weapons and world leaders found themselves unable to communicate. As the outage persisted, air traffic would slow and then grind to a halt with the growing loss of air traffic control capabilities triggering widespread flight cancellations. Cell phone networks and traffic lights would begin to fail, leaving emergency responders hard-pressed to find or even reach those calling for help—and that's just in the first 18 hours.

On the Bright Side
A more hopeful presentation during a Civil GPS Service Interface Committee (CGSIC) meeting leading into ION GNSS+ 2019 made clear that U.S. policy

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ION GNSS+ 2019 . . . We Got This!
More than 900 of the world’s technical GNSS experts, manufacturers, and policy makers gathered in Miami, Florida, in September at ION GNSS+ 2019 for a week of technical presentations and an exhibit hall showcasing GNSS technologies, products, and services. It was the 32nd International Technical Meeting of the ION’s Satellite Division — the world’s oldest GNSS conference.

I found it can often be very difficult to attend all the paper presentations that I have planned, as it was simply too easy to become engaged in the opportunities to network with so many of my international colleagues! The entire week went like a whirlwind (and not, thank goodness, a hurricane!).

The Cognizant Autonomous Systems for Safety Critical Applications (CASSCA) Conference on Monday introduced an array of dynamic speakers who are new to the ION community. They brought insights from different perspectives and engaged the pre-conference audience in interesting discussions of the potentials and challenges with autonomous systems.

On Tuesday evening, our plenary session speakers, Dr. Pål Brekke and Dr. Nicola Fox, took us for an exciting ride to outer space for a closer view of our Sun and an inspiring lesson of heliophysics and space weather. Throughout the meeting, there were too many exciting panels and interesting talks to choose from.

I was especially impressed with the quality work and presentations given by the growing number of young, and often new, attendees at the conference. If my own students are mirrors of other young professionals, I can appreciate how much time, effort, and courage it takes for them to present in front of an ION audience filled with experts and share their latest discoveries and ideas.

The success of the meeting would not have been possible without an army of dedicated organizers. I would like to thank all of the Satellite Division officers who tirelessly contributed to ION GNSS+ 2019, as well as the event’s sponsors, media participants, course instructors, exhibitors, authors, session chairs, peer reviewers, and those who attended and actively participated over the course of the week.

The Military Division’s JNC 2019
The Military Division also “got it” this year with a superb Joint Navigation Conference (JNC).

I have it on very good authority that the quality of the presentations and network was exceedingly high and that the JNC has become the “go to” conference for program managers and PNT developers operating in a DoD environment. The conference hosted a
record number of exhibitors and boasted four days of perfect California sunshine.

I want to thank all the organizers who hosted the Military Division’s JNC this past July in Long Beach. See page 18 for more details.

**ION Council Meets**

The ION Council met prior to ION GNSS+ 2019 in Miami, during which Council members ratified the Publications addendum to the ION’s Code of Ethics, clarified some policies for the annual awards nominations process to take effect beginning with next year's cycle, and received an update on the GNSS Software Radio Metadata Standard.

Dr. Li-Ta Hsu, an elected Technical Representative, also proposed that the ION form a working group to propose open-sourcing and benchmarking localization data collected in urban canyons, including Tokyo and Hong Kong; benchmarking various positioning algorithms using open-source data; and raising awareness about urgent navigation requirements in highly urbanized areas — especially in Asian-Pacific regions.

The Council supported the idea and suggested that working group members collaborate with Dr. Allison Kealy (RMIT) and Dr. Charles Toth (The Ohio State University) on this initiative. Dr. Kealy, also an ION Technical Representative, suggested this initiative could become a special study group for the International Association of Geodesy (IAG) to turn it into a joint effort of IAG and ION.

**Preparing for ITM/PTTI 2020 in San Diego**

Preparations are now underway for the ION’s International Technical Meeting (ITM) and Precise Time and Time Interval (PTTI) Systems and Application Meeting, taking place January 21–24, 2020, in San Diego.

A joint ITM/PTTI plenary session will feature three fantastic speakers. Marco Falcone, Galileo System Manager in the European Space Agency’s Galileo Project Office, will be telling the story of the European GNSS system and, given recent Galileo events, he is sure to have some nail-biting tales to share.

Dr. Xiaochun Lu, director of the Chinese Academy of Sciences’ National Time Service Center, will share the history of China’s time and navigation technologies and how they played an immeasurable role guiding the ancient Chinese people in their exploration of navigation. Tom Van Baak, a “time enthusiast” (reflected in his leapsecond.com website) will share his adventures in atomic timekeeping as a hobby (be prepared to be both amused and amazed!).

Additionally the ION’s annual awards will be presented, and 2020 Fellows will be named. It goes without saying, there is sure to be plenty of San Diego sunshine. See you there!
makers are already working out how to manage through a loss of positioning, navigation, and timing (PNT) service.

Diana Furchtgott-Roth, the U.S. Department of Transportation’s (DoT’s) new deputy assistant secretary for research and technology, told attendees that testing on possible GPS backups would begin in March.

Her team had just released a solicitation for commercial providers of GPS backup technologies to demonstrate their different capabilities. DoT will let up to 20 such contracts in its search for a practical combination of approaches to back up all the services that the GPS constellation provides.

“This effort will inform implementation of a system that is, to the maximum extent possible, required to be terrestrial, wireless, have wide area coverage, be difficult to disrupt and capable of expansion to provide positioning and navigation services,” said Furchtgott-Roth. “We might not be able to do all those things, but we are very much going to try our best possible. We are seeking the best solutions to ensure that America has a combination of PNT systems which, when used together, will be difficult to disrupt.”

Spoofing: Detection or Resilience?

Disruption by Russian and Chinese spoofers, including mysterious crop circle-like patterns of spoofing in China, were at the heart of a paper presentation in an ION conference session on PNT Security and Robustness. Dr. Todd Humphreys, an associate professor at the University of Texas-Austin at the head of its Radionavigation Laboratory, described his work with the Washington, D.C.-based Center for Advanced Defense Studies that produced a study released in March. That report, which was based on public information sources, showed consistent, widespread GNSS disruptions in and around the Russian Federation, Crimea, and Syria. Some of the problems were so severe they amounted to denial of PNT service.

“Keep in mind that improved spoofing detection without improved spoofing resiliency opens the door to spoofing for denial of service,” Dr. Humphreys told his audience. “That means that if you build a lot of great and sensitive detectors into your receiver so that it will always trigger and tell you ‘I have a spoofing fault and I cannot provide you an authenticated solution and so I won’t provide you any solution.’ — this becomes an avenue for an adversary to deny you service of GNSS.”
Dr. Humphreys also described his latest research project — figuring out how ships in the Shanghai harbor were being spoofed such that their false locations were, as a group, forming a circle in a Shanghai neighborhood. “The last data point we have was just two weeks ago,” Humphreys told the audience. “Like I said, I can’t explain it.”

**Anti-Spoofing: Signal Authentication**

Thwarting such spoofing is at the heart of a new experimental signal called Chimera, according to Logan Scott of LS Consulting, who co-chaired the PNT Security and Robustness session. Short for “Chips Message Robust Authentication,” Chimera uses encrypted watermarks to authenticate that a signal is coming from where it should be.

In his presentation to the CGSIC, Mr. Scott explained that the key for the encryption changes quickly and is broadcast only after the watermark is received. Once the key is broadcast it is changed.

“The key [comes] from the satellite — so, the control segment has it; the satellite has it. The user segment does not have this key in real time. It’s always given this key with a delay,” said Mr. Scott, one of six ION Master Instructors who offered pre-conference short courses that were free to ION GNSS+ attendees.

“The watermark itself is hard to forge,” Scott added, “because this is at a chip-level type of thing it’s very below thermal noise. So, yeah, you can read this stuff if you have high-gain antenna pointed at it, but for somebody trying to build a single generator or that high school kid that’s downloading stuff off the Internet, he’s not able to forge it.”

The presentations were part of hundreds of peer-reviewed research papers, commercial and policy sessions, tutorials, and panel discussions attended by nearly a thousand people during the week of events, which included an accompanying exhibition featuring dozens of GNSS-related manufacturers, research organizations, and media.
AWARDS/RECOGNITION AT ION GNSS+ 2019

ION GNSS+ 2019 Program Committee Recognized
Dr. Chris Hegarty, General Chair; Dr. Oscar Pozzobon, Track Chair; Dr. Di Qiu, Track Chair; Samantha Smearcheck, Track Chair; Tim Murphy, Program Co-Chair; Dr. Heidi Kuusniemi, Program Co-Chair; Dr. Sabrina Ugazio, Track Chair; Dr. Daniele Borio, Track Chair; Dr. Mathieu Joerger, Track Chair; and Dr. John Raquet, Tutorials Chair. (Not Pictured: Patricia Doherty, Plenary Chair.)

2019 Peer Reviewers Recognized with Bouquets of Red Pencils
These individuals were recognized as people who demonstrated outstanding contributions to the Institute this past year in their role as a peer reviewer who selflessly provided quality and timely reviews when called upon to do so.

Student Paper Awards
The Satellite Division awarded four students with Student Paper Awards. Recognized industry and academic experts selected winners. (left to right) Alex Minetto, Politecnico di Torino, Italy; Surabhi Guruprasad, York University, Canada; Jiang Guo, Wuhan University, China; and Guohao Zhang, The Hong Kong Polytechnic University, China.

THE 2019 KEPLER AWARD
The Institute of Navigation’s (ION) Satellite Division presented Prof. Peter Teunissen with its Johannes Kepler Award September 20, 2019, at the ION GNSS+ Conference (Miami, Florida) for his influential and groundbreaking contributions to the algorithmic foundations of satellite navigation, and for sustained dedication to the global education of the next generation of navigation engineers.

Prof. Teunissen invented the Least Squares Ambiguity Decorrelation Adjustment (LAMBDA) method, the worldwide standard for ambiguity resolution, which revolutionized high precision GNSS positioning capabilities. LAMBDA has thus become an indispensable tool that is most widely used in land, air and space navigation; positioning and attitude determination; differential and network processing; and in surveying and geodesy. He also extended the method to MC-LAMBDA, a multivariate constrained resolution method for optimal GNSS attitude determination.

Among others, Prof. Teunissen laid the mathematical and algorithmic foundation of reliability theory, which enables a proper understanding of the quality of different integer ambiguity resolution methods and a rigorous characterization of their failure rates, which even led to the development of an optimal test for ambiguity validation. His findings are particularly important for multi-GNSS processing, which require a proper understanding of individual system characteristics and their respective contributions to achieve navigation solutions of the highest precision and integrity.

Prof. Teunissen has made contributions in the field of precise point positioning, the exploitation of triple-frequency observation, and the joint use of new GNSSs such as Galileo, BeiDou and QZSS. Pioneering work in this area include the early setup of multi-GNSS receiver test beds in the Asia-Pacific area; the discovery and proper handling of mixed-receiver inter-satellite-type biases, which were vital to fully exploit ambiguity resolution in the regional, BeiDou-2 system; and the first demonstrations of mixed GPS/Galileo/IRNSS/QZSS L5 processing for precise positioning applications.

Prof. Teunissen has made significant contributions to educating future generations. He is currently a Professor of Satellite Navigation at Delft University of Technology, The Netherlands and Curtin University, Australia. He received his PhD at Delft University of Technology in Mathematical and Physical Geodesy. He holds several honorary professorships and fellowships of numerous international organizations, including Australia’s prestigious Federation Fellowship of the Australian Research Council. He has published over 300 papers, seven books, is co-editor and author of the Handbook of Global Navigation Satellite Systems, and is a member of 13 editorial boards. He is a regular contributor to ION and ION programs. He is a Fellow of the ION, the RIN and the Royal Netherlands Academy of Sciences.

The Johannes Kepler Award recognizes and honors an individual for sustained and significant contributions to the development of satellite navigation. It is the highest honor bestowed by the ION’s Satellite Division.
Thank You, Exhibitors!

Our generous exhibitors contribute to the success of our conferences. Please show your support.

Dr. Y. Jade Morton (at right) and Patricia Doherty, ION Satellite Division Vice Chair

ION Hosts Women in PNT at ION GNSS+ 2019

The ION hosted its fifth Women in Positioning, Navigation, and Timing (PNT) event in conjunction with this year’s ION GNSS+ technical meeting. The ION’s Women in PNT is a voluntary networking initiative designed to support and engage women who are in the early stages of their PNT careers.

This year’s event hosted an informal evening of roundtable discussions moderated by leaders in the field and designed to promote intimate, thought-provoking discussions on a variety of topics important to women in PNT. Topics included juggling professional and personal priorities and advancing oneself professionally.

The discussions included lively conversation centered on time-management skills, survival skills when facing challenges, different tools used to organize, and networks for support. The roundtables were full of fresh and innovative ideas.

The ION would like to thank this year’s Women in PNT corporate sponsors: Spirent Federal Systems, L3Harris Technologies and the Munich Satellite Navigation Summit, who supported the activity financially and with their organizations’ female talent.

Kelly Garcia, L3Harris, and Antje Tucci, with the Munich Satellite Navigation Summit

Women in PNT attendees participate in a roundtable discussion.
**ION GNSS+ 2019 Best Presentation Awards**

**Session A1: Applications of Raw GNSS Measurements from Smartphones**

*GNSS NLOS Pseudorange Correction based on Skymask for Smartphone Applications: Hoi-Fung Ng, Guohao Zhang, Li-Ta Hsu, The Hong Kong Polytechnic University, Hong Kong*

**Session B1: GNSS Augmentation Systems and Integrity 1**

*Fault-Free Integrity Analysis of Mega-Constellation-Augmented GNSS: Danielle Racelis, Virginia Tech; Boris Pervan, Illinois Institute of Technology; Mathieu Joerger, Virginia Tech*

**Session C1: Land-Based Applications**

*Autonomous Vehicle High-Accuracy Position and Integrity Engine Performance Results: E. Dominguez-Tijero, A. Chamorro Moreno, M.T. Fernández-Calzón, GMV, Spain; J. García, FICOA, Spain; J. Ibanez-Guzmán, E. Stawiarski, RENAULT, France; Philippe Xu, University of Technology of Compiegne, France; G. Avellone, F. Pisoni, STMicroelectronics, Italy; E. Falletti, LINKS Foundation, Italy; M. Ortiz, IFSTTAR, France*

**Session D1: Connected and Collaborative Autonomy**

*Cooperative Localization of Networked Multi-agent System: Jiaying Lin, Jan-Jörn Gehrt, René Zweigel, and Dirk Abel, RWTH Aachen University, Germany*

**Session F1: Atmospheric Science and Space Applications with GNSS**

*Characterization for DFMC Error Standardization: Stefano Caizzone, Mihaela-Simona Circiu, Wahid Elmarissi, Christoph Enneking, Andreas Winterstein, German Aerospace Center (DLR), Germany*

**Session A2: Navigation in Urban Environments**


**Session C2: Aviation and Aeronautics**

*Airborne Antenna and Multipath Error Characterization for DFMC Error Standardization: Stefano Caizzone, Mihaela-Simona Circiu, Wahid Elmarissi, Christoph Enneking, Andreas Winterstein, German Aerospace Center (DLR), Germany*

**Session E2: GNSS Augmentation Systems and Integrity 2**

*Network-Based Ionospheric Gradient Monitoring to Support GBAS: Maria Caamano, German Aerospace Center (DLR), Germany & Polytechnic University of Catalonia, Spain; Michael Felix, Daniel Gerbeth, DLR, Germany; Jose Miguel Juan, Guillermo Gonzalez-Casado, Jaume Sanz, Polytechnic University of Catalonia, Spain*

**Session F2: GNSS Signal Processing in Degraded Environments 1**

*Galileo E6-B Tracking with Non-coherent Integration and Kalman Filtering: Melanie Susi and Daniel Borio, European Commission, Joint Research Centre, Directorate for Space, Security and Resilience, Italy*

**Session B3: GNSS Augmentation Systems and Integrity 3**

*Muli Gaussian Distribution for ARAIM SISRE Overbound: Santiago Perea, Airbus Defence and Space GmbH, and RWTH Aachen University, Germany; Michael Meurer, RWTH Aachen University & German Aerospace Center (DLR), Germany; Boris Pervan, Illinois Institute of Technology*

**Session C3: Marine Applications and Search and Rescue**

*SAR/Galileo Return Link Entry in Service: Chiara Scaleggi, Sylvain Delattre, CNES, France; Igor Stojovic, ESA; Antonio Rolla, Javier Perez-Bartolome, European Commission; Jeremie Benoist, Pol Novell, GSA*

**Session D3: Navigation Using Environmental Features**

*Tracking of Digital FM OFDM Signals for the Determination of Navigation Observables: Mark L. Psiaki and Brian D. Slosman, Virginia Tech*

**Session E3: Aided GNSS and Sensor Fusion in Challenging Environments 1**

*On the use of an Ultra-tight Integration for Robust Navigation in Jammed Scenarios: Calogero Cristodaro, Politecnico di Torino, Italy; Gianluca Falco, LINKS Foundation, Italy; Laura Ruotsalainen, University of Helsinki and Finnish Geopolitical Research Institute, Finland; Fabio Dowis, Politecnico di Torino, Italy*

**Session F3: Low-Cost High Precision GNSS Positioning**

*Accuracy Trend Analysis of Low-cost GNSS Chips: The Case of Multi-constellation GNSS PPP: John Aggrey, Sunil Binsath, Nacer Naciri, Ganga Shinghal and Sihan Yang, York University, Canada*

**Session A4a: GNSS Chipset Manufacturer Showcase**

*Positioning Performance Evaluation of Automotive-grade Chipsets: Nataliya Mishukova, Stefan Junker, Ramzi El Khayat, Trimble Terrasat GmbH, Germany*

**Session A4b: Interference Detection and Mitigation using Raw Measurements from Smartphones**

*Supercorrelation as a Service: S-GNSS Upgrades for Smartdevices: Ramsey Faragher, Matthew Powe, Paulo Esteves, Nicolas Couronneau, Mark Crockett, Henry Martin, Emanuele Ziglioli, Chris Higgins, Focal Point Positioning Ltd., UK*

**Session B4: Spectrum: Protection and Optimization**


**Session C4: Autonomous Applications**

*An Efficient Tuning Framework for Kalman Filter Parameter Optimization using Design of Experiments and Genetic Algorithms: Alan Zhang and Mohamed Maher Atia, Carleton University, Canada*

**Session E4: Advanced Integrity Algorithms for Multisensor Navigation**

*UAV Integrity Monitoring Measure Improvement Using Terrestrial Signals of Opportunity: Mahdi Maaref and Zak M. Kassas, University of California, Irvine*

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**The Bradford W. Parkinson Award**

The Bradford W. Parkinson Award was awarded to Dr. Santiago Perea Diaz, RWTH Aachen University, Germany for his thesis, “Design of an Integrity Support Message for Offline Advanced RAIM”. Awarded annually to an outstanding graduate student in the field of Global Navigation Satellite Systems (GNSS), the award honors Dr. Parkinson for his leadership in establishing both the U.S. Global Positioning System and the Satellite Division of the ION, includes a personalized plaque and a $2,500 honorarium.
Session F4: Next Generation RF, Antenna Techniques, and Receiver Processing
Impact of Receiver Front-End Characteristics on High Order BOC Tracking: Jan Wendel, Airbus DS GmbH, Germany; Alexander Rügamer, Johannes Rossouw van der Merwe, Santiago Urquijo, Fraunhofer IIS, Germany; Daniel Pfaffelhuber, Andre Waclikens, David Rüegg, Airbus Defence and Space GmbH, Germany

Session A5: Development of Indoor Positioning
Indoor Positioning via WLAN Channel State Information and Machine Learning Classification Approaches: Erick Schmidt, Yufei Huang, David Akopian, The University of Texas at San Antonio

Session B5: Trends in Future Satellite Navigation Technology, System Design and Development
Devising High-Performing Random Spreading Code Sequences Using a Multi-objective Genetic Algorithms: Tara Yasmin Mina and Grace Xingxin Gao, Stanford University

Session D5: UAV Navigation Technology and Algorithms
Sensitivity Analysis of RADAR Altimeter-aided GPS for UAS Precision Approach: Andrew Videmsek, Ohio University; Maarten Uijt de Haag, TU Berlin, Germany and Ohio University; Timothy Bleakley, General Atomic Aeronautics Systems Inc.

Session E5: Interference Detection and Alternative PNT
Characterizing Terrestrial GNSS Interference from Low Earth Orbit: Matthew J. Murrian, Lakshay Narula, and Todd E. Humphreys, University of Texas at Austin

Session F5: Scientific Uses of Raw GNSS Measurements from Smartphones
Use of PPP Processing for Next-generation Smartphone GNSS Chips: Key Benefits and Challenges: John Aggrey, Sunil Bisnath, Nacer Naciri, Ganga Shinghal, Sihan Yang, York University, Canada

Session B6: GNSS Applications in Space
Space GNSS Receiver Performance Results with Precise Real-Time On-board Orbit Determination (P2OD) in LEO Missions: Jose Maria Palomo, Paolo D’angelo, Pedro Freire da Silva, Antonio J. Fernández, DEIMOS Space, Spain; Pietro Giordano, Paolo Zoccarato, ESA-ESTEC; Javier Tegedor, Ole Oerpen, Fugro Norway AS, Norway; Lasse Bundgaard Hansen, GomSpace AS; Chris Hill, Terry Moore, The University of Nottingham, UK

Session G6: Aided GNSS and Sensor Fusion in Challenging Environments
Assessment of Differential Carrier Phase Measurements from Orbcomm LEO Satellite Signals for Opportunistic Navigation: Joe J. Khalife and Zaher M. Kassas; University of California, Irvine

Session C6: Authentication and Augmentation Services
SBAS Data Authentication: A Concept of Operations: Andrew Neish, Todd Walter, J. David Powell, Stanford University

Session D6: Technologies for GNSS-Denied Environments
Indoor Localization with LTE Carrier Phase Measurements and Synthetic Aperture Antenna Array: Ali A. Abdallah, Kimia Shamaei, Zaher M. Kassas, University of California, Irvine

Session E6: Remote Sensing, Timing and Clock Technology
Ocean Vector Wind Retrieval from Delay-Doppler Maps Using Ambiguous Stare Processing: Ian Collett, Y. Jade Morton, University of Colorado Boulder

Session F6: GNSS Signal Processing in Degraded Environments
Modified Open/Closed Loop Tracking Through VDFLL for LEO Satellites: Sara J. Hrbek, Damian Miralles and Dennis Akos, University of Colorado Boulder

Session G6: Aided GNSS and Sensor Fusion in Challenging Environments
Assessment of Differential Carrier Phase Measurements from Orbcomm LEO Satellite Signals for Opportunistic Navigation: Joe J. Khalife and Zaher M. Kassas; University of California, Irvine
CASSCA 2019 Recap continued from page 1

Dr. Robert Leishman, a research assistant professor at the Air Force Institute of Technology and the CASSCA Program Chair, kicked off the event by discussing the idea that efficiency is the underlying principle driving society’s fascination with autonomous systems — efficiency in terms of time, cost, fuel, safety, man-power and the environment. He related some of the key successes within the areas of autonomous systems: advances in perception and sensor processing; successful applications in the domains of industrial, mining, and agriculture; and progress in the area of aerial delivery.

Dr. Leishman then shared some interesting observations about current gaps in the capabilities of autonomous systems. These include the effects of weather changes, interactions with pedestrians and bystanders, and interdependent failures within multiple systems or sensors. This last capability gap represents the most difficult to foresee and prevent or diagnose and debug, according to Dr. Leishman.

In his keynote address, CASSCA General Chair Dr. Zak Kassas, an assistant professor of Mechanical & Aerospace Engineering and Electrical Engineering & Computer Science at the University of California, Irvine, highlighted the astounding potential societal and economic impact of future cyber-physical systems (CPS), specifically unmanned aerial vehicles (UAVs) and self-driving cars. He then took up the technical challenges that must be met to ensure that these autonomous CPSs meet the requirements for safety critical applications.

First, GPS and other global navigation satellite systems (GNSS) are coming to pose a single point of failure as evidenced by the increase in cyber attacks (jamming and spoofing) on these systems, which can leave them paralyzed or result in catastrophic incidents.

Dr. Kassas showed two videos summarizing the latest research results from his Autonomous Systems Perception, Intelligence, & Navigation Laboratory that address this challenge by exploiting ambient radio signals of opportunity in GNSS-challenged and GNSS-denied environments. The first video showed a UAV navigating with sub-meter-level accuracy by listening to cellular long-term evolution signals. The second video showed a UAV navigating with meter-level accuracy by exploiting low Earth orbit satellites in a simultaneous tracking and navigation fashion.

The second challenge is our over-reliance on artificial intelligence (AI) and the consequences this could lead to, according to Dr. Kassas. The third challenge is malicious cyber-attacks in which no sensor is safe (vision, lidar, IMUs, radio channels), leading to crashes or city-wide gridlock.

A fourth challenge lies in the rush to operate these systems in the public realm before they possess trustworthy autonomy capabilities. This was seen in recent fatal crashes involving Tesla’s Autopilot where a standby operator seized control of the Autopilot but could not intervene fast enough to prevent the accident. The fifth challenge is the unintended consequences of an under-informed or facile public acceptance of autonomous systems. We need only reflect on the controversies surrounding social media as a cautionary tale of how autonomous systems could unpredictably affect the fabric of our society.

Finally, and most importantly, are ethical challenges. One has to wonder, by creating an autonomous CPS and endowing it with some form of intelligence, are we creating the next “Terminator”? Are we OK with an autonomous CPS making decisions of life or death?

Following these introductions to the conference themes, CASSCA continued with a plenary session and then divided into two parallel tracks with topics addressing trust, autonomous ground vehicles, autonomous aerial vehicles, human-machine symbiosis, and ethics and policy.

Plenary

Dr. Jonathan Sprinkle, an associate professor at the University of Arizona and a former National Science Foundation program director, provided a great “so what?” discussion for autonomous vehicles. Why do we want these systems? Why are they important? He also helped us all to appreciate the importance of highlighting the “so what?” in all our presentations and proposals. He then highlighted some extensive test results on the capability of autonomous cars to damp out those rolling “traffic waves” that we all love so much.

Dr. Randy Beard, a professor at Brigham Young University, discussed some interesting UAV research that is ongoing at BYU. He gave us a view of the state of the art in onboard, real-time visual tracking from a UAV and how these aerial systems are becoming increasingly autonomous.

Dr. Joseph Lyons, Collaborative Interfaces and Teaming Lead at Air Force...
Research Laboratory, offered an insightful introduction to the subject. How do users, bystanders, and fellow travelers know that they can rely on an autonomous vehicle to behave in a predictable, logical manner? One key insight was that to have trust, risk must also be involved, which can be a challenge to test. That, in turn, creates an associated challenge in determining when and whether individuals will trust an autonomous system. Dr. Giorgio Rizzoni, a professor at The Ohio State University, came at the subject of autonomous vehicles by detailing world energy consumption and production. He helped to ground the discussion of efficiency in terms of what is the current state of energy supply and demand. One interesting concept was his analysis of the equivalent miles per gallon of an electric vehicle by country, depending on the major methods for producing electricity in that country. He discussed how advances in autonomous systems, even if they end up being relatively modest, might help reduce our energy consumption.

**Ground Vehicle Autonomy**

As expected, the ground vehicle autonomy session, chaired by Dr. Rizzoni, generated a lot of enthusiasm as self-driving cars are on everyone’s mind these days. Experts and their topics included Dr. Junmin Wang, University of Texas at Austin, Optimal Personalization in Ground Vehicle Automation and Autonomy; Dr. Craig Lennon, U.S. Army Research Lab RDECOM, Verification & Validation for Learning Systems; Dr. Tyler Reid, Ford Motor Company, Localization Requirements for Autonomous Vehicles; Dr. Mathieu Joerger, Virginia Tech, Multisensory Navigation Safety Monitoring for Autonomous Vehicles; and Mr. Ajay Vemuru, Spirent Communications, PNT Testing and Validation: Trends Picked up from Industry.

**Aerial Vehicle Autonomy I**

Tuesday morning got off to a great start with the first of two sessions on Aerial Vehicle Autonomy. This session included the following presenters: Dr. David Casbeer, U.S. Air Force Research Laboratory, Cooperative Planning and Control for Autonomous Multi-vehicle Defense; Dr. Raj Sharma, University of Cincinnati, Cooperative Localization and Autonomy; Dr. John Raquet, IS4S, UAVs vs. Natural Autonomous Vehicles (NAVs) — Are We Closing the Gap?; Mr. Mitch Narins, Strategic Synergies, Aviation and Autonomy — Issues of Respect, Reaction, Responsibility, and Regulation; and Dr. Richard Scott Erwin, Air Force Research Laboratory, High-Assurance Autonomy for Military Space Environments. Much of the discussion and Q&A focused on the debate between innovation and regulation and helped us realize the challenges associated with striking that balance.

**Aerial Vehicle Autonomy II**

Dr. Kassas chaired the second installment of the aerial vehicle autonomy session, which featured the following experts: Dr. Evangelos Theodorou, Georgia Tech, The Science of Autonomy: A Happy Symbiosis Among Learning, Control and Physic; Dr. Jason Gross, West Virginia University, Resilient Navigation for Aerial Autonomy; Mr. Nathan Sebok, Lockheed Martin, Challenges in Deploying Autonomous Marine Systems; and Dr. Kevin Brink, Air Force Research Laboratory Munition Directorate, In Search of Scalable, Collaborative Navigation for Autonomous Systems. The Q&A panel focused on if/how we can achieve symbiosis between AI versus classical model-based approaches.

**Ethical Systems and Policy**

Dr. Leishman chaired this conference wrap-up session, which offered a unique set of insights to consider as we move forward with autonomous vehicle development. Dr. Joseph Nichols, Raytheon Missile Systems, Dr. Dorota Grejner-Brzezinska, The Ohio State University, and Dr. Yvonne Masakowski, U.S. Naval War College, discussed many challenging open questions in testing and certification of autonomous systems, their integration within current policy, regulations and societal constructs, and the ethics associated with militarized autonomous systems. We left the session truly perplexed by all the mindful, open questions that we will need to resolve as a society to be able to fully integrate autonomous systems into society.
This column features one of ION’s Technical Representatives each quarter to highlight the depth and breadth of their work, research, and interests. During their two-year terms the ION’s Technical Representatives guide and advise The Institute of Navigation and the positioning, navigation, and timing (PNT) community. — Interview and write-up by Dr. Kyle Wesson

Dr. Li-Ta Hsu is an assistant professor in the Interdisciplinary Division of Aeronautical and Aviation Engineering at The Hong Kong Polytechnic University (PolyU). His current research projects revolve around improving the implementation of navigation algorithms on smartphones (hello vector tracking!), making better high-definition maps in challenging urban areas like Hong Kong, developing novel tracking techniques that leverage 5G, and creating open source datasets for urban navigation. — Interview and write-up by Dr. Kyle Wesson

Dr. Li-Ta Hsu

1. How did you first get involved with ION?
ION GNSS 2009! I was a first year Ph.D. student in Taiwan. I presented my first conference paper titled “Development of an Indoor Location Based Service Test Bed.” I won the best presentation award for the session. It really encouraged me to continue my career as a researcher in the navigation field.

2. What is your favorite aspect of being a member of ION?
Oh . . . there are many! It’s difficult to identify a favorite aspect. Since I have to, I will say it’s the network. Meeting and learning from all the brilliant researchers always gives me new insights to apply to my own research endeavors. The ION network is especially valuable because it includes not only academic researchers but also the industrial innovators. Talking to them and learning the needs of different real-world applications helps me develop new algorithms and ideas.

3. What type of GNSS work do you do currently or have you done in the past?
GNSS multipath and NLOS have been the longstanding problems that I am trying to solve. In a way, my move to become a professor in Hong Kong has challenged me to continue my GNSS research in one the most urban cities in the world.

A lot of my focus is on self-driving car navigation. Recently, I proposed a combination of LiDAR and camera perception to detect the surrounding environment of the GNSS receiver to model the effect of multipath and NLOS (non-line-of-sight signals). The benefit here is that the car can perceive the environment in real-time and model the changing environment around the receiver. I wrote an article on this very idea in the July/August 2019 issue of Inside GNSS.

My research career started with indoor positioning based on the wireless sensor network ZigBee. Soon after, I started to work on GPS signal acquisition and tracking.

My first academic GNSS project was sponsored by the National Space Organization, Taiwan. I designed a new code correlator to mitigate multipath effects in Galileo GIOVE-A signal tracking. Then, I worked on the development of a prototype system of Wide Area Differential GNSS in Taiwan, which was sponsored by the National Land Surveying and Mapping Center, Taiwan. In the project, I worked on developing the master station algorithm using the existing e-GPS stations.

Dr. Paul Groves of UCL (University College London) invited me to conduct research to assess the potential of vector tracking in multipath mitigation and NLOS detection. Our result was fruitful and helped me win a student paper award at ION GNSS+ 2013. This award gave me confidence that my research was valuable within the GNSS community, and I decided to continue my academic career.

The next year, I worked as a postdoctoral researcher in the Institute of Industrial Science, the University of Tokyo, Japan. I was responsible for researching and developing a 3D mapping–aided
GNSS algorithm for autonomous driving. During my three years of research at the University of Toyko, I expanded my knowledge from navigation to perception, and I found my passion — enabling self-driving car navigation in highly urbanized areas.

4. What do you consider some of the most important current research, education, policy, or technical topics in GNSS for the next year?

In terms of commercial applications, I believe it’s low-cost dual-frequency GNSS RTK and integration with MEMS IMUs. Of course, the integrity assessment of the GNSS RTK/INS integrated system will be critically important.

In terms of technical topics, we will need to continue improving GNSS positioning in urban canyons, since as the U.N. reports, more than 50 percent of the global population will soon live in urban areas. More robotics and ITS (intelligent transportation system) innovations will take place in these areas. We must make GNSS useful and reliable in these multipath-challenged areas. I believe GNSS will still stand in the center of the navigation suite despite new technologies coming along.

In terms of education, I would like to praise Professor Akio Yasuda (Japan) who has hosted the international GNSS summer school since 2016. International students and entry-level engineers from East and South Asia are taking this opportunity to build their careers in GNSS. I have to say the one-week course is intense and fruitful. I was invited to teach the fundamentals of GNSS for the 2018 summer school.

5. What areas of ION have you been involved in, and what areas do you hope to see grow in the future?

I have been involved in GNSS positioning in urban canyons, navigation using environmental features, and multi-sensor integration for challenging environments. It would be great if we can see the involvement of ION in the development and realization of self-driving vehicles.

I believe the researchers in the self-driving field should learn the beauty of GNSS RNP (required navigation performance). Security should always be a priority in the realization of automotive systems. After all, the self-driving car is meaningful because it can potentially reduce the excessive road fatalities.

6. If you were not in your current field, what would you want to do for a living?

I would move back to my hometown of Tainan, Taiwan, and become a fish farmer. It could be satisfying to help develop the family business. A simple life may give me more time to develop my interests in philosophical meditation and provide a great balance between work and life.
This is the second in a series of articles describing the development and growth of automotive navigation systems. The first article recounted humans’ quest for land vehicle navigation going as far back as the Chinese empires in the 11th century. Despite the fact that by the 1950s the automobile had become the engine that drove the American economy, little progress was made toward a versatile, commercially successful, navigation system.

Looking back, 1974 was a particularly interesting year.

The Watergate scandal dominated the headlines and eventually culminated in Richard Nixon becoming the first and only president of the United States to resign from office, an action he took to avoid being removed by impeachment.

The Rumble in the Jungle took place in Kinshasa, Zaire, where Muhammad Ali knocked out George Foreman in eight rounds to regain the heavyweight boxing title. The New York State Athletic Commission had stripped him of the title a year earlier for his refusal to be drafted into U.S. military service.

Personally, I began teaching navigation courses as part of an in-house education program at the Naval Air Development Center. They were non-matriculated courses that subsequently morphed into Master’s Degree specialty programs at Wilkes and Pennsylvania State Universities. And they would eventually lead into exploration of a brand new navigation technology that has come to underlie modern car navigation systems.

The Road to GPS

My first course featured a 14-week syllabus, taught once a week for two hours, titled “Fundamentals of Navigation.” I spent about three weeks teaching the various types of measurements used for position-fixing — such as range, range-range, angles, and hyperbolic — and how they led to lines of position (LOPs) and then to position fixes at the intersections of the LOPs.

A few lessons addressed the shape of the Earth, including definition of coordinate systems and the roles of geodesy and cartography as sciences closely related to navigation. Students learned how to solve classical navigation problems such as calculation of distances, true and relative bearings, distances and time to reach a destination. They used the first generation of programmable handheld calculators such as the Hewlett Packard 65 and Texas Instruments 2550 to solve these problems.

The principles of celestial navigation were taught not from a practicing navigator standpoint (as I did not own a sextant until 2016), but from a mathematical perspective of solving intersecting circular LOPs on a spherical Earth. Several lessons were dedicated to radionavigation systems such as Decca, Loran, Omega and Lorac. This was followed by two lessons on the principles of inertial navigation, which at the time was limited to the province of expensive military platforms.

I gave a class on the Navy Navigation Satellite System (NNSS, aka TRANSIT), which became operational for Polaris submarines in 1964 and was approved for civil use with the leadership of Vice President Hubert Humphrey in 1968. Finally, if time in the course permitted, the course included a brief lesson on time systems, horology, and a look into the future of navigation.

One of those futuristic technologies, which had just been granted Department of Defense approval in December 1973 for initial concept feasibility, was the NAVSTAR Global Positioning System, which came to be known in more abbreviated form by the acronym GPS.

And the Answer Is. . . .

These courses, being non-matriculated, did not require students to take tests or a final exam. However, periodically I would pose “Thought Questions,” which the students were asked to complete.
The first “Thought Question” challenged the students to “Design a Car Navigation System,” including details on size, weight, power, display, cost, technology, and accuracy. The students submitted some interesting ideas, but they frequently evinced a strong undercurrent of resistance to the usefulness of car navigation systems. Most of the students felt such systems were unnecessary, and they wouldn’t pony up the $1,000 that the students frequently estimated the cost would be. They were fine with their paper maps, which they could get for free at local gas stations!

In 1974, the typical method to navigate to a new destination would be to find paper map(s) that covered both the starting point and desired end point, unfold the 24-panel chart, search one of the panels that had an index consisting of six-point type for the starting and ending street names, locate those two street names written in an even more miniscule type on two of the twenty-four panels, and then, emulate an experimental rat’s brain by figuring out the maze to traverse the route from start to end without the knowledge of speed limits, one way streets, or numbered addresses.

During the traverse a co-pilot, who in my case was usually my wife, would have to ingeniously fold, rotate, and flip the map in real-time in such a way as to show the current position and the destination position simultaneously. If the destination was finally reached without triggering a marriage-threatening dispute, the motorist or a companion/navigator faced the daunting challenge of folding the paper map back into its original configuration.

The lessons that I learned from this “Thought Question” were:

1) The students in the class were not at all a random sample of the population, but a collection of penurious government engineers.

2) A vindication of Steve Jobs’ observation that “A lot of times, people don’t know what they want until you show it to them.”

3) Necessity is relative to the user and not always the mother of invention because it took almost a decade later before commercial car navigation systems began appearing.

Japan Shows the Way

Before the rise of the Silicon Valley and Steve Jobs-like influence on consumers, Japanese companies were the leaders in electronic gadgetry — remember the Sony Walkman? — and it was Japan that led the way in automobile navigation systems.

One of the first optional built-in automotive navigation systems was the Honda/Alpine/Stanley Electric co-developed Electro Gyro-cator, introduced to Japan, in 1981. This “inertial navigation system” used a small helium gas gyroscope as its direction-change indicator and a connection to the car’s transmission as its distance-traveled meter. Transparent maps had to be placed onto a screen manually, and these would scroll over the monochrome six-inch cathode-ray-tube (CRT) screen used for lighting and pinpointing purposes.

 Needless to say, Electro Gyrocator was not able to provide turn-by-turn directions but it was still a nifty tool to use and more efficient than conventional maps. Speaking of which, the transparent maps had to be tailor-made to the navigation system and were inserted in a slot for display on the monochromatic illuminated screen. The CRT display provided adjustments for brightness, contrast, position, display scale, and position. An optional kit came bundled with a marking pen to allow users to draw the necessary locations of interest, including the starting point.

To use the system, an operator would select a map out of an enormous binder of plastic maps, draw on it like children and elementary school teachers with a love of overhead projectors — or as 1950s viewers of the Winky-Dink and You television show did — shove the map into a slot in the nav system, position it just right to make sure it’s not off by 500 feet or so, and off you went. The vehicle would appear as a little blinking blip, with a trail of dots behind it, and you’d follow along on the map that you inserted to determine where you were.

The Electro Gyrocator weighed in at a chunky nine kilograms (about 20 pounds) and was offered as a dealer option on Honda Accord and Vigor cars for the equivalent of about $2,750—nearly 25 percent of the price of the actual cars themselves. Launched in August 1981, unsurprisingly it was discontinued within a year.

In 2017, The Institute of Electrical and Electronics Engineers awarded Honda an IEEE Milestone for the Electro Gyroca- tor, which is generally accepted as being the first commercially available map-based car navigation system.

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Unless I have been misinformed, the GPS Directorate was unceremoniously disestablished in the margins of a picnic held at the Los Angeles Air Force Base Space and Missile Center (SMC) at the end of July 2019.

Under the SMC realignment initiative, referred to as SMC 2.0, pieces of what used to comprise the GPS Program are now distributed among a collection of SMC sub-organizations, with no direct management oversight of the entire “Program.”

The SMC 2.0 structure is headed by an Air Force Three Star (Lt General John F. Thompson) and the elements of GPS [noted in brackets in the following list] are dispersed across four SMC sub-organizations. Those sub-organizations are: (1) Air Force PEO/Space [OCX]; (2) PEO Production Corps [GPS III, GPS IIIIF, MGUE Inc. 1, MGUE Inc. 2, GPS III COps, MCEU, GPS UE FMS, OCX Block 3]; (3) PEO Enterprise Corps [GPS Space & Ground Sustainment]; and (4) Portfolio Architect [PNT Mission Integration].

A March 2019 Space News article (see https://spacenews.com/air-force-just-months-away-from-completing-smc-2-0-reorganization>) foreshadowed how the new organization will be different, stating, “that these new organizations will be led by civilians, which will ensure continuity.”

An unidentified industry source was quoted in the article, saying, “I think the bigger story is about how so many colonels are leaving, changing roles, and how SMC is really working to remedy inconsistencies by creating more long-term civilian roles.” The source went on to say, “It’s hard to be a true enterprise with constant shuffling by leaders in uniform.”

Retracing the Path to Success

The successes associated with GPS are clearly found in the centralized, one-program organizational structure of the Department of Defense (DoD) GPS Joint Program Office, which was established in 1973 and retained that “GPS JPO” designation until 2006. A long line of well-known Air Force colonels has led the evolution of GPS to its globally recognized status as the unquestionable “gold standard” among all the Global Navigation Satellite Systems (GNSS) in place today.

In 2006 the GPS JPO was re-designated as the Global Positioning Systems Wing (Directorate) but remained structured as a separate command with an O-6 lead (the GPS Director) who maintained oversight responsibilities of the three segments (space, ground control, and user equipment) that comprise the military functionality of GPS while also addressing the dual-use functionality that supported civil capabilities, interface standards, modernization, and compatibility with other emerging GNSS programs.

Well, all of that has changed in the stroke of a picnic announcement. Now the question is, where do we go from here in the world of military and civil positioning, navigation, and time (PNT) — to ensure a true “PNT Enterprise” still fundamentally enabled by GPS?

Lt. General Thompson made a presentation at the June 2019 ION Joint Navigation Conference (JNC) plenary session that gave the impression that SMC 2.0 is an attempt to do more with less. Interpreting General Thompson’s JNC message, SMC 2.0 basically turns SMC into a General Motors of space where SMC will focus on economies of scale and commonality among programs through common satellite buses and components, with movement toward a common control segment for all programs.

Preserving the PNT Enterprise

As this process evolves it would be prudent to ensure that the importance of GPS as a critical national asset and international resource does not suffer at the hands of trying to promise “Faster, Better, Cheaper.” Such promises have far too often demonstrated that typically only one out of those three is achieved, and “Better” usually comes in last.

Unfortunately, that would not be an acceptable outcome, as the DoD and the Joint Force face an increasingly challenged PNT battlespace where the
requirements for NAVWAR compliance and PNT resilience at the user level only grow stronger.

Viewed from the user’s perspective, one might conclude that the Air Force’s action to pursue SMC 2.0 was more focused on addressing the Space and Control segments of GPS with less attention given to evolving to a multi-source “PNT Enterprise” future. Given that possibility, it is probably not useful to expect a return to “the way things used to be.”

At the same time, it is important that the Air Force establish a way to speak coherently about a “GPS Program” to the rest of the DoD and to the world — at least until there is something in place to carry forward the “PNT Enterprise” that GPS has created, and as envisioned in the recently released Strategy for the Department of Defense Positioning, Navigation and Timing (PNT) Enterprise document (see: <https://www.gpsworld.com/us-department-of-defense-pnt-strategy-gps-is-not-enough>)

**A Way Ahead**

From the perspective of ensuring a common and well-coordinated path to strategy execution, how SMC 2.0 will be responsive to the PNT Enterprise would appear to be an excellent topic for the Four-Star DoD PNT Enterprise Oversight Council.

As the previously noted DoD strategy document implies, it is most important at this point in time that the implementation of M-Code capability proceed rapidly and smoothly for all the Services, and simultaneously that the transition to a Modular Open-System Approach for incorporation of complementary PNT capabilities along with GPS be accelerated.

Both actions require strong coordination between and among the Services to both maintain and enhance interoperable NAVWAR capabilities for the Joint Force. The DoD cannot afford to stovepipe its PNT Enterprise initiatives within a Service and ignore the need for preserving a strong multi-Service atmosphere of coordination and cooperation to jointly move towards a new phase of PNT evolution.

As it may turn out, SMC 2.0 and the July picnic announcement dissolving the GPS Directorate may ultimately prove to be the wakeup call that both the DoD and the civil government counterparts need to accelerate the implementation of new strategies and to strengthen the resilience of the overall PNT Enterprise for the future by being less reliant on GPS alone to carry the PNT load.
T he ION’s Military Division hosted more than 800 attendees at the Joint Navigation Conference (JNC) July 8–11 in Long Beach, California. The event demonstrated the continued energy and enthusiasm for positioning, navigation, and timing (PNT) technologies as the foundation for the United States’ military ops and homeland security with a strong joint services and government participation.

Pre-Conference Tutorials Prove Popular
This year’s tutorial track had the greatest attendance ever. Our outstanding lecturers brought forward tutorials in areas that were mostly new to JNC, while a few were on “tried and true” topics that have stood the test of time.

Dr. John Raquet, now with IS4S, who provides JNC’s primary “staple” offering — “GPS 101” — year after year, drew both new JNC participants as well as several “old hands” looking to brush up on their familiarity with the subject. And Dr. John Burke, DARPA, returned with a session on “Precise Timekeeping and Applications.”


With seven tutorials in the lineup and eight slots, conference organizers decided to repeat the DoD PNTA Standard course, and it was a great move. Both sessions were nearly standing room only as Sam Griffin informed the audience regarding the progressive move taking PNT to Open Architecture enabling.

Technical Program Highlights
The technical program hosted parallel sessions on a variety of topics. Popular topics included Autonomous Systems and PNT, followed by a full day of three Complementary PNT–focused sessions highlighting Naturally Occurring Measurement Sources, RF Aided (Non-GPS), and Vision Aided topics, respectively. Emerging PNT requirements and solutions were covered with an emphasis on how the Air Force is addressing PNT as an enterprise moving to field new technologies more

Exhibitors, Sponsors and Media Partners

JNC is already recruiting tutorials for next year’s JNC, if you have ideas or would like to volunteer, please speak with tutorials chair Paul Olson, CCDC/C5ISR and/or program co-chair Joe Schnecker, NIWC Pacific.

Special Thanks to . . .

The ION expresses its appreciation to The Aerospace Corporation for their generous sponsorship of the facilities and security support for the classified session, as well as Northrop Grumman who sponsored lunch on the classified day. Other sponsors included NovAtel, GPS Source, Systron Donner Inertial, Harris, Lockheed Martin, LinQuest, and Raytheon.

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rapidly. Space applications topics continue to grow and became a larger focus this year with three sessions devoted to space and satellite applications.

Key technologies were highlighted for the GPS III program, and future signals were discussed. Also of keen interest was the ability to employ military GPS user equipment as a battlefield sensor; presentations of this topic were well attended.

Another highlight that was new this year was a presentation by Capt. (Ret.) Richard White, now with SI2 Technologies, Inc., who described the use of additive manufacturing technology to enable Ka-band communication links with low Earth orbit (LEO) and medium Earth orbit (MEO) satellites by developing a radome-integrated Ka-band antenna system for submarine masts. Be sure to look for an update in 2020!
NEW GSA MARKET REPORT

The GNSS Franchise Becomes a Multi-Billion Industry

So, it’s finally happened: GNSS has reached the scale of McDonald’s hamburgers.

For many years, outlets of the international food franchise would post signs under the their iconic golden arches listing how many hamburgers they had collectively sold. The totals began in the millions, which over the years became tens of millions, then hundreds of millions. Finally the signs just read, “Billions and billions served.”

According to the latest European GNSS Agency (GSA) market study released October 15, the global installed base of GNSS devices in use will reach 6.4 billion in 2019, with 1.7 billion units shipped this year alone. The report estimates that annual GNSS “downstream market revenues” from both devices and services worldwide have reached nearly €150 billion (US$167.5 billion).

Over the next 10 years, the report predicts that the installed base will increase nearly 50 percent to 9.5 billion (1.1 receivers for every person on the planet), and GNSS-related revenues will more than double to €324.4 billion (US$362.4 billion). Asia-Pacific nations, led by China, South Korea, and Japan, contain more than half of the installed base of GNSS receivers and capture nearly a third of product and service revenues. On a national rather than regional basis, however, the United States retains its initial GPS-driven lead, gaining about a quarter of GNSS-based revenues, and timing information;

• Cybersecurity issues involving GNSS vulnerabilities
• A sharing economy that began with ride and accommodation services but spread to other applications and businesses.

Editor’s Special: NewSpace

An evolving concept that Prof. Dr. Guenter Hein, Professor Emeritus of Excellence at University FAF Munich, has described NewSpace as being based on “a globally emerging, private spaceflight and aerospace industry which is more socio-economically oriented. In other words, working commercially and independent of governmental-funded (political) space programs with a faster, cheaper, and better access to space.”

“Whatever their mission type (e.g., telecommunication, EO, space science, navigation), providing reliable real-time GNSS data to Earth-orbiting satellites can bring many financial, technical and societal benefits,” the report asserts, including accurate timing, more precise relative navigation, and linking position/location with Earth observation data.

Under the NewSpace heading, the report also discusses “Galileo’s essential contribution to the Space Service Volume (SSV),” that is, the region of space extending from 3,000 to 36,000 kilometers where terrestrial GNSS performance expectations do not apply due to substantially different geometrical constraints and signal availability.

Advocated in particular by NASA and other national space agencies, the International Committee on Global Navigation Satellite Systems (ICG) has proposed creation of an interoperable multi-GNSS SSV to enable new space missions (even extending beyond geostationary orbits up to the Moon) and to drive associated technological developments.

The report was produced over the last two years by a team of 20 GSA experts from various market segments, assisted by more than 50 outside experts who helped to verify the data. The free 112-page report can be downloaded from the GSA website at https://www.gsa.europa.eu.
RISING TALENT IN THE FIELD

Autonomous Snowplow Competition, 10th Annual Event — January 2020 Edition

The Autonomous Snowplow Competition (ASC) Committee is excited to announce that this year’s competition will be hosted by Dunwoody College of Technology, located at 818 Dunwoody Boulevard, Minneapolis, Minnesota.

Dunwoody College of Technology has participated in the ASC all nine of the previous years. Their campus will be a great venue for teams and spectators. ASC team members will have a warm facility to complete final adjustments to their autonomous snowplows, as well as access to the College’s tool crib and machine shop.

The centralized location in the Twin Cities will be convenient for many spectators. While watching the competition, spectators will be able to enjoy food and snacks from the onsite cafeteria and tour some of the common areas at the college. Hockey Day Minnesota is taking place at the same time as the ASC event day, and many of those hockey games will be played just across the street from the ASC competitive trials; so, all spectators can take in two fun winter events during the same day.

The Institute of Navigation (ION) will remain a sponsor of the 10th Annual ASC and support the event with judges and volunteers. Dunwoody College of Technology will take over the role of the primary event organizer and host.

The objective of the competition is for teams to design an unmanned snowplow vehicle that will autonomously remove snow from pre-defined paths. The competition invites and challenges teams in the area of high-performance autonomous vehicle guidance, navigation, and control. The competition is also designed to encourage student interest in the areas of science, technology, engineering, and mathematics. Teams are made up of students from colleges and universities. Many teams are returning from past competitions, but new teams are also entering for the first time.

The following exciting events — all held at Dunwoody College of Technology — comprise the ASC competition week:

**Thursday, 16 January 2020: Student Final Presentations**
Teams will present their final snowplow vehicle designs to the general public and answer questions. Vehicles will be on display for public viewing.

**Friday, 17 January 2020: Vehicle Final Qualification and Review**
Teams will demonstrate the operability and safety of their snowplow vehicles and run final tests of their autonomy.

**Saturday, 18 January 2020: Competition Day!**
Teams will compete on the single straight ‘I’-shaped snowfield in the morning, and the double straight ‘I’-shaped snowfield in the afternoon. Public is encouraged to come and cheer on the plows!

More event and schedule information is available online at <www.autosnowplow.com>.

Two GPS Pioneers Pass Away

Dr. James J. Spilker, Jr., passed away peacefully the end of September in his California home at the age of 86. Dr. Spilker is known for his technical leadership in GPS signal and receiver design and for his contribution to the development of GPS instrumentation.

In the early 1970s, Spilker, together with two other senior engineers at Ford Aerospace, formed Stanford Telecommunications, where he, in cooperation with others, co-invented a separating system, split spectrum mode, which allowed GPS to broadcast civilian and military signals using different frequencies. Spilker remained at Stanford Telecommunications until 1999. In 2001 Spilker joined Stanford’s faculty as a consulting professor, where he contributed to design of the L5 civil signal.

In addition to promoting GPS technologies, Dr. Spilker also focused on education and philanthropy throughout his career, donating much of his time and money to the improvement of engineering education and the fields of aeronautics and astronautics.

Dr. Spilker contributed regularly to NAVIGATION the Journal of the Institute of Navigation during the early decades of GPS, authoring several papers in the ION’s Red Book series on GPS. He was the recipient of the ION’s Burka Award (2002) and the Kepler Award (1999) and was an IEEE Fellow and an ION Fellow (1999). He was recently awarded the 2019 Queen Elizabeth Prize for Engineering.

Ronald Hatch passed away on September 25 in Torrance, California. Mr. Hatch was one of the founders of NavCom Technology (which was acquired by John Deere in 1999). His prior work included roles at Johns Hopkins Applied Physics Laboratory, Boeing, and Magnavox Marine Systems Group.

Mr. Hatch’s 50-year career was devoted to satellite navigation and surveying, first with the TRANSIT system and then with
Corporate Profile
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Ideal Aerosmith has been providing solutions to its customers since 1938. What started as an avionics instruments lab, the company evolved through the development of the Scorsby Motion table and early automated test equipment (ATE) to become the versatile turnkey test solutions provider it is today.

Ideal Aerosmith has expertise in inertial guidance, build-to-print, ATE, as well as modeling and simulation. To support Positioning, Navigation and Timing (PNT) domain needs, Ideal Aerosmith offers a range of products: One-, two- and three-axis rate table systems for inertial sensors/systems testing and verification; flight motion simulators for hardware-in-the-loop (HWIL) testing of seekers, guidance modules, navigation modules, control (GNC) modules or entire missile/aircraft systems; and complex avionics test equipment, including SATCOM, RF and dedicated airline testers.

In step with agile development of modern technologies, Ideal Aerosmith offers a wide variety of services to support short development/production cycles, from a built-to-print service with fast turnarounds to testing-as-a-service in a fully equipped inertial testing lab in Phoenix, Arizona. Its complete turnkey solutions transform test equipment into an independent decision-making unit by planning, collecting, analyzing and implementing results of the testing. It operates with integrated engineering, manufacturing and support teams out of four locations in the United States.

For more information on corporate membership in the Institute of Navigation, please contact Kenneth P. Esthus at 703-366-2723 extension 1004

the high-accuracy applications of GPS. He is perhaps best known for his innovation of smoothing the GPS code measurements with the carrier phase measurements to mitigate multipath effects.

Mr. Hatch served the ION extensively throughout his professional career, both as Chair of the Satellite Division (1998–2000) and as ION President (2001–2002). He also contributed regularly to NAVIGATION the Journal of the Institute of Navigation and the ION’s Red Book series on GPS, authored many survey and navigation papers, and held more than two dozen patents involving GPS processing techniques.

He was the recipient of the Thurlow Award (2000), Kepler Award (1994), and was named an ION Fellow (2000). He had been a member of the U.S. National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board since 2011.

ION’s second group of ION Fellows (inducted June 2000). Back Row: Dr. AJ Van Dierendonck, Dr. William Klepczynski, Phil Ward, Ronald Braff, Dr. Ken Seidelmann and Dr. Per Enge (ION president presenting the Fellow awards – Enge would be awarded Fellow in 2001). Front Row: BG Robert Duffy, Ron Hatch, Mortimer Rogoff and Col. Leonard Sugarman.

SECTION NEWS

New England Section
The ION New England Section met at Draper Laboratory in Cambridge, Massachusetts, on September 5. The Section Chair, Dr. Keith McDonald, opened the meeting by reviewing opportunities for upcoming ION conferences and the benefits of ION membership. Dr. McDonald also highlighted the opportunity for other members/attendees to become more involved in the New England ION leadership.

Jan Anszperger, Draper, offered to fill the vacant spot of treasurer, and attendees voted unanimously to accept his offer. Next, Program Chair Rochelle Moore introduced the speaker, Dr. Chris Hegarty of The MITRE Corporation. Dr. Hegarty provided a presentation and fielded a multitude of questions on the subject, “GNSS Avionics for Civilian Aircraft: Current and Future.” Attendees enjoyed dinner and networking as well as a Draper exhibit on the Apollo Moon Landing. The next meeting is tentatively scheduled for the spring, 2020.

Dayton Section
The first meeting of the Dayton Section’s new season was held September 12 at Northrop Grumman Corporation’s Beavercreek, Ohio, offices. Capt. Aaron Canciani of the Air Force Institute of Technology’s engineering faculty was the featured speaker.

Capt. Canciani described his recent work with a machine learning technique called Empirical Dynamic Modeling
(EDM). In EDM, a time-lagged history of a platform’s motion is used to derive a model of its dynamics. These historical data exist on high-dimension manifolds, which allows for both interpolation and extrapolation. The learned dynamic model can thus be used with a traditional Kalman filter to propagate the state space forward in time.

Capt. Canciani explained that EDM has advantages over other machine learning approaches, such as neural networks, especially when the available datasets are small. He presented some results from applying EDM to a pedestrian dead reckoning dataset and noted that he is preparing a paper on this work.

Calendar of Upcoming Events

NOVEMBER 2019
18-21: International Navigation Conference (INC), Edinburgh International Convention Center, UK
Contact: The Royal Institute of Navigation (RIN)
Web: www.rin.org.uk

JANUARY 2020
Contact: ION
Web: ion.org

MARCH 2020
16-18: Munich Satellite Navigation Summit 2020, Alte Kongresshalle, Munich, Germany
Contact: Munich Satellite Navigation Summit
Web: www.munich-satellite-navigation-summit.org

APRIL 2020
Contact: ION
Web: ion.org

MAY 2020
11-14: European Navigation Conference (ENC 2020), International Congress Center, Dresden, Germany
Contact: German Institute of Navigation
Web: www.enc2020.eu

JUNE 2020
1-4: ION Joint Navigation Conference (JNC) 2020, Northern Kentucky Convention Center, Cincinnati, Ohio/Covington, Kentucky
Contact: ION
Web: ion.org

SEPTEMBER 2020
21-25: ION GNSS+ 2020, St. Louis Union Station Hotel, St. Louis, Missouri
Contact: ION
Web: ion.org
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