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POSITION
NAVIGATION
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**UAV Report**

How Drones Are Changing Our Lives

## NAVIGATING TESTING OPTIONS

Our Simulator Innovator Q&As Map Out Solutions & Trends

**GPS IIIs Roll off Production Line**

**Why Regulation Is Necessary for UAVs**

**Monitoring Sea Level in the Arctic**

A NORTH COAST MEDIA PUBLICATION

OCTOBER 2019 | Vol 30 | No 10


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OCTOBER 2019



THIS TONGUE-IN-CHEEK PHOTO, courtesy of Racelogic, underlines how simulators help GNSS engineers "road test" multiple positioning products in multiple scenarios.

Photo and cover: Racelogic

## SPECIAL SECTION

## 2019 UAV REPORT



From growing crops to making movies, unmanned arial vehicles (UAVs) are changing the way we work. UAVs — managed by unmanned aerial systems, or UAS — range from small indoor inspection units to giant Predator drones. They are streamlining how we manage mines and plants, deliver packages, and keep people safe. Check out the latest in this skyrocketing market.

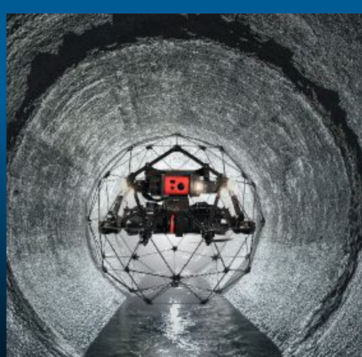

Photo: Flyability

## LAUNCHPAD



## MARKET WATCH

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# ONLINE**NOW**

## NOAA and the Search for Deep-Sea Corals

BY William Tewelow
CONTRIBUTING EDITOR, SURVEY

**This newsletter column includes National Oceanic and Atmospheric Administration (NOAA) undersea camera livestreams and an interview with an undersea expedition coordinator.**

Corals have always fascinated us, like treasures from another world — not from this dry land called Earth ruled by air-breathing, upright beings, but from a world of water with bizarre and terrifying creatures and plants made of stone.

Corals, as it turns out, are not plants at all. They are the smallest of animals, called a cnidarian, and millions of them together form the broad-limbed, rock-like structures. They take many thousands of years to develop into the large, picturesque arrangements beneath the waves.

Colonies of corals form reefs. The largest of these is the Great Barrier Reef in Australia's northeastern waters.

Corals are the cornerstone of the ocean. By some estimates, the world's corals are worth nearly $10 trillion,

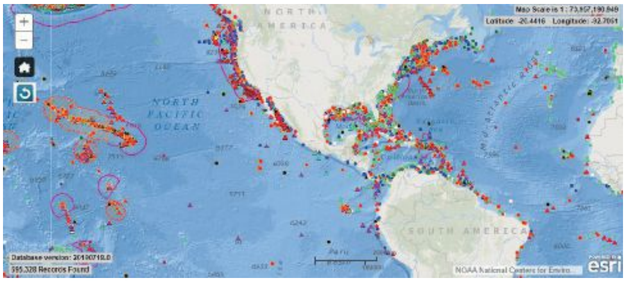


Image: NOAA

**THE NOAA DEEP-SEA CORAL and Sponge Map Portal provides information from reefs around the world.**

but that diminishes their real value because if they perish the ocean itself could die. Corals are the proverbial canary in the coalmine, and throughout the world they are ailing.

The ocean's health is in decline. There have been six severe coral bleaching events in the past 30 years and they are occurring more frequently and for longer periods each time. Over 20% of the world's corals are already gone. Saving them is a concern for us all.

Read the full Full article at **geospatial-solutions.com/category/opinions/**.

# Regulation is Necessary to Advance Drone Operations

BY BRIAN WYNNE
AUVSI PRESIDENT AND CEO

> "Remote ID is a crucial next step to gain the confidence of federal defense and security agencies, manned aviation users and the public."

A recent analysis found that just 10 percent of the unmanned aircraft systems (UAS) included in the Unmanned Systems and Robotics Database maintained by the Association for Unmanned Vehicle Systems International (AUVSI) can operate beyond the visual line of sight (BVLOS) of its operator. While the technology for BVLOS operations has existed for years, under current federal regulations, only the military is permitted to use it. The absence of federal regulation allowing BVLOS operations hinders the full value and benefits that the UAS industry has to offer.

Regulations that provide guidance and rules for operating unmanned systems are necessary for the industry's advancement. Earlier this year, the Federal Aviation Administration (FAA) issued a proposed rule for UAS operations over people, and the UAS community is eagerly anticipating the agency will offer an additional rule requiring UAS to be equipped with remote identification. However, the rulemaking process for remote ID has been delayed by the FAA twice this year and is now slated to be released in December. The need for remote ID cannot be overstated, as the advancement of the UAS industry depends on identifying and tracking UAS flying in the airspace.

Furthermore, remote ID is a crucial next step to gain the confidence of federal defense and security agencies, manned aviation users and the public. With this confidence, UAS can further integrate into the national airspace to perform important BVLOS operations such as inspection of utility rights of way, widespread search-and-rescue missions, and package delivery.

A clear, national regulatory framework and the support of the federal government is needed to drive the adoption of unmanned systems technology and its applications. Currently, the UAS industry is working with our government partners on remote ID and tracking standards, but we recognize that more needs to be done and at a faster pace than the regulatory process allows. That is why the UAS industry is stepping up to explore near-term solutions before remote ID regulations are finalized and published.

In May, AUVSI and the Airports Council International-North America commissioned a Blue Ribbon Task Force on UAS Mitigation at Airports. The task force is working to refine procedural practices and provide a policy framework to address the timely and critical issue of incursions by unauthorized UAS at airports and how best to mitigate this threat, including industry and government recommendations for remote ID. The task force will release a report this year.

Applications of unmanned systems aren't limited by technology or imagination; they're only limited by regulations. We need a streamlined regulatory environment that allows for the safe deployment of unmanned systems into our nation's transportation infrastructure so we can begin to reap the full benefits of this technology.

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# A Day without Satellites

BY Tracy Cozzens
SENIOR EDITOR

You wake up and turn on the TV. Your usual shows aren't airing. You flip on the radio and learn that the Paris and Tokyo stock markets have closed. Back on TV, CNN is trying to use Skype in an attempt to cover what's happening around the world following a solar superstorm.

In a U.S. bunker, the military has lost contact with armed drones flying over hostile areas in the Middle East. Loss of global communication satellites makes it difficult to send commands and surveillance data to soldiers, ships and aircraft, rendering them vulnerable to attack.

Throughout the day, more challenges arise. First responders don't have access to their location systems. Delays in ground and air traffic begin to develop. Systems that depend on GPS time stamps — ATMs, power grids, computer-data and cell-phone networks — begin to fail, and the cloud becomes unstable. The internet soon collapses.

These events take place just a few hours into "A Day Without Satellites" as presented by Pål Brekke, solar physicist and senior advisor at the Norwegian Space Agency. Brekke spoke at the plenary session of ION GNSS+ on Sept. 17 in Miami.

Brekke reviewed the Carrington Event of September 1859, the first documented solar superstorm. In that event, a solar coronal mass ejection (CME) hit Earth's magnetosphere, and its effects were observed and recorded by British astronomers. The storm wrought havoc with telegraph systems.

Today, a solar storm of this magnitude would cause widespread disruptions, blackouts and damage from extended outages of the power grid, communications networks, and of course, GNSS. The solar storm of 2012 was probably as big, but we were lucky — Earth wasn't in the ejection path.

Without more data, it's difficult to predict how often such superstorms take place, but it's a sure bet that the scenario Brekke presented will happen eventually. To prepare, agencies around the world are studying and planning for the phenomenon, including the United Nations Office for Outer Space Affairs (COPUOS), the World Meteorological Organization (WMO) and the International Civil Aviation Organization (ICAO). Space and emergency agencies in the U.S, European countries and other countries are also developing plans.

Good to hear in the face of a threat that would undoubtedly affect us all.

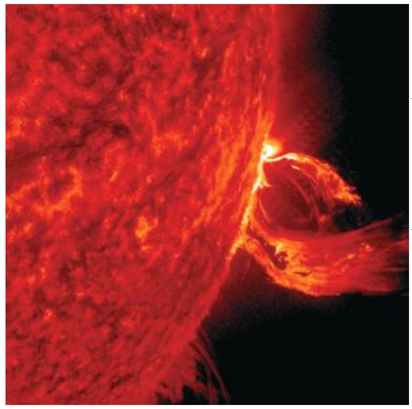

Photo: Solar Dynamics Observatory, NASA

A SOLAR flare in 2015.

## PNT Q&A — EDITORIAL ADVISORY BOARD

**We used to divide GPS receivers into consumer grade, resource grade and survey grade. Have these categories been replaced by a continuum of GNSS capabilities?**

"In the U.S. commercial telematics market, GPS remains the primary source of location data, with very little reliance on other GNSS networks. A bigger issue is the generation of cellular networks used to transmit GPS data, with 3G network sunsets pending and 5G on the horizon. As autonomous commercial vehicles become closer to a reality, multiple GNSS networks and differential techniques will become essential. These solutions are currently in development."

— Clem Driscoll, C.J. Driscoll & Associates



"No. These categories still define important hardware distinctions (such as antenna) and required correction services that define the achievable specifications. Although they all have correlators, they have very different architectures; however, resource and survey have a blurrier line."

— Greg Turetzky, Consultant




emcore
EN-2000

# GPS IIIs Roll off Production Line, Head to Space

After its launch Aug. 22, the U.S. Air Force's second next-generation GPS III satellite, built by Lockheed Martin, is responding to commands and behaving as designed, just like its older sibling.

Engineers at Lockheed Martin Space's Waterton, Colorado, facility are commanding the satellite using elements of the GPS Next Generation Operational Control System (OCX) Block 0. On-orbit checkout and tests include extensive signals testing with the L3Harris-designed advanced navigation payload.

The first GPS III satellite and its navigation payload, launched in December 2018, has performed beyond expectations on-orbit during pre-operational testing, according to L3Harris.

Because it is a public broadcast system, people have taken notice of changes in the constellation. "There's a very passionate community that has provided great feedback, and I've gotten lots of compliments and kudos from various parts of the world on the quality of the signals," said Johnathon Caldwell, Lockheed Martin Space's vice president for navigation systems. "GPS III SV01's performance exceeded expectations during testing. On July 12, we officially completed all on-orbit check-out and test activities. We are excited to see this satellite move to the next phase and perform in an operational environment."

In all, Lockheed Martin is under contract to build up to 32 next-generation GPS III/IIIF satellites for the Air Force. Additional IIIF capabilities will begin being added at the 11th satellite. These will include a fully digital navigation payload, a regional military protection capability, an accuracy-enhancing laser retroreflector array, and a search-and-rescue payload.

# On the Road to a Refreshed Constellation

With GPS III SV01 and SV02 now on orbit, GPS III satellites continue to roll off the production line at Lockheed Martin's GPS III Processing Facility near Denver. Johnathon Caldwell, Lockheed Martin Space's vice president for navigation systems, provided *GPS World* with an update to the entire GPS III family.

**SV01.** The first GPS III satellite is in a holding state pending readiness by 2SOPS [the Second Operations Squadron] to take the vehicle onto the system for operational checkout, a transfer expected to take place later this year, Caldwell explained. The satellite completed on-orbit testing in July.

"We're in the process of getting the 2SOPS crews trained up to operate a GPS III vehicle," Caldwell said. "By the end of this year, they will be able to take [SV01] into the constellation and start flying it as a live, set-healthy vehicle."

**SV02.** Launched Aug. 22, SV02 is following in the footsteps of its older sibling, with a quiet checkout and no major findings. Like SV01, once it completes testing, it will stay in temporary holding until 2SOPS is ready to bring it into the constellation.

**SV03.** On May 27, the Air Force declared SV03 available for launch. It is now in final preparations for shipment, with an expected launch date in January 2020 aboard a Falcon 9 rocket.

**SV04.** The Air force declared SV04 available for launch; it is now in storage awaiting a launch date.

**SV05.** The fifth satellite is wrapping up environmental tests. Lockheed Martin anticipates that it will be available for launch early next year.

Photo: Lockheed Martin

**Thermal Vacuum testing verifies that a satellite can operate in space's extreme environment.**

**SV06.** The satellite has been moved into the thermal vacuum testing chamber and begun a rigorous testing campaign before it meets the harsh environment of space.

**SV07**, **SV08** and **SV09** are on the assembly line.

**GPS IIIF Satellites.** In 2018, the Air Force selected Lockheed Martin to build 10 GPS IIIFs, adding new features and resiliency to the original GPS III satellite design. The company has been on the path to meet the critical design review for the GPS IIIF spacecraft, which is due to take place next spring.

David GNSS Receiver

Oscar GNSS Receiver Ultimate Version

# TERSUS GNSS RECEIVERS INCREASE PRODUCTIVITY IN THE PHILIPPINES

The ability to provide accurate positioning in extreme conditions can determine whether an expensive survey project will be a success or failure.

In the Philippines, which has thousands of miles of rugged terrain, companies are using the Tersus GNSS David and Oscar real-time kinematic (RTK) receivers to increase productivity from field data collection to the office, said Maritess Enciso, Tecphil Geosolutions general manager.

"The performance of Tersus GNSS RTKs, even in extreme conditions, increases productivity and stream-lines work flows," Enciso said, adding that the receivers track, acquire and lock satellites in seconds.

## COUNTRY'S CONDITIONS REQUIRE ACCURATE SURVEYING

Survey companies in the Philippines not only contend with a tough environment, but strict government accuracy regulations.

"Practically all kinds of surveys in the Philippines require high accuracy position," Enciso said. "There is a certain accuracy requirement for every survey depending on the application, but one of the most delicate surveys in the Philippines, that really require high accuracy, are the property surveys, control surveys [establishment of control] and cadastral surveys."

## TERSUS DAVID AND OSCAR TOP PHILIPPINE SURVEY MARKET

Tecphil, which is the exclusive Tersus GNSS distributor in the Philippines, doesn't conduct surveys, but frequently tests the systems.

"I can vouch, based on the number of tests we have conducted and the feedback from our satisfied customers, that Tersus GNSS RTK has topped all competitions in the Philippine market in terms of performance," he said.

Tecphil offers both the Tersus David and Oscar RTK GNSS receivers. Tersus David includes five base/rover kits and delivers high-precision signal reception, integrated in a small and lightweight package.

Tersus GNSS RTKs perform well in extreme conditions, which increases productivity and streamlines work flows, Enciso added. Their Tersus users say the equipment saves them time when conducting surveys.

"The ability of the Tersus GNSS RTK to track, acquire and lock satellites and get fixed status in seconds, even under extreme conditions like [tree] canopies, blockage and obstructions, saves users time as well as employing other applications of the software like offsetting that may increase or complicate workflows," he said.

The David GNSS receiver supports GPS L1/L2, GLONASS L1/L2 and BeiDou B1/B2. With David, surveyor users can take full advantage of common platforms such as smartphones, tablets or traditional handheld modules to collect data.

The Tersus Oscar is an all-in-one GNSS receiver that can be used as rover or base system. Paired with a Tersus TC20 controller or T17M controller, Oscar can more efficiently meet customer application requirements for the optimal surveying solution, according to Xiaohua Wen, Tersus GNSS CEO and founder.

Enciso said feedback from users has been positive—particularly about the systems' ease of use.

"The equipment is easy to use. This includes data gathering and downloading," he said. "According to our users, surveying now becomes enjoyable and is something to look forward to."

**www.tersus-gnss.com**
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TERSUS

# China Adds Two More Satellites to BeiDou Constellation

China has launched two more BeiDou III satellites. The launch took place on Sept. 22 using a Long March 3B rocket which lifted off from the Xichang space center at 2110 GMT (5:10 p.m. EDT), according to the Xinhua News Agency.

The satellites have been confirmed as MEO23 and MEO24, and are the 47th and 48th spacecraft launched in the BeiDou navigation program.

About four hours after liftoff, the upper stage delivered the BeiDou satellites into a nearly circular orbit with an average altitude of 13,500 miles (21,800 kilometers) and an inclination of 55 degrees.

The satellites were produced by the China Academy of Space Technology, a government-owned satellite builder.

With this launch, China has added five new satellites to the BeiDou network this year, and is halfway to its stated goal of 10 BeiDou satellites launched this year. 🌐

Photo: Xinhua News Agency

# Software-Defined GPS Simulation: Modeling Jammed and Spoofed Signals to Protect Critical Systems

orolia DEFENSE & SECURITY

An increased number of GPS jamming and spoofing attacks have been reported and documented in recent years. High-quality software-defined radios (SDRs) are becoming more affordable, meaning that hardware capable of GPS jamming and spoofing is more available than ever. Open source projects have been found to turn these low-cost SDRs into GPS jammers and spoofers. It is more critical now than ever to ensure the necessary precautions are taken to protect your PNT systems. The most common and trusted way to do this, is by testing your PNT system with a GPS/GNSS Simulator.

## BroadSim

BroadSim was developed to simplify the creation of advanced jamming and spoofing scenarios with Navigation Warfare (NAVWAR) testing in mind. BroadSim supports high dynamics, jamming, spoofing, and encrypted military codes. Powered by Orolia's Skydel GNSS simulator engine, BroadSim is able to simultaneously simulate multiple constellations including: GPS, GLONASS, Galileo, Beidou and SBAS. With high-performing hardware, a robust and innovative software engine, and an intuitive user interface; BroadSim outperforms and exceeds features offered by the competition.


BroadSim is revolutionizing the GNSS industry because of its extraordinary flexibility, low cost, upgradability, and rapid development cycles. Leveraging the Skydel navigation engine and commercial-off-the-shelf (COTS) Software-Defined Radios (SDRs), simulation of GNSS signals can be achieved at a fraction the cost of today's industry standards. The ability to generate military and multi-constellation signals on COTS hardware maximizes scalability, value, and time to market.

| Old Jamming Testing Method Without BroadSim | New Jamming Testing Method with BroadSim |
|---|---|
| Users were required to attach a separate signal generator for each interference waveform. | An unlimited number of interference signals can be generated with 1 RF output. |
| The number of interference sources was limited to the number of available signal generators. | Each interference signal within the 1 RF output can have different power levels, modulations and locations. |
| Signal generators had to be integrated into software and/or operated in real time. | Jamming can be turned on and off through the GUI and API. |
| Jamming power levels were determined based on the signal level to be received at the receiver front end, independent of the simulated jammer or transmitted power source location. | Users can specify the location and power of jamming transmitters. BroadSim calculates the received power at the receiver, based on the transmitter's location and user-selected signal loss model. |

## BroadSim Wavefront

Does your application require normal specifications to be scaled? Leveraging the same proven software-defined architecture as our BroadSim platform, Orolia Defense & Security developed BroadSim Wavefront to enable easier and more affordable CRPA receiver testing.

### BroadSim Wavefront Key Features

- Over 1000 signals per element supported
- Simulate multiple spoofers, repeaters, and jammers simultaneously
- Single computer operation using PXE (pixie)
- Simulate alternate PNT sensor data
- Scalable from 4-16 elements
- Real-time phase compensation (+/-1 degree sigma)
- Dynamic jamming capable of 130+ J/S

## Software-Defined Simulators are the Future

No matter which BroadSim platform you choose, you can better protect your PNT system from threats. The bottom line: software-defined simulators will save you time, money and provide unmatched flexibility. For more information, contact sales@OroliaDS.com or visit www.OroliaDS.com.

www.OroliaDS.com
sales@OroliaDS.com

SENSOR FUSION

# Sony Sensors Not Just for Robot Puppy

BY Kevin Dennehy
*GPS WORLD* CONTRIBUTOR

DENVER — The importance of sensors, whether they be incorporated in cute dog robots or autonomous vehicles, is gaining more traction.

At September's Custom Electronic Design and Installation Association (CEDIA) Expo here, Sony Electronics President and COO Mike Fasulo told *GPS World* that its foundation sensors are going into autonomous vehicles, drones, agricultural solutions and other platforms.

"A lot of people also don't know that more than half of the hardware in most smartphones is ours," Fasulo said. "These sensors we are working on do things you and I can't do. They can assess sunlight and darkness. They can put a safety cocoon around a vehicle."

At the conference, Sony displayed a nearly $3,000 Aibo dog robot, which has many of the same sensors that go into many of the company's other products, including its venerable camera line. Aibo has facial recognition technology and uses artificial intelligence to mimic a real puppy's behavior.

Sony sensors seem to be a cornerstone in several new announcements. Less than two months ago, Sony and Yamaha Motor Co. announced the joint development of the SC-1 Sociable Cart, a small autonomous vehicle that will be deployed to golf courses, amusement parks and commercial facilities, the company said.

The SC-1, which is not for sale, features five seats, replaceable batteries, front and rear scope of view thanks to image sensors, an innovative vehicle design, and other improvements over an original prototype vehicle.


Photo: Sony/Yamaha Motor

**SONY AND YAMAHA MOTOR plan to roll out the SC-1 later this year in Japan.**

In addition to the image sensors, the vehicle has ultrasonic sensors and a two-dimensional laser detection and ranging (lidar) system, the company said. These sensors allow the vehicle to gather cloud travel data for safe-driving analysis.

Sony is working with Japan's NTT Docomo to test the vehicle's 5G mobile technologies for remote-controlled functions, the company said.

## Geotab Leverages Sensor Data

Canada-based Geotab has made big announcements this year, although the huge one is from the U.S. government to equip more than 200,000 vehicles with its telematics systems. While that contract itself is massive, the company believes the more than 2 billion data points gathered each day, from millions of Geotab-equipped vehicles on the road, is the real valuable commodity

The data gathered with the company's connected-car technology can help companies and governments assess how their fleets are operating, said Mike Branch, Geotab vice president of data and analytics.

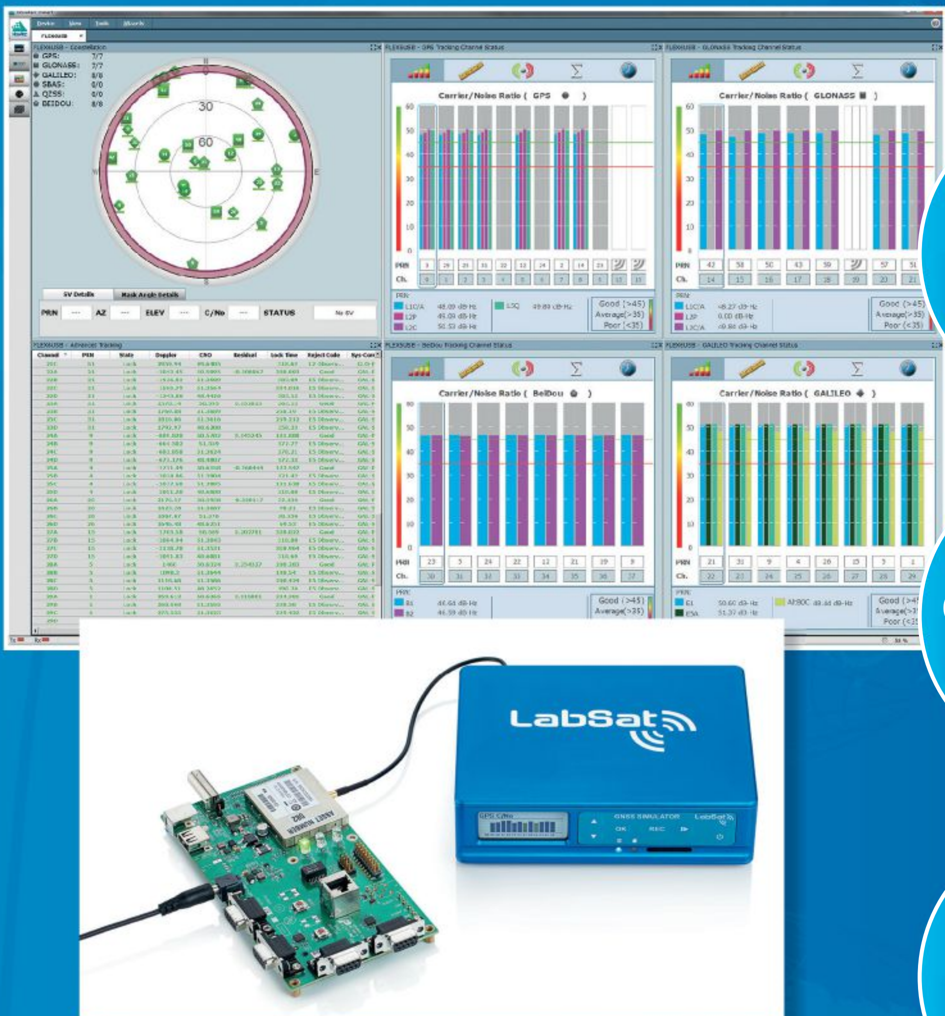
Branch, who leads a team of 40

Photo: Kevin Dennehy

**THE AIBO ROBOT dog uses artificial intelligence to mimic a real puppy's behavior.**

employees, said the company uses the data to help cities assess road impediments — not only road quality. This includes analyzing ABS activation to look at black ice or other hazards. "While weather companies can only estimate conditions, we have sensors in vehicles that can give hyperlocal reports and ground truth," he said. "People

CONTINUED ON PAGE 16. >>


LabSat

<< *Continued from page 14.*

consistently slamming on their brakes in one area is an example [of aggregative data].”

Back in the day, which is less than 10 years ago, all that many companies expected from their fleet management systems was to let them know where their drivers were, by using GNSS and mapping technology. Today, the sensors — and data provided by them — allow managers to assess dangerous driving areas, save on fuel costs by rerouting trucks and compare routes throughout the United States, not just in big cities, Branch said.

In the smart cities space, Branch said that Geotab is working with municipalities for fuel intersection insight mapping. “This means if 20 vehicles, or even just two, are stopped at an intersection, our sensors can detect the wait times,” he said. “The big thing for us is looking at this smart-city deployment to leverage organic data in a private manner.”

Because of the nature of data procurement, privacy is big topic for the company, Branch said. “We treat it with high importance. Our view is that the data is owned by the customer,” he said. “They have full access to it. We will go through it, aggregately, so we can improve our customer’s experience.”

## Keeping OBD Port Secure

The future of open on-board diagnostic (OBD) vehicles — and procuring secured and open data from them — is a concern for Geotab, Branch said.

“We have a full port safety committee with the goal of security and access to the port,” he said. “We believe in open access to this port. This gets to be a concern with mixed-fleet Fords, Mercedes, BMW and others as the data can slow down the port at any time.”

Branch said the company does not want to remove the entrepreneur, who is interested in working with the port in a safe manner. “We work with the OEMs on the future of telematics not just by pulling the data from our device, but pulling it from their feed,” he said.

Branch said that technology may make the port dongle obsolete in five to 10 years, but until then, the company has created an ecosystem to enable the use of the data. “There is going to be an aftermarket as cars are lasting an average of 11 years,” he said.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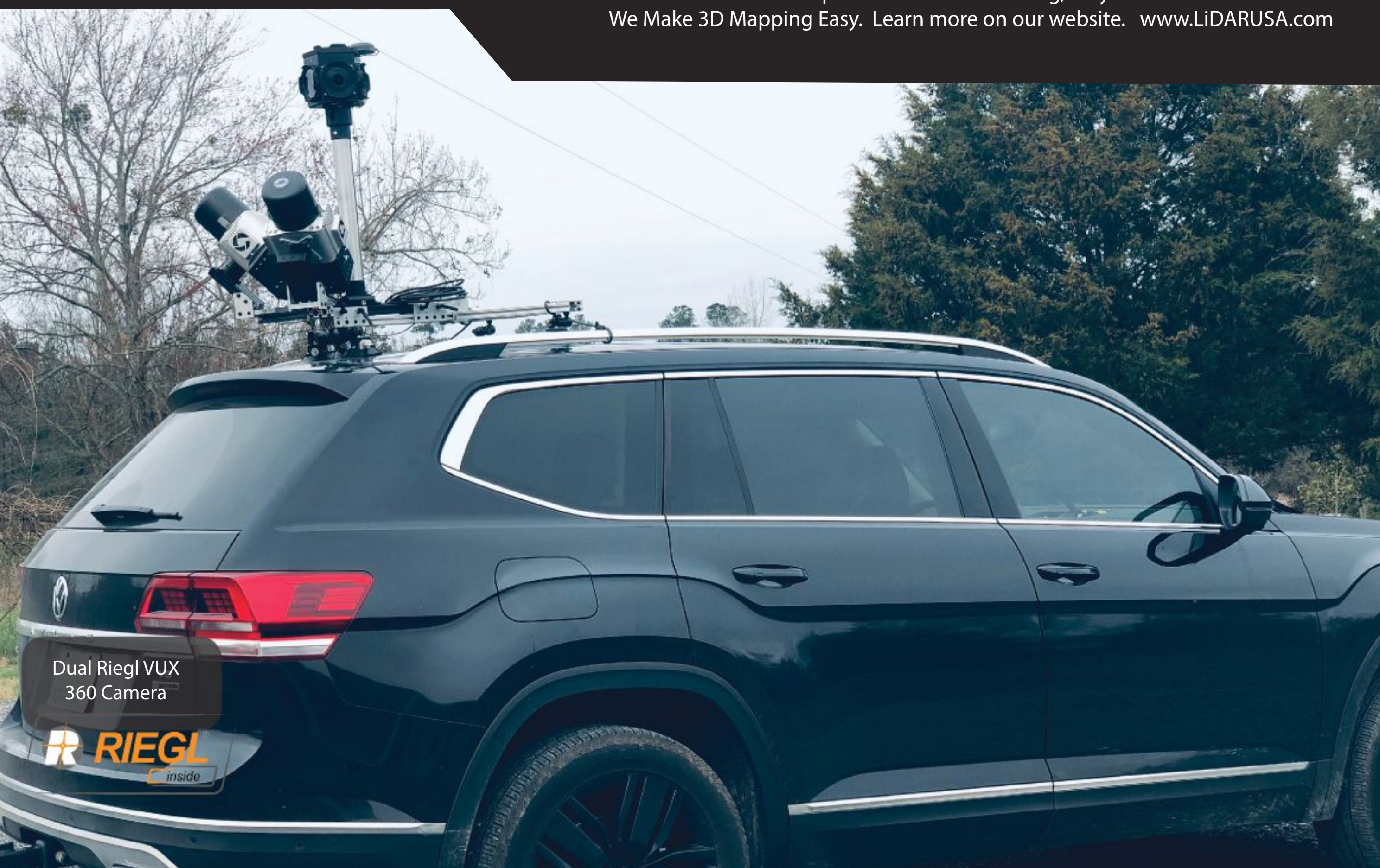
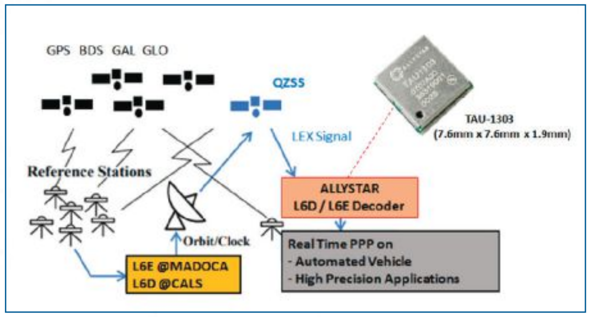
Spend more time scanning, only 30 seconds to initialize.
We Make 3D Mapping Easy. Learn more on our website. www.LiDARUSA.com



1




3

2

4

## 1. MULTI-GNSS RECEIVER

### REFINED IN THE GALILEO ONLINE PROJECT FOR RAIL APPLICATIONS

The multi-GNSS receiver GOOSE, distributed by TeleOrbit GmbH and developed by Fraunhofer IIS, is now available in a new housing. GOOSE now also includes the new OS-NMA beta standard, available by the end of 2019, which was integrated within the research project PRoPART. GOOSE is a flexible, professional GNSS receiver development platform with an open software interface, which can be adapted to a variety of applications and application-specific correction services. The flexible development platform offers multi-system and multi-signal real-time processing; integrated antenna receiver combination (smart antenna); guaranteed stable phase center for all GNSS frequencies; and deployment in commercial PC or as an embedded platform. It allows deep coupling and vector tracking in real time; access to correlation values; and record and replay of IF samples. It also offers access to SBAS data including upcoming augmentation systems and differential augmentation systems. The platform has been refined in the Galileo Online project for specific usage in rail applications. It has also been further upgraded as a robust and reliable Galileo position sensor for autonomous truck applications.

**TeleOrbit, teleorbit.eu**

## 2. INERTIAL MEASUREMENT

### LOW-NOISE PERFORMANCE FOR HIGH DYNAMIC APPLICATIONS

The LandMark 007 inertial measurement unit (IMU) combines low noise, high range sensors and Velox high-speed output in a rugged package measuring 0.7 inches square. With rate ranges up to 2000°/s and acceleration ranges as high as 200 g, the LandMark 007 IMU provides demanding, precision performance for a range of high dynamic, rugged applications. High-speed output data rates (up to 10 kHz) for measurement accuracy and flexibility are complemented by low-noise gyros and accelerometers. A development kit is available.

**Gladiator Technologies, gladiatortechnologies.com**

## 3. DECODER

### CORRECTIONS DATA FROM L6D AND L6E

The QZSS L6 decoder module TAU-1303 supports tracking QZSS signals L6D (CLAS) and L6E (MADOCA). It can decode corrections data broadcast from L6D and L6E signals, and assist developers in applying the centimeter-level accuracy by PPP-RTK algorithm with the correction data. Within its 7.6 × 7.6-millimeter size, the module provides six channels to support tracking L6D and L6E at the same time. CLAS on L6D channel corrects satellite clock, orbit, code bias, phase bias ionosphere delay and tropospheric delay. MADOCA on L6E channel corrects satellite clock, orbit, code bias and phase bias. The TAU-1303 offers superior performance through an on-board 26-MHz temperature-compensated crystal oscillator (TCXO) and a reduced time to first fix because of its dedicated 32-KHz real-time clock oscillator. Based on 40-nanometer manufacturing processes of the Cynosure III GNSS chipset, the TAU-1303 has very low power consumption of less than 40 mA at 3.3V.

**Allystar Technology Co., www.allystar.com**

## 4. GPS SPLITTER

### USES ONLY ONE RACK SPACE

ViaLite's new Local Integrated GPS Splitter was designed to minimize rack space. The unit provides a fan-out of GPS/GNSS signals within a local area, can accept optical inputs from up to four antennas, and has a 1000-1800-MHz frequency range. Though it has a height of only one rack unit, the system is useful for feeding timing and synchronization signals to single or multiple floors or rooms through eight to 32 optical fiber links with no system loss. It includes built-in simple network management protocol (SNMP) control as well as dual-redundant power supply units. Built for data centers, banking institutions, scientific research establishments, cellular test environments, fixed satcom stations, oil and gas platforms, and big data.

**ViaLite, vialite.com**


JAVAD

www.javad.com

Front

# SPOOFING SUMMARY ...

As we explained on inside pages, in addition to the shape of spectrum and AGC, there are eight indicators that show the health status of GNSS signals:

The eight indicators for each signal are:

1. Number of signals tracked.

2. Diversion of SNR from its expected value.

3, 4. Level of additional power and its RMS.

5, 6. Diversion of  AGC from its normal value and its RMS.

7. Extra noise.

8. Number of signals spoofed.

The figure on the top right is a compact view of status of all GNSS signals in our TRIUMPH-LS receiver, showing **normalized** values of the above eight indicators. “0” means “good” and “9” means “bad”.

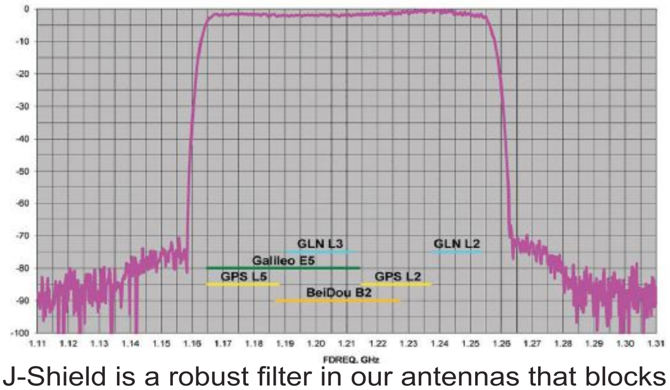
The figure below it shows the normalized **weighted average** of the above indicators. It is to show a general view of the status of that band at a glance.

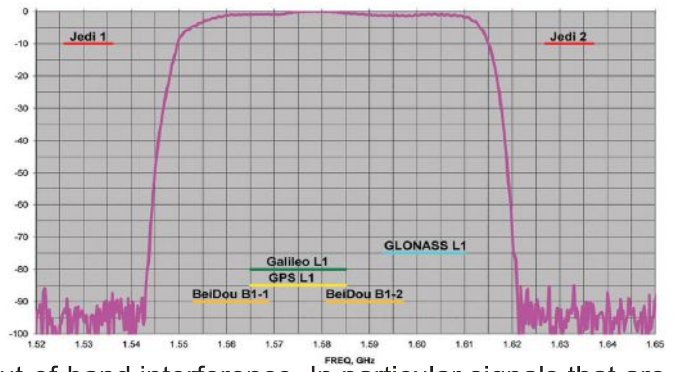


Click on any of the signal buttons to see the actual and normalized values of  the eight indicators for that signal.

Click on the action buttons shown to see:
Details of all signals,
View Spoofing details,
View Spectrum screens,
and take new spectrum.

# J-Shield Filters
## and Near Band Interference



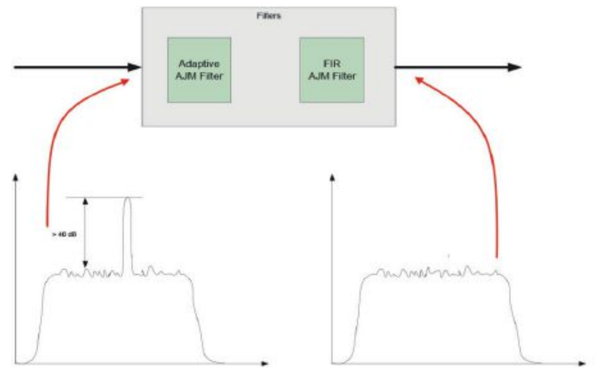




J-Shield is a robust filter in our antennas that blocks out-of-band interference. In particular signals that are near the GNSS bands like the LightSquared signals. The above graphs show the protection characteristics of our J-Shield filters. They a sharp 10dB/KHz skirt which provide up to 100 dB of protection. It makes the precious near band spectrums available for other usages and protects GNSS bands now and in the future.

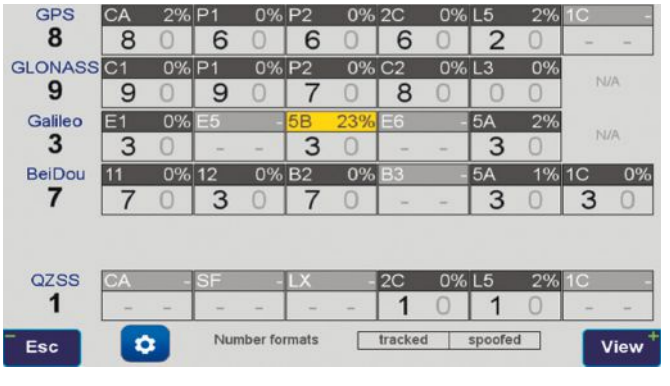
# Antijam Digital Filters

We have sixteen 255th order FIR antijam digital filters to protect against **static** in-band interference, like harmonics of TV and radio stations, or against illegitimate in-band transmissions.

Also we have sixteen adaptive 80th-order digital filters to protect against **dynamic** interference. These AJM-filters can be combined in pairs for complex signal processing. These filters can simultaneously suppress several interference signals.




# In-Band noise
Measurement



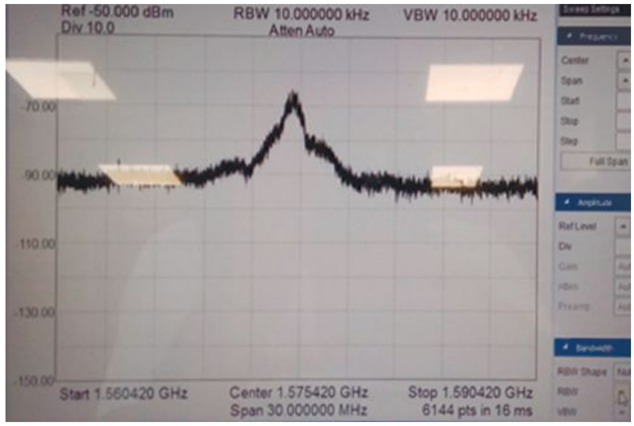


We measure the level of interference as percentage of noise above the normal condition. The above left screenshot shows the condition in a clean environment. 8 GPS satellites were visible (according to the almanac). 8 C/A, 6 P1, 6 P2, 6 L2C and 2 L5 GPS signals were tracked. The noise level is 2% on C/A and L5, and 0% on P1,P2,and L2C. The screenshot on the right shows 290% noise in GPS C/A and %121 on Galileo E1. Only one of 8 GPS C/A code and none of 5 Galileo E1 signals were tracked due to this level of interference.

# Spectrum Shape

We have a very powerful spectrum analyzer within our GNSS TRIUMPH chip. Each spectrum shows the power and the shape of the interfering signals and jammers. This is more powerful and more efficient than a $30,000 commercial spectrum analyzer to evaluate the environment. The screenshot on the right shows the shape of the GPS L1 band spectrum when the band is not jammed. The GPS C/A code peak at the 2-MHz center of the L1 band is visible. The height of the spectrum is 11.2 dB.

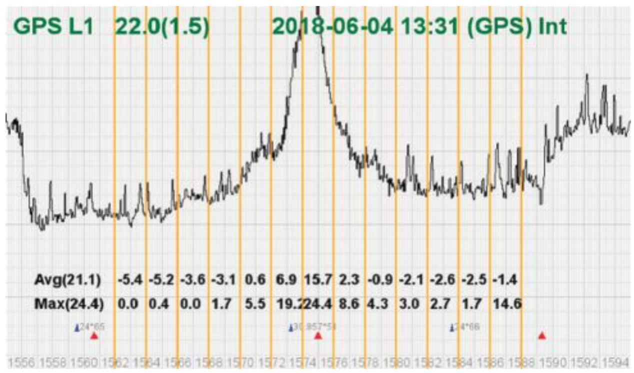

This is an example of GPS L1 spectrum with a commercial $30,000 spectrum analyzer.




Our integrated spectrum analyzer has the advantage that it monitors the spectrum inside the chip where it matters. It has effective bandwidth of 1 KHz.

Our embedded spectrum analyzer also has the advantage that it can be programmed to automatically record the spectrum (and other information) periodically or according to the set conditions, and monitor the environment continuously.

This is the spectrum example of a GPS L1 band when it is jammed. There is a huge peak in the center where the C/A code is. The number on the bottom left is the height of the peak.




The height of the spectrum is 21.1 dB, which compared to the calm 11.2 dB, indicates about 10dB of jammer.

Average energy and its RMS are shown in the graphs.

# AGC

## Automatic Gain Control

In addition to the spectrum, we also keep record of Automatic Gain Control which is another indicator of external signals.

The AGC monitors the environment and adjusts the gain to keep the voltage at a certain level. The change in AGC is an indicator of interference.

The narrow orange line in the middle of the band in this screenshot shows a quiet AGC. Average AGC and its RMS are shown in the top left of the graphs.


AGC in the second screenshot shows there are activities in this band which our AGC was able to defend against it.


Our AGC mitigates the effect of such interference completely.

# Spoofers & 2 Peaks

Spoofers are quite different from jammers. They don't disturb the environment and the spectrum shape. They broadcast a GNSS-like signal to fool the GNSS receivers to calculate wrong positions.

**We detect spoofers by digital signal processing. With 864 channels and about 130,000 Quick Acquisition Channels in our TRIUMPH chip,** we have resources to assign more than one channel to each satellite to find ALL signals that are transmitted with that GNSS PRN code.

If we detect more than one reasonable and consistent correlation peak for any PRN code, we know that we are being spoofed and can identify the spoofer signals. Figure on the right is an example of two peaks. We isolate and ignore the wrong peak.

The screenshot on the right shows details of each signal peaks. The first six lines in this screenshot show the spoofed signals that we detected as soon as they appeared (numbers "1" in those line). The two section columns represents the characteristics of each peak. Second SS column show if the second peak is a consistent signal.

While six satellites were spoofed, there was no indication on the noise level (0%) and no indication on the spectrum shape and level as shown on the screenshot on the right below the chart.

If the spoofer strategy is to cover the real satellite signal and then put the fake signal on top of it to produce only one peak, we notice that by more that 200% of noise level that it has to introduce.

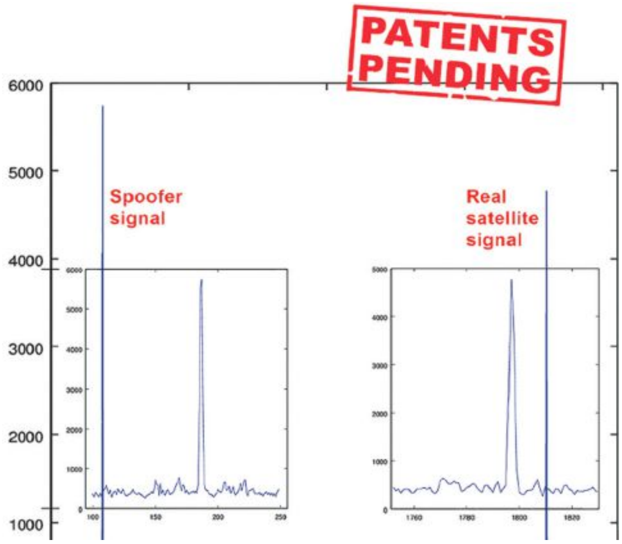
**We reject infected signals and then among all the available GPS, GLONASS, Galileo, BeiDou, IRNSS and QZSS multiple signals we use the healthy ones.**

Usually there are over 100 signals available at any given time, and we need only four good signals to compute position. In rare cases that all signals are affected, we inform the user and guide them to use compass and altimeter to get out of the Jammed area.

It is extremely unlikely that we can be spoofed without our knowledge. We will immediately recognize and take corrective actions

In the Spoofing Summary screenshots on the right, 10 GPS satellites were visible (according to the Almanac). 6 of the 9 GPS satellites that we tracked were spoofed, as indicated by the red number, while the noise level was 0% in the GPS C/A band.

In the second screenshot, 5 of the 6 GPS C/A signals were spoofed while the noise in the band was only 2%.




**GPS C/A**

| SAT | EL | SIG | SS | MIN | C1 | SS | MAX | C1 | NV | SN | Spec | noise | stat |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GPS1 | 67 | C/A | 37.2 | 4.5 | 17 | 23.0 | 25.5 | 3 | 77 | -- | -0.4 | 13% | QS |
| GPS10 | 15 | C/A | 35.2 | 4.5 | 4 | 6.4 | 25.5 | 1 | 77 | 37 | -0.4 | 13% | QT |
| GPS11 | 54 | C/A | 27.9 | 4.5 | 17 | 10.9 | 25.5 | 3 | 4 | -- | -0.4 | 13% | QS |
| GPS14 | 68 | C/A | 37.7 | 4.5 | 17 | 12.2 | 25.5 | 3 | 4 | -- | -0.4 | 13% | QS |
| GPS17 | 18 | C/A | 6.2 | 4.5 | 10 | 3.4 | 25.5 | 0 | 4 | -- | -0.4 | 13% | Q |
| GPS18 | 67 | C/A | 33.2 | 4.5 | 17 | 14.2 | 25.5 | 3 | 4 | -- | -0.4 | 13% | QS |
| GPS22 | 52 | C/A | 35.2 | 4.5 | 17 | 15.3 | 25.5 | 3 | 4 | -- | -0.4 | 13% | QS |
| GPS3 | 30 | C/A | 11.6 | 4.5 | 10 | 2.4 | 25.5 | 0 | 74 | 43 | -0.4 | 13% | QT |
| GPS31 | 20 | C/A | 10.2 | 4.5 | 10 | 2.5 | 25.5 | 0 | 56 | -- | -0.4 | 13% | Q |
| GPS32 | 52 | C/A | 37.7 | 4.5 | 17 | 16.1 | 25.5 | 3 | 77 | -- | -0.4 | 13% | QS |
| GPS8 | 13 | C/A | 36.7 | 4.5 | 4 | 6.4 | 25.5 | 3 | 71 | -- | -0.4 | 13% | QS |

Esc  Last Reset: 00:13:16  0+0+0+0+0+0=0  dPos: No Ref.  Age: <1s  Reset

This above screenshot shows details of each signal. In the last column (T) indicates the signal was tracked by the main channels, (Q) by the Fast Acquisition Channels and (U) signal was used in position calculations.

Percentage numbers show the percentage of interference above the normal level.

In the above example seven GPS signals are spoofed.

The "SN" color coded column shows the signal-to-noise ratio of tracked signals. Blue is perfect, green is 3 dB down, and red is 6 or more dB down.

**Deviation of SNR from the expected value is another important indicator of interference**

| GPS 10 | CA 0% | P1 - | P2 - | 2C 0% | L5 4% | 1C - |
|---|---|---|---|---|---|---|
| | 9 6 | - - | - - | 5 0 | 4 0 | - - |

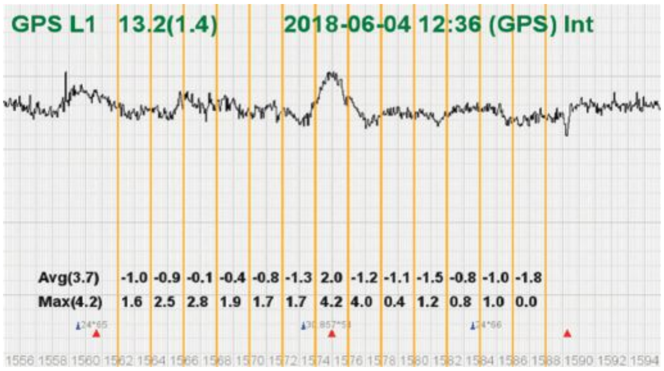
| System | | | | | | |
|---|---|---|---|---|---|---|
| GPS 9 | CA 2%: 6 5 | P1 0%: 4 0 | P2 0%: 4 0 | 2C 0%: 4 0 | L5 3%: 3 0 | 1C -: - - |
| GLONASS 9 | C1 0%: 9 0 | P1 0%: 8 0 | P2 0%: 7 0 | C2 0%: 8 0 | L3 0%: 1 0 | N/A |
| Galileo 5 | E1 0%: 2 0 | E5 -: - - | 5B 24%: 4 0 | E6 -: - - | 5A 3%: 4 0 | N/A |
| BeiDou 10 | 11 0%: 10 0 | 12 0%: 4 0 | B2 0%: 10 0 | B3 -: - - | 5A 3%: 4 0 | 1C 2%: 3 0 |
| IRNSS 3 | N/A | N/A | N/A | N/A | L5 2%: 3 0 | N/A |

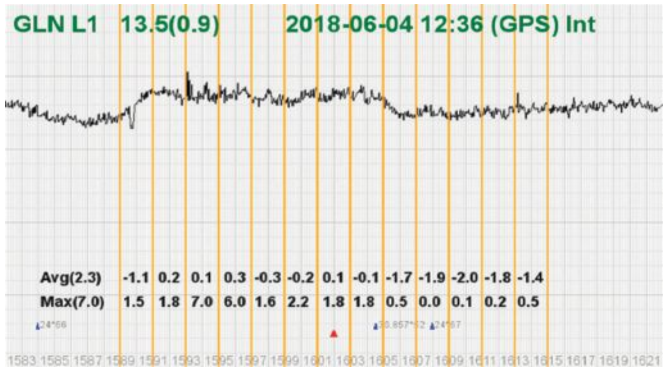
Esc  Number formats: tracked spoofed  View

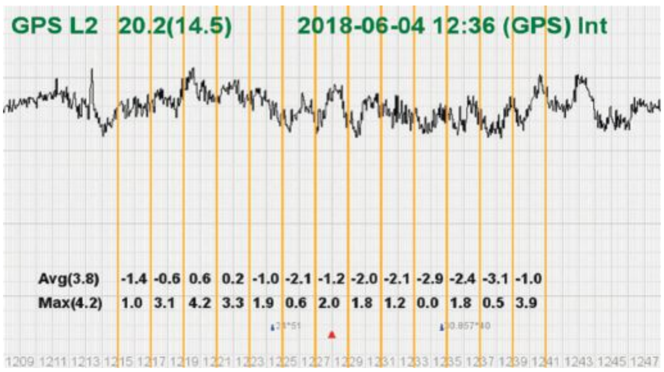
# And Examples of when the world is peaceful.

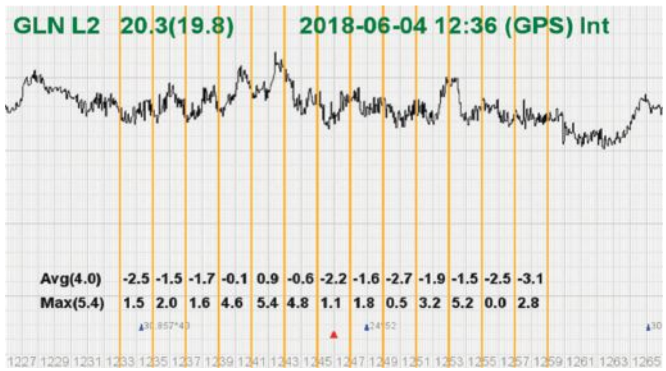
Jamming and Spoofing protection option is available in all of our products and OEM Boards.

## All screenshots are from our TRIUMPH-LS Receiver.

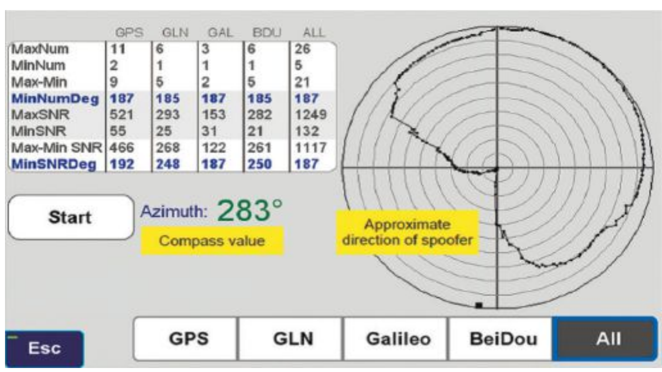



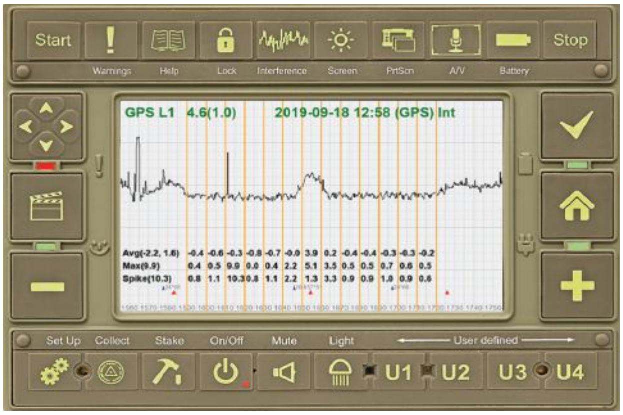



When you detect that spoofers exist, you can also try to find the direction that the spoofing signals are coming from. For this, hold your receiver antenna (e.g. TRIUMPH-LS) horizontally and rotate it slowly (one rotation about 30 seconds) as shown in the picture and find the direction that the satellite energies become minimum. This is the orientation that the spoofer is behind the null point of the antenna reception pattern.

After one or more full rotations observe the resulting graph that shows approximate orientation of the spoofer as shown in figure below.



# ... and TRIUMPH-LS




30 MHz-wide spectrum of the signal.


Two-peak information and spoofer.


Noise and spoofed signals.


Six parallel RTK engines.


Status of RTK survey collection.


Horizontal and vertical result of each engine.

# TRIUMPH-3

The new TRIUMPH-3 receiver inherits the best features of our famous TRIUMPH-1M.

Based on our new third generation TRIUMPH chip enclosed in a rugged magnesium alloy housing.

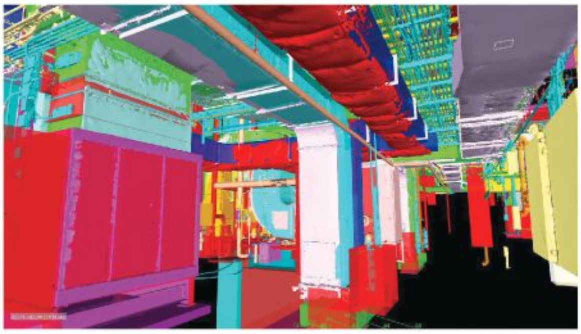

The TRIUMPH-3 receiver can operate as a portable base station for Real-time Kinematic (RTK) applications or as a receiver for post-processing, and as a scientific station collecting information for individual studies, such as ionosphere monitoring and the like.

It includes options for all of the software and hardware features required to perform a wide variety of tasks.

- UHF/Spread Spectrum Radio
- 4G/LTE module
- Wi-Fi 5 GHz and 2.4 GHz (802.11 a, b, g, n, d, e, i)
- Dual-mode Bluetooth and Bluetooth LE
- Full-duplex 10BASE-T/100Base-TX Ethernet port
- High Speed USB 2.0 Host (480 Mbps)
- High Speed USB 2.0 Device (480 Mbps)
- High Capacity microSD Card (microSDHC) up to 128GB Class 10;
- “Lift & Tilt”
- J-Mobile interface


**Ideal as a base station**

# SURVEYING & MAPPING | LAUNCHPAD



①


⑤


②

③

④

## 1. POINT-CLOUD SOFTWARE

### CREATES INTELLIGENT 3D MESH MODELS

Pointfuse point-cloud processing software converts the millions of individual measurements captured by laser scanning and photogrammetry into 3D mesh models. The latest release features streamlined classification to ensure maximum efficiency and multicore processing for unlimited conversion power. The ability to classify objects and compare as-built objects with the design enables more accurate clash detection, reducing the number of false clashes being flagged. Intelligently ptimized mesh models reduce the working data size by a factor of up to 100, making them easy to share with online 3D collaboration platforms, such as BIM 360, 3D Repo, Revitzo and Trimble Connect.
**Pointfuse, pointfuse.com**

## 2. ANDROID SOFTWARE

### MOBILE DATA COLLECTION IN THE FIELD

FieldGenius for Android, version 1.0, is multi-platform data-collection software built on Android OS. The brand-neutral data-collection software supports most popular GNSS sensors on the market. Features include dynamic data panels synchronized with map views, intuitive interface, simplified workflows and readily available data that surveyors require to make informed decisions in the field. Early adopters receive additional benefits and participate in the newly created MicroSurvey Technology Innovation Group.
**MicroSurvey Software, microsurvey.com**

## 3. HANDHELD GNSS RECEIVER

### CAMERA-ENABLED CENTIMETER LOGGING

The SP20 handheld GNSS receiver offers innovative camera-enabled centimeter-accurate logging in an everyday GIS and survey tool. Rugged, lightweight and versatile, the SP20 delivers high-end performance. It is an easy-to-use tool that delivers accuracy from meter to centimeter, depending on the job. Android-based, it is useful for cadastral, construction or topographic surveys; a range of GIS jobs from data collection to inspection and maintenance; and non-traditional geospatial professionals. The 5.3-inch screen displays the new workflow using a camera to ensure 2D centimeter accuracy handheld and 3D centimeter accuracy with monopole setup.
**Spectra Geospatial, spectrageospatial.com**

## 4. OFFLINE DATA TRANSFER

### ALTERNATIVE TO THE CLOUDS

TerraFlex users can now synchronize data directly to their on-premise Esri geographic information system without cloud services. The new software workflow — called offline data transfer — is possible through the integration of Trimble TerraFlex and the Trimble Positions Desktop add-in for Esri ArcGIS Desktop. TerraFlex is a field solution that enables mobile workers to easily collect, manage and edit their geospatial feature data. The new workflow provides an alternative to using Trimble cloud services for storing and transferring GIS feature data collected with the TerraFlex platform. In addition, TerraFlex field data collected via this workflow using a Trimble GNSS receiver can be post-processed directly inside the Trimble Positions Desktop add-in for improved positional accuracy. The mobile apps are available in Apple's App Store and the Google Play store. The Trimble Positions Desktop add-in is available through the Trimble Geospatial distribution channel.
**Trimble, www.trimble.com**

## 5. GPS RECEIVER

### NOW COMPATIBLE WITH IPHONE AND IPAD

The Geode GNS2 sub-meter GPS receiver features connectivity with a range of iPhone and iPad devices, made possible by the Geode's new MFi certification. Features of the Geode GNS2 include an IP-68 rating to withstand harsh environments, all-day battery life, multiple correction sources for precise real-time data, and an open interface that works with a wide range of Windows, Android, iPhone, and iPad devices as well as Juniper Systems' handhelds.
**Juniper Systems, junipersys.com**


# NAVIGATING TESTING OPTIONS

## Simulator Innovators Map Out Solutions & Trends

BY **Matteo Luccio** / *GPS WORLD* CONTRIBUTOR

The number of GNSS signals, the frequency and sophistication of intentional and unintentional threats to those signals, and the need for integration between GNSS and other positioning, navigation and timing (PNT) sources — especially for indoor and autonomous navigation — are continuing to increase, as is the number of new applications for GNSS. In response, manufacturers of GNSS simulators are creating new and improved models able to simulate all these new signals and scenarios.

Additionally, as GNSS chipsets continue to be further commoditized, simulator manufacturers must address the needs of new entrants into the GNSS receiver market that have lower accuracy requirements and require less technical expertise and, therefore, require units that are smaller and cheaper and have simpler interfaces.

Photo: Racelogic


**THIS TONGUE-AND-CHEEK PHOTO, COURTESY OF RACELOGIC, underlines how simulators help GNSS engineers "road test" multiple positioning products in multiple scenarios.**

No single manufacturer can address the full spectrum of challenges that these trends present. So, while their products overlap in capabilities and SWaP-C (size, weight, power and cost), each one has chosen its market niche and preferred mix of features.

Even on the deceptively simple question of definition ("What is a GNSS simulator?"), the seven manufacturers featured here give different answers, covering the following capabilities:

- Simulating GNSS signals as well as inertial navigation data.
- Enabling users to test hardware, software and new solutions in the lab before deployment.
- Enabling users to test systems under pristine or extreme conditions, including error conditions.
- Enabling users to test systems during rare, transitional and prohibited events.
- Helping to retrofit existing equipment to new and emerging standards.

Innovations being introduced or developed include:

- an anechoic simulator to test continuous radiation pattern antennas (CRPAs).
- simulation of a full M-code modernized signal.
- software-defined simulators.
- increased automation of repetitive tasks.
- the capability to record and replay real-world signals.
- the capability to record and synchronize data on the conditions faced by a test vehicle.

While the universe of GNSS satellites and receivers continues to grow and evolve, the universe of GNSS simulators is keeping pace — or even a step ahead.

## CAST Navigation LLC

**John F. Clark,**
Vice President, Engineering

In the lab, simulators allow users to "drive" a piece of equipment through 3D space, performing flight testing or checking equipment integration. Simulators also validate operational flight programs (OFPs) for pilots before they are fielded, to ensure that the software is working correctly.

**Innovation.** CAST's latest simulator is the CAST 5000 wavefront generator. It allows users to drive GNSS and interference signals that represent a continuous radiation pattern antenna (CRPA), which consists of multiple, smaller antennas all combined into one unit. In real life, each one of those antenna elements is in a different location; therefore, when they receive signals from a jammer or any of the GNSS satellites, each one will see that signal in a slightly different phase from the other elements. "Our simulator allows us to present signals to these antennas that model the same type of phase differentiation that you see in real life," Clark said.


**Coming Next.** CAST Navigation is constantly improving its software based on user feedback. "We are in the process of enhancing our user interface to make it much more powerful but also much simpler to use," Clark said. Hardware is also being improved, with implementation of the latest available GNSS always on the list.

**Looking Ahead to 2022.** Jamming and spoofing are becoming more prevalent, not just for the military but also for consumers. Consumers are starting to encounter more instances of jamming, denying their phone the ability to track a GPS satellite or transmitting incorrect GPS data so the solution that their device gives them is not correct. "Our focus is on products and capabilities that help our customers simulate those types of environments and mitigate those kinds of reactions," Clark said.

## Jackson Labs Technologies Inc.

**Said Jackson,**
President and CTO

Jackson Labs' simulators take a position, navigation or timing signal, re-encode it into an RF signal through a GPS simulation procedure, and output a real-time RF signal that encodes the position, navigation and timing (PNT) information, within milliseconds, into an RF signal that can be fed into existing equipment. "We came up with a general-purpose simulator that is basically a no-frills, low-cost, highly accurate, highly stable, highly reliable, extremely small GPS-only simulator," explained Jackson. "We only provide GPS L1 simulation, to keep the cost of the product down, because GPS L1 C/A code is the only code required to generate an accurate and assured PNT fix, and because we are looking at simulating to embedded systems, where you only need an L1 C/A code simulator."


**Coming Next.** Jackson Labs' simulators don't require an external computer for data processing or control. That makes it possible for companies like Toyota to plug the unit into a car on the assembly line, and generate RF output that is fed into their GPS-based navigation systems to pass final quality-assurance checks on the production line. Jackson Labs expects to further reduce SWaP-C (size, weight, power and cost) requirements and potentially add other signals. "We are also looking to potentially combine our simulators with other product lines that we have, such as our comprehensive atomic clock product line," Jackson said.

**Looking Ahead to 2022.** Jackson predicts that the sector will split into two paths: an industrial sector with units for manufacturing and deployment, and companies that introduce emerging GNSS systems at much lower price points, smaller SWaP, and with more modular deployment. Inertial navigation systems (INS) are critical for autonomous driving and assured capabilities during spoofing and jamming events, Jackson said. "It is not possible today to very easily simulate INS units.There is a market for innovation in terms of integrating what the military calls 'assured PNT,' which includes things like dual navigation."

# AP100 FAMILY

## HIGH-PRECISION OEM GNSS RECEIVER MODULES

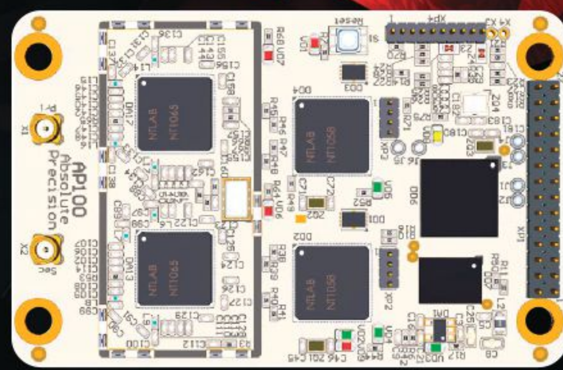
ABSOLUTE PRECISION
PROFESSIONAL NAVIGATION EQUIPMENT

Single/dual-antenna high-precision OEM GNSS receiver modules of AP100 family provide precise millimeter-level RTK positioning combined with 3D attitude (yaw, pitch, roll) determination.

With our OEM modules, navigation data can be concurrently received from: GPS L1/L2, GLONASS L1/L2, Galileo E1BC/E5a/E5b, BeiDou B1/B2, NavIC L5/S and SBAS.

The modules will be the best solution for a wide range of navigation applications owing to small power consumption, industry standard size (71x46x10 mm) and easy integration.

Moreover, the raw measurement data are available for user's secondary processing, as well as API functions to control the baseband chip. Using Absolute Precision OÜ open platform, users are free to create an effective solution for each specific application.



***Firmware freedom** for your effective GNSS solutions!*

### POWER CONSUMPTION FROM 0.25 W

### RAW DATA UPDATE RATE UP TO 100 HZ

### FEATURES

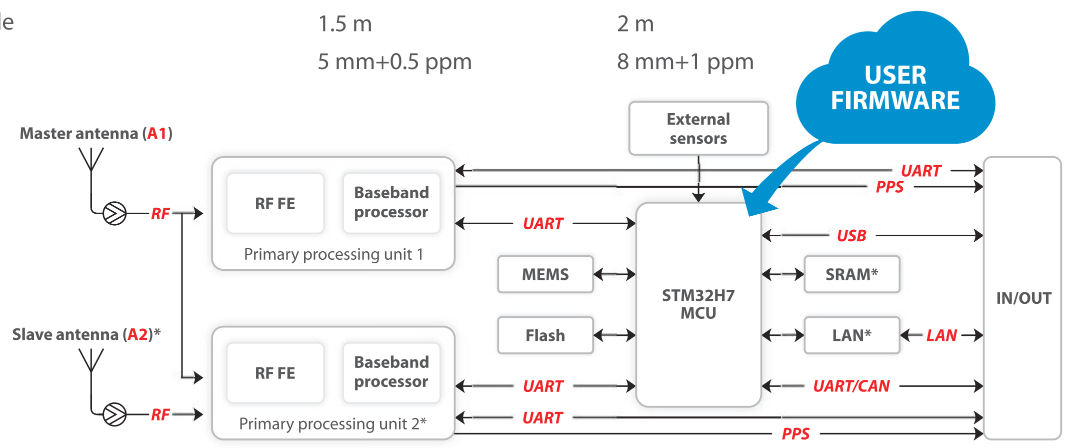
- On-board STM32H7 MCU for the development of user's applications
- On-board 9-axis MEMS IMU
- Loosely-coupled GNSS/INS integration algorithm
- Raw measurements data output: code and carrier phase measurements

### MEASUREMENT PRECISION

| | |
|---|---|
| Code phase accuracy | 20 cm |
| Carrier phase accuracy | 0.8 mm |

### POSITION ACCURACY

| | Horizontal | Vertical |
|---|---|---|
| Standalone mode | 1.5 m | 2 m |
| RTK mode | 5 mm+0.5 ppm | 8 mm+1 ppm |




*Optional. It depends on AP100 modification

## Orolia

Stéphane Hamel, Director, Testing and Simulation

According to Orolia's Hamel, a simulator's purpose is two-fold: first, it must reproduce threats and second, it must prove the solution is working.

**Innovation.** When Skydel Solutions joined Orolia in March, it brought a professional software-defined simulator that makes possible fast prototyping and development cycles. It integrates advanced interference simulation and can simulate hundreds of threats simultaneously. "When you want to do a repetitive step, automation is the key," Hamel said. "Our simulator can teach you how to automate, just by clicking on a button and generating source code." In 2018, Skydel introduced an anechoic simulator to test Controlled reception pattern antennas (CRPAs). Also new is a waveform simulator, so CRPA units can be tested in a conducted (rather than radiated) way.

**Coming Next.** In the next three years, Orolia is looking at adding Galileo PRS, GPS M-code, or the next-generation signal. "Being software-defined means that we are very flexible and we can allow our partners to develop their own plug-ins," Hamel said. "They can build custom signals, restricted or modernized signals. Our simulator will take care of the dynamics of the signal and our partners can focus on the characteristics of the signal, or the things that are secret, classified, or if they simply want to protect their IP."

**Looking Ahead to 2022.** Resilience to serious spoofing and jamming threats is high on Orolia's list, as well as ensuring secure or valid positioning, navigation and timing (PNT) in GPS-denied environments. Alternative signals, sensors and increased complexity require a simulator to address all of these. Companies that develop complex proprietary hardware platforms will be challenged to keep up with the increasing complexity. and a software-defined approach will be an advantage. ◍

## Racelogic

Julian Thomas, Managing Director

Racelogic's first LabSat was a recorder with player — the signals were recorded outside, and then replayed in the lab. Racelogic's simulators now also provide simulation of the signals using software to generate the signals as though they are being sent by the satellites.

**Innovation.** In 2018, Racelogic introduced the LabSat wideband, which uses the company's SatGen software. It records at 56 MHz and up to 6 bits of resolution and streams the data to an internal SSD hard drive. It can also replay real-world simulations or ones generated with SatGen. For the automotive world, it records and replays signals such as CAN, RS232, RS485, IMU and other data channels, synchronizing them at the same time. VBOX allows users to record and replay video with the perfectly synchronized recording made on the LabSat. "You see exactly the kinds of conditions of the test vehicle or person who has been subjected to the test," Thomas said.

**Coming Next.** Racelogic is providing wider bandwidth, greater bit depth, and multiple channels in a small battery-powered device that records even more signals, including lidar, EtherCAT (an automotive Ethernet format) and CAN-FD (a faster version of the CAN format). It will be able to synchronize with multiple video cameras instead of just one in high resolution. "It is basically the same as what we are selling, but on steroids, and at a very similar price point," Thomas said.

**Looking Ahead to 2022.** With multi-GNSS going mainstream, both chip manufacturers and simulator manufacturers will be challenged by the cost of test equipment. Chip makers need to be able to test the new signals on their production lines, while simulator makers will need to provide devices at a price point and ease of use for customers with less stringent or slightly less technical requirements. "They need a simpler interface and a smaller, cheaper unit," Thomas said. ◍

## Rohde & Schwarz

**Markus Irsigler,**
Product Manager, Signal Generators

An increasing number of GNSS applications depend on multi-frequency GNSS.

**Innovation.** In response, Rohde & Schwarz added multi-frequency test capabilities to its entry-level and mid-range test solutions. "We have launched a new GNSS simulator based on the new mid-range vector signal generator R&S SMBV100B," Irsigler said. A simple and flexible option concept allows users to turn the instrument into a full-featured and powerful GNSS signal source. It addresses a wide range of test applications, from single- and multi-frequency production testing to multi-frequency receiver characterization. The instrument can be equipped with an internal noise generator that allows users to simulate GNSS plus noise or CW interference without using additional external hardware.

**Coming Next.** GNSS test solutions from R&S are based on general-purpose vector signal generators. With this approach, GNSS and other signals can be generated at the same time in the same instrument allowing coexistence and interference testing without additional external signal sources. As this results in test solutions that are compact and very flexible to use, R&S will continue to use this approach for upcoming product upgrades and enhancements as well as for its next generation of GNSS test solutions. The company's upcoming activities will mainly focus on the high-end segment, where the R&S SMW200A with up to 4 RF outputs and up to 144 channels addresses multi-antenna and multi-vehicle GNSS test applications.

**Looking Ahead to 2022.** With the safety demands of autonomous driving or aircraft landing procedures, multi-frequency testing will become standard. Because such applications must be sufficiently robust against spoofing and jamming threats, there will be an increasing need to test navigation systems against such influences. "Simulating GNSS alone is not enough," Irsigler said. "Test solutions for autonomous driving will require several other techniques and signals to be applied or simulated, such as RTK/PPP or outputs from other vehicle sensors to perform sensor fusion."

## Spirent Federal Systems Inc.

**Roger Hart,**
Director of Engineering

**Jeff Martin,**
Director of Sales

Spirent's simulators test with "real-world" signals as well as allowing tests under pristine conditions or under extreme conditions that may never occur in the real world, including error conditions.

**Innovation.** In December 2018, Spirent released the SimMNSA, which provides a full M-code modernized signal solution. Until now, the GPS Directorate limited M-code simulation to either pseudo-M-code, which provides the same spread-spectrum but uses a commercial encryption standard, or a system of playing back a canned set of M-code limited to certain satellites and dates and times. With the policy change, Spirent can now implement M-code based on the modernized Navstar security algorithm (MNSA), and now offers both an M-code solution with the SimMNSA and a full Y-code with the SimSAAS.

**Coming Next.** Spirent plans to provide customers an increased channel count to help test multi-constellation, multi-frequency receivers against multipath, jamming and spoofing. "We are in a period of intense development in terms of AVs, UAVs, and so forth, which don't use GNSS exclusively," Hart said, explaining that Spirent is working on testing of GNSS/sensor-fusion platforms.

**Looking Ahead to 2022.** "As new interface specifications are released, we are proactive in developing new signals," Hart said. Spirent also is supporting efforts to achieve assured PNT solutions. It is investigating interference-mitigation techniques such as algorithms, directional antennas, and other anti-jam technologies. Signal authentication is another need. "As the systems are becoming more integrated and networked, we are conscious of cyber-security threats and are looking in that area," Hart said.

## Syntony GNSS

**Cyrille Gernot,**
GNSS Receiver Development and Product Manager

GNSS receiver manufacturers use simulators to ensure that their products are robust in challenging situations that can't be clearly assessed using real-world data. "That's where the GNSS simulator comes into play," Gernot said, "by offering controlled and repeatable scenarios."

**Innovation.** Syntony's new pseudo-random-noise code (PRN code) server allows the GNSS simulator user to dynamically send the pseudo-random sequence modulating a carrier. It is especially useful for testing encrypted signals such as the GPS military signal or the IRNSS RS signal. "Access to encryption keys is extremely difficult for a simulator manufacturer to obtain," Gernot said. "However, the simulator does not actually need to have knowledge of those encryption keys; only the resulting pseudo-random sequence to modulate is required." The Syntony PRN server allows users to dynamically input their own pseudo-random sequences to be modulated on the target carrier into the simulator.

**Coming Next.** Syntony's next simulator will simulate spoofing and synchronous multi-antenna signals for CRPA and antenna network testing.

**Looking Ahead to 2022.** As the threat of spoofing and jamming increases, the receiver industry will have to develop countermeasures and mitigation strategies. One of the best methods remains the use of antenna arrays, Gernot said. "Antenna arrays allow for spatial discrimination that is especially efficient to counter spoofing, jamming or unintentional interferences.To meet the industry's future demands, Syntony is already working on accurate simulation of antenna arrays while accounting for inherent errors such as inter-antenna phase and amplitude offsets and overcoming obstacles, including phase coherency at the output of the simulator RF channels."

# MARKET WATCH

Segment Snapshot: Applications, Trends & News

OEM

## Spirent Enhances GSS9000 Simulator

Image: Spirent

The enhanced GSS9000 series features sophisticated spoofing test capabilities.

Spirent Communications has launched its enhanced GSS9000 series GNSS constellation simulator.

Providing significantly improved capability, flexibility and performance, the GSS9000 series has been updated to meet the ever more demanding test needs of high-performance satellite navigation systems. It doubles the number of supported channels (320 in a single chassis) while maintaining its full performance specification in key areas such as signal iteration rate and low latency under maximum signal dynamics.

These attributes, together with the ability to produce a comprehensive range of emulated multi-GNSS, multi-frequency RF signals, enables full and future-proofed testing of advanced applications.

Greater signal flexibility is also built into the enhanced GSS9000 series, through its open API and flexible system architecture. This delivers a highly sophisticated arbitrary waveform generator (AWG) capability.

### SIM3D PROVIDES REALISTIC MULTIPATH SIMULATION

SPIRENT COMMUNICATIONS PLC has launched Spirent Sim3D, a 3D modeling solution that enables testing of realistic multipath and obscuration effects on GNSS signals in a true-to-life synthetic environment.

Sim3D is suitable for use by automotive, chipset, handset and receiver manufacturers, as well as in aerospace, military, mining and precision agricultural applications.

The system has been developed in partnership with OKTAL Synthetic Environment. During simulation with Sim3D, the GNSS signals interact with fully customizable 3D environments to simulate real-life applications in operation, like a vehicle on a highway, or a wearable device on a pedestrian.

## IP-Solutions Launches GNSS RF Simulator

Photo: IP-Solutions

Portos Team paired with the Ninja.

Japan-based IP-Solutions has introduced Portos Team, a new GNSS RF signal record-and-playback system.

The Portos Team can record and play back — or simulate —multi-frequency, multi-system GNSS signals when paired with the company's Replicator. It can do the same for CRPA signals when paired with the Ninja (see photo).

The Portos itself can also operate as multi-frequency or CRPA front end for a GNSS software receiver.

## Firmware Release Increases Acquisition

NovAtel's latest 7.07.03 firmware release brings users improved processing speed and accuracy as well as significantly reduced signal acquisition time.

The firmware works best with the TerraStar-X correction service, which delivers accuracy and reliability, as well as the OEM7, SPAN CPT7 and PwrPak7 products, which use signals from all GNSS constellations and frequencies to provide users with reliable autonomy and exceptional positioning availability.

Photo: NovAtel

The SPAN CPT7.

The 7.07.03 firmware offers a significant improvement to the SPAN GNSS + INS (inertial navigation system) technology. SPAN with 7.07.03 shows improvements of up to 20% in the horizontal position over the entire SPAN IMU catalog and across various industry use cases including agriculture and marine.

The upgrade also provides improved motion detection, resulting in more robust time to convergence.

## SURVEYING

# New i90 GNSS Receiver Improves RTK

CHC Navigation has released and is immediately shipping its new i90 IMU-RTK GNSS Series receiver. It is designed to dramatically increase GNSS real-time kinematic (RTK) availability and reliability.

The i90 is powered by the company's latest inertial measurement unit (IMU) and RTK technology to provide robust and accurate GNSS positioning in any circumstances.

Unlike standard micro-electro-mechanical (MEMS)-based GNSS receivers, the i90 GNSS IMU-RTK combines a high-end calibration and interference-free IMU sensor with a state-of-the-art GNSS RTK engine and advanced GNSS tracking capabilities.

The i90 is designed to increase the productivity and reliability of survey projects. No complicated calibration process, rotation, leveling or accessories are necessary.

A few meters' walk will initialize the i90 internal IMU sensor and enable RTK survey in difficult field environments.


Photo: CHC Navigation

The i90 GNSS automatic pole-tilt compensation boosts survey and stakeout speed by up to 20%.

## MAPPING

# Laser Scan Data Improves Response in Active Shooter Simulation

A security technology firm reduced the time needed for public-safety personnel to engage a simulated active shooter by providing the team with site floorplans created from 3D laser scan data.

Before the exercise, the firm scanned the entire 112,000-square-foot building interior in 2.5 hours with the GeoSLAM ZEB-HORIZON 3D mobile scanner.

"In the role-playing scenario staged at a mega-church, the off-duty police officers reached the shooter in up to 21 percent less time using a 2D floorplan generated from the laser scans," said Robert W. Myers, CEO of Entropy Group. "However, we expect engagement times to drop considerably by leveraging the 3D scan data to create virtual reality training simulations."


Photo: GeoSLAM

**Entropy Group's Robert Myers scanned the interior and exterior of the facility.**

Based in San Ramon, Calif., Entropy Group was established to save lives during active shooting incidents at schools and churches by providing law enforcement with the situational awareness information they need to reach perpetrators more quickly inside complex building spaces.

**Handheld mapping.** The firm uses the ZEB-HORIZON to capture 3D scans of school and church interiors, including small offices, classrooms and closets. The GeoSLAM software generates highly accurate 2D floorplans for use by responders, either hardcopy or digital, to navigate the interior of the building.

The same data set can also be used to create virtual environments where multiple officers train on computers to respond to attack scenarios in realistic, immersive 3D simulations of actual schools and churches in their jurisdictions.

"Eventually, we plan to utilize machine learning technology that will allow individual officers or first responder teams to be dispatched to specific locations within the facility in real time to quickly reach shooter engagement locations within the buildings," Myers said.

The handheld ZEB-HORIZON laser scanner allows users to map interior and exterior spaces in 3D at walking speed. The lightweight device captures up to 300,000 points per second with an accuracy of 1-3 centimeters up to 100 meters from the user.

Photo: GeoSLAM

**ZEB-HORIZON handheld 3D scanner.**

# TRANSPORTATION

## GMV to Develop Autonomous Vehicle Positioning for BMW


Photo: BMW Group

GMV has been awarded a contract for development of a precise GNSS positioning system with integrity for the new generation of autonomous vehicles of the German carmaker BMW Group.

The Spanish multi-national's technology solution is going to be developed for the first time in BMW Group's autonomous vehicles. GMV's positioning software calculates the vehicle's position and other quantities, using advanced GMV-developed algorithms, including components that have already been patented. These algorithms have been modified and adapted to meet BMW Group's performance and safety requirements.

The developed software will abide by the most demanding automotive standards and the highest quality levels of safety-critical software, GMV said in a press release.

Another key component provided by GMV is a GNSS correction service to be run in a secure infrastructure using data from a global network of monitoring stations to be set up by GMV under the contract.

The new project cements GMV's position as a supplier of GNSS-based autonomous-car positioning solutions, the company said. GMV has been investing for years in GNSS technologies for autonomous driving systems. "For our company this contract represents a unique opportunity to capitalize on all that effort, providing a product of outstanding performance for the automotive industry," said Miguel Ángel Martínez Olagüe, GMV general manager.

# MACHINE CONTROL

## Topcon Releases Digital Farm Management Tools

Topcon Agriculture has launched a number of digital farm management tools, including updates to its cloud-based farm management platform Topcon Agriculture Platform (TAP). According to the company, TAP integrates connectivity, cloud services and data analytics, and is designed to suit virtually any agricultural machine, implement or technology.

TAP features a new interface designed to increase productivity and profitability for farmers. It also has the ability to provide data on a number of variables, including yield, soil, fertility, imagery and topography.

"We've worked with farmers and institutions while beta testing and are excited to roll the platform out to farmers worldwide," said Brian Sorbe, vice president of global production solutions for Topcon. "It is the ideal solution for mixed fleets, so farmers can focus solely on decisions and action.

Photo: Topcon

**Topcon Agriculture launched a number of digital farm management tools, including updates to TAP.**

"Additionally, the platform can provide seamless connectivity for sharing information so those supporting the farmers, such as dealers and agronomists, can provide real-time support, recommendations and tasks directly to the cab."

The company also released yield data-management tools, an autosteering tool and a GNSS base receiver. The company's Smart Cart solution is designed to provide farmers with the capability to gather highly accurate, weight-verified, geo-referenced harvest data that automatically uploads to TAP for visualizing, post processing and yield reporting.

**YM-2 YieldTrakk.** The other yield monitoring solution released by Topcon is the YM-2 YieldTrakk, which services crops — such as potatoes, sugar beets, grapes, onions and tomatoes — using conveyor-type harvesterspos.

Topcon debuted the HiPer VR mobile base station to provide the latest GNSS tracking technology and RTK capability in a compact, rugged design to bring satellite guidance and value to any agricultural application, as well.

Finally, the company launched its AGS-2 auto guidance system, which provides autosteering for agricultural machine types and models. The system will leverage the new TAP Cloudlynk connectivity devices for RTK corrections via cellular or radio.

## Septentrio Introduces Rugged GNSS/INS System

Septentrio has expanded its GNSS/INS portfolio with the AsteRx SBi, a new housed GNSS/INS receiver. The ruggedized AsteRx SBi fuses high-accuracy GPS/GNSS with a high-performance inertial sensor to provide reliable positioning and 3D orientation for machine control and logistic applications.

Within its rugged, waterproof enclosure, a high-performance GPS/GNSS is coupled with an industrial-grade inertial sensor to provide high-accuracy, reliable positioning and 3D orientation (heading, pitch, roll).

Offering the flexibility of either single or dual antenna, AsteRx SBi is designed for quick and easy integration into any machine monitoring or control system.


Photo: Septentrio

**The AsteRX-SBi has a rugged housing, making it suitable for machine control and other outdoor uses.**

Reliable location and 3D orientation data is streamed with a high update rate and constant low latency.

Septentrio's reliable centimeter-level positioning is based on true multi-frequency, multi-constellation GNSS (GPS, GLONASS, Galileo, BeiDou, QZSS) technology. AsteRx SBi combines GPS/GNSS and an industry-grade inertial measurement unit (IMU) to deliver precise positioning together with 3D attitude.

Septentrio's GNSS–IMU integration algorithm enables continuous positioning in environments of low satellite visibility where short GNSS outages are possible. This makes AsteRx SBi a robust positioning solution for machinery operating in environments challenging for GNSS, such as in container yards, urban canyons or near cliffs.

AsteRx SBi comes with built-in Advanced Interference Mitigation (AIM+) technology.

MOBILE

# One Billion Now Use Galileo Smartphones

The estimated number of Galileo-enabled smartphones in use has reached one billion. The milestone was achieved the same week that the European GNSS Agency (GSA), responsible for operation of the Galileo programme, celebrated its 15th anniversary on Sept. 10.

The company BQ pioneered Galileo use in smartphones in July 2016 with its Aquaris X5 Plus. Since then, market uptake of Galileo-enabled smartphones has been rapid as other manufacturers were quick to embrace the fledgling European navigation constellation.

Global annual GNSS receiver shipments are forecast to grow from 1.8 billion units in 2019 to 2.7 billion units in 2029.

Currently, 156 Galileo-enabled smartphone models are on the market. The "1 billion users" milestone is based on the number of smartphones using Galileo sold across the world. The actual number of Galileo users around the world is much larger. Those interested can track which devices, including smartphones, are Galileo-enabled on the **UseGalileo.eu** website.

*SEE ONE BILLION ON PAGE 40.* >>


Image: GSA

**THE NUMBER OF GALILEO-ENABLED smartphones in use has soared to 1 billion in three years.**

# MOBILE

## ONE BILLION

<< *Continued from page 39.*

Today, 95% of companies that produce smartphone chips for satellite navigation make chips that enable Galileo. According to figures in the latest GSA *GNSS Market Report*, to be published soon, global annual GNSS receiver shipments are forecast to grow continuously across the next decade, from 1.8 billion units in 2019 to 2.7 billion units in 2029. Most of these shipments are for receivers costing less than €5, and 90% of receivers in this price segment are used in smartphones and wearables.

"Galileo is now providing high-quality timing and navigation services to 1 billion smartphone users globally," said Elżbieta Bieńkowska, commissioner for internal market, industry, entrepreneurship and SMEs. "This has been made possible by a truly European effort to build the most accurate navigation system in the world, with the support and dedication of the GSA. I am confident that our space industry will continue to thrive with more work, ideas and investment under the new EU Space Programme."

"One billion smartphone users is a significant milestone and a major achievement for the Galileo programme and for the GSA," said GSA Executive Director Carlo des Dorides. "The GSA has worked tirelessly to build bridges with research and industry and create a strong community of service providers who trust Galileo and understand the technological innovation opportunities it brings.

"Chipset and receiver manufacturers in particular have been quick to leverage Galileo's outstanding performance," des Dorides said. "These manufacturers believed in Galileo from the beginning, when Galileo was still an idea, and invested in the technology. It is thanks to them and the unique blend of expertise and knowledge of the GSA team that we are now celebrating 1 billion Galileo-enabled smartphones."

The GSA was set up as the European GNSS Supervisory Authority in 2004 to oversee the development of the European space programmes EGNOS and Galileo.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## DEFENSE

### Portable JPALS Landing System Sets up Fast

A Raytheon Company team has conducted a rapid set-up demonstration of a land-based expeditionary version of its Joint Precision Approach and Landing System (JPALS) to a group of global military officials at Naval Air Station Patuxent River, Maryland.

JPALS is a GPS-based precision landing system that guides aircraft to precision landings in all weather and surfaces conditions.

"The entire system was fully operational in 70 minutes on day one and 50 minutes on day two," said Matt Gilligan, vice president at Raytheon's Intelligence, Information and Services business.

During the demonstration, military officials from all four services, as well as representatives from Japan, the United Kingdom, The Netherlands and Italy, watched multiple F-35Cs land on the same designated runway landing point every time over the course of six different approaches.

This was the second proof-of-concept event in 2019 showing how F-35s can use a reconfigured mobile version of JPALS to support landings in austere environments.

JPALS is a differential, GPS-based precision landing system that guides aircraft onto carriers and amphibious assault ships in all weather and surface conditions up to the rough waters of Sea State 5.

It uses an encrypted, jam-proof data link to connect to software and receiver hardware on the aircraft and an array of GPS sensors, mast-mounted antennas and shipboard equipment.

Photo: Raytheon

A RAYTHEON TECHNICIAN operates the rapidly installed JPALS equipment.

# A TIDAL SHIFT

## Monitoring Sea Level in the Arctic using GNSS

**TRADITIONAL TIDE GAUGES ARE IN CONTACT WITH THE WATER SURFACE and as a result are susceptible to measurement error and damage during extreme weather. An alternative approach is the use of GNSS reflectometry. We learn how this innovative use of satellite navigation signals works in this month's Innovation column.**

BY SU-KYUNG KIM AND JIHYE PARK

Seawater level is conventionally monitored by tide gauges that measure the vertical distance of the water surface from a point on the ground. As the tide gauges provide seamless and highly accurate measurements, many countries operate a tide-gauge network to monitor sea-level changes and to assess flood risk. For example, the National Oceanic and Atmospheric Administration (NOAA) operates a permanent observing system, the National Water Level Observation Network (NWLON), with more than 400 gauges throughout the United States. However, some challenges of tide gauges can be identified. Firstly, tide-gauge measurements require direct contact with the water, which causes limitations in installing and maintaining the equipment. The equipment requiring direct sensing is highly vulnerable to coastal hazards, such as coastal flooding and tsunamis, resulting in potential measurement errors or even equipment destruction during severe natural events. Furthermore, tide gauges require maintenance on a regular basis, which is expensive because it requires the use of divers. This greatly limits the operation of tide gauges, especially in extreme environments such as in the Arctic. Alaska, for example, has significant gaps in its available spatially-varying tidal information. However, in the Arctic, it is also very important to constantly and closely monitor the long- and short-term variation of water levels because this area has a significant impact on global climate and ecosystems. Consequently, more support is needed for sea-level monitoring and coastal mapping in this region.

GNSS can serve as an alternative approach for water-level monitoring. GNSS satellites continuously transmit radio signals and ground-based, space-based, and airborne receivers access the signals regardless of weather conditions. Some of the received signals are reflected from obstacles or surfaces near the antenna, a phenomenon referred to as multipath (see **FIGURE 1**). Multipath tends to be regarded as one of the major error sources for GNSS positioning where it causes unexpected phase delays when compared to the direct signal. Consequently, various procedures have been developed to mitigate the multipath effect. However, the GNSS signals reflected from the Earth's surface contain information about the geophysical properties of the reflecting surface. The use

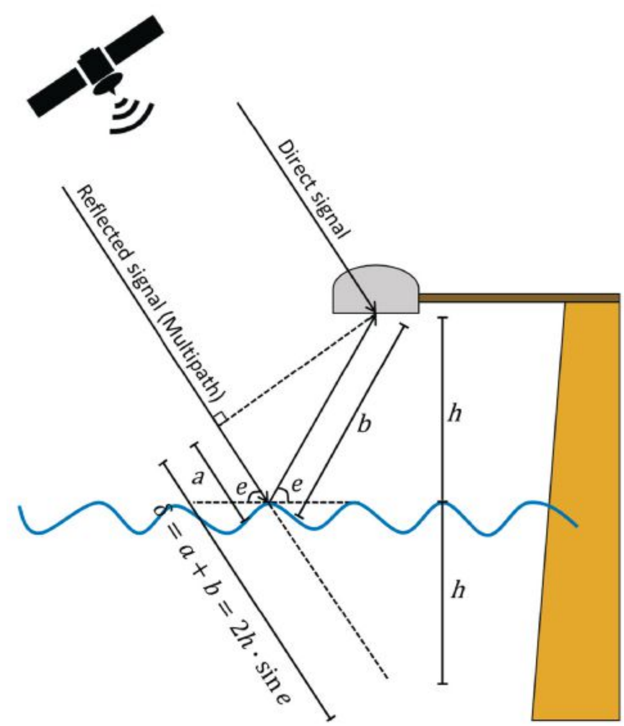



**FIGURE 1** **Schematic drawing of the GNSS-based tide gauge.**



of these signals is known as GNSS reflectometry (GNSS-R). GNSS-R allows us to monitor the temporal variation of water levels by calculating phase delays of GNSS signals reflected from the water surface. A GNSS-R-based tide gauge does not require direct contact with the water because it measures the water levels based on a remote-sensing technique. Thus, a GNSS-R-based tide gauge can be effectively applied to water-level monitoring.

However, several challenges exist in processing GNSS signals observed at high latitudes compared to mid-latitudes. Not only do we have to contend with extreme weather conditions and limited infrastructure availability, but also with problematic satellite geometry and ionospheric effects on the GNSS signals. To overcome these limitations in the use of GNSS-R in the Arctic, we introduce enhanced algorithms to improve the temporal and spatial resolutions of GNSS-R sea-level

SUPPLEMENT TO

GPS WORLD
GNSS
POSITION
NAVIGATION
TIMING

# 2019 UAV REPORT

# UAVs SKYROCKET TO INDUSTRY PROMINENCE

BY TONY MURFIN
CONTRIBUTING EDITOR FOR OEM AND UAV



Photo: © Flyability

Photo: Quantum Systems/u-blox

# UAVs SKYROCKET TO INDUSTRY PROMINENCE

**FROM GROWING CROPS TO MAKING MOVIES, unmanned arial vehicles (UAVs) are changing the way we work. UAVs — managed by unmanned aerial systems, or UAS — range from small indoor inspection units to giant Predator drones. They are streamlining how we manage mines and plants, deliver packages, and keep people safe. Read on to find out the latest in this skyrocketing market.**

BY TONY MURFIN
CONTRIBUTING EDITOR FOR OEM AND UAV

The unmanned aerial system (UAS) industry is in great shape! In the United States., the Federal Aviation Administration (FAA) appears to be helping commercial operations get off the ground, at least for those wishing to fly small unmanned aerial vehicles (UAVs).

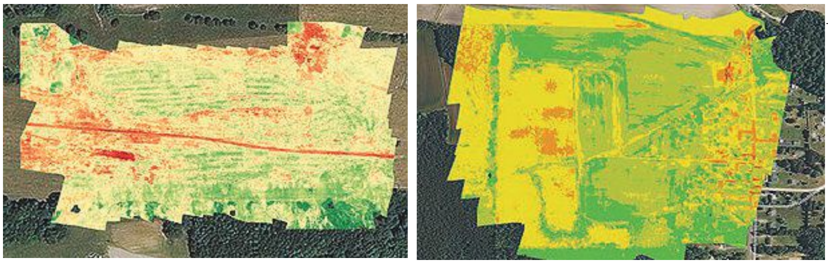
Things are certainly hopping for unmanned aircraft in agriculture, mining and construction, facility inspection, newsgathering, movies and promotion. Package delivery is on the way, and, of course, defense is cooking with new innovations. Everywhere you look, a specialized drone or new application seems to appear that has good prospects for success.

One helpful aspect of today's landscape for UAS operators in the U.S. is the FAA's supportive approach to small UAS (sUAS) for commercial activities. After providing a regulatory framework with Part 107 rules, albeit with quite a few caveats that require a written waiver application, *qualified* drone operators are now able to fly their drones in many places — as long as they are below 400 feet, well away from airports, and nowhere near any *restricted* airspace.

Pilot qualification courses and proficiency testing are both readily available — at 676 commercial facilities across the U.S. according to the FAA website — and a successful online application process should result in a remote pilot's certificate.

With a drone registered with the FAA, you can use the FAA's B4UFLY mobile app to check if it's safe to operate where you intend to. If it is, you can get approval in real time using the FAA's Low Altitude Authorization and Notification Capability (LAANC) system. The FAA qualified LAANC to clear commercial drone operations, and the service is now provided by a large number of independent UAS service providers.

With the regulatory and approval path in place, it's now possible for companies and individuals to earn a living with turn-key drone operations, providing services for many applications that have blossomed. There's work to do beforehand, but it's less arduous



Maps: PrecisionHawk

**PRECISIONHAWK'S SOFTWARE PrecisionAnalytics—Agriculture automatically generates georeferenced orthomosaics from data collected with drone sensors. At left is a crop health analysis; at right is a sample prescription map.**

than for manned flight operations.

Let's look at a few of the applications benefiting from the automation, enhancement and remote operations provided by UAVs as well as their on-board sensor suites and after-flight processing:

- agriculture
- mining and construction
- facility inspection
- newsgathering, movies and promotion
- package delivery
- defense

## Agriculture

Agriculture has readily adopted UAVs to monitor, control and improve overall crop growth rates — a part of what is known as precision agriculture. Drones carrying optical, thermal and laser scanning payloads gather stacks of information about the condition and rates of growth in fields. The information is then fed into various analysis tools. A picture emerges over time that indicates the health of crops. This enables farmers to generate a formulas for the nutrient and weed-reduction chemicals used for spraying at various times of the year. It's a customized "prescription" for each growing area.

Continuing UAV overflights during the growing cycle monitor the effects of growing conditions and the effectiveness of treatments, providing more feedback that lead to even further improvements.

Smaller tech-savvy farms might run their own programs, supported by local agrochemical suppliers that may provide analysis services or sell analysis tools. However, there has been a real growth in the number of companies that supply an entire turn-key package — supplying and flying drones, gathering data, running analyses and providing written and graphic output to support the farming operation.

Unmanned aircraft are truly an integral part of this approach, which might only have been possible because of semi-autonomous UAS and the evolution of compact sensors: UAV-mounted infrared, high-precision optical and lidar.

## Mining and Construction

Any mine site is a busy — even chaotic — place to conduct a commercial business. Drones provide a way for mining operations to

- quickly collect information to enable volume calculations;
- provide relatively inexpensive site surveys; and
- manage traffic and set up daily road layouts.

In effect, drones enable more rapid control of a complex and dynamic undertaking. Additionally, they improve safety. Ground surveyors no longer need to dodge huge operating machines and tumbling ore, or scramble around difficult terrain.

An autonomous drone can gather timely, georeferenced imagery that can be turned into a precise 3D model of the site. Site managers can have immediate access to details of the UAV survey. They can see the extent of existing deposits and know where to support further mineral exploration, receive estimates of stockpiles and tailing volumes, ensure that personnel and equipment are in the correct locations, and compare aerial video and photography day by day to check progress and for record-keeping. Drones can carry a wide variety of imaging and sensor packages including visual, infrared, hyperspectral, lidar, sonar and radar.

Screenshot: SenseFly

**DRONES AID IN MANAGEMENT of complex, dynamic environments such as at this quarry in Ireland. Safety is also improved. This screenshot is from a fly-through animation generated using Pix4D Mapper software.**

Photo: General Electric

**INCREASINGLY, drones are being used to inspect dangerous facilities.**

Photo: Oil and Gas Photographer/Shutterstock.com

**AN OFFSHORE oil and gas construction platform vents gases to relieve pressure. Flame stacks such as these require regular inspection.**

It's also quicker. For instance, using the senseFly eBee fixed-wing drone, a full aerial survey of an 88-hectare site took four to five hours, with about half of that time spent placing control points. To achieve the same level of detail, terrestrial surveying would take a single surveyor two to three weeks.

**Construction Operations.** The construction sector uses the same drone data-capture techniques for site details, off-line analysis and results tabulation to manage operations of complex work sites. Compared to mining, change can be more intensive during a construction project, so drone surveys might be repeated more often.

**Surveying and GIS.** Using drones is an industry unto itself, with high-precision RTK GNSS in the air and on the ground, and specialized analysis tools for high-accuracy applications. The speed of data gathering is the principal benefit to an industry that continues to be essential in many sectors. Lower precision GIS for asset tracking and the like could become a subset of the applications and tools already discussed.

**Facility inspection.** Outdoor and indoor facility inspection is definitely benefiting from the automation that suitably equipped drones and customized analysis tools can bring to both regular and infrequent inspection tasks. The number of regular complex refinery inspections can be significantly reduced. Inspections will no longer interfere with production and will improve safety for inspection staff. For instance, flame stacks that burn off excess gases can be prone to failure, so regular inspection is essential. Using a drone for the task is clearly much safer than using personnel.

## BVLOS for Pipelines and Rail

Automated pipeline and railway track inspection have

Photo: KDOT, Division of Aviation

**LAUNCHING A UAV FOR A BVLOS FLIGHT are (at left) Travis Balthazor, UAS flight operations manager, and Mike Kuni, UAS flight instructor/pilot, both of Kansas State University Polytechnic Campus.**


Photo: © Flyability

**THE ELIOS 2** **indoor inspection UAV is encased in a collision-tolerant frame to protect both the drone and the environment it's inspecting.**

both become possible as drones are used over much greater distances, thanks to beyond visual line of sight (BVLOS) operational approvals by the FAA.

For BVLOS, users first need a validated sense-and-avoid technology on the drone. Also required is proven radio telemetry with uninterrupted command-and-control of the vehicle during flight, and an independent ground-monitoring system that confirms how the drone maneuvers throughout the flight.

In the case of a BVLOS flight this summer along the Trans-Alaska oil pipeline, a Perimeter UAV manufactured by Skyfront flew about 4 miles, maintaining a constant above-ground altitude of 400 feet with multiple ascents and descents of 1,000 feet on 45-degree slopes. The long-range hybrid multicopter drone was equipped with Iris Automation's computer vision collision-avoidance system and was monitored by Echodyne radars along the pipeline path, providing airspace situational awareness.

Another BVLOS operation built on the achievements of the Trans-Alaska pipeline trial has been authorized to fly a nine-mile linear inspection of power lines in rural Kansas. Once again, the Iris Automation system will provide collision avoidance, but this drone also has an independent automated avoidance capability. This gives the drone the self-contained ability to fly around obstacles, so no ground radar or visual tracking is required.

Relieving the requirement for radar tracking or visual observers makes many new operations affordable. Previously, FAA Part 107 BVLOS waivers have all required visual observers or ground-based radar tracking — requirements that are not only expensive, but also restrict where flights are possible.

BVLOS operations like these demonstrate the cost-effectiveness of the technical solution, making long-duration, long-distance inspection using drones feasible.

## Indoor Inspection

Indoor inspection is becoming possible with specialized drones that circumvent the need to expose inspection staff to especially difficult facility environments, which in the past also required production shut-down to protect them. Thermal and visual sensors on swivel mounts enable protected inspection drones to fly into tight spaces — or even back out of tricky situations — and make visual records that may otherwise be virtually impossible.

Searching and recording inside containment vessels at the failed Fukushima nuclear facility may have been significantly advanced by using inspection drones.

## Newsgathering, Movies and Promotion

All those panoramic, overhead, moving shots you see on the news, in movies and in ads used to be taken from a manned helicopter or fixed-wing aircraft. Now they are mostly taken by multi-copter drones with high-resolution cameras. This makes cinematography and newsgathering much more afforable, making these fields accessible by smaller operations. In the past, only

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All-in-view
GPS L1/L2/L5;
SBAS L1/L5;
Galileo E1/E5A;
BeiDou B1;
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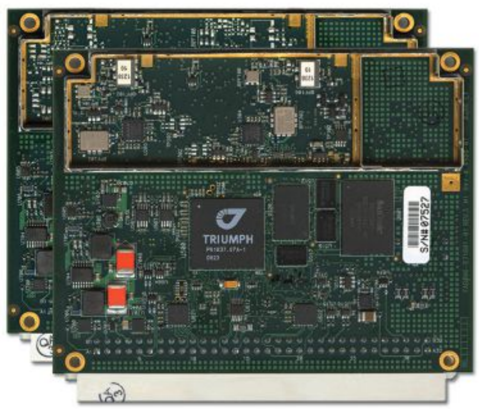

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SBAS L1; Galileo E1;
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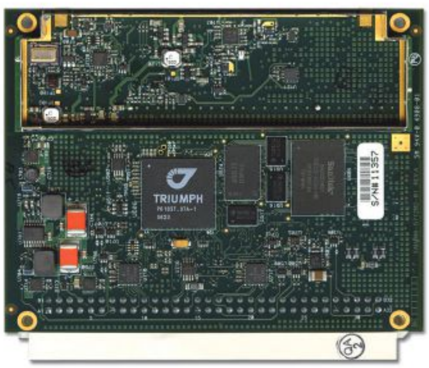
All-in-view
2 groups of GPS L1/L2;
SBAS L1; Galileo E1;
Ethernet; Up to 50 Hz
Heading rate



### TRE-G2T
All-in-view
GPS L1/L2/L5;
SBAS L1/L5;
Galileo E1/E5A;
BeiDou B1;
QZSS L1/L2/L5;
Ethernet ***

### TRE_DUO
All-in-view on 2 antennas
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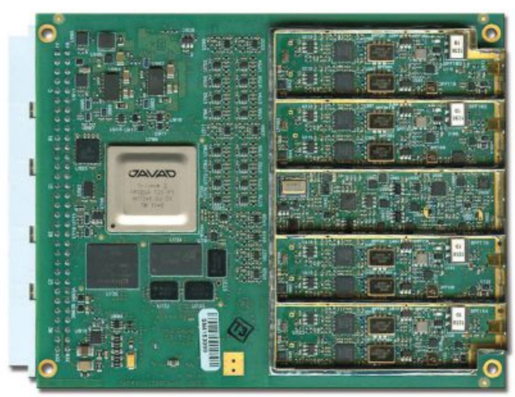
Galileo E1/E5A/E5B/AltBoc;
GLONASS L1/L2/L3;
BeiDou B1/B2;
QZSS L1/L2/L5

### TR-3N
All-in-view
GPS L1/L2/L2C/L5;
Galileo E1/E5A/E5B/AltBoc;
GLONASS L1/L2/L3;
BeiDou B1/B2;
QZSS L1/L2/L5;
SBAS L1/L5

### TRE-3N
All-in-view
GPS L1/L2/L5
Galileo E1/E5A/E5B/AltBoc;
GLONASS L1/L2/L3;
BeiDou B1/B2;
SBAS L1/L5;
QSZZ L1/L2/L5/LEX



### TRE-Quattro
All-in-view on 2 antennas
GPS L1/L2/L2C/L5;
Galileo E1/E5A/E5B/AltBoc;
GLONASS L1/L2/L3;
BeiDou B1/B2;
QZSS L1/L2/L5

### TRE-3/TRE-3L
All-in-view, GPS L1/L2/L2C/L5;
Galileo E1/E5A/E5B/AltBoc/E6;
GLONASS L1/L2/L3;
BeiDou B1/B2/B3;
QZSS L1/L2/L5

** Not available in this board: Reduced MinPad; RS232(A) 460 kbaud; USB; Event; IRIG A/B*
*** Not available in this board: Reduced MinPad; RS232(A) 460 kbaud; USB; 1PPS; Event; IRIG A/B*
**** May be not applicable for simultaneous tracking of Galileo and BeiDou*

Image: @DJIGlobalc

**UAVS HAVE FOUND THEIR WAY onto movie sets, where cinematographers are taking advantage of improved cameras, better gimbals and sophisticated software.**

large media groups could affor to rent a helicopter. And, of course, it's much quicker to bring a UAV onto an incident site, operated by a crew on the ground.

You'll need FAA approval to use a drone for commercial newsgathering purposes, or find a suitable qualified UAV and operator. After gaining FAA qualifications, news people are also taking on the job, buying and flying the equipment and managing the video-processing software themselves.

Others using drones for similar purposes are movie makers, producers of TV commercials and real estate agents, to name a few.

## Delivery by Drone

The ultimate objective of many internet suppliers is to deliver goods that were just ordered within minutes of the order being placed. This is a pretty big objective. It requires a whole network of "fulfillment centers" in and around many cities, a massive purchasing and goods movement capability to keep these centers stocked, and a system that delivers to the end-customer. Currently, we mostly have manned panel trucks of various flavors handling that last step of the delivery process, with real people reading the notes we put on the porch about where to leave our package if we're out.

**Order and Receive.** The next wave of delivery changes are expected to include drones carrying your package from the fulfillment center to your backyard. Amazon is looking for approval to begin trials with its larger 88-pound MK-27 Prime Air delivery drone, initially in sparsely populated areas. The MK-27 is equipped with intelligent sense-and-avoid capability, flying around any obstacles it encounters in flight and even during delivery.

UPS is also hoping to get to qualification of its own UAS delivery system by the end of this year, to the same standards that manned aircraft delivery systems are certificated.

**Medical Deliveries.** Many other trials are underway, especially involving medical deliveries and support. In Africa, trials are underway in Ghana, Malawi and Rwanda. UPS recently proposed a medical supplies delivery service using drones in North Carolina. Many companies that claim expertise in medical deliveries are operating drones.

**Food on the Fly.** Restaurant food delivery services have seen an upsurge in popularity. It seems likely that soon you'll be able to order and receive lunch really quickly by drone food delivery services. Ground robot food deliveries at George Mason University are already a huge hit! Uber-Eats is experimenting with drone food deliveries, and 17 drone delivery routes have already been approved in an industrial park in Shanghai.

Meanwhile, Bell has flown its autonomous pod transport (APT) 70 near its base in Fort Worth, Texas, for the first time. The APT 70 can carry a 70-pound package load at over 100 mph, far faster and farther than existing drone delivery systems.

Bell is aiming for package delivery and critical medical transport for disaster relief for APT type drones. It is also participating in the NASA SOI program along with General Atomics' SkyGuardian.

## Defense in Front

The defense segment is going from strength to strength — despite a phase not too long ago when defense spending appeared to be dropping.

Image: Bell Helicopter Textron Inc.

**BELL'S APT 70 will be used as part of a NASA program in 2020. Bell aims to begin BVLOS tests in 2020, and begin commercial service soon after. The electric APT 70 can carry 70 pounds, cruise at 75 mph and cover 35 miles with a fully charged battery.**

Widespread drone use received a boost with specialized equipment developed for military applications.

The General Atomics Predator has gone from a long-distance loiter-and-observe UAV to frontline precision-strike capability, and has been adopted by many military forces around the world. From first flights in1994 to initial production in 1997, the Predator has now evolved into many configurations equipped with piston engine, turboprop and jet engines; line-of-sight radio and satellite command and control; synthetic aperture radar and multi-spectral targeting system; video, TV and thermographic cameras; and laser designators and other payloads.


Photo: UPS

**A UPS DRONE carries medical supplies.**

From pure reconnaissance to various strike and attack configurations, the names have also changed. Predator, Reaper, Gray Eagle, Avenger, Protector, Guardian and SkyGuardian have a host of RQ/MQ designations. For instance, in the RQ-4 Global Hawk name, the "R" means reconnaissance, the "Q" means unmanned aircraft, and the "4" is the series.

The SkyGuardian version of the Predator is a certifiable variant anticipated to ultimately become fully authorized for controlled airspace. It will take part in the NASA Systems Integration and Operationalization (SOI) demonstration program in mid-2020, which will highlight commercial UAS missions using larger drones in the national airspace.

The Predator family has now been evolving for more than 25 years. Unfortunately, the popularity of the Predator family of military unmanned aircraft has led to recent headline news about Predators shot down in the Gulf of Hormuz, or crashed in Afghanistan — such is the price of success!

The Northrop Grumman Global Hawk has become a U.S. mainline, high-altitude intelligence gathering asset, deployed by both the U.S. Air Force (RQ-4 Global Hawk) and Navy (MQ-4C Triton). Other friendly nations have also shown various levels of interest in acquiring variants, including Germany, Australia, Canada, Japan and South Korea.

Northrop Grumman has reintroduced the Firebird


Photo: General Atomics Aeronautical Systems

**THE MQ-9B SKYGUARDIAN will participate in NASA-sponsored flight tests in 2020.**

as a contender in the airborne intelligence, surveillance and reconnaissance (ISR) field. The Firebird can be configured as unmanned (ground control), autonomous or piloted, and has payload flexibility through open architecture, plug-and-play integration.

The North Dakota UAS test range facility at Grand Sky has initiated procurement of two Firebird UAVs, which they intend to supply to their customers for mapping, inspection and monitoring applications using their extensive, long-range BVLOS capabilities.

Then there's the U.S. Air Force Skyborg program, which aims to drag the most possible out of artificial intelligence (AI) and automation in an airborne fighter support roll. Kratos has flown the drone hardware a couple of times – the XQ-58A Valkyrie is a "low-cost" unmanned aircraft designed to fly alongside front-line attack aircraft like the F-35 and F-18.

The Air Force Research Laboratory (AFRL) is researching the technology, new sensors, payloads and networking capability with which these drones will be outfitted to fly alongside manned fighter jets.

A whole slew of other extremely capable drones are already being operated by the U.S. Army and Navy in a variety of support roles.

## Payloads and Equipment

In the past, UAS manufacturers either developed their own onboard control, navigation and sensor systems or adapted existing avionics systems for drone use.

Now an entire industry is growing to supply specialized products for UAV payloads. These include sense-and-avoid technology, navigation autopilots, radios, satellite communications, cameras (high-resolution still and video), infrared (IR), forward-looking infrared (FLIR), laser/lidar, infrared sensors and combined sensor packages optimized for drones.

Hydrogen power cells to extend range and endurance are a different kind of specialized product. Another is auto-release parachute systems designed to protect crowds in the event of a malfunction.

Let's not forget the ground control systems — the radio links and the space-based satellite links that are evolving almost as quickly as the drones themselves. From air-conditioned enclosures packed with communications, displays and computing power all the way down to a smartphone application, these ground systems have evolved considerably from the simple joystick hand-controllers of the past.

## Anti-Drone Detection and Prevention

In the past several years, an entirely new related industry segment has come about, usually adapting existing radar, sound, infrared or other ground-based detection systems. This segment is aimed at preventing or mitigating unwelcome drone encroachment over sensitive facilities. Airports, government agencies, prisons, and energy and water utilities are among the facilities that want to prevent unwanted drones from penetrating their airspace.

Solutions may be portable and short range, or ground-based and longer range, with the capability to take down an invading drone or detect its launch location and provide significant warning time.

One solution uses an attack drone that ensnares an intruder-drone in a net and brings it to the defender's location to support second-level investigations. Whatever the solution, drone defense is a growing field.

Artwork: Air Force Research Laboratory

**A PROTOTYPE for the Skyborg is planned for the end of 2023.**

## UAV Market Outlook

Many, many other specialized drones and applications now exist for drones, including:

- high-altitude pseudo-satellites that may significantly reduce the cost and time to put communications into service
- specialized police and security applications
- auto-charging systems that enable longer drone endurance
- drone pollination systems for fruit trees
- blimp-like tethered drones for both static and dynamic applications
- cargo drones and people-carrying taxi drones
- drones with facial-recognition capability
- suicide drones carrying explosives
- drone swarms and their applications.

With the support of the FAA and other agencies around the world, many sUAS applications and tools to support them are taking off. Ag, indoor and outdoor, and local and long-distance inspection applications, mining and construction, newsgathering, aerial photography for movies and advertising, trials leading to packages being dropped at your door, and rapidly growing military innovation and adoption — all of these areas have increased the demand for drones, as well as the software applications that support them and companies that supply commercial services to operations that need them.

Nevertheless, consolidation is accelerating in the drone universe. A number of start-ups have failed, even though they had significant venture capital funding. More than 50 companies have been acquired by bigger fish.

The companies that remain have grown stronger through these acquisitions, and their businesses appear to be on good footing. As expected, no business has an infinite capacity for growth, and the market size is finite. Investors rushing to pour money into drones should probably hesitate and watch for a while.

Venture capital flowing into more than 90 drone-related companies has been worth over half a billion U.S. dollars in the past few years. Investment sources may not be too pleased as most will not make money anytime soon.

For instance, in fall 2018, software and drone company Airware folded after absorbing significant investment from several key players, rumored to include Intel, Google, Caterpillar and GE. Delair in France purchased key Airware assets, including Redbird analytics software along with Airware's worldwide customers and dealers, but Airware's employees had to find new jobs.

No matter how we count these widely differing airborne systems or their applications, we can be sure that tomorrow there will be new and surprising turns in the drone story. Someone will come across a problem that needs a solution, perhaps a difficult or lengthy task, and a new drone application will arise from it.

Drones are a new tool. The UAS industry will continue to change and adapt these products and this technology in as-yet-unthought-of ways. It's an exciting time, and right now, there seems to be no end in sight.

Photo: DroneShield

**THE DRONEGUN TACTICAL in use in an operational scenario.**

CASE STUDY

# Congested Airport Gets Maintenance Boost

Airports are extremely congested spaces, both on land and in the air, making it difficult to conduct surveys that provide insights into their continued monitoring and maintenance.

Unmanned aerial vehicles (UAVs) create the opportunity to survey such sites safer and faster, reducing disturbances to everyday operations while collecting higher level of detail compared to conventional surveying techniques.

Texas-based civil engineering company Gessner Engineering used senseFly's fixed-wing eBee drone to locate and accurately capture areas in need of maintenance and management throughout a 650-acre airport, said Troy Hittle, general manager, North America, at senseFly.

Following several drainage and grading issues, the survey team had to navigate the saturated airspace and conduct the survey with minimal impact on the everyday operations of the runways. By coordinating with the airport's air traffic operators directly, the team was able to plan a 6–8-hour flight window, with just a couple of pauses required for ongoing traffic, while the airport operated for the most part as usual.

**Mission prep.** Prior to the flight, senseFly eMotion flight planning software was used to carry out pre-flight risk assessments and plan all flights in advance. For the survey, the eBee completed four flights of about 20 minutes. With its autonomous aerial mapping capabilities, the UAV captured all of the aerial photos needed to map the 650-acre airport.

The data was processed with Pix4D Mapper to generate a topographic model including a point cloud with a ground sample distance (GSD) of 1.5 inches.

**Quality Data.** The comprehensive point cloud created showed four more areas where with drainage issues. The level of detail would not have been possible with conventional surveying techniques.

By using UAV technology, the airport survey was completed in less than one day, compared to the four weeks it would have taken the Gessner team using a regular GPS station unit. The cost of the survey was halved and the UAV minimized disturbances to airport operations.


Photo: senseFly

UAVs SLASH inspection and surveying times.

# Ready for Rescues

uAvionix provided free pingRX unmanned aircraft system (UAS) ADS-B receivers to first responders and UAS service organizations who participated in rescue and recovery efforts associated with Hurricane Dorian in September.

In 2017, in response to Hurricane Harvey's landfall in Houston, Texas, UAS were used extensively for the first time in recovery and rescue efforts. The use of UAS for disaster response has continued to grow ever since.

Photo: ICEYE

THIS ICEYE-X2 satellite image shows Grand Bahama island covered by Hurricane Dorian's storm surge.

measurements. Our approach includes an enhanced spectrum analysis based on multi-frequency signals and statistical reliability verification. Moreover, we include the signals transmitted by the Galileo constellation in addition to GPS to improve the quantity and the quality of GNSS observations in the Arctic. We have tested the proposed method with an experiment in Alaska and validated the results with nearby tide gauges. The experimental results clearly show the feasibility of employing GNSS-R-based tide gauges in the Arctic.

## GNSS-R-BASED WATER-LEVEL MONITORING

Martin-Neria first introduced a method of monitoring sea level using the GNSS-R technique in 1993. Thereafter, many studies have been conducted to apply GNSS-R to water level estimation. Anderson proposed a method to estimate sea level using the interference pattern caused by the direct and reflected GNSS signals, which relies on the fact that the spacing between peaks in the interference pattern is almost entirely dependent on the height of the antenna above the reflecting surface.

The phase difference in the GNSS receiver between the direct and the reflected satellite signals varies while the geometry of a GNSS satellite changes (see Figure 1), generating the interference pattern. The interference pattern is particularly noticeable in signal-to-noise ratio (SNR) data. The reflected signals contribute to the SNR data in the form of oscillations, while the smoothly rising overall arc mostly depends on the signal strength and the antenna gain pattern. The reflected signals can be isolated from the SNR data by removing the main trend — for example, by polynomial fitting — indicative of the direct signal. The frequency of the remaining dSNR oscillations is constant with respect to the sine of the elevation angle, assuming that the water level does not change during the satellite arc and the reflection surface is horizontal. Consequently, the frequency of the oscillation is linearly proportional to the height of the antenna above the reflecting surface.

The frequency can be derived from the dSNR data by spectral analysis. Among a number of spectral-analysis methods, the Lomb-Scargle periodogram (LSP) is commonly applied since it allows for processing of unevenly sampled data.

**Determining the frequency of the oscillations.** The antenna height above the water surface is directly calculated from the frequency of the oscillations derived from LSP processing.

**FIGURE 2** **The surrounding area of AT01 in St. Michael, Alaska: south view.**

However, it is difficult to determine the dominant frequency because of the roughness of the water surface, especially in extreme environments such as Arctic regions with high currents and strong winds. In addition, the observed SNR data is easily affected by obstacles near the GNSS antenna. Therefore, it is difficult to distinguish the spectral peak of the signal reflected from the water surface from other additional reflected signals, especially when additional and unexpected reflections occur near the sea surface.

To minimize the erroneous determination of the frequency of the oscillations using dSNR, we can take advantage of the multiple frequencies of modern GNSS signals. In our study, we processed signals from both the GPS and Galileo constellations, with GPS transmitting three carrier signals (L1, L2 and L5) and Galileo transmitting five carrier signals (E1, E5a, E5b, E5ab and E6). By comparing the spectrum peaks from the multiple signals on different frequencies, one can analyze the dominant peaks across the different frequencies on the same raypath. This algorithm is based on the fact that the multiple frequency signals should detect consistent sea-level heights because they are transmitted along the same raypath during the same period. One of the biggest advantages of this approach is that no additional data or equipment is required to accurately determine the frequency of oscillations of the GNSS signals reflected from the water surface.

**Statistical Testing of Retrieved Sea Levels.** Reflected signals are not necessarily all from the sea surface. To remove erroneous solutions, we conducted a statistical test. Data including measurement errors and/or some noise can be approximated to the model by the least squares method that determines the model parameters by minimizing the sum of squared residuals. However, this method yields an incorrect result when many outliers deviating from the normal distribution are included in the data set. This problem can be overcome by applying RANdom SAmple Consensus (RANSAC). RANSAC stochastically estimates the model parameters maximizing consensus, that is, the parameter supported by the largest number of sample data through an iterative process. However, the RANSAC results can act differently each time for the same input data because it is essentially a statistical estimation method using random samples. Therefore, we perform RANSAC with rough constraints primarily to remove outliers significantly out of normal range, then the remaining noise in the data can be excluded by performing secondary fitting using tightly constrained least squares. For the least squares procedure, a series was applied for the fitting model, which represents various motions of the sea surface such as ocean tide loading, as a sum of trigonometric functions.

## SEA-LEVEL MONITORING IN ST. MICHAEL

The Plate Boundary Observatory (PBO) network operated by UNAVCO (formerly the University NAVSTAR Consortium) is primarily designed to monitor long-term tectonic and volcanic deformation. However, it can also be used for GNSS-R applications. A new PBO station, AT01, was installed in May 26, 2018, in St. Michael, Alaska, which is designed to be suitable as a GNSS-R-based tide gauge with a clear and wide-open view toward the sea covering from 0° to 230° in azimuth (see **FIGURE 2**). The equipment at this site consists of a Trimble choke-ring geodetic antenna and a Septentrio PolaRx5 receiver that can receive not only GPS signals but also those of Galileo, with data recorded every 15 seconds.

We have used this station to assess our technique using one month of SNR data from June 2018. It should be emphasized that not only GPS but also Galileo signals were processed, and the Center for Orbit Determination in Europe's Multi-GNSS Experiment final orbit and satellite clock products were used to minimize the satellite orbit error. Additionally, NOAA tide gauge stations (9468132 and 9468333) were used for comparison and verification of the water levels measured from the GNSS-R-based tide gauge (see **FIGURE 3**). The 9468132 tide gauge in St. Michael is the nearest tide gauge at approximately 1.5 kilometers from AT01. However, since it is not operational, NOAA only provides water-level predictions (just high and low tides) based on the harmonic constituents, not the actual measurements. On the other hand, the 9468333 tide gauge in Unalakleet is approximately 74 kilometers away from AT01. This makes it difficult to use the tide gauge as ground truth, but it does provide the actual sea-level measurements including any abnormal daily variations during the observation period. Therefore, we used the water-level predictions and measurements from both stations to validate the GNSS-R-based water-level measurements at AT01.

**Determination of Water Level.** The GPS and Galileo SNR data were independently analyzed using our in-house software package (written in MATLAB) using the following procedures.

As a preprocessing step, each SNR data series was examined to filter out the signals reflected from other surfaces surrounding the antenna and to isolate the signals that were reflected by the sea surface. Since AT01 PBO station was installed to investigate the feasibility of its use as a GNSS-R-based tide gauge, the most effective azimuth and elevation ranges were given, which are 0° to 230° and 10° to 25°, respectively. The azimuth and elevation angle ranges were applied, which effectively removed reflected signals from surfaces other than the sea surface. After identifying the SNR data affected by the reflection from the sea surface, the processing windows were dynamically determined by the continuous path and direction (ascending and descending) of the satellites, and the height of the sea surface was estimated using only a portion of the satellite arc contained within each processing window. For example, **FIGURE 4** shows the processing windows determined for the GPS satellite PRN 1 on June 1, 2018. The red dots in the figure show the parts of the satellite arcs affected by multipath from the sea surface. The data was divided into three processing windows due to the arc discontinuities and satellite path directions. It should be noted that only the processing windows with a data span of 30 minutes or longer were used for water level estimation. This minimum data span duration of 30 minutes was empirically determined by observing the probability of failure of the water

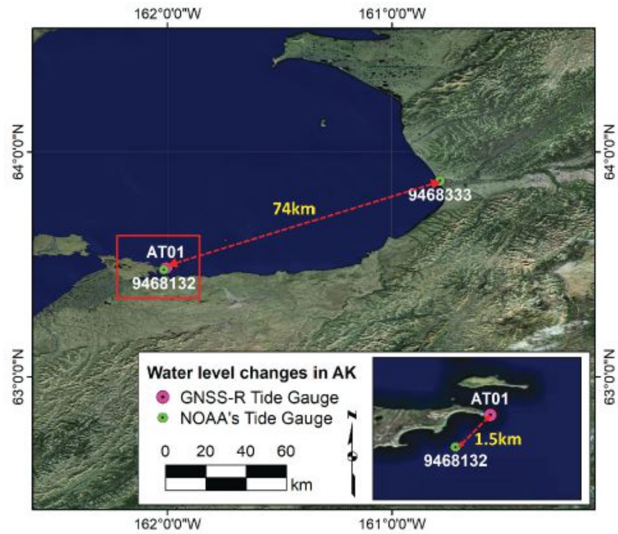



**FIGURE 3** **Locations of AT01 and two NOAA tide-gauge stations (9468132 in St. Michael and 9468333 in Unalakleet). The red box represents the zoomed area at the bottom right.**

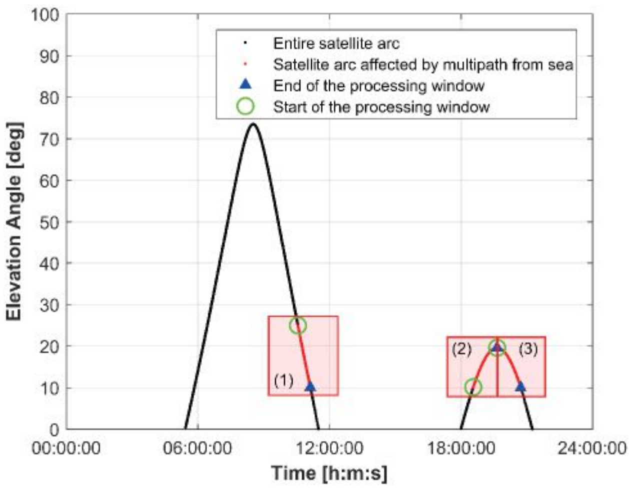



**FIGURE 4 An example of the processing window determination for GPS satellite PRN 1 on June 1, 2018.**

-level calculation for shorter spans.

To isolate multipath effects from the SNR observation, we removed the trend in the SNR by a second-order polynomial fitting using only the portion of a satellite arc contained within each window. **FIGURE 5 (b)** shows the detrended SNR (dSNR) from **FIGURE 5 (a)**, and the impact of the multipath is clearly identified in the form of the oscillation. As discussed earlier, the oscillation frequency is related to the antenna height above the sea surface. Accordingly, the dSNR data was analyzed through an LSP. As shown in **FIGURE 5 (c)**, multiple peaks are founded from the LSP results of each dSNR series, and it is not easy to distinguish the frequency of the reflected signal from the sea level among these peaks. Since multiple frequency signals from the same satellite must detect the same sea-level height, the final dominant peak was determined by checking the consistency of the resulting heights from each dominant peak among the multi-frequency signals. After that, the dominant frequency was converted to the antenna height above the reflection surface, which was then subtracted from the orthometric height of the antenna (the height above the geoid or, approximately, the height above mean sea level [MSL]) to refer the height of the instantaneous sea surface to MSL.

After analyzing all SNR data observed during one day, we carried out the reliability test of the retrieved sea levels to reject erroneous sea-level solutions.

## RESULTS AND VALIDATION

The water-level changes from the GNSS-R-based tide gauge at St. Michael were compared to the independently predicted and measured sea levels from the neighboring St. Michael and Unalakleet tide gauges during June 1–30, 2018. Although the tide gauges are considered reliable ground truth, our experimental study must take into account the physical distance between the sites (about 1.5 and 74 kilometers from AT01, respectively) as well as the difference coming from the model versus the actual measurement. In addition, a vertical offset between the data time series of the GNSS-R-based tide gauge and the standard tide gauges should be considered due to their different datums. Whereas the GNSS-R-derived sea level refers to a geodetic datum — namely the U.S. National Spatial Reference System (NAVD 88) — a standard tide gauge is highly localized with reference to a tidal datum such as local mean sea level. Generally, the difference between the geodetic and tidal datums is provided by NOAA, which allows us to convert between two vertical datums. However, the vertical datum in Alaska has significant gaps in the spatially varying tidal information because of the difficulties of operating tide gauges there so that accurate information for datum conversion cannot be obtained. Therefore, the averages of the vertical differences were calculated (–6.44 centimeters for the St. Michael tide gauge and 9.54 centimeters for the Unalakleet tide gauge), which were then applied to each of the time series to make the comparisons. In fact, such a problem implies another advantage of a GNSS-R-derived tide gauge: it already returns a water-level height based on the terrestrial datum so that the datum of the land and the ocean can be consistently retained.

**FIGURE 6** shows the sea level derived from the GNSS-based

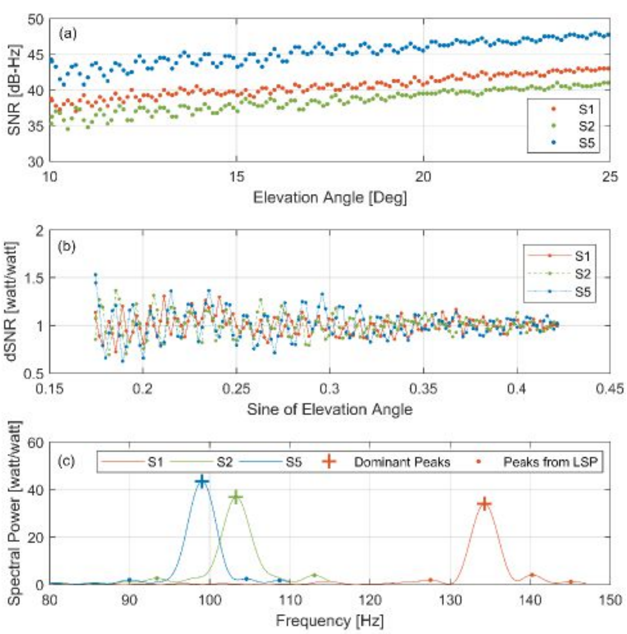



**FIGURE 5 SNR data-analysis procedures with PRN 1 GPS on June 1, 2018: (a) The SNR data affected by the reflection from the sea surface, (b) detrended SNR data through a second-order polynomial, and (c) LSP results and dominant peaks of each frequency.**

tide gauge measurements using GPS (red dots), Galileo (blue dots), the predicted sea level from the St. Michael tide gauge (green dots and lines) and measured sea level from the Unalakleet tide gauge (blue line). The overall results show good agreement with the tide predictions at the nearby St. Michael tide-gauge station. It should be noted that the St. Michael tide gauge only provides high- and low-tide predictions so these were interpolated. However, some tidal characteristics not represented in the published predictions were also confirmed. In particular, as shown in the red-shaded segments of the time series marked (a) and (b) in Figure 6, larger and lower amplitudes than the tide predictions for the St. Michael tide gauge were identified on June 3 and 16, respectively. These inconsistencies can be explained by the comparison with actual sea-level measurements at the Unalakleet tide gauge (solid blue line in Figure 6), which show very similar sea-level changes compared to those of the GNSS-R-based tide gauge. In addition, the overall larger amplitudes in the time series from the Unalakleet tide gauge can be explained by considering the fact that the amplitudes of the water levels vary along the coastline in Alaska and the Unalakleet tide gauge is approximately 74 kilometers from AT01.

| Sites | Mean [m] | Max [m] | RMS [m] | Std. [m] |
|---|---|---|---|---|
| AT01 – Unalakleet | 0.20 | 0.78 | 0.24 | 0.23 |
| AT01 – St. Michael | 0.23 | 1.55 | 0.31 | 0.29 |

**TABLE 1 Statistical analysis of the sea-level differences between the GNSS-R-based tide gauge (AT01) and the standard tide gauges (Unalakleet and St. Michael).**

To quantitatively investigate the agreement between the GNSS-R-based tide gauge and the standard tide gauges, we computed correlation coefficients. To ensure simultaneous data, the standard tide-gauge measurements and predictions were interpolated to the time tags of the GNSS-R-based time series. The correlation coefficients are 0.87 and 0.81 with the St. Michael and Unalakleet tide gauges, respectively.

The statistical analysis of the comparison result is summarized in **TABLE 1**. The mean and maximum values were computed using the absolute sea-level differences. From the results, it could be established that the GNSS-R-derived sea level shows better agreement with actual sea-level measurements at the Unalakleet tide gauge even though it is approximately 74 kilometers away from AT01.

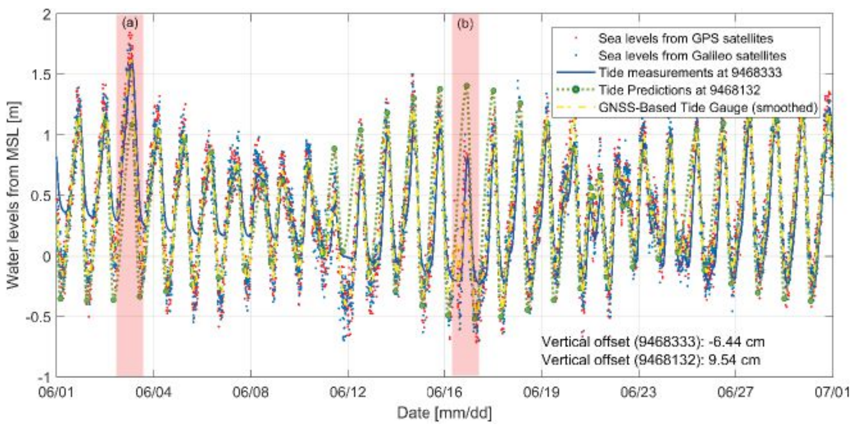



**FIGURE 6** **Time series of sea level derived by GNSS-R-based tide gauge (AT01) in St. Michael, Alaska, during a month (red and blue dots for GPS and Galileo satellites, respectively; yellow dashed lines for the smoothed time series from two hours' moving average filter) together with sea-level measurements from the Unalakleet tide gauge (blue solid line) and sea-level predictions from the St. Michael tide gauge (green dots for high- and low-tide predictions and green dashed line for interpolated predictions).**

Spectral analysis was additionally conducted to validate the sea levels from the GNSS-R-based tide gauge. Because the St. Michael tide gauge does not provide actual measurements (only predictions), only the Unalakleet tide gauge was used in the spectral comparison. A fast Fourier transform (FFT) was applied to convert the time series of the sea levels to the frequency domain. The GNSS-R-based tide gauge showed good agreement with the Unalakleet tide gauge overall. In addition, from the corresponding spectral analysis results, we were able to find meaningful harmonic constituents, $M_2$, $K_1$ and $O_1$. The harmonic constituents estimated from the sea-surface measurements of the GNSS-R-based tide gauge have amplitudes most similar to the published harmonic constituents of the nearest St. Michael tide gauge, although the difference in amplitudes of the three harmonic constituents averages 12.3 centimeters. In fact, the Unalakleet tide gauge also does not exactly match the amplitude of the estimated harmonic constituents and the published harmonic constituents. But by summarizing the corresponding results, we can conclude that the harmonic constituents estimated from the GNSS-R-based tide gauge are reliable.

As mentioned earlier, in our study, we estimated the water-level change by using GPS and Galileo satellite signals to overcome the degradation of GNSS performance due to the satellite geometry in the Arctic. The smoothed time series, calculated from a moving-average filter of two-hour intervals, is shown in Figure 6 (yellow dashed lines). The time series of sea level derived by the GNSS-R-based tide gauge during the whole month were used as ground truth for evaluating the accuracy. This was done because the Unalakleet tide gauge is approximately 74 kilometers away from AT01 and the St. Michael tide gauge does not provide actual measurements, making it difficult to use as ground truth. As a result, the sea levels determined using the Galileo and GPS signals showed very similar accuracy with an average difference of 0.11 meters. Therefore, even if Galileo is additionally used, the estimated final water levels were at a similar level of accuracy. However, the number of water-level observations dramatically increased (approximately doubled) when GPS and Galileo signals were both involved, even though the number of Galileo satellites is fewer than the number of GPS satellites. This is because Galileo transmits on five frequencies while GPS transmits on just three, so we can achieve more robust solutions by including Galileo.

We investigated how adding Galileo satellites changes the temporal resolution of the final sea-level measurements. At this time, several sea-level measurements pointing to the same epoch (such as sea levels from several frequency observations of the same satellite arc) were considered as one measurement for the time interval computation. Overall, sea-level measurements using only Galileo satellites show lower temporal resolution compared to GPS satellites alone, with a mean time interval of 48.97 minutes because Galileo is not fully operational yet and fewer satellites are available. However, combining GPS and Galileo satellites to the sea-level analysis significantly increased the time resolution. When only GPS satellites were used, the maximum time interval between two water-level measurements was greater than 3 hours, while the maximum time interval was shortened to about 1.5 hours when Galileo satellites were included in the water-level measurement. However, even if both GPS and Galileo satellites were used, the average time interval was still 14.1 minutes, which is considerably longer than the time resolution of the standard tide gauge of 6 minutes. The lower time resolution of a GNSS-R-based tide gauge is explained by the limited ranges (azimuth and elevation angle ranges of 0° to 230° and 10° to 25°, respectively) toward the ocean at station AT01. It means the time resolution can be improved by securing a wider view of the ocean from the GNSS-R-based tide gauge.

## SUMMARY AND CONCLUSION

The purpose of our study was to evaluate and verify the feasibility of using GNSS-R for sea-level monitoring in the Arctic. We used data from a GNSS station in St. Michael, Alaska, and applied an advanced algorithm that accurately determines sea levels through the comparisons of results from multiple GNSS signals along with an effective filtering procedure. Our results were validated through comparisons with measurements and predictions from nearby standard tide gauges.

From the corresponding analysis, we could confirm that the GNSS-R technique overcomes the limitations of standard tide gauges in the Arctic and successfully estimated the sea-level change in St. Michael, Alaska. The results from this study show many promising applications for a GNSS-R-based tide gauge in the Arctic, such as tsunami and flood monitoring and tidal datum determination.

In future studies, additional research should be conducted on how well the GNSS-R-based tide gauge can operate in extreme conditions such as low temperatures, wind gusts, storms, and snow. And, for further improvement of the temporal resolution of the technique, all active GNSS constellations including GPS, GLONASS, Galileo, and BeiDou should be included — that will certainly improve the temporal resolution and also potentially improve the accuracy and reliability. It would be also worth studying the spatial variations of sea-level changes by investigating the specular reflection points of GNSS multipath signals.

## ACKNOWLEDGMENTS

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# SEEN & HEARD


### THERE'S AN APP FOR THAT

For 17 years, Kersey Valley Attractions in Archdale, N.C., created its annual corn maze by using a GPS-enabled tractor to cut paths out of grown corn. Instead of being limited by a tractor's turning radius, this year's "Maize Adventure" used a GPS planter programmed with a maze design from the MazePlay app. Based in Idaho, MazePlay provides maze design and cutting services throughout North America. The Apollo 11 example here is from Richardson Adventure Farm in Spring Grove, Illinois.


### GPS MAKES IT (TOO?) EASY

Animal rights groups are suing California over rules that allow animals to be hunted with the aid of hunting dogs wearing GPS tracking devices on their collars. The Animal Legal Defense Fund called the hunting method "unusually cruel and unfair" because tracking devices allow dogs to chase prey to the point of exhaustion, and then hunters follow the GPS signal to find an animal that can no longer flee and is easily shot. The lawsuit says the commission violated state environmental law by failing to conduct an assessment of how the use would affect wildlife.

### JUST HIT IT ALREADY!

To speed play, officials for the PGA European Tour are using a GPS tracking system. Tracking devices were placed on one golf bag in each group in the BMW Championship, held Sept. 19–22 in Surrey, UK. When a group completed a hole, the information was sent to officials and displayed at five holes. Next year, all 18 holes will have displays, which include player names and indicate if the group is behind. The tour plans to increase fines for pace-of-play violations.


### GOOGLE MAPS COME ALIVE

Google Maps is beta testing a new Live View feature, allowing travelers to use augmented reality (AR) to better see which way to go. Arrows and directions are placed in the real world to guide the walker. Google has tested Live View with its Local Guides and Pixel community for several months, and has now expanded the beta to Android and iOS devices that support ARCore and ARKit.

PHOTO CREDITS: BMW PGA Championsip/BMW; dog with GPS collar/iStock.com/gchapel; corn maze/MazePlay.com; Live View/Google



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