduct automatic satellite oscillator anomaly detection. Preliminary detection results validate the effectiveness of the proposed method. On average, one-to-three satellite oscillator anomaly events are detected daily at each receiver location. (<https://www.ion.org/publications/abstract.cfm?articleID=102876>)

**Article Citation:** Liu, Y, Morton, YJ. Automatic detection of ionospheric scintillation-like GNSS satellite oscillator anomaly using a machine-learning algorithm. *NAVIGATION*. 2020; 67: 651–662. <https://doi.org/10.1002/navi.385>

**November 12, 2020 Webinar:** Residual-based Multi-filter Methodology for All-source Fault Detection, Exclusion, and Performance Monitoring

By Juan Jurado

(<https://www.ion.org/publications/webinar-jurado.cfm>)

**Abstract:** All-source navigation has become increasingly relevant over the past decade with the development of viable alternative sensor technologies. However, as the number and type of sensors informing a system increases, so does the probability of corrupting the system with sensor modeling errors, signal interference, and undetected faults. Though the latter of these has been extensively researched, the majority of existing approaches have constrained faults to biases and designed algorithms centered around the assumption of simultaneously redundant, synchronous sensors with valid measurement models, none of which are guaranteed for all-source systems. As part of an overall all-source assured or resilient navigation objective, this research contributes a fault- and sensor-agnostic

fault detection and exclusion method that can provide the user with performance guarantees without constraining the statistical distribution of the fault. The proposed method is compared against normalized solution separation approaches using Monte-Carlo simulations in a 2D non-GPS navigation problem. (<https://www.ion.org/publications/abstract.cfm?articleID=102867>)

Article Citation: Jurado, J, Raquet, J, Schubert Kabban, CM, Gipson, J. Residual-based multi-filter methodology for all-source fault detection, exclusion, and performance monitoring. *NAVIGATION*. 2020; 67: 493–509. <https://doi.org/10.1002/navi.384>

Dr. Richard B. Langley