VOLUME 9 ISSUE 5

LIDAR MAGAZINE

FALL 2019

SPECIAL ISSUE

SENSOR INTEGRATION

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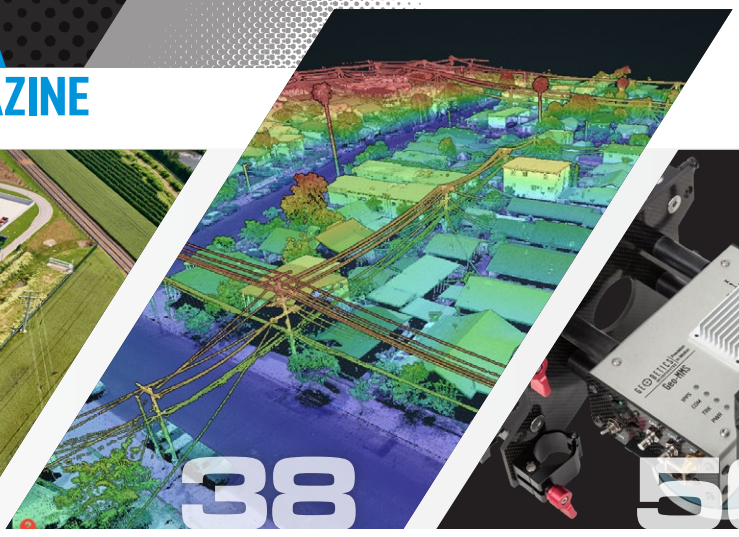

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ALLEN E. CHEVES

The More Things Change...

LIDAR Magazine—so what's *that* about? Over the years, when asked this question, I've honed my response to inquire as to one's familiarity with geomatics; when that elicits a stare, I explain that lidar is an incredibly efficient measurement technology that digital mapping systems have evolved to accommodate.

Having operated publications for land surveyors and other geospatial technology professionals since the early 2000s, we decided in 2010 to create a property that would focus on one of the technologies that was changing these markets the most—*lidar*. But why?

The 1990s witnessed a revolution in geospatial process and methodology. Advances in GNSS and other satellite technologies primed the proverbial pump as systems became location-aware. We like to think that there are parallels between the democratization of GNSS and what's happened with lidar. The difference has been the pace. Where GNSS brought accuracy by the point, lidar brought it by the truckload.

While the 2000s brought volume, the 2010s were the decade of the sensor, seeing incredible advances as unit size and cost reduced in tandem. We can now imagine sensors collecting data from anything that moves. While there's no shortage of ideas for what to do with the data, considerable guidance is needed from an integration standpoint.

It's now estimated that close to 100 firms are working on next-gen lidar solutions, most in pursuit of the autonomous navigation market. New players bring new methods, many of which stem from the automotive industry's relentless pursuit of miniaturization and (preferably) zero moving parts; a recent stand-out in this regard, Blackmore, explain their frequency modulated, continuous wave technology (FMCW) on page 56.

We created this supplement with an emphasis on integration. In addition to highlighting key players, we travelled far and wide to interview trailblazers within the integration realm—the kind of groups that make sensor development viable to broader markets. We close with a piece from Ray Mandli highlighting his company's 36-year evolution alongside a prescient warning for those intent on remaining relevant in the "age of change". Ray's firm has collected and reduced hundreds of thousands of miles of 3D data across North America; his experience is unique.

The second great wave of GeoTech dissemination is underway. As with other industries, we can expect vision to come from outside thanks to all the minds now cognizant of the power of the map (and lidar)! Few communities are better positioned to benefit from all the innovation momentum, or more capable of responding to the challenges posited by globalization, than GeoTech.

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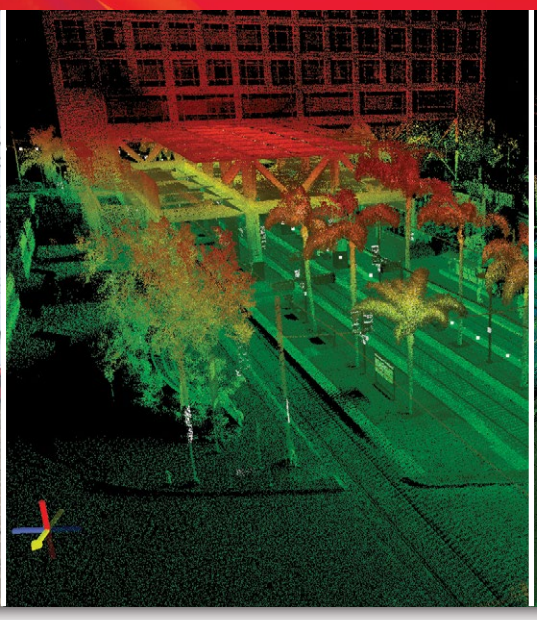

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Lidar Market to reach USD 6 billion by 2024

KEY TAKEAWAYS:

- The lidar market is on track for fast growth, driven by robotic vehicles
- Massive investments show high expectations for autonomous driving
- Yole expects the total lidar market to reach US $6 billion by 2024

Editor's Note: Just how big are the "lidar markets"? Each Year, the French firm Yole publishes an exhaustive review of activities within the lidar marketplace. Here are some of the basics from their 2019 announcement, edited for length and clarity.

LYON, France, courtesy of Yole Développement (Yole)**:**

The lidar market reached US $1.3 billion in 2018. For the second year, Yole Group of Companies has issued a comprehensive analysis of the lidar industry. Combining market, technology and IP data, the partners, Yole Développement, System Plus Consulting and Knowmade offer a wide collection of reports to get a better understanding of the industry's evolution, challenges and opportunities.

> "Driven by lower production costs and the emergence of new technologies, lidar is becoming a key component for automotive applications."

With its Lidar for Automotive & Industrial Applications report, the company pursues its investigations to understand the latest technical challenges and the strategy of key players. Yole's analysts identified strong investments in this sector. Competition is fierce and many announcements related to innovative technologies and investments have been made. From its side, Knowmade announced many new players within the lidar IP landscape: Since 2010, Knowmade's analysts have witnessed increasing amounts of patenting activity. The swift development of autonomous vehicles has opened many opportunities, with the established and strongest IP holders increasingly challenged by new entrants in the marketplace.

Yole expects the total lidar market to reach US$6 billion by 2024 with 70% of the total market dedicated to automotive applications. Highly and fully automated driving will become a reality in the very near future. Driven by lower production costs and the emergence of new technologies, lidar is becoming a key component for automotive applications.

Yole Group of Companies is involved in the analysis of technical breakthroughs dedicated to automotive applications. Based on a combination of their expertise and knowledge, analysts

help the automotive players understand markets, follow technology trends and develop their business. They are able to propose a global analysis taking into account all current and emerging technologies and market updates. As an example, in both technology & market reports, lidar for Automotive & Industrial Applications and Radar & Wireless for Automotive: Market and Technology Trends, Yole proposes an alternative scenario taking into account the whole sensing technologies: lidar, radar and camera. Technological requirements for autonomous driving are still blurred today and might evolve in a new future to more sensors, different types of sensors and much more computing capabilities.

For more information, visit:
http://bit.ly/lidar-rationalization

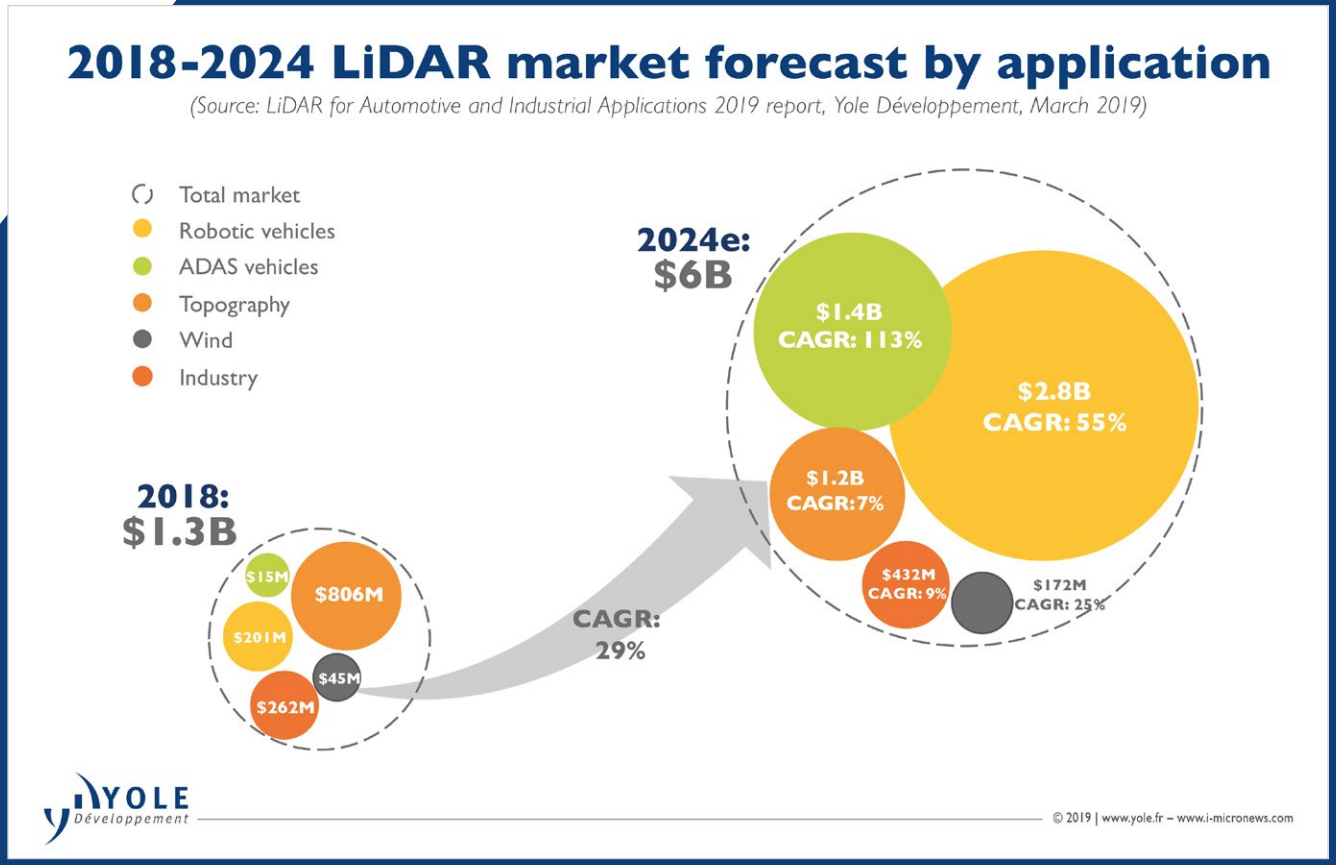

Figure 1: Part of the SICK campus in Reute.

SICK

the world's largest one-stop-shop for industrial lidar solutions

Incredibly durable sensors known for toughness and quality

SICK GmbH, founded by Dr. Erwin Sick in 1946, is a large European manufacturer of sensors and sensor solutions, offering a wide portfolio of more than 40,000 products aimed at an astonishing spectrum of industrial applications. It is perhaps less well known in the world of geospatial lidar than some others, so LIDAR Magazine *seized avidly on an invitation to visit the company. In late 2018, publisher Allen Cheves and managing editor Stewart Walker toured the SICK plants in Reute and Waldkirch, Baden-Württemberg, Germany. Here is what they discovered.*

BY ALLEN **CHEVES** &
DR. A. STEWART **WALKER**

The day of the visit

The drive to SICK in Reute (**Figure 1**) was a privilege in itself, through the spectacular southwest German countryside as it gloried in an Indian summer. We were hosted by Carolin Baumgartner, strategic product manager, 3D lidar sensors, and Harald Weber, head of product management, ranging. The plant consisted of a mixture of buildings of different ages and its pristine appearance struck us. The Reute campus hosts production of many components and sensors, including lidar R&D,

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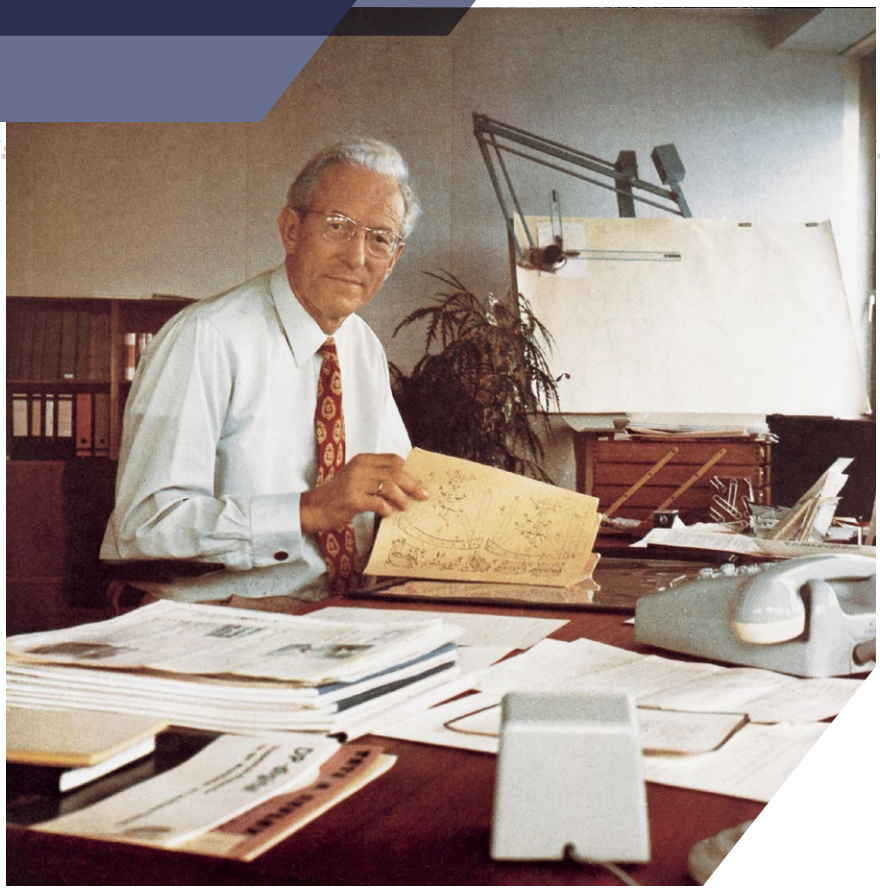

Figure 2: Dr. Erwin Sick, founder of SICK AG, at his desk.

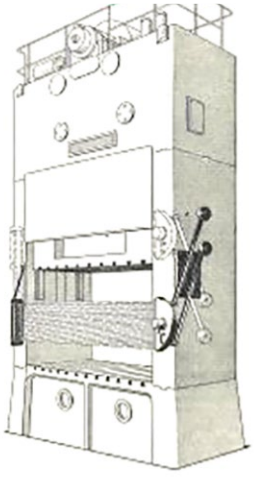

Figure 3: Sick's first marketable accident prevention light curtain, which debuted in 1952.

Above: SICK ANM006 LVU—one of the first sensors based on the light curtain principle to enter large-scale production.

product management, as well as product testing, where the elaborate facilities include a state-of-the-art rain chamber and many other testing facilities.

Harald Weber is head of medium- and long-range lidar. He joined in 1996 in sales and started in 2D lidar for industrial applications. He anticipated much wider opportunities for the product range. Then he moved to product management. So he has had significant exposure to lidar over the years. He had been involved with robots playing games at university and this led to thoughts about an automated lawnmower. He was involved in projects with Carnegie Mellon University, which used SICK lidar units in its Groundhog autonomous vehicle (AV) in 2002. Now he's been with SICK for 21 years, though such lengthy employment is unusual these days. SICK's expertise is in sensors to steer processes as well as industrial automation, yet the company is increasingly involved in MMS and lidar from drones.

Carolin Baumgartner joined SICK in 2010. She has been leading product management for the LMS1xx family and in the last year has been instrumental in bringing to market the new 3D LiDAR family MRS1000 and as well as the 2D lidar LMS1000. During the last decade she worked with customers in all kinds of industries from agriculture to mining and automation, to enable the successful integration of lidar products in various applications. Currently her focus is to develop the 3D lidar portfolio of SICK for industrial applications. Carolin gave the company overview.

Background on SICK

The founder of the company, Dr. Erwin Sick (**Figure 2**), was a passionate inventor. Born in Heilbronn in 1909, he apprenticed in optics and worked in the laboratories of several leading companies. He married Gisela Neumann in 1944 and the following year started on his own, working from a former barracks in Vaterstetten, near Munich.

Seeing other firms concentrating on optics or electronics, but not both, he single-mindedly followed his technological development aims to produce opto-electronic devices, supporting his family with earnings from selling radios that he made himself. He founded what was later to become SICK AG on 26 September 1946. He was apolitical, so received a permit from the American military government to practice his profession as an engineer. After a slow start, orders flowed from 1949 onwards.

In 1950, SICK introduced its first photoelectric switch based on an autocollimation principle. The following year, at the German Inventor and New Development Trade Fair in Munich, Sick presented the first wooden model of his "light curtain" and received a certificate for exceptional creative performance. This invention, based on the same autocollimation principle was the technical breakthrough that would form the basis of an entire range of devices. The first marketable accident prevention light curtain (**Figure 3**) debuted in 1952 at the Second International Machine Tool Trade Fair in Hanover. The orders that followed led to serial production and eventually to the company's economic breakthrough.

The location decision to Waldkirch was an interesting one. In 1954, Sick tried in vain to obtain a loan from the Free State of Bavaria to build up the company. When Baden-Württemberg offered to lend him the money he needed, he moved from Munich to Oberkirch in Baden and, in 1956, the company and its 25 employees were relocated to Waldkirch. In October that year, he was granted the patent for a new type of photoelectric retro-reflective sensor that would later become the product with one of the company's strongest sales performances. Twenty-one years later, the company moved into its new premises on Sebastian-Kneipp-Strasse, which remains the company's headquarters to this day. As it grew, Sick received a series of awards. Erwin Sick died in 1988 at age 79. His widow, Gisela (**Figure 4**), has continued to be involved with the company and has initiated several community projects including kindergarten education and music projects at the edge of the campus.

Figure 4: Frau Gisela Sick, who has been involved with the company since its foundation and remains involved in community initiatives on the firm's campuses.

Carolin pointed us to several videos the company has posted on YouTube. SICK presents itself as, "worldwide, one of the leading manufacturers of sensors and sensor solutions for industrial applications". She emphasized the autocollimation technology and the light curtain, which stopped a machine when someone reached in. As word spread, SICK made more and more of them. 1972 saw the start of internationalization, with a presence in France. In 2013 it exceeded €1b in revenue. Besides production in Waldkirch, Reute and other locations in Germany, manufacturing takes place in Minneapolis, MN; Hungary; China; and Malaysia. There are also three Regional Competence Centres—the German one has been copied in Asia and US—and six development centers in addition to the one at headquarters. The distribution model is a familiar one: much of the world is covered by subsidiaries and representatives, but third-party "agencies" do the work in some countries. The 2017 numbers were: orders €1.543b, sales €1.512b, EBIT €149m, R&D expenditure €169m—more than 10% of sales is spent on R&D. The number of employees is growing at 10% per annum: there were 8809 in 2017, of whom 5224 were in Germany and more than 900 were engineers, compared to 1700 in 1996. Carolin stressed the importance of a flow of young employees to maintain the company's technical strength: in 2017 there were 324 trainees. The company has dual arrangements with colleges. There are five men on the Executive Board, chaired by Dr. Robert Bauer, but there have also been women over the years!

Carolin emphasized the continuity and showed an impressive time series of developments. SICK sensors are focused on the automation of three areas: factory, logistics and process automation. The second and third of these include numerous applications of distance measurements using lidar; these are not expressly geospatial and the majority are short-range in terms of requirements. In 2016 the SICK AppSpace concept was introduced, which the company describes as, "… intelligent software tools, high-performance programmable devices, and a dynamic developer community create

a solid foundation for designing customized sensor solutions", i.e. it provides capabilities to create and manage bespoke application solutions. SICK's emphasis on quality—the toughness of its products to perform for many years in tough industrial environments—was a theme stressed throughout our visit. There is also an increasing emphasis on services. In terms of company structure, SICK divides its activities into nine broad product generating divisions known as Global Business Centers: Carolin and Harry are in identification and measuring.

Lidar at SICK

There are 15 2D and 3D lidar sensor families in the SICK portfolio. Their history stretches back to 1968, when the company launched Watchman, the forefather of the PLS safety laser. In 1976, polygonal mirrors and laser diodes were introduced and in 1981, the first industrial use of the pulse-delay or time-of-flight method for distance measuring sensor technology. In 1989, SICK accomplished its first distance determination with laser light using this approach, operating at 20-25 Hz and giving a precision of 5 cm. Indeed, in 1991, this same principle was applied to the positioning of autonomous vehicles and was used in its first safety laser scanner two years later. In 1996, came the LMS200, the first of a series of laser scanners using the pulse-delay method for general indoor and outdoor industrial applications, with an accuracy down to 2 cm. SICK acquired a 90% stake in ibeo automotive in Hamburg in 2000. Ibeo also developed a sensor for Trimble, which to this day is in SICK's on-site museum in Waldkirch.

Figure 5: A sample from SICK's current range of lidar sensors. Clockwise from top left: LMS5xx, LMS1xx, MRS6000, RMS320, TiM5xx, TiM1xx, MRS1000.

In the first DARPA Grand Challenge in 2004, not only the CarnegicMellon Sandstorm but several other contestants sported SICK lidars. They were popular in 2005 too: Carnegie Mellon entered an upgraded Sandstorm as well as H1ghlander, both of which carried four SICK lidars. Other teams embraced these sensors equally enthusiastically, including the winner, Stanley, a Lexus SUV from the Stanford SAIL lab led by guru Sebastian Thrun, who had moved there from Carnegic Mellon. The next event in the series was the DARPA Urban Challenge in 2007, in which both winner and runner-up carried SICK and ibeo lidars. The DARPA events fomented intense lidar development from SICK and its competitors, benefiting non-military applications too, such as earth-moving equipment, lawnmowers and UAVs. The SICK LD-MRS, at 0.77 kg with an IP69K (Ingress Protection) certification, has performed well on UAVs and the company's lidars are offered, for example, on the mdLiDAR1000 system from Microdrones.

It took only 10 years to progress from the PLS to S3000, the current model of the safety laser. The LMS200, with a range of 30 m for black targets, was designed for and used heavily in outdoor industrial applications such as ports, toll collection systems and outdoor autonomous ground vehicles. Although phased out some years ago, many LMS200 systems are still in use owing to their impressive robustness. SICK first exploited multiple-echo technology in 2008 in the LMS1xx series (dual-echo-technology). The LMS500 (2010) is a

Figure 6: SICK MRS1000 3D laser scanner working in tough conditions—"outdoors is SICK's fourth dimension".

multipurpose lidar, designed for outdoor applications, with 5 echoes and longer range (40-50 m to black targets, up to 120 m to more reflective ones). On the 2D side, the LMS1000, for example, uses a wavelength of 850 nm and scans, at a frequency of 150 Hz, over a field of 275° at 0.75° resolution, with three returns (multi-echo-technology). The maximum range is 64 m, but the unit is typically used in shorter-range applications and offers 16 m range to targets with 10% reflectivity and 30 m to 90%. The 2D sensors scan in a 2D plane, based on a rotating mirror or prism. The LMS is one of several product families—others are TiM, NAV and LD-LRS.

Whereas SICK's 2D lidar systems scan in a single plane, the 3D ones build points clouds by scanning in more than one plane. There are numerous models in each category, some of which are shown in **Figure 5**). They use silicon laser sources with wavelengths in the 850-905 nm range. The company's vibrant R&D activities ensure that the stream of developments will continue.

The 3D lidar sensors come in fewer families, so are a little easier to assimilate! These include the MRS1000 (**Figure 6**), giving 3D with measurement in four planes. This enables the sensor to view the ground and still see hanging objects in the direction of travel. Similar to the LMS1000, the MRS1000 has a wavelength of 850 nm and scans, at a frequency of 50 Hz, over a field of 275° horizontally and, through the four planes, 7.5° vertically, at an angular resolution of 0.25°, with three returns. The maximum range is 64 m, but the unit is typically used in shorter-range applications and offers 16 m range to targets with 10% reflectivity and 30 m to 90%. This sensor is especially designed for challenging outdoor applications such as collision prevention and driver assistance for all sorts of vehicles in applications such as factories, ports and mines, but also for reliable monitoring in traffic management, building security, access control and people counting. Navigation, both indoor and outdoor, e.g. in warehouses or agricultural environments, is another application focus. The latest model is the MRS6000, also designed for outdoor applications, with 24 planes. The corresponding figures for this sensor are: 850 nm; frequency of 10 Hz, over a field of 120° horizontally and, through the 24 planes, 15° vertically, at an angular resolution of 0.13° horizontally and 0.625° vertically, with four returns. The

maximum range is 200 m, with 30 m range to targets with 10% reflectivity and 75 m to 90%. The third 3D lidar sensor is the especially rugged LD-MRS with four planes and working range up to 300 m.

The newest generation of lidar sensors uses SICK's innovative, patented technologies HDDM and HDDM+. There are ~100 short laser pulses per measurement. They input multiple low-energy pulses to a statistical analysis to give the results[1]. To the author, there was a similarity in the thinking to that behind Geiger-mode lidar, though the underlying technology is not the same. The MRS1000, for example, uses HDDM+.

SICK also makes two radar sensors. The company emphasizes its "sensor intelligence" and use of all physical principles. The radar sensors are the RAS4xx and RMS3xx, aimed at collision avoidance and driver assistance, i.e. automotive applications in poor weather. The radar frequency is 24-24.5 GHz, corresponding to wavelengths of 12.5-12.2 mm.

SICK views the world as semi-automated, automated and autonomous. We discussed sensor complementarity, which of course is well known to SICK, with its portfolio of thousands of products. SICK and its customers have exceeded 54 billion hours of laser sensing. A gallimaufry of applications includes automated machines to position cars in a parking garage; measurement of bulk materials; movement of cranes, e.g. in ports; perimeter protection; stopping vehicles with overheated components from going into tunnels (with a combination of thermal camera and lidar sensor). The sensors have 10-15 years industrial life; as an additional service, SICK offers an extended warranty of up to 5 years which customers can book with their order. The company is driven by reliability and uses the catchphrase, "Outdoors is our fourth dimension." Harsh environments are welcome, for example the LD-MRS has IP69K certification—it can withstand a high-pressure cleaner. Ports are salty and tunnels suffer from H_2SO_4—sulfuric acid—but SICK sensors sustain this challenge too. The conversation strayed on to start-ups that focus on automation on public roads; SICK does not have this aspiration, so does not perceive start-ups as a threat.

After the introduction, we enjoyed a factory tour, starting with the product test area. We saw sensors, for use in an airport, which monitor where the pieces of luggage are going. Testing is critical to SICK's culture and success: the company accepts enormous expenses for testing. There is little compromise: all sensors, not a sample, undergo a variety of tests in special environments such as chambers, ovens and test ranges with targets. We saw testing of the LMS400, which FedEx and DHL use in a 3D grid to estimate volumes and weights of packages. SICK has full traceability of sensor parts. Continuous improvement is practiced assiduously. There are electronics to protect against oversaturation. The comprehensive nature of the test procedures, the set-up of the test environments and the commitment of the test workforce to excellence will not be easily forgotten!

Space is proving a problem as SICK has been growing with dramatic speed. The success stems from making "industrial sensors", not just measurement devices. We drove to the plant in Waldkirch (**Figure 7**), where the customer center, distribution center and outdoor test center are housed. The campus experiences fog owing to a stream beside the factory, which facilitates the testing of sensors in demanding conditions. We were shown an electric autonomous vehicle, which is based on the vans used by the German post office. But our hosts stressed, very strongly indeed, that the van enables them to work with and demonstrate their sensors—it does not indicate that SICK has AV ambitions! The van was stacked with sensors of all kinds and in the back there were racks of electronics, including a SIM4000 (Sensor Integration Machine) controller and two large battery enclosures. The sensors have firmware that can be updated. We saw the van moving autonomously in

1 Further information on HDDM+ can be found at https://cdn.sick.com/media/docs/1/11/511/Whitepaper_HDDM_INNOVATIVE_TECHNOLOGY_FOR_DISTANCE_MEASUREMENT_FROM_SICK_en_IM0076511.PDF.

Figure 7: The SICK Outdoor Test Center in Waldkirch. In the foreground, the autonomous van can be seen on its test track, alongside several product test ranges. At the top right is the River Elz, which gives rise to the foggy conditions that facilitate the outdoor testing of lidar sensors.

a pre-programmed way by orientation on way points. SIM is part of the SICK AppSpace ecosystem and opens up new possibilities for application solutions. Data from SICK sensors and cameras can be merged into a point cloud, evaluated, archived, and transmitted, e.g. to cloud platforms, surely an indication of SICK's ambitions beyond just sensors.

As SICK is dedicated to be one of the leading global manufacturers of sensors and sensor solutions, its wide variety of sensors, worldwide sales and service network, and customer-oriented developments are crucial success factors. With this worldwide network it is possible to support all kinds of different customers, such as port operators in Dubai or Singapore, mining companies in Australia or South Africa, or robotic manufacturers in the US or China. SICK customers can count on an outstanding level of application knowledge through the long-term experience and close customer relationship of the company's international and national application engineers, product managers and industry managers.

We talked briefly about safety lidar sensors, which are in another portfolio, mainly indoors. Even 1.8% reflectivity still gets a signal. The lineage of these sensors can be traced all the way back to the light curtain.

Endnote

To those of us in geospatial lidar, especially on the airborne side, SICK has been rather a silent partner. Our visit, however, left a lasting impression, of a company rooted in the provision of sensors and other tools for use in industrial environments, ensuring through remarkably rigorous testing that the highest standards of ruggedness, quality and endurance would be met. The company supports a vibrant R&D activity for the development of new sensors and incremental improvements to existing ones. SICK is already a player in TLS, MMS and other aspects of geospatial lidar applications, and its role can only grow. We look forward to learning more about this successful enterprise, expanding from a family business to a multinational in seven decades, and we are already planning a second article, focused on a SICK customer.

Allen Cheves is Publisher of the magazine.

Dr. A. Stewart Walker is the Managing Editor of the magazine. He holds MA, MScE and PhD degrees in geography and geomatics from the universities of Glasgow, New Brunswick and Bristol, and an MBA from Heriot-Watt. He is an ASPRS-certified photogrammetrist.

SENSOR INTEGRATION SPOTLIGHT

The following pages provide an overview of key sensor hardware, software and component part manufacturers, in addition to system integrators.

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COMPANY PROFILE

Cepton Technologies, Inc. was founded in 2016 with the mission of developing industry-leading 3D sensing solutions for automotive, industrial and mapping applications. Cepton's patented Micro Motion Technology (MMT™) delivers unrivaled performance and resolution at a low cost to enable advanced perception for smart machines. Cepton has a leadership team that recognizes where the automotive industry and Internet of Things (IoT) market are headed and have deployed four advanced lidar solutions that are mapping the future. Cepton Headquarters is located in the heart of Silicon Valley. We also have offices in Ottawa, Detroit, and in the United Kingdom.

CEPTON

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cepton.com

Cepton's P60L—Solid state UAV lidar solution

3D Lidar for Smart Machines

The Cepton SORA™ P60L is the lightest high-performance lidar for UAV. At a lightweight of 550 grams, the SORA™-P60L payload enables longer trips with less need to stop to refuel or recharge. With its 200 meter range, the SORA™-P60L allows unmanned vehicles to cover more ground and drones to fly higher reducing the total amount of trips needed for map creation. With multi- return, a dense point cloud up to 625,000 points per second is generated, allowing for stronger lidar penetration for more accurate map building. A 400 Hz frame rate allows vehicles to operate faster while maintaining high-quality map data collection. Additional Cepton sensors include the VISTA P, VISTA X, SORA P60 and VISTA-EDGE.

In September, Cepton announced its newest Vista lidar sensor, the Vista™-X120, an industry-leading lidar solution for Advanced Driver Assistance Systems (ADAS) and autonomous applications. Vista-X120 offers a 120° horizontal field of view (FOV), 0.15° angular resolution and a maximum detection range of up to 200 meters at 10% reflectivity, delivering a best-in-class lidar solution ideal for ADAS and autonomous vehicles (AVs), and well suited for smart machines used in other autonomous applications.

RIEGL

COMPANY PROFILE

With 40 years experience in the research, development and production of laser rangefinders, distancemeters and scanners RIEGL delivers proven innovations in 3D. The combination of RIEGL's state-of-the-art hardware for terrestrial, industrial, mobile, airborne, bathymetric and UAV-based laser scanning with appropriate, equally innovative RIEGL software packages for data acquisition and processing results in powerful solutions for multiple fields of application in surveying. Worldwide sales, training, support, and services are delivered from RIEGL's Austrian headquarters and its offices in Vienna, Salzburg, and Styria, main offices in USA, in Japan, in China and in Australia and by a worldwide network of representatives covering Europe, North and South America, Asia, Australia, and Africa. The RIEGL headquarters provides more than 40,000 square feet work space for research, development, production, as well as for marketing, sales, training and administration. Another 350,000 square feet of open-air ground are used for product testing.

RIEGL®

Founded 1977
230+ Employees
Horn, Austria
Orlando, USA

Riegl.com

APPLICATIONS:

- AIRBORNE
- BATHYMETRIC
- MINING
- MOBILE
- INDUSTRIAL
- TERRESTRIAL
- UNMANNED
- WIDE-AREA

Innovation in 3D

RIEGL terrestrial laser scanners provide detailed and highly accurate 3D data rapidly and efficiently. Applications are wide ranging, including Topography, Mining, As-Built Surveying, Architecture, Archaeology, Monitoring, Civil Engineering and City Modeling.

RIEGL airborne laser scanners make use of the latest state-of-the-art laser and signal processing technology. They are exceptionally compact, lightweight and cost effective, and are designed to meet the most challenging requirements in airborne surveying.

Unmanned Laser Scanning, utilizing high-end unmanned airborne platforms, provides the possibility to acquire data from dangerous and/or hard-to-reach areas, whilst offering a high cost to benefit ratio for numerous applications, for example Agricultural and Forestry, Defense, Wide Area Mapping, Flood Zone Mapping, Topography and Mining. For years, RIEGL Laser Scanners have been successfully used in this sector. Our current efforts in R&D guarantee to provide the user with state-of-the-art laser scanning engines of the highest quality, to meeting the specific challenges of surveying applications using advanced UAS/UAV/RPAS platforms. Furthermore, we are proud to be the first major LiDAR manufacturer to develop its own unmanned aerial system.

Mobile laser scanning describes terrestrial data acquisition from moving platforms (e.g. boats, trains, road and off-road vehicles) also known as kinematic laser scanning. Both RIEGL 2D and 3D laser scanners are ideally suited for mobile mapping applications.

RIEGL's industrial laser scanner product line is ideally suited to meet demanding industrial customer expectations.

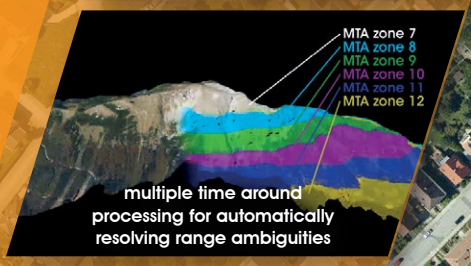
RIEGL's software packages are the ideal companion software for RIEGL laser scanners. Furthermore, smooth data transfer to numerous third party post-processing packages is a matter of fact.

RIEGL VQ-1560i

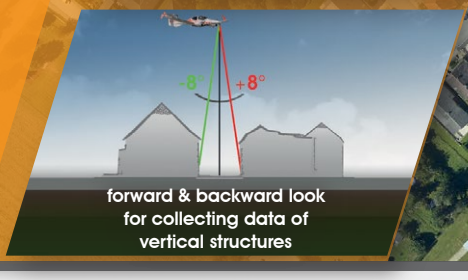
Dual Channel Airborne Mapping System

Waveform Processing LiDAR Solution
for Demanding Airborne Surveying Missions


unrivaled scan pattern for best point spacing on the ground



multiple time around processing for automatically resolving range ambiguities



forward & backward look for collecting data of vertical structures

Turnkey Airborne System for Demanding Large Scale and High Altitude Environmental Mapping

- *RIEGL* Waveform-LiDAR Technology –
  excellent multi-target capability and multiple-time-around (MTA) processing, unsurpassed information content on every single target
- 2 MHz pulse repetition rate, 1.3 million meas./sec, high-performance IMU/GNSS unit and integrated cameras –
  ideally suited for aerial survey of ultra-wide areas as well as complex urban environments
- operation at varying flight altitudes up to 15,500 ft –
  wide range of point densities, most efficient flight planning, and safe flights
- unique and innovative forward/backward scan angle –
  for effective and accurate data acquisition from multiple angles

newsroom.riegl.international

www.rieglusa.com

RIEGL®

RIEGL LMS GmbH, Austria | *RIEGL USA Inc.* | *RIEGL Japan Ltd.* | *RIEGL China Ltd.* | *RIEGL Australia Pty Ltd.*

SICK AG

APPLICATIONS:

- AUTOMOTIVE
- MAPPING
- SHIPPING
- LOGISTICS
- SECURITY
- SURVEILLANCE

COMPANY PROFILE

SICK AG, based in Waldkirch, Germany, is a global manufacturer of sensors and sensor solutions for industrial applications. Founded in 1946, the company now has more than 50 subsidiaries and equity investments as well as numerous agencies around the globe. SICK achieved Group sales of about EUR 1.6 bn. in the 2018 fiscal year with almost 10,000 employees worldwide. The company is particularly well known for its lidar sensors, which are used as sensors in a variety of applications e.g. for collision prevention in ports, classification in traffic, detection in building security or position evaluation in navigation. SICKs lidar portfolio is unique throughout the world and unites diverse industry knowledge and extraordinary capacity for innovation in all dimensions, tasks and environments. The sensors offer comprehensive performance and boundless flexibility even in rough environments.

SICK
Sensor Intelligence.

Founded 1946
10,000+ Employees
Baden-Württemberg
Germany 79183

sick.com

Sensor Intelligence

The SICK MRS1000 is a 3D lidar sensor (multi-layer scanner) that accurately and reliably detects and measures objects quickly and in multiple dimensions. By collecting large volumes of data on multiple scan layers and from different angles, it can detect and respond to objects on the floor as well as objects that are obstructing the path of a machine.

The MRS1000 is highly rugged and can withstand adverse environmental conditions, such as rain, dust, and fog, which makes it ideally suited for outdoor applications. The sensor detects up to 55,000 measurement points across four layers. The MRS1000 emits three echo signals per measuring beam, which increases the number of measurement points to up to 165,000 per second. The layers are arranged horizontally, one on top of the other, and fan out from the sensor. At a distance of 20 meters, for example, the MRS1000 covers a height of 2.70 meters.

The 3D lidar sensor has a configurable echo filter that screens out unwanted measurement data and signals caused by rain, dust, snow, and other disruptive environmental conditions, for example. The field evaluation takes place in the sensor itself with a high scan speed and measurement field coverage.

In addition, the new HDDM+ procedure with multi-echo evaluation allows measurements to be made over long distances and produces low noise levels in the measurement data as well as having multi-echo capability.

The SICK lidar portfolio also includes the 3D lidars MRS6000 and LD-MRS as well as a broad variety of 2D LiDAR sensors such as LMS1xx, LMS5xx, LD-LRS, LMS4xx, TiM and safety lidar sensors.

LiDAR sensors from SICK: OUTDOOR IS OUR FOURTH DIMENSION

THIS IS SICK

Sensor Intelligence.

2D and 3D LiDAR (Light Detection and Ranging) sensors from SICK offer solutions for a wide range of applications. The technology is ideal for indoor and outdoor applications, e. g. anti-collision in ports, classification in traffic, detection in building automation, or position evaluation in navigation. As intelligent sources of data, they deliver precise, accurate and reliable information and measurement data for nearly any application. Equipped with high-developed technologies and a wide range of interfaces. Discover a unique portfolio unparalleled throughout the world which unites diverse industry knowledge and extraordinary capacity for innovation in all dimensions, tasks and environments. Comprehensive performance and boundless flexibility even in rough environments – combined for your success. We think that‘s intelligent.

www.sick.com

TELEDYNE OPTECH

APPLICATIONS:

- AIRBORNE
- MOBILE
- TERRESTRIAL
- INDUSTRIAL
- MINING
- SPACE
- UNMANNED

COMPANY PROFILE

Teledyne Optech has been a world leader in the design, development and manufacture of advanced lidar instruments for 40 years. Teledyne Optech is widely recognized for its technological depth in lidar and related technologies, with decades of experience in lidar and photogrammetry, as well as auxiliary technologies such as GPS, inertial measurement systems, and waveform digitization. Our rugged, reliable, and innovative lidar and camera products are deployed on all seven continents—and even on other planets, where a Teledyne Optech lidar provided proof of precipitation on Mars.

We offer standalone and fully integrated lidar and camera solutions in airborne mapping, airborne bathymetry, mobile mapping, terrestrial laser scanning, mine cavity monitoring, and industrial process control, as well as space-proven sensors. Complete with extensive survey planning, operation and automated post-processing software, Optech systems enable clients to collect, manage and deliver survey data to their customers quickly and profitably.

TELEDYNE OPTECH
Everywhereyoulook™

Founded 1974
250+ Employees
300 Interchange Way
Vaughan, Ontario, Canada

Teledyneoptech.com

Introducing Compact Lidar from Teledyne Optech

The Power to See Your World Differently

CL-90 features sought after airborne lidar design features, now available for UAS integration. CL-90 is designed for exceptional canopy penetration, low-noise, high-quality survey-grade data boasting exceptional performance in accuracy and precision, best-in-class range performance offering full lidar performance across the entire operating altitude of the UAV and a unique variable field of view for users looking to maximize single-pass point density. With a unique programmable scanning FOV, the CL-90 also provides superior point density and operational flexibility.

CL 360 boasts survey-grade data precision synonymous with Teledyne Optech lidar sensors and is specifically designed to meet the needs of OEM hardware manufacturers to develop products for mobile, static, UAV or airborne surveying markets. The CL-360 is a versatile lidar sensor featuring a long maximum range and short minimum range to suit mobile applications. Designed with more ground points for better vegetation penetration and stronger returns off power lines thanks to tighter laser beam divergence and faster scan frequency, the CL-360 boasts better point distribution and higher density where it matters most. With true 360 degree scanning, the CL-360 has no blind spots.

LIDAR AND IMAGING SOLUTIONS




Maximize Your Accuracy and Productivity

Teledyne Optech's high-precision lidar sensors provide state-of-the-art solutions for airborne, marine, mobile, UAV, and terrestrial surveying. Teledyne Optech makes it easy to achieve optimum results through a unified solution providing unrivaled terrain and seafloor mapping.

LEARN MORE about Teledyne Optech
www.teledyneoptech.com

TELEDYNE OPTECH
Everywhereyoulook™

Part of the Teledyne Imaging Group

SURESTAR LIDAR

COMPANY PROFILE

Beijing SureStar Technology Co. Ltd. is a high-tech enterprise focused on lidar technology development and production. SureStar's product range is comprehensive, encompassing a full range of navigation and survey lidar development capabilities.

SureStar holds complete and comprehensive lidar core technologies and has reported nearly 100 intellectual property rights (patents, software copyrights and trademarks), including 18 invention patents, 3 PCT international patents, 16 utility model patents, 24 software copyrights, and more than 30 trademarks.

SureStar has continuously won different prizes since its establishment, including Beijing Space Innovation Enterprise Gold Award (2013), Zhongguancun Top 100 Most Innovative Enterprise (2014), Surveying and Mapping Science–Technology Progress First Prize (2015, 2016), Surveying and Mapping –Technology Progress Second Prize (2018), National Entrepreneurship and Innovation Week–Chinese Innovation Pioneer Top 20 (2017) and Beijing Independent Innovation Products (2016 – 2017).

SureStar

Founded 2005

200+ Employees

Beijing, China

isurestar.com

APPLICATIONS:

- AIRBORNE
- AUTONOMOUS
- MOBILE
- NAVIGATION
- ROBOTICS
- TRANSPORT
- UNMANNED

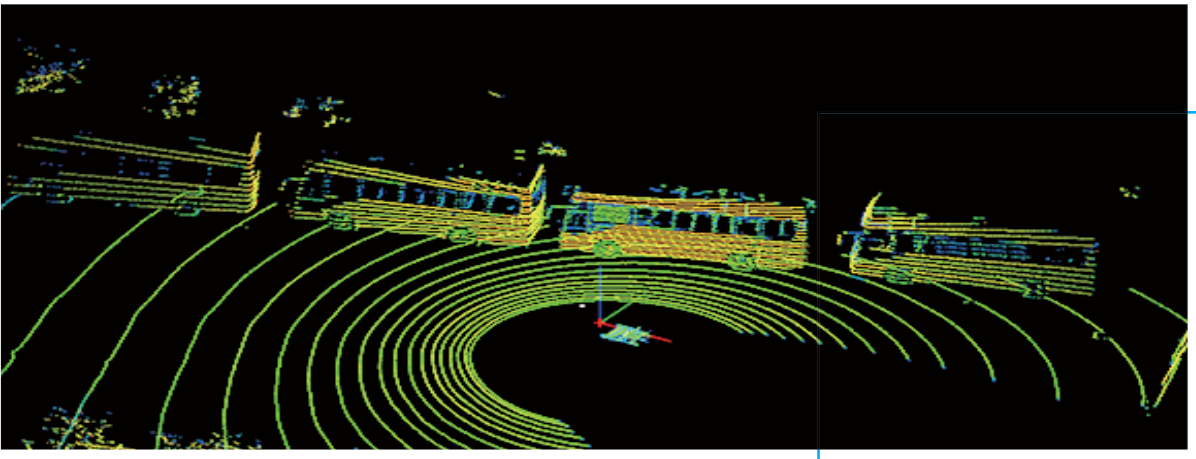
Continuous Innovation

SureStar embraces complete and comprehensive lidar core technologies. Quick roll-out of new products comes from a talented and fast-growing R&D team. SureStar has its headquarters and R&D center in Beijing, production facilities in Suzhou, and software team in Hefei (China). In 2018, SureStar set up a representative office in Wixom City, near Detroit, to provide timely technical support to North American clients. SureStar currently has more than 200 employees, of which more than 50% are involved in R&D and technical support.

As one of most important lidar providers for both mapping and automotive applications, Surestar has distributed lidar sensors into USA, Europe, Russia, Australia, South Korea and South East Asia. The Fortune 500 clients of SureStar include several Chinese leaders in power and transportation, and many big names in autonomous driving. SureStar sensors were also seen in Malaysia's first self-driving car in which Prime Minister Tun Dr Mahathir Mohamad took a ride on April 2019. Mid-2019, SureStar was notified that it had met the requirements of IATF16949:2016. This international standard was published in 2016 by the International Automotive Task Force to supersede ISO/TS 19649. The standard is aimed at the development of a quality management system that provides for continual improvement, emphasizing defect prevention and the reduction of variation and waste in the automotive industry supply chain. SureStar's commitment to automotive lidar is clear, while it continues to offer products across the lidar spectrum, including the rapidly growing UAV-lidar market.

Tel : +86 10-58717175; +1-248-773-7768
Email : bkth@isurestar.com
Website : www.isurestar.com

SureStar



R-Fans

C-Fans

Mapping & Navigation LiDARS

Genius
1168 g

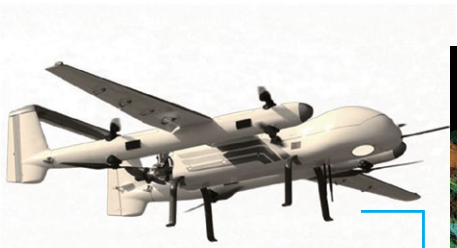
Magic
1180 g

Mini UAV LiDAR

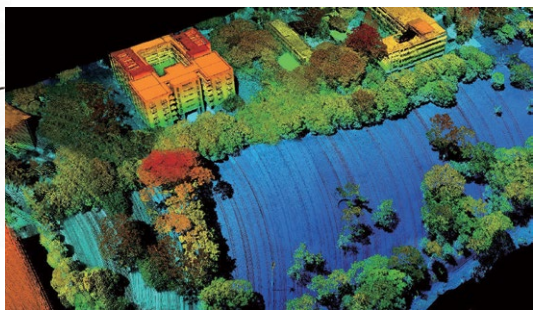
-- Weight below 1.2 kg

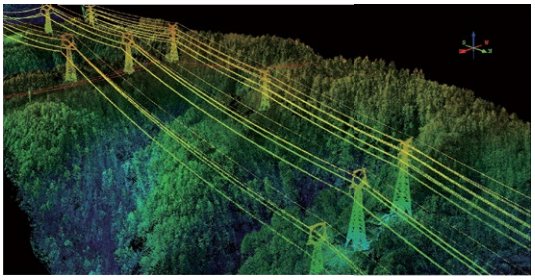
-- Range beyond 200 m

Sky-Lark



Clouds





Survey grade UAV LiDAR

PICKETT AND ASSOCIATES

APPLICATIONS:

- AIRBORNE
- MAPPING
- IMAGERY
- UNMANNED
- SURVEYING
- CADD/GIS
- CONSULTING
- ENGINEERING

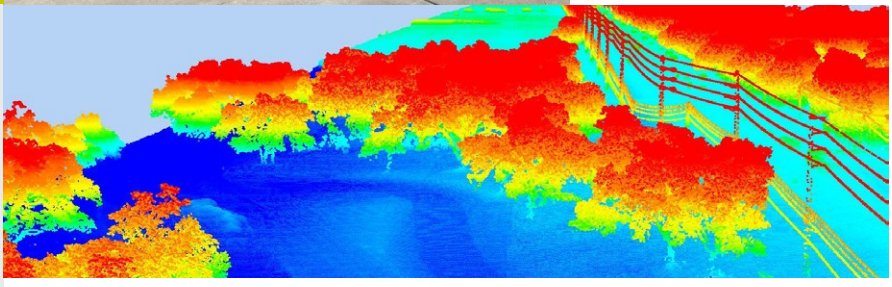
COMPANY PROFILE

Pickett provides aerial lidar, aerial mapping and imaging, land surveying, hydrographic surveying and engineering services to clients throughout the US and Caribbean. Pickett specializes in offering the simultaneous collection of high resolution 4-Band Aerial Imagery combined with engineering-grade airborne lidar, allowing us to turn around baseline imagery and lidar-derived data quickly and efficiently. We deliver CADD and GIS-ready products to meet unique client specifications. Our clients come to us for the most complex projects because of our proven track record of producing deliverables efficiently, safely, cost-effectively and on schedule. With over 50 years of experience, we have established ourselves as leaders and innovators in the surveying and geospatial industry. Contact us today to see how our geospatial services can benefit your next project.

PICKETT

Incorporated 1963
51-200 Employees
Tampa, Florida, USA

PickettUSA.com



Advanced Geospatial Solutions

Our airborne lidar focuses on the energy, mining, and land development sectors. We specialize in small to medium-sized projects and can provide anything from raw data to a complete final product. Using data fusion, Pickett can merge results from ground surveys, hydrographic surveys, aerial lidar and digital imagery into a complete, all-encompassing map product.

The Teledyne Optech Galaxy PRIME lidar sensor is one of many tools we use for a myriad of lidar applications. When used in conjunction with our iXU-RS 1000 medium-format camera, this system produces a complete picture of site conditions.

In the energy sector, we perform aerial surveys of corridors with lengths of 1 mile to several hundred miles, with a point density of 50 points per square meter, or more. For the mining sector, we provide aerial surveys ranging in size from 1-acre stockpiles to several thousand acres, using the data to create digital surfaces and compute high-accuracy volumes for accounting purposes. Land development projects range in size from 20 acres to more than 100 square miles, finalizing into a detailed topographic survey.

We utilize a RIEGL terrestrial scanner for smaller projects where high-resolution, high-accuracy lidar data is required. In combination with the top-mounted DSLR camera, we can create photo-realistic point clouds to survey and document as-built conditions of almost any feature.

Our aerial platform consists of a 2015 Cessna T-206H Turbo Station Air, modified with FAA approved camera ports for aerial surveys. Pickett has an FAA Section 333 exemption, and currently complies with FAA Part 107 regulations, to provide UAS services commercially.

Success can be Measured

Aerial Mapping & Imaging
Land & Hydrographic Surveying
Unmanned Aerial Systems

PICKETT

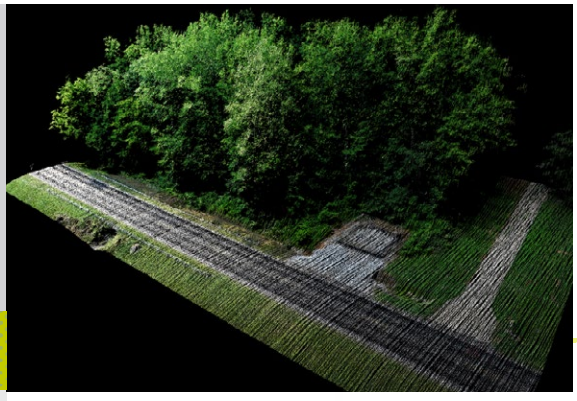
Visit our website to learn more about how our geospatial services can benefit your next project.

www.PickettUSA.com
813.877.7770

GEOCUE GROUP

APPLICATIONS:

- AIRBORNE
- CONSULTING
- MAPPING
- MINING
- PROCESSING
- SURVEYING
- TELECOM
- UNMANNED



COMPANY PROFILE

GeoCue Group was founded in 2003 by a group of engineers with extensive experience in developing hardware and software solutions for primary remote-sensed data acquisition. Our initial products were aimed at reducing schedule and cost risk in geospatial production workflows by providing organizational, productivity and data management tools for base geospatial data production. These tools have been realized as the GeoCue product family. Today GeoCue workflow management tools are used by a majority of North American geospatial production shops. In 2005, GeoCue began selling and supporting Terrasolid tools for kinematic lidar data production. This was followed in 2009 by our acquisition of QCoherent Software LLC, the creator of the point cloud exploitation toolset, LP360. Today GeoCue is the largest supplier of kinematic lidar processing tools in North America and LP360 is the world's most widely used tool for exploiting point cloud data.

Founded 2003
11-50 Employees
Huntsville, Alabama

geocue.com

True View

Leveraging our expertise in production, risk reduction, and point cloud processing tools, we are continuing to bring new services and products to market to provide surveyors and other geomatics professionals exciting tools for geospatial data extraction using low cost drones including Loki, our plug-and-play PPK direct positioning system, and now our new True View lidar/Imagery fusion sensors.

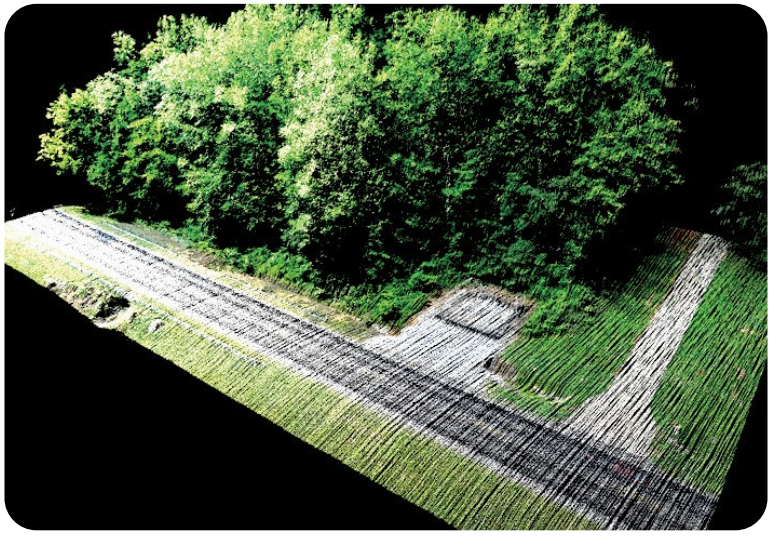
True View sensors offer surveyors an innovative lidar + dual oblique mapping camera configuration integrated in a single lightweight payload for use on commercial drone platforms. True View allows for fast, easy automated generation of true 3D colorized point clouds, oblique imagery and orthophotos from a single flight. The first sensor of the product line, the True View 410, is the industry's first integrated lidar/camera fusion platform designed from the ground up to generate high accuracy 3D colorized lidar point clouds. Featuring dual GeoCue Mapping Cameras, a Quanergy M8 Ultra laser scanner and Applanix Position and Orientation System (POS), the result is a true 3D imaging sensor. With its wide 120° fused field of view, the True View 410 provides high efficiency 3D color mapping with vegetation penetration in a payload package with a mass of about 2 kg.

In addition to its advanced fusion technology, the True View 410 includes a revolutionary business model option. Customers can purchase the complete system (hardware and full workflow software) as a standard purchase or enroll in a subscription service. The base subscription includes enough processing minutes to complete about 20 projects of 50 acres each. Additional processing is purchased by the minute.

TrueView

GeoCue

UAS LIDAR/Imagery Sensor Fusion



Dual Cameras

LIDAR Scanner

Google Processor

TrueTrack Flightlines

Workflow Software

Applanix Positioning

The True View 410 is the industry's first integrated LIDAR/camera fusion platform designed from the ground up to generate high accuracy 3D colorized LIDAR point clouds. Featuring dual GeoCue Mapping Cameras, a Quanergy M8 Ultra laser scanner and Applanix Position and Orientation System (POS), the result is a true 3D imaging sensor. With its wide 120° fused field of view, the True View 410 provides high efficiency 3D color mapping with vegetation penetration in a payload package of 2.2 kg.

GeoCue Group

www.GeoCue.com

LiDAR USA

COMPANY PROFILE

We are an aggressive team of pioneers in geomatics searching for new, innovative, and affordable solutions. We build economical UAV & mobile mapping systems, that push technology to the edge using the latest tools for scanning, imaging, and navigation.

The idea to develop the Snoopy and ScanLook LiDAR systems came out of our need to find an affordable light weight solution that was easy to use and operate. We have developed solutions for indoors and outdoors. The key technologist and principal investigators are Daniel and Jeff Fagerman. We are experienced in photo control work with conventional total stations, levels, etc., and also with the latest GPS technology. We consider software development a particular interest and hardware integration something we excel at. We seek out ways to improve workflows using existing technology in an unconventional way.

20 YEARS ANNIVERSARY CELEBRATION
LiDAR USA
Fagerman Technologies Inc.

Founded 1999
20+ Employees
Alabama, USA

lidarusa.com

APPLICATIONS:

- AIRBORNE
- EDUCATION
- MAPPING
- MOBILE
- INDUSTRIAL
- MILITARY
- UNMANNED

LiDAR USA—We Are LiDAR!

Snoopy A-Series HiWay Mapper HD + UAV Package

Weighing in at only 2.5kg, Snoopy A-Series is a smaller, evolved version of our Snoopy. This unit is also configurable but is designed to be an extremely accurate solution for multi-vehicle mounting. The A-Series is light-weight and easy to use. With just a click of a button on your smartphone you can scan anywhere with this little guy.

M200 Series Snoopy LiDAR Package

The M200 Snoopy Series LiDAR Package is designed specifically for the ever-popular DJI M200/M210 UAV. Custom designed for the Velodyne A-Series Scanner and weighing only 1.63kg, the M200 Snoopy Series is light, fast and easy to use. With deployment from an easy to carry case and just a click of a button on your smartphone, you are ready to scan. The M200 Snoopy Series is a smaller, evolved version of our Snoopy system. This unit is designed to be an affordable yet extremely accurate solution.

Revolution 60, 120 and HD

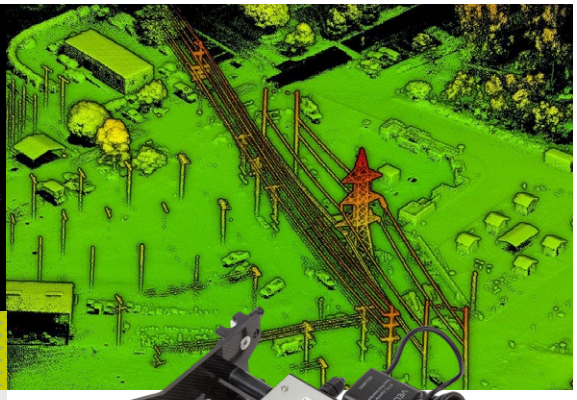
Ready-To-Fly-Ready-to-Scan package. Endless coordinate systems; LAS/LAZ, etc., formats; Control point registration; Point Cloud filtering; Coordinate measurement update tool.

We also offer the Snoopy Mini-VUX and VUX (RIEGL); Snoopy Dual-VUX (Riegl); SCANLOOK TreX, for Trimble shops; our PhaseOne Photogrammetry Package, a host of supporting products and more! Sensors we integrate and resell include the Velodyne Puck Hi-Res,Velodyne Puck LITE, Velodyne HDL-32E, Velodyne Puck. Sensors we inegrate include the FARO FOCUS 3D, Quanergy M8 and the Z+F Profiler.

One System.
Dual Use.
Yes, You Can Do Both!

Designed to easliy move from a UAV to a ground vehicle. Optimize your ROI.
Spend more time scanning, only 30 seconds to initialize.
We Make 3D Mapping Easy. Learn more on our website. www.LiDARUSA.com

GEODETICS



APPLICATIONS:

- FORESTRY
- TOPOGRAPHY
- TRANSPORT
- AGRICULTURE
- CONSTRUCTION
- MINING
- URBAN PLANNING
- OIL & GAS

COMPANY PROFILE

Geodetics is the go-to provider for lidar Drone mapping, Assured PNT and sensor fusion for mobile applications in the air, on land and at sea. Founded in 1999, Geodetics has been delivering state-of-the-art products to its commercial and defense customers for over two decades. Geodetics' technical expertise spans lidar drone mapping, Positioning, Navigation and Timing solutions as well as advanced sensor fusion technologies. Geodetics' team consists of innovators, technical experts and partners focused on making technology accessible to customers with mission critical challenges. With our core competencies in Advanced algorithms, data and sensor fusion and national security measures, Geodetics offers cost-efficient products that can be tailored to support our customer's unique applications.

GEODETICS INCORPORATED | Precision in Motion.

Founded 1999
25–50 Employees
San Diego, California

geodetics.com

State-of-the-Art Lidar and Photogrammetry Solutions

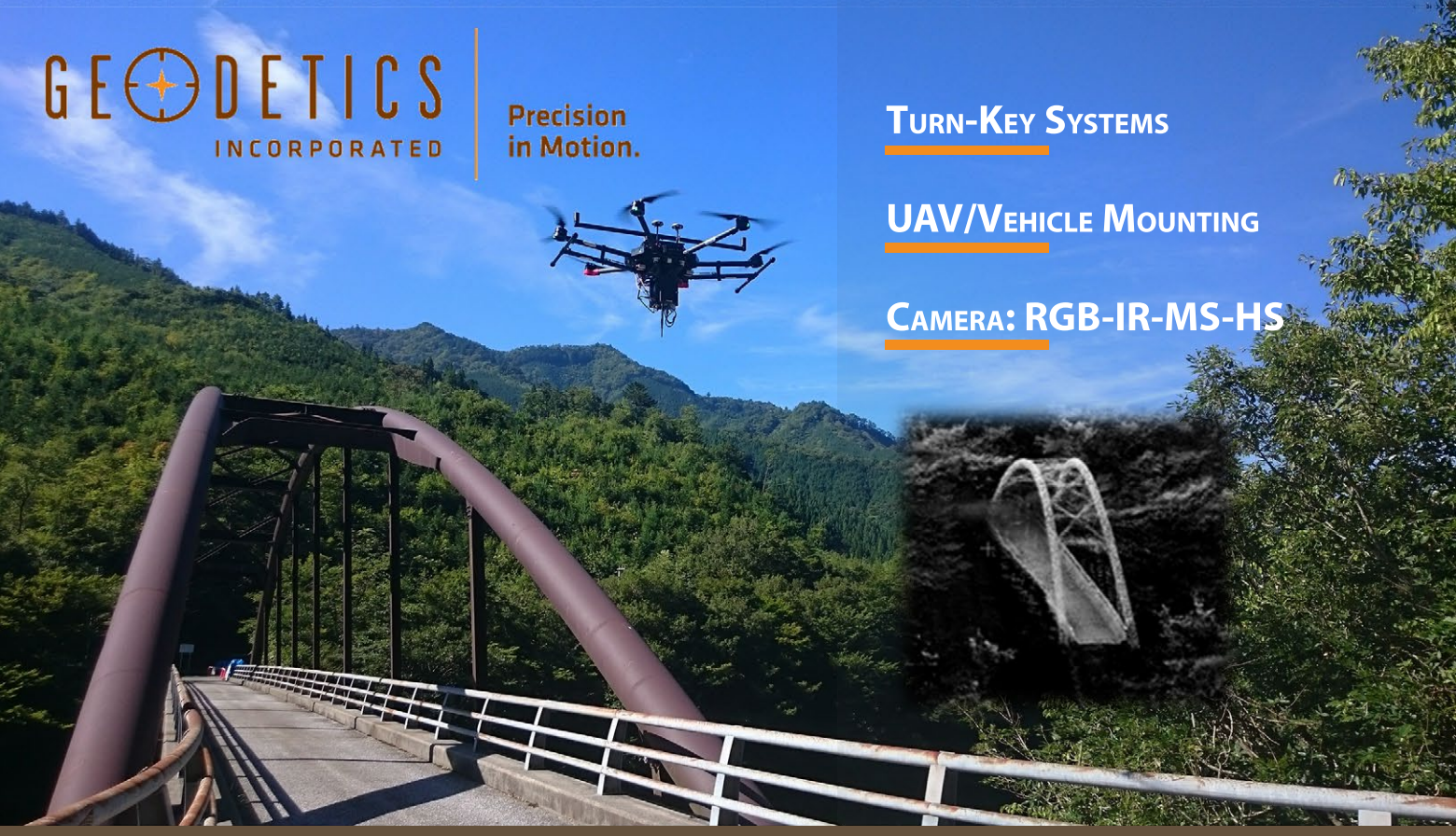
Geodetics' Geo-MMS Mobile Mapping System is a cost-effective modular system for Drone and Vehicle-based Photogrammetry, lidar mapping and creation of RGB/multi-spectral colorized lidar point clouds. At the heart of Geo-MMS is Geodetics' Geo-MMS Navigator, a dual-antenna inertial navigation system integrated with lidar, RGB, multi-spectral and hyper-spectral sensors. The Geo-MMS Navigator was designed from the ground up by Geodetics specifically for mobile mapping applications, leveraging our expertise from years of delivering high-performance navigators to our defense customers. The Geo-MMS Navigator offers many features unique to mobile mapping applications and supports dual GNSS receivers, a variety of IMU grades, and includes our advanced Extended Kalman filter software to optimally integrate the sensor data. When your workflow moves to post-processing, Geodetics' extensive "one-click" processing suite of software provides a powerful, easy to use toolbox for your mobile mapping applications.

Through the advancement of technologies in UAV lidar mobile mapping systems which output LAS files, Geo-MMS users can easily create DEM/DTM/DSM (surface models), geospatially corrected aerial images, 3D building models, contour maps, planimetric features and volumetric surveys—just to name a few applications. The Geo-MMS family includes 1) Geo-Photomap, which tightly integrates GPS/IMU with RGB/multispectral imagery resulting in directly georeferenced images enabling corridor mapping and vertical mapping. 2) Geo-MMS lidar, our lidar payload, offers a wide range of lidar sensors with ranges from 50 – 600 meters.

3) Our Point&Pixel technology provides a tight coupling of RGB/Multispectral images and lidar sensor data delivering stunning colorized lidar points clouds. Geodetics' products and technologies advance the state-of-the-art, while offering significant time/cost savings to our customers.

GEODETICS INCORPORATED

Precision in Motion.



Turn-Key Systems

UAV/Vehicle Mounting

Camera: RGB-IR-MS-HS

An Advanced Sensing and Navigation Company Based in the U.S.A.

Geo-MMS Family of LiDAR & Photogrammetry Products

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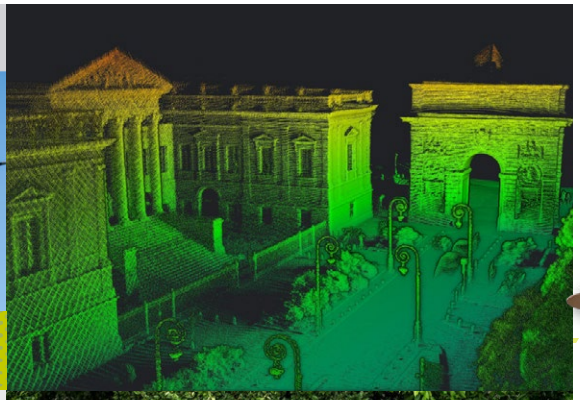
YELLOWSCAN



APPLICATIONS:

- AIRBORNE
- CONSTRUCTION
- MAPPING
- MOBILE
- SURVEYING
- INSPECTION
- TRANSPORT
- UNMANNED

COMPANY PROFILE

YellowScan lidar products are fully-integrated systems designed for commercial UAV applications. Our lidar solutions include the laser scanner, IMU, GPS, embedded computer and batteries. The processing software provided enables the generation of a georeferenced point cloud in the projection of your choice. Output format is .LAS (lidar industry standard) or .TXT. YellowScan is committed to provide users with the most reliable fully-integrated lidar imaging systems and customer support for demanding UAV applications. Since 2012, the team's dedication to fulfill high resolution and high-quality survey requirements has fueled research and development. Our next generation of fully-integrated lidars are ergonomic, robust and easy-to-use, designed by surveyors to serve surveyors, civil engineers, archeologists and other professional users with a turn-key solution that can be mounted on most commercial-scale drones. The Mapper II, Ultra and YellowScan Vx models complete the "Just press the Yellow Button" product line, complementing the original YellowScan Surveyor, the successful world lightest fully integrated lidar for UAV.

YellowScan

Founded 2005
25-50 Employees
Montferrier su lez, France
Utah, USA + Tokyo, Japan

Yellowscan-lidar.com

Fly & Drive

YellowScan Fly & Drive is a combo that can-do mobile mapping & aerial survey using the same lidar (Surveyor or Surveyor Ultra). It combines high resolution laser scanning and precise positioning to collect georeferenced point clouds for a wide range of applications. This will move the user into another level of possibilities and productivity. The swap can be done in less than 5 minutes. It reduces project duration through fast implementation, collection and data analysis.

Fly & Drive can be rapidly deployed on road vehicles as well as on any types of UAVs (multirotor, helicopter, VTOL or traditional fixed-wing), expanding the range of applications and thereby hastening your return on investment.

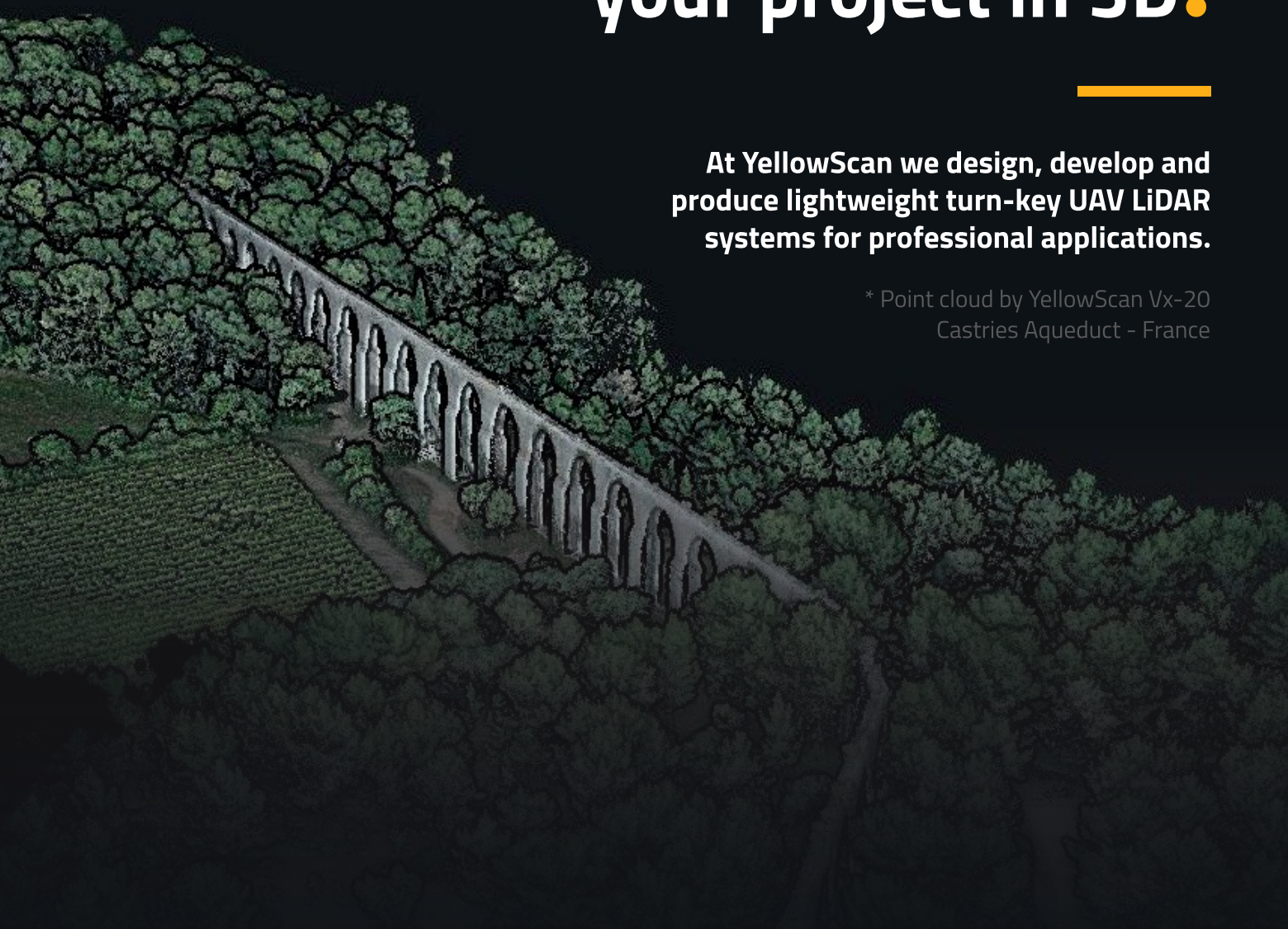
Fly & Drive is an extension of our Surveyor and Surveyor Ultra, consisting in set of mobile mapping gear: a pod, an adaptable bracket and a GNSS antenna.

The possibility to switch the lidar system from UAVs to land vehicles and vice versa, allows the user to perfectly complement a top view acquisition of building roofs with a detailed façade survey. Or, in a light forest, a canopy and tree trunks survey.

It also allows to survey flight restricted zones, such as urban areas, power plant, refineries and more. The main purpose of the point clouds you acquire with Fly & Drive are road, pipeline, renewable energy construction pre-survey or quarries in presence of vegetation.

As the swap is easy and fast to operate, both acquisitions can be done in 1 day.

Make it easy to capture your project in 3D.



At YellowScan we design, develop and produce lightweight turn-key UAV LiDAR systems for professional applications.

* Point cloud by YellowScan Vx-20
Castries Aqueduct - France

User-friendly
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Effective
Optimize your workflow, expand your business, reduce your bother

Expert
Full-integrated LiDAR solution with all tools and support

APPLANIX

APPLICATIONS:

- AIRBORNE
- MAPPING
- MOBILE
- OEM
- SURVEYING
- INERTIAL/IMU
- UNMANNED

COMPANY PROFILE

Applanix Corporation builds, delivers, and supports products and solutions designed specifically for the unmanned aerial survey industry. Applanix Direct Georeferencing technology works with UAV mapping sensors—including cameras, Light Detection and Ranging (LiDAR), and hyperspectral sensors, to perform highly efficient mapping and surveying from a UAV. Direct Georeferencing drastically reduces or even entirely eliminates the use of Ground Control Points (GCPs), thus shortening both the flight and processing time required to generate final map products. Since 2003, Applanix has been a wholly owned subsidiary of Trimble.

applanix™
A TRIMBLE COMPANY

Founded 1991
51-200 Employees
Ontario, Canada

applanix.com

APX-18 UAV

The Trimble APX-18 UAV is an OEM GNSS Inertial solution with dual GNSS antenna input, designed to georeference lidar and other imaging data when collected from Unmanned Aerial Vehicles (UAV) at low speeds or when hovering. Comprised of a small single OEM board containing a precision GNSS receiver with two antenna heading and inertial sensor components plus POSPac UAV Differential GNSS-Inertial office software, the Trimble APX-18 UAV produces a highly accurate position and orientation solution for directly georeferencing lidar point clouds and imagery.

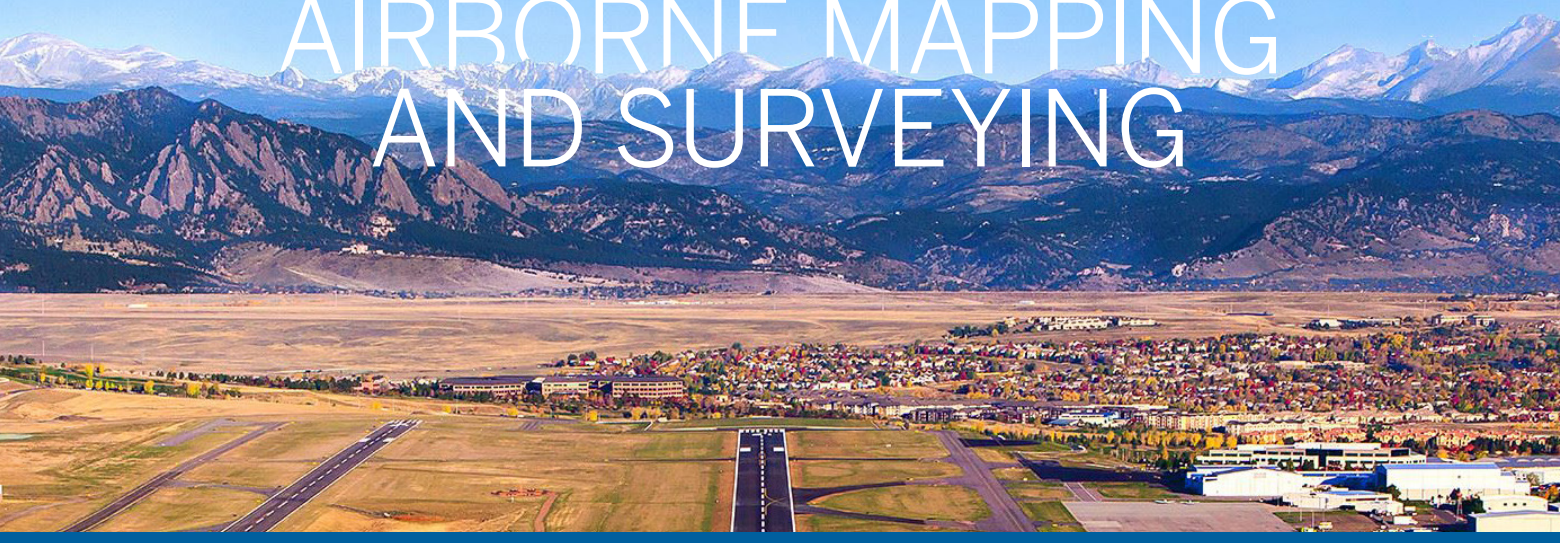
High accuracy, extremely small package

Measuring just 100 x 60 mm and weighing only 62 grams, the APX-18 UAV provides unparalleled performance in an extremely small package. With the included POSPac UAV postmission software, it produces a highly accurate position and orientation solution for direct georeferencing of cameras, lidars and other UAS sensors.

Key features:

- High-performance Direct Georeferencing solution for improved efficiency and accuracy of mapping from small Unmanned Aerial Vehicles
  - Reduce/eliminate GCP's
  - Reduce sidelap
  - Accurate lidar georeferencing
  - Instant alignment through dual GNSS antenna heading
- Compact single-board OEM module complete with survey-grade multifrequency GNSS receiver and MEMS inertial components
- Applanix IN-Fusion™ GNSS-Inertial and SmartCal™ compensation technology for superior position and orientation performance
- POSPac UAV Differential GNSS Inertial post-processing software for highest accuracy
- RTK real-time position for precision landing applications
- Supports all common RTK corrections such as CMR, CMR+, RTCM

WORKSHOP ON AIRBORNE MAPPING AND SURVEYING



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CONTENT

- ✓ How Direct Georeferencing (Applanix DG™) improves mapping efficiency and accuracy
- ✓ A deep dive into GNSS-aided inertial technology
- ✓ Automated mapping with DG for UAVs using LiDAR, hyperspectal, and cameras
- ✓ Complete mapping, monitoring, and data collection with integrated PhaseOne Industrial cameras

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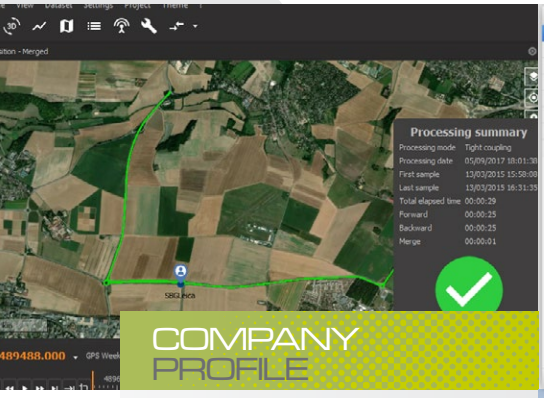
SBG SYSTEMS



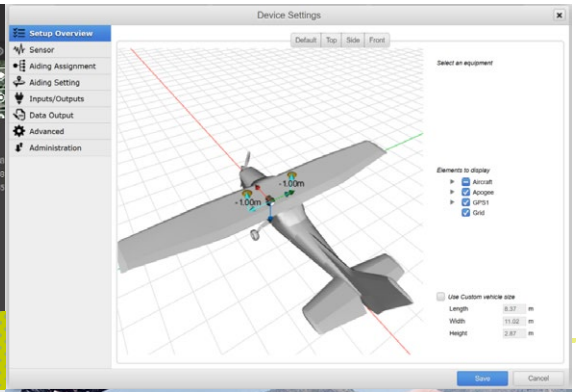
COMPANY PROFILE

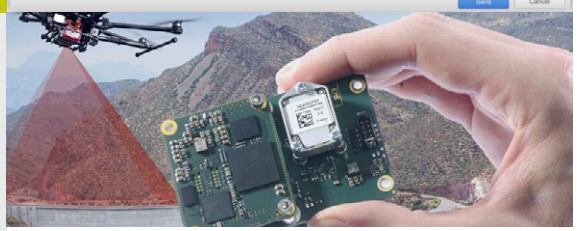
SBG Systems is a fast-growing supplier of miniature, high performance and innovative motion sensing solutions. SBG Systems is headquartered in Carrières-sur-Seine, France and operates in North America from its subsidiary in Huntington Beach, CA. SBG Systems offers a complete line of inertial sensors, such as Attitude and Heading Reference System (AHRS) or Inertial Measurement Unit (IMU), based on the state of the art MEMS technology. This technology, combined with advanced calibration techniques offers miniature and low-cost solutions while maintaining a very high performance at every level. Our sensors are ideal for industrial, defense & research projects such as unmanned vehicle control, antenna tracking, camera stabilization, and surveying applications. From hydrography to mobile mapping and aerial cartography, SBG Systems offers a complete solution including the IMU, PPK software and services.

SBG SYSTEMS

Founded 2007
11–50 Employees
Carrières-sur-Seine, France
Huntington Beach, CA

sbg-systems.com





APPLICATIONS:

- AIRBORME
- AUTOMOTIVE
- DEFENSE
- INERTIAL
- MAPPING
- MARINE
- SURVEYING
- UNMANNED

Direct Georeferencing Solution

Quanta embeds high-quality gyroscopes and accelerometers that are factory calibrated from -40 to +85°C. It also integrates an RTK GNSS receiver providing a centimetric position. The internal Extended Kalman Filter fuses inertial and GNSS data for the highest performance in the most challenging conditions. Quanta can be integrated within a UAV or a land based mobile mapping solution, delivering real-time and post-processing data thanks to Qinertia PPK software.

Lidar & Photogrammetry—UAV or Land based Applications

Quanta directly and precisely geotags your point cloud whether your platform is a UAV or a car. In UAV-based photogrammetry, it also reduces the need for ground control points and overlapping thanks to precise orientation and position data.

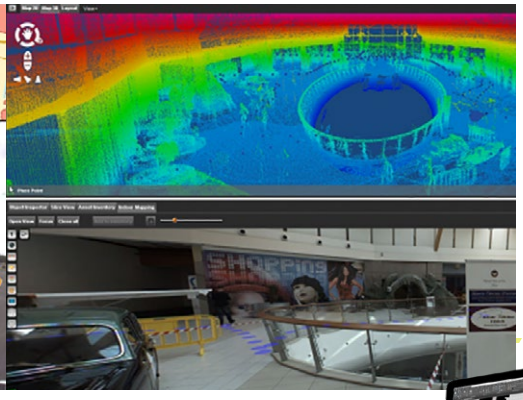
One Year Free Post-processing with Qinertia UAV

Both Quanta model embeds a data logger for post-processing. Qinertia post-processing software enhances SBG INS performance by post-processing inertial data with raw GNSS observables. One year of Qinertia is offered for UAV applications.

Single or Dual Antenna

If a single antenna solution tends to be more practical, the dual antenna mode allows a more precise heading for low dynamics flights (pipes or electrical lines surveys). Quanta is a powerful and flexible INS+GNSS designed to be tightly integrated in mobile mapping solutions whether they are aerial or land. Quanta combines excellent orientation and navigation data in real-time with a powerful and easy-to-use post-processing software.

ORBIT GEOSPATIAL



COMPANY PROFILE

Orbit GeoSpatial Technologies was founded in 1972 as a development company named Eurotronics, aiming to develop tools for the automation of mapping production using aerial imaging and photogrammetry. The company's first full digital map production was achieved in 1978. At the outset of the new milenium, Orbit GT was among the first to embrace mobile mapping and drone mapping. In October 2010, the company founded as Eurotronics was renamed to Orbit GeoSpatial Technologies. In January 2014, the company separated from the government and public safety business to focus fully on mobile mapping, and other emerging 3D mapping markets. Orbit GT built a portfolio unique in the market to manage massive volumes of data typically used in Mobile Mapping, feature extraction and online sharing.

Today, Orbit GT is the market leader in 3D Mapping software solutions, with unique capacities for managing massive volumes of data, hardware-neutral solutions, and real-time fusion of street-level, aerial, drone, indoor and static data collection.

Founded 1972
25+ Employees
Lokeren, Belgium
Singapore, Malaysia

orbitgt.com

APPLICATIONS:

- AIRBORNE
- CONSTRUCTION
- MAPPING
- SMART CITY
- SURVEYING
- TELECOM
- TRANSPORT
- UNMANNED

3D Solutions

3DM Content Manager

The 3DM Content Manager is the must-have for any data collection professional. 3DM Content Manager provides management, optimization and delivery of any 3D Mapping content. 3D Mapping Content, however collected, is massive. 3DM Content Manager feels at home with the terabytes of data, imagery and point clouds alike.

3DM Feature Extraction

Feature Extraction or Modelling summarizes a range of tools to exploit 3D Mapping content—from simple measurement to analysis and automated object detection. The Basic version includes all non-automated measurement tools, allowing to store each measurement in a layer of feature list. It also includes a variety of easy-to-use analysis tools. The Standard version adds an Asset Inventory database (with snapshots and documentation) and many automated measurement tools, as well as dynamically accessible autodetection tools. The Team version is ideal to deploy for multiple users sharing a central Asset Inventory database.

3D Mapping Cloud

3D Mapping Cloud is Orbit GT's solution to host all of your 3D Mapping content in the cloud and have fast and dynamic access to all of your data. The extensive capabilities to manage your resources, bundle, tag, organize and share them, is unique in the business. Using a subscription model, 3D Mapping Cloud is to ideal tool for both small and large organizations.

SDK & Plugins

The 3D Mapping Viewer SDK provides equal viewing capabilities as the 3D Mapping Cloud viewer and the 3DM Publisher viewer. Orbit GT provides such plugins for a number of popular GIS hosts, such as Esri Arc Online, Esri ArcMap, Esri ArcPro, QGIS, Microstation / Bentley Map and AutoCAD Map.

Figure 1: Phoenix LiDAR's miniRANGER UAV system is designed to acquire survey-grade LiDAR data and high-resolution 42 MP RTK photogrammetry at up to 100 meters AGL. This modular system can also be mounted on vehicles and backpacks for more flexibility.

Automation in UAV-Lidar Unleashes Business Potential

Phoenix LiDAR Systems powers Precision Aerial Compliance Solutions

At the end of 2017, managing editor Stewart Walker visited Phoenix LiDAR Systems to learn about their core competency in integrating lidar systems with UAVs[1]. One year later, Walker visited both Phoenix and one of its UAV-lidar clients, Precision Aerial Compliance Solutions, to examine use of this new technology over the vast plains of Texas.

Phoenix LiDAR Systems[2] specializes in building lidar systems for UAV integration, producing hardware and software for surveying and mapping companies to collect the data they need with as little operating overhead as possible. This magazine's focus on the innovation and application

1 Walker, A.S., 2018. Phoenix LiDAR Systems: excellence in UAV integration, *LIDAR Magazine*, 8(1): 22-29, January/February.

2 Further detail is available at www.PhoenixLiDAR.com.

BY VU MARK **NGUYEN** AND A. STEWART **WALKER**

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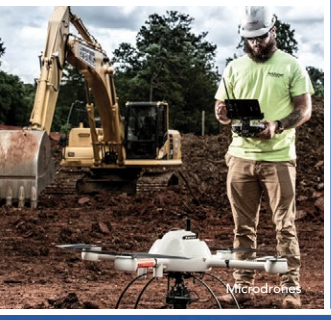

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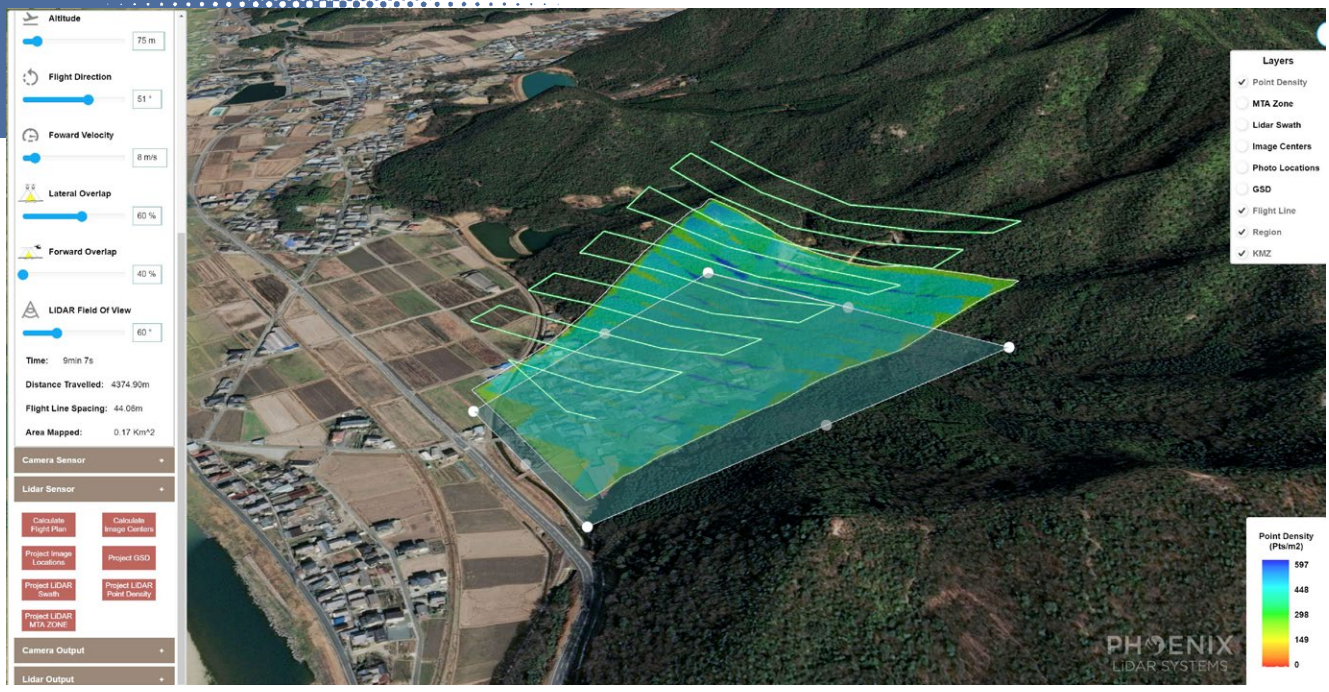


Figure 2: Phoenix Flight Planner enables clients to build flight plans that optimize data collection based on factors such as laser strength, vegetation, terrain, and more. The resulting KMZ can be uploaded for autonomous UAV flight, further simplifying the lidar workflow.

of lidar technology led to our meeting in December 2017, where managing editor Stewart Walker met with Phoenix CEO Grayson Omans and several of his colleagues to discuss opportunities presented by integrating lidar technology with unmanned aerial vehicles. At that time, UAV-photogrammetry was a popular option, but for lidar, the weight and operating complexity continued to present obstacles for UAV integration. Omans's idea to use UAVs for aerial lidar gave operators the option to take on projects typically considered too small for manned missions, and with the added benefit of lower costs and liabilities. Indeed, Phoenix's completion of the industry's first UAV-lidar flight was a major part of last year's *LIDAR Magazine* story.

As readers can attest, there are a host of sensing technologies for surveying and mapping, each with its own strengths and weaknesses. Lidar can be used to produce survey-grade data (**Figure 1**) in situations where other options, such as photogrammetry, may be limited by factors of vegetation, light, and more. In this article, we explore Phoenix's progress in the past year, and look into the work of a successful aerial inspection company whose reliance on Phoenix solutions has contributed to its rapid expansion nationwide.

While UAV-lidar sensing fills a valuable need, the complexity of its operation can be an obstacle to surveying and mapping professionals. Learning how to fly a drone, operate lidar equipment, and post-process the raw data can itself be a major investment on top of the financial costs of these systems. "UAV-lidar is already changing the industry, but if it's too difficult or expensive, companies will be hesitant," said Omans. In response, Phoenix set its sights on building "end-to-end" packages that include hardware, software, and training to make it easier for clients simply to buy and operate.

The UAV-lidar workflow

Phoenix's UAV-lidar workflow can be simplified into three major phases: flight planning, data collection, and post-processing. Last year's article covered Phoenix's work to streamline the first two of these phases, resulting in Phoenix Flight Planner and Software Suite respectively.

Through Flight Planner (**Figure 2**), operators can develop an autonomous flight path to optimize data collection based on laser strength, terrain, swath width, and more. The software produces a KMZ for the UAV's flight system.

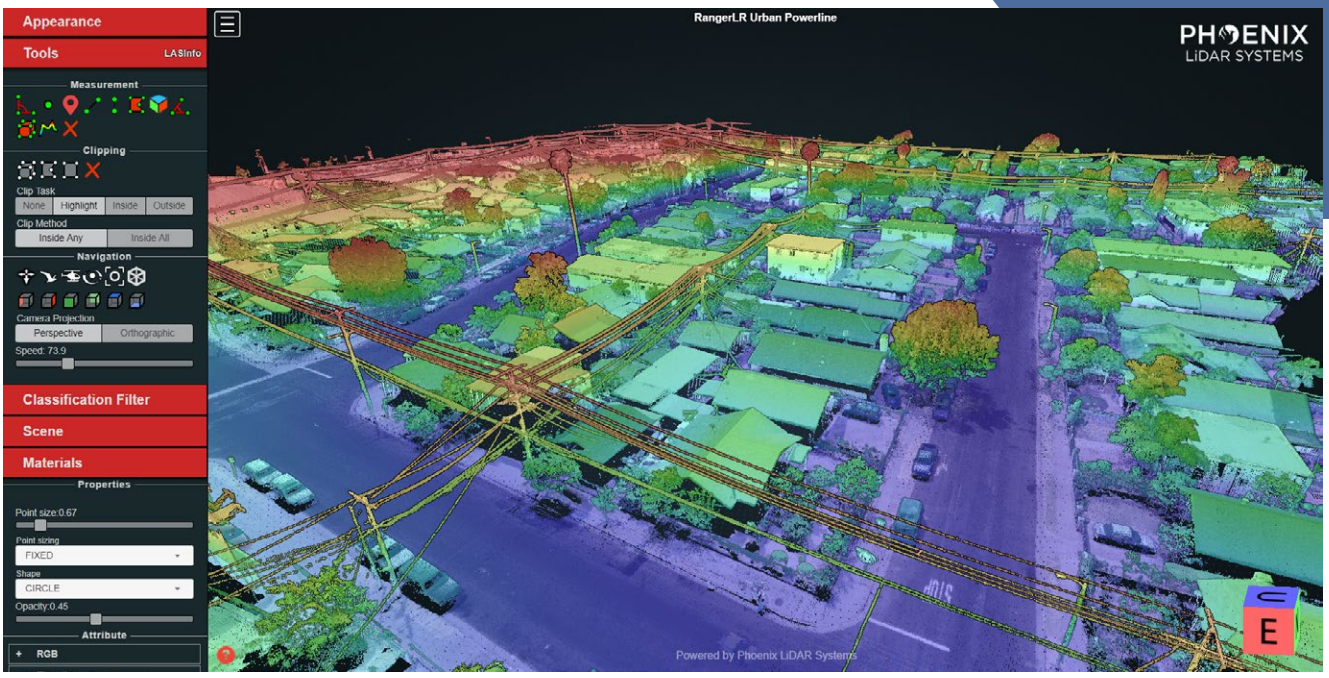


Figure 3: Phoenix LiDARMill produces a smoothed trajectory, automatic flight-line detection, minimization of offsets from overlapping flight lines, and classification of ground/non-ground surfaces. Phoenix believes that it can drive down UAV-lidar costs through LiDARMill's automation and subscription-based cloud service.

Once the flight is planned, Phoenix Software Suite monitors and controls the lidar hardware during flight, enabling operators to review raw data in real time and make adjustments and corrections while still in the field. The system seamlessly down-samples and transmits collected data to the base station laptop via 4G or local WiFi.

The developing story in the last article was the solution for the third phase: post-processing. While Phoenix LiDARMill was in its nascent stage, its goal was to become the industry's first cloud-based lidar post-processing system, using a subscription model and automation to bring down costs for the end user. In our recent visit, Omans was pleased to report a successful launch and growing user base, and gave us a taste of some of the upcoming features that Phoenix co-founder and software lead, Dr. Ben Adler, is driving. These details will be part of a forthcoming article on the technical developments that can lead the expansion of UAV-lidar.

The marriage of hardware and software

While a UAV-lidar system requires powerful GNSS and IMU componentry, the heart of the system is its lidar sensor. The automotive industry's heavy investment in lidar sensor development for autonomous driving has been a beneficial coincidence, as sensors decrease in cost and grow in accuracy. As these manufacturers compete to produce more powerful and accurate sensors, Phoenix tests and integrates successful models into its own systems, offering, in turn, greater mapping accuracy to its own clients.

The relationship between Phoenix's hardware and software is best understood in the light of the final application of the system: many of Phoenix's customers are service providers in various industries, such as surveying for power utilities, damage assessment, construction, and more. In these environments, lower-cost technologies such as photogrammetry struggle, though they thrive and may even be preferable in suitable conditions. UAV-lidar must be able to provide survey-grade data despite dense or downed vegetation, poor ambient lighting, and more. Phoenix hardware and software work together to collect and feed data from integrated sensors into the Navigation Box, or "NavBox," from which it is then downloaded after the mission for post-processing.

The information collected from onboard GNSS, IMU, and lidar

hardware is used to produce detailed survey-grade data to be included in final deliverables. This stage, known as post-processing, is so daunting that some UAV-lidar providers don't offer training or service for this phase at all, instead pointing clients to third-parties that specialize in this area. This reaction is understandable, as post-processing costs quickly balloon: from software licensing that can run in the tens of thousands of dollars, to the investment in computing power that handles the data, to the engineer(s) who must be trained to operate it all, lidar post-processing can be cost-prohibitive for medium-sized surveying and mapping organizations. To lower the barrier to entry, Phoenix launched LiDARMill as the first cloud post-processing platform for lidar.

Adler and his team of engineers have worked for several years to develop algorithms and operations that can take into account GNSS and IMU data, combined with pattern identification within raw lidar data, and a host of other factors to perform LiDARMill's four main features: a smoothed trajectory, automatic flight-line detection, minimization of offsets from overlapping flight lines, and classification of ground/non-ground (**Figure 3**). Through automatic flight-line detection, LiDARMill reduces post-processing time by detecting and omitting mapping data collected during extraneous flight maneuvers, such as turns and calibration patterns. LiDARMill's end result is a LAS file and gridded DTM that can be used for further processing or delivered directly to the client. Among other features to be detailed in an upcoming *LIDAR Magazine* piece, future LiDARMill releases will include in-depth reporting and analytics based on post-processed data.

In cases requiring more precise classification and post-processing, Phoenix continues to offer training and licensing for the major software bundles that would be required. Clients thus have the option to choose between traditional post-processing training and LiDARMill automation, whichever is more suited to the needs of their own customers.

Figure 4: Precision's "quick response team" prepares to launch its miniRANGER system on a surveying mission. Due to the nature of their surveying missions, the Precision team includes FAA-licensed UAV pilots who oversee all aspects of flight operations.

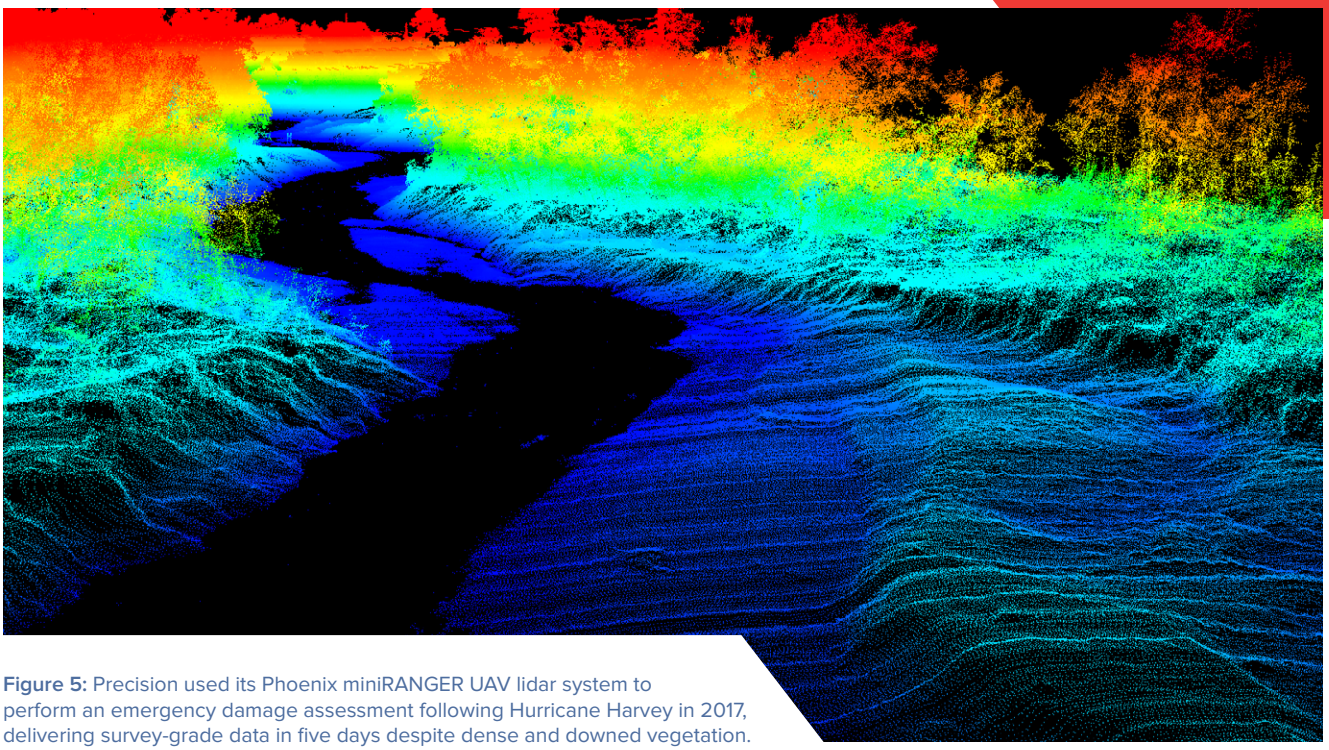


Figure 5: Precision used its Phoenix miniRANGER UAV lidar system to perform an emergency damage assessment following Hurricane Harvey in 2017, delivering survey-grade data in five days despite dense and downed vegetation.

Precision Aerial at work

Phoenix, which specializes in UAV-lidar integration and data processing, leaves mapping operations to its clients, for example, Precision Aerial Compliance Solutions[3], of Conroe, Texas. Their symbiotic relationship has produced a number of "win-win" scenarios: Phoenix's hardware and software enable Precision to take on more challenging surveying projects, while Precision in turn offers Phoenix feedback and insights that enable the manufacturer to develop a more competitive product ecosystem.

"Precision is in the data business," says founder and CEO Scott McGowan, explaining the relationship with Phoenix, "but if I collect data and can't process it or give useful insight to my client, the UAV and sensors are no good." As the Precision team (**Figure 4**) continues to push Phoenix technology to its limits, "we call Phoenix a lot," he continued. "We're super happy with these guys. It's a strong relationship that works." The feeling is mutual, and, in our interview, Omans added, "Phoenix LiDAR is the tool-maker, and Scott has the insight."

In establishing Precision, McGowan assembled a team that would focus on surveying and engineering services using UAVs and a variety of sensing tools, including photogrammetry. To expand Precision's offerings beyond photogrammetry, McGowan began a year-long search for the right lidar provider and determined that, although Phoenix was more expensive, it was more competent than its competitors. In our interview, he particularly noted that Omans has been a pathfinder in bringing lidar to UAVs.

When starting the company, McGowan sought to combine his interest in radio-controlled hobby planes and helicopters with his years in Wall Street energy trading. True to his history, Precision offers inspection services mainly to the oil and gas and engineering/surveying industries. The company has performed projects for numerous county and city entities within Texas, including both general survey and disaster response work to help them develop flood-planning strategies.

Use case: damage assessment

Following Hurricane Harvey in 2017, Precision conducted a disaster response survey for The Woodlands, a Texas community of over 90,000 residents. Local authorities wished to analyze

3 Further detail is available at www.PrecisionAerial.co.

changes in the watershed to determine what actions would be necessary to avoid such catastrophic flooding in the future. They further hoped to preserve the natural beauty of the area by making adjustments to existing streams and creeks in lieu of large concrete drainage canals, a solution adopted in other cities prone to flash flooding, such as Los Angeles and Las Vegas.

Dense vegetation and damaged infrastructure presented significant obstacles to the Texas survey, both for conventional land surveying and UAV-photogrammetry. These exact challenges, however, offered a strong case for Precision's UAV-lidar system, a Phoenix miniRANGER (**Figures 1** and **5**). To perform the damage assessment, Precision mobilized its quick-response team (**Figure 4**) to map the area. Their ability to provide a fast, survey-grade assessment produced data critical to city planning for future disasters. By comparison, McGowan explained that dispatching a two-person survey crew to work this project would have required 30-40 days to cover the forested area. Precision not only collected the data, but post-processed and delivered it to the client in five days.

> "Precision is in the data business, but if I collect data and can't process it or give useful insight to my client, the UAV and sensors are no good."

Figure 6: A Precision team member prepares their miniRANGER for the mission. Most lidar systems by Phoenix are modular and can be unclipped from their UAVs and mounted onto vehicles, backpacks, and more.

Use case: volumetrics

In another mission, Precision was asked to help with a complex volumetrics challenge to calculate the amount of silt removed during a major dredging project. In one of Texas's busiest ports on the Gulf of Mexico, Precision was tasked with measuring large silt deposits moved by contractors on to a local island, which had over time become densely overgrown. Not only is the site surrounded by a port area busy with channel traffic, but land survey teams had been unable to complete their measurements because of constant dangers of sinking in the quicksand-like spoils.

Precision knew from its experience that its UAV-photogrammetry equipment would have produced accurate results, but only in areas where no vegetation had grown over the deposits. Precision instead opted to use its Phoenix miniRANGER system (**Figure 6**). A team placed ground control points around the perimeter and in solid areas where they could safely venture, then launched the miniRANGER. The system was able to penetrate vegetation and perform

survey-grade measurements to calculate the location and volume of spoils deposited. Despite the challenges faced by photogrammetry and manned teams, along with obstacles from natural and man-made causes, Precision was able to produce an accurate lidar volumetric assessment. "We solved the unsolvable on that one," said McGowan.

Where is Precision now?

With its rapid growth throughout Texas, Precision eventually caught the eye of LJA Engineering, a Houston-based engineering company that boasts more than 650 engineers, 80 of whom are professional land surveyors (PLS). In July 2017, Precision agreed to be acquired by LJA, increasing its reach and growth potential far beyond Texas.

Since that time, Precision has expanded into North Carolina, South Carolina, Louisiana, Georgia, and Florida, but McGowan has his sights set on the rest of the United States. Joking that, "being the shiniest tool in the shed is not enough," McGowan pointed out that his team had also made its contributions felt in the wider LJA community, completing 73 successful UAV-lidar projects in 2018, a statistic that he aims to double in 2019.

Endnote

When Omans had the idea in 2012 to combine his love of UAVs and technology, little did he and Adler know that they would disrupt the industry by developing the first commercial UAV-lidar system. Their work was an important step forward in aerial surveying not only because of its novelty, but because it filled such a significant gap. UAV integrations existed for other technologies such as photogrammetry, but lidar sensing was still confined to manned aircraft, MMS and TLS. Their continued development through the years has enabled a host of other industry "firsts," and helped to establish a global client base.

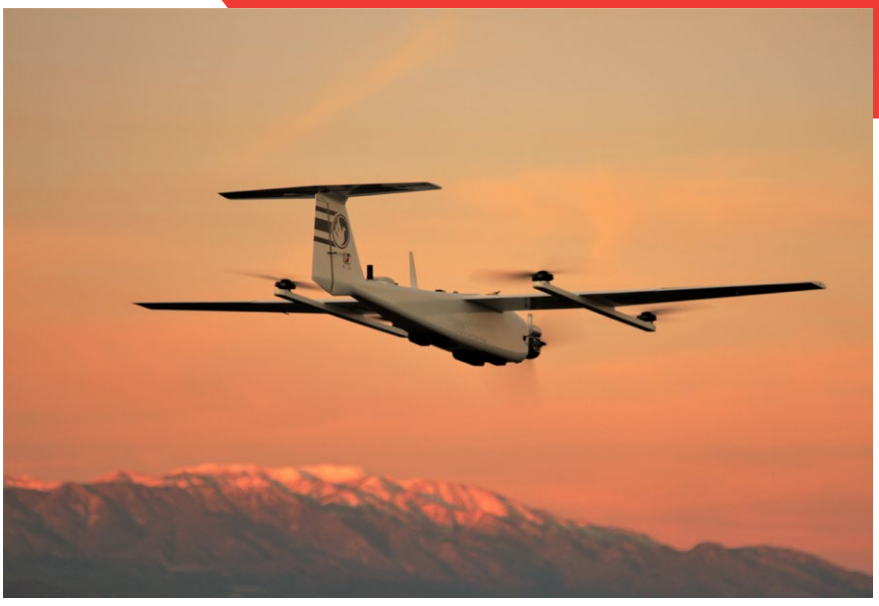


Figure 7: The Phoenix TerraHawk CW-20 is a powerful fixed-wing UAV-lidar platform, enabling operators to combine the altitude, stability, and speed of a fixed-wing aircraft with the safety and convenience of a vertical take-off and landing (VTOL) system.

With the support of industry partners such as Precision, Phoenix continues to build custom UAV-lidar integrations for clients of all sizes, including national and local governments, research institutions, and commercial mapping companies. With its focus on flexible and modular systems, Phoenix's lidar systems can be integrated with a variety of UAVs, from the traditional multi-rotor to fixed-wing drones, for example the Phoenix TerraHawk CW-20 (**Figure 7**).

As *LIDAR Magazine* continues to monitor the growth and development of lidar in various industries, we look forward to taking a deep dive into the software development that will drive LiDARMill into its next phases, with more refined automatic classification and data analytics. We'll also investigate the contribution of Dr. Ben Adler, whose engineering team at Phoenix are the faces behind the developments that serve to make lidar more attainable for a larger number of organizations.

Vu Mark Nguyen served as director of marketing at Phoenix LiDAR Systems until 2018, during which time he helped with the launch of several new Phoenix's UAV integrations, as well as the Flight Planner and LiDARMill platforms. He specializes in marketing strategy for technology companies and continues to collaborate with the Phoenix team as a Dallas-based consultant.

Dr. A. Stewart Walker is the Managing Editor of the magazine. He holds MA, MScE and PhD degrees in geography and geomatics from the universities of Glasgow, New Brunswick and Bristol, and an MBA from Heriot-Watt. He is an ASPRS-certified photogrammetrist.

WITH LEWIS GRAHAM

Drone Mapping

Lewis Graham, President and CEO of GeoCue Group

Few technological processes have evolved as quickly as drone-based mapping—as a result, even fewer people can consistently predict where it's all headed, fully grasping the impact unmanned sensors will have on mapping as we know it. Lewis Graham is one of those people. Most that know him will attribute his innate vision to a remarkable curiosity and deep knowledge of physics. But there's more to it… One of the great GeoTech marvels of the last twenty years—a source of infinite value extraction—stems from the integration of imaging and location tech. Lewis, the former CEO of Z/I Imaging and developer of numerous mapping systems, has long occupied this intersection.

> "Hard trends are easy to find if you know where to look..."
>
> — Daniel Burrus

Editor's note: For the charter installment of "State of the Art", our new "quick-takes" department addressing key developments in geotechnology and the people behind them, we caught up with Lewis Graham, President and CEO of GeoCue Group, to gather his thoughts on the state of drone mapping.

LIDAR Magazine (LM): Thanks for taking time to catch up with us, Lewis. You've been offering drone mapping solutions going on several years now. How has GeoCue's product line evolved during that time?

Lewis Graham (LG): We first entered drone mapping around 2013 with the goal of opening a new market for our product, LP360. This desktop software is a good tool for processing point clouds derived from imagery as well as lidar data collected by drones.

We built a "foamy" fixed-wing drone equipped with a digital mirrorless prosumer camera (erroneously called a "digital, single lens reflex, DSLR") for demonstrations and went on the road to visit a number of quarry sites in the eastern United States. Potential clients immediately understood the return on investment for routine but necessary operations such as stockpile volumetrics. However, they were hesitant about internalizing this new technology because of the perceived complexity and the then very complex 333 FAA rules. In response to this, we decided to stand up a small services group to ease customers into adopting drones for routine mapping. Since that time we have performed over 3,000 metric drone mapping operations. This has certainly been drone university for us!

Like many companies pursuing drone mapping solutions, we started with ground control points, located using static GNSS. Occupying each control point for 20 minutes was obviously a

terrible approach so we soon found ourselves equipped with RTK survey kits. However, in many situations, laying out control points is just not an option due to safety and access constraints. This motivated us to develop on-board direct geopositioning systems which, in turn, led us down a long and arduous path of characterizing drone cameras and developing techniques for minimal control, high accuracy mapping. We reached the point where we could reliably achieve less than 4 cm vertical error with no control at all.

In 2014 we developed a multifrequency GNSS Post-Process Kinematic (PPK) direct geopositioning system for a multirotor mapping drone (based on the DJI S900) that we simultaneously developed. We started with RTK but soon realized that maintaining radio line of sight was a problem in low altitude flying and hence switched to PPK. We were using prosumer DSLR cameras on this system and achieved amazingly accurate results. So out of necessity, I found myself back in the hardware business!

In 2016 we set out to prove that accurate mapping could not be achieved with lower cost DJI drones using DJI cameras since we (like everyone else providing drone mapping technology) saw DJI as an existential threat to our business. We tested a few cameras with rolling shutters and, sure enough, the results were inaccurate and unpredictable. Then we tested DJI's new (at that time) X4s camera that featured a mechanical shutter mode. Much to our surprise, no matter how hard we tried, we could not get bad results with this new camera! DJI soon followed with essentially the same camera on the Phantom 4 Pro. It was obvious that those who did not embrace DJI were going to have a tough row to hoe.

DJI Phantom RTK with Trimble GNSS base station

The only thing missing from the low end DJI solutions was direct geopositioning. We spent about 6 months figuring out how to synchronize our next generation PPK system with these drones in a non-invasive manner. This led to the development of Loki, our PPK solution for low end DJI drones as well as prosumer DSLR cameras.

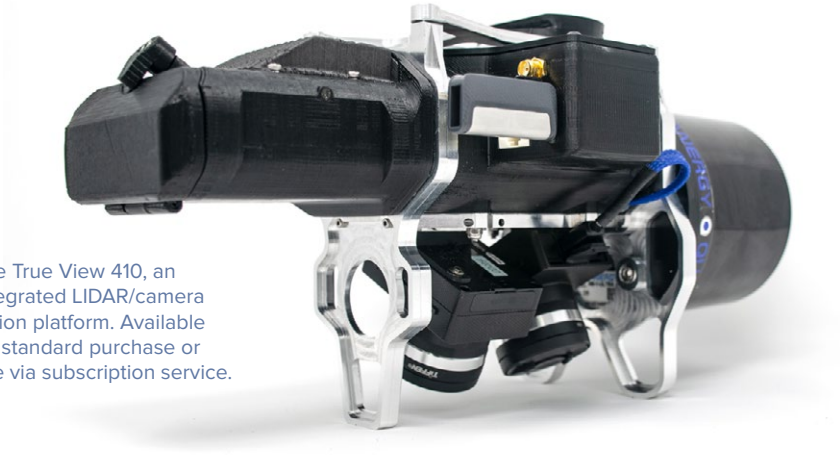
We have now released our True View LIDAR/Camera imaging system. This

is an integrated system of laser scanner and dual cameras that allows single pass collection of all of the data needed to produce a colorized point cloud as well as an orthophoto. We are also bundling in all of the software needed to process the raw data to finished products. We have even put a wrapper around POSPac, allowing this part of the post-processing flow to be integrated into our True View Evo software (a special version of LP360). Just last week we flew a small site for topographic analysis. From mission planning to delivering 1 ft contours was a total time of ½ day. This dramatic decrease in throughput time is a game changer.

LM: A game changer indeed! From which areas are you seeing the most interest?

LG: Our focus is on high accuracy mapping using rotary wing drones. This is an admittedly narrow area of the overall drone market. For example, a lot of experimentation is occurring in multispectral mapping, thermal imaging and other sensor payloads. While I am closely tracking these areas of drone mapping, we are sticking to the area where we have deep domain expertise.

There is still a lot of education to be done in high accuracy mapping. There is a school of thought amongst some practitioners that this work can only be performed by credentialed experts. We know that, other than proper FAA licensing (or equivalent outside the USA), any competent technician can learn to do high accuracy work. In fact, even very experienced persons such as those in my own company with a very long history in airborne photogrammetry are learning new things about these workflows every day.



The True View 410, an integrated LIDAR/camera fusion platform. Available for standard purchase or use via subscription service.

The primary interest I am seeing now on the photogrammetry side is for minimal on-site time. Clients would like to show up on site, fly the drone, pack it up and leave. They would really like to remove additional steps such as setting base stations, laying out control and any other operation that adds time or complexity to the on-site portion of mapping. This is leading to a new interest in Virtual Reference Station (VRS) solutions when a local VRS network is available and Precise Point Positioning (PPP) solutions run in real time or post-processed mode for remote use.

Unfortunately, the same clients who want to go baseless want the highest accuracies! No matter what purveyors may advertise, PPP solutions are going to be hard pressed to consistently give results with better than around 6 cm root mean squared error (RMSE) in vertical. Most of our customers in the USA are shooting for the magical 1/10 foot (about 3 cm). So, again, we are faced with a lot of education about what is achievable using a specific type of technology. As a result, we are spending a considerable amount of time developing best practices for various mapping scenarios.

I believe that drone lidar is close to "crossing the chasm" in terms of customer acceptance. We started reselling lidar solutions from YellowScan (Montpellier, France) in 2018 to fill this gap in our offerings. Sites smaller than about 1,000 acres (400 hectares) are ideal for drone lidar rather than a manned aircraft system. These projects range from repetitive work such as open pit mine sites to time-limited new land development. Today's topographic mapping is often performed with boots on the ground using GNSS rovers so the return on investment for drone lidar is immediately clear.

LM: Any exciting trends of note? Who's "doing it right"?

LG: To me the big opportunity and challenge is the fact that the need for longer range lidar and positioning technology for vehicles (for both autonomous operations and automated safety systems) is driving an accelerated development of technologies. I visited the Consumer Electronics Show (CES) in January with the sole purpose of evaluating new trends in LIDAR technology. I talked with over 30

vendors and still did not cover all of the offerings. While most of what was on display was "vaporware", the energy and money going into compact, long range lidar is going to result in revolutionary changes for drone mapping. For example, there are several companies offering doppler-enabled systems that can measure the relative speed between the vehicle and target. I am not sure how this might apply to our business area but I know someone will come up with a very clever use case.

We are within 12 months of having lidar systems with no moving parts (if we consider micro-electro-mechanical system, MEMS, components as non-moving). This is exciting because it promises to reduce both the mass ("weight") of small lidar systems as well as their power requirements. I think we will soon see small lidar systems with true ranges (say from 10% reflective surfaces) of 250 meters. When you consider that the ubiquitous VLP-16 has a useful range of no more than 50m (though it advertises 100 m!), you can see what a game changer this will be. Several manufacturers are hedging their bets and looking at mapping as a secondary market to automotive. These vendors (for example, Cepton, LeiShen Intelligent System Co., Quanergy and others) recognize that features such as multiple return capability are a non-negotiable requirement for a mapping LIDAR and are addressing these auxiliary requirements.

The other very exciting thing I see happening is a very big push to reduce the cost and complexity of multifrequency GNSS receivers. There was an announcement by u-blox (a major GNSS supplier to the automotive industry) of a new multifrequency, multi-constellation GNSS chip set for around US $200. While several startups have attempted to build low cost GNSS capable of RTK/PPK centimeter-level performance, none have hit reliability sufficient for kinematic mapping. This new offering from u-blox is going to dramatically change this landscape. We will see complete base/rover kits for under US $2,000 within the year.

> "We will see complete base/rover kits for under US $2,000 within the year."

Low cost inertial measurement systems (IMS) and Attitude, Heading Reference Systems (AHRS) are already available and are rapidly improving in accuracy/precision. Currently the most expensive support component in a drone lidar system, these systems are descending below US $3,000 for a unit with sufficient accuracy to be used in low altitude lidar. Right now Inertial Navigation System (INS) processing software remains the sole obstacle to a low cost position and orientation system (POS). I would guess that within this year, a project similar to RTKLib will evolve to address this gap.

Without a doubt, complete drone lidar systems will see an order of magnitude reduction in cost within the next two to three years. At that point, we will see fused imagery/ lidar as the standard for all drone mapping. Exciting times, indeed!

LM: Any ongoing challenges or concerns?

LG: As I have already mentioned, the biggest challenge I see right at the moment is effectively educating everyone involved in the drone mapping chain. End users of the products that can be produced from drone mapping platforms need to know how to select the technology appropriate for their requirements as well as have a fundamental understanding of accuracy and precision.

Service providers really need to understand how to use drone mapping systems (photogrammetric and lidar), the measures (pun intended) they need to take to achieve a target accuracy and how to achieve consistent results.

We all need to learn to speak in plain language so that all involved fully understand how to specify and respond to work. For example, most customers for stockpile inventory work want to speak of error in terms percentage or cubic meters/yards of error. They have a difficult time understanding how a specified vertical error expressed in RMSE relates to their needs (indeed, so do most providers of the service, for that matter!)

We are still in the early adopter phase of this business. We do not really know enough yet for anyone to have any significant "secret sauce" that provides some huge competitive advantage. We need to widely share information so that the ultimate buyers of this technology can feel comfortable in moving from their current solutions to ones deployed on drones.

Overall, I am very optimistic about the future of this business. We are in the midst of a revolution in how small mapping projects are performed and it is very exciting to be a part of the change.

LM: A revolution, indeed! Thanks again, Lewis.

GNSS/IMU the heart of lidar integration

Geodetics prospers through science and balanced customer base

Geodetics, Inc. is a technology company based in San Diego, California. Its visionaries are scientists who are experts in geodesy and GNSS/IMU integration. Indeed, they have contributed three articles to LiDAR Magazine*[1-2-3]. Founded with commercial markets in mind, the company next prospered as a defense contractor and has always been willing to diversify. When UAV systems for photogrammetry and lidar entered the market-place, enabled by Part 107, its time had come. Managing editor Stewart Walker visited Geodetics to find out more about the company's path through the years. Here is what he discovered.*

1 Moafipoor, S., L. Bock and J.A. Fayman, 2017. LiDAR/camera point & pixel aided autonomous navigation, *LIDAR Magazine*, 7(7): 36-47, October/November.
2 Nagarajan, S. and S. Moafipoor, 2017. A new approach for boresight calibration of low-density lidar, *LIDAR Magazine*, 7(8): 40-43, December.
3 Moafipoor, S., L. Bock, and J.A. Fayman, 2018. Realizing the potential of UAV mapping, *LIDAR Magazine*, 8(6): 40-45, November/December.

BY DR. A. STEWART **WALKER**

Geodetics' beginnings and the forces that directed it

Geodetics, Inc. is housed in an industrial park tucked between La Jolla and the Pacific Beach and North Claremont neighborhoods of San Diego, just to the east of the I-5 freeway. I was hosted by president and CEO Dr. Lydia Bock, vice president business and product development Dr. Jeff Fayman, and chief navigation scientist Dr. Shahram Moafipoor.

Fayman provided a succinct history of Geodetics. The company was founded in 1999 with the idea of assembling a group of scientists from academic settings in precise GPS positioning to develop products and services for various civilian markets. Their field was geodetic science, hence the name Geodetics. One of their early endeavors was CR-NET, a

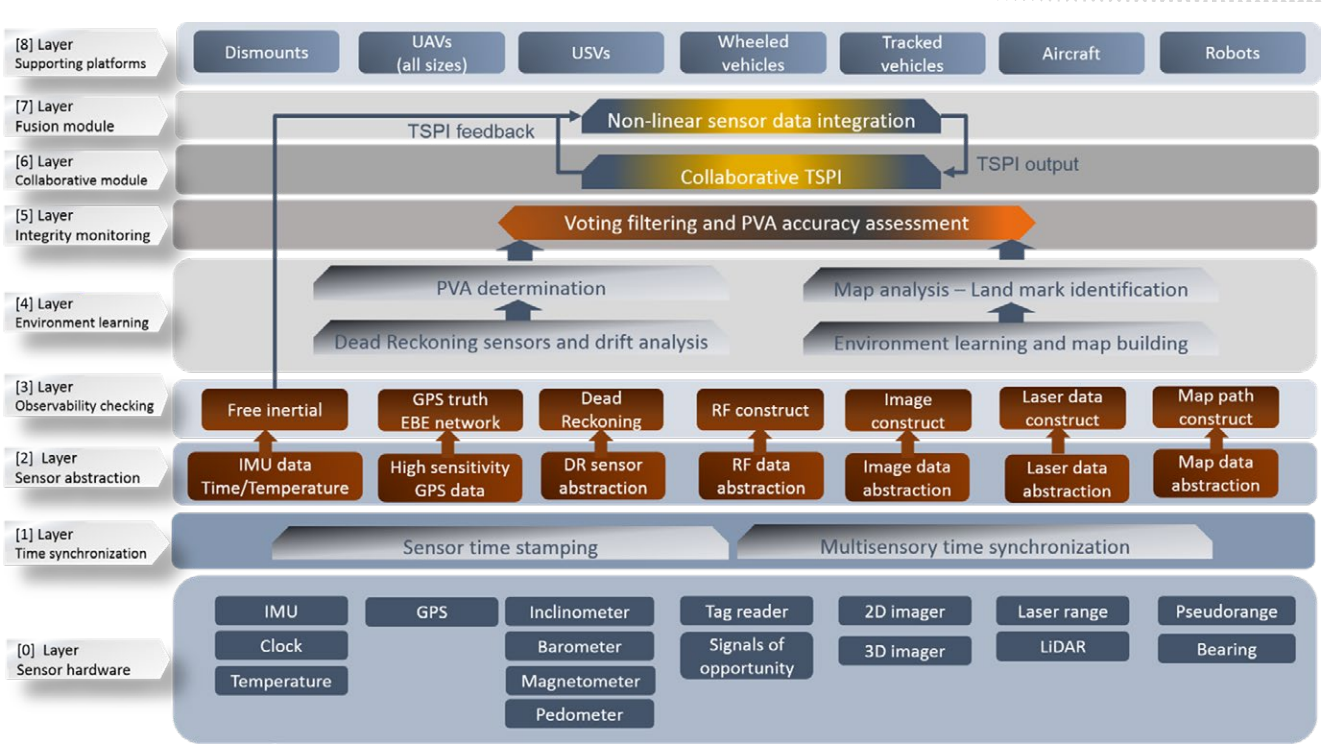


Figure 1: Geodetics's multisensor integration architecture. This schema of the company's multilayered approach helps explain how it can apply its expertise, starting from its GNSS/IMU roots, to a broad range of applications.

reference network monitoring system for large GPS networks, the first of its kind in the world and still in use today. In 2000 the US Department of Defense became aware of the company. DoD's staple pursuit was ever higher precision in positioning, navigation and timing (PNT), for anything that moved, whether on land, at sea, or in the air—including, as time passed, UAVs. Geodetics gradually transitioned, therefore, into defense technologies, expanding from algorithms and science to various turnkey systems. The foundations of PNT are GPS, GNSS and IMUs. Accepting that many companies do similar work, Fayman argued that Geodetics's unique contribution is to exploit its GNSS/IMU core competence as the foundation of larger capabilities. Interesting applications include systems for relative navigation, mobile mapping, sensor fusion, GPS-denied positioning (**Figure 1**). GNSS/IMU is the expertise, but that's just the starting point.

Market diversification

As time went by, Geodetics' products evolved into turn-key hardware and software navigation solutions. In 2008, moreover, defense expenditure waivered due to sequestration. Geodetics, therefore, decided to diversify its portfolio to ride the vicissitudes of defense funding. An emerging market became part of the vision: the prices of UAVs were falling and their use was becoming more widespread and no longer restricted to defense applications. Fayman felt that part of AUVSI's territory had been ceded to Commercial UAV Expo, a sign of increasing UAV activity in the commercial world. Then they saw a sensor that had started to become reasonably priced—lidar! The downward driver on prices, of course, was autonomous vehicles (AVs), i.e. vehicle manufacturers were investing heavily in the development of lidar technology and the large volumes facilitated economies of scale. Geodetics was able to piggyback on these trends. But the real "game changer" was the transformation of the FAA regulations with the introduction in 2016 of Part 107 to manage the use of UAVs in civil airspace for commercial purposes, whereas the process for waivers and exemptions under Section 333 of the FAA Modernization and Reform Act of 2012 had been rather unsatisfactory since the first approvals were granted in 2014. This trifecta of lower cost UAVs, lower cost lidar, and a more appropriate regulatory environment enabled Geodetics to

Figure 2: Fighter aircraft refueling from Boeing KC-46 air tanker. Geodetics provides the relative navigation system, including GNSS-denied capabilities.

prosper: mushrooming UAV applications would be the hedge against fluctuations in the defense industry, so Geodetics invested heavily in building out the Geo-MMS product line, the company's mobile mapping system. Geo-MMS started as UAV-lidar only, but expanded to include photogrammetric image acquisition with low requirements for overlaps and sidelaps, including RGB and multispectral sensors to enable colorized point clouds. The company's roadmap includes hyperspectral and other sensors, for example for methane detection. The company considers to be within its ambit applications that previously were prohibitively expensive, such as BIM, surveying, oil and gas, environmental, infrastructure, forestry and archaeology.

While Geodetics successfully moved into several of these markets, defense budgets recovered and the company's defense business has taken off too. The company benefits from cross-pollination between them and technologies can be used in both. Lidar has been integrated on UAVs operated by US defense forces. Working in the GPS-denied and autonomous vehicle navigation areas are other big markets, where Geodetics uses multi-sensor fusion as the keystone of its solutions. One of Geodetics's claims to fame is its success in relative navigation for mid-air refueling (**Figure 2**) and autonomous ship-board landing. These solutions are based on GPS, but it can be replaced when the need arises by other sensors that can generate relative positions, for example lidar or cameras.

The crux of the company

Bock's PhD was in material engineering at MIT, but her master's was in civil engineering at The Ohio State University, where she was exposed to the university's excellence and vibrant activity in geomatics. After graduating, she worked for Raytheon then SAIC, i.e. leading defense contractors, before founding Geodetics. It briefly occupied an office on Pearl Street, La Jolla, before moving to its current location, which was selected as it was near the center of gravity of the principals' homes and because there was access to the roof to mount the antennae and other equipment that would be needed for GNSS work. The company was able to double its space, two years after moving in, by adding the office next door and has up

to 30 employees—the number grows when there's a need to manufacture for defense contracts.

Fayman, a San Diego native with BA and MSc degrees from San Diego State University (SDSU) and a PhD in computer science from Technion Israel Institute of Technology, joined the group in 2001 and Moafipoor, who earned his PhD in geodetic science from The Ohio State University. The company is privately held, so it can work on whatever it finds interesting. The foci are innovation and new products that take science into the real world. The team consists of scientists, i.e. their profession gives them a major advantage over GNSS/IMU integrators or, indeed, less able firms that just package lidar with UAVs.

We probed this more deeply, exploring how Geodetics differs from other players. Fayman explained that Geodetics was one of the first developers of epoch-by-epoch RTK. Bock explained the role of Geodetics in the development of the RTK approach to GPS positioning, using the lambda method developed by Professor P.J.G. Teunissen at Delft University of Technology in the 1990s. The company developed epoch-by-epoch RTK for kinematic ambiguity resolution, its own variants of the Kalman filter and relative extended Kalman filter, and the tight coupling of sensors. Geodetics builds its own hardware and argue that it exploits the rawest form of data from the sensors and molds it to create the optimal solution: it gains flexibility by working with the raw GNSS measurements, not the position computed by the receiver; thus it is immediately above the sensor, GNSS and IMU manufacturers in the food chain. Bock said, "The idea of our building this here is that it gives us flexibility, adaptability, and the ability to innovate." Fayman exemplified, "We can respond to our customers. If they have a question about Kalman filter tuning, who better to ask than the people who developed it?" When customers see Geodetics's Assured PNT suite of defense products and request changes, Geodetics can deliver. Geodetics purchases sensors, as well as GNSS and IMU components, from their manufacturers.

The company has plenty of customers now and has enjoyed significant growth over the last few years. It continues to improve and respond to feedback from customers—new ideas are implemented every month. Fayman concurred, arguing that the UAV/lidar/sensor-fusion market is a large one, for which competition is a boon, ensuring good products at lower prices. Geodetics experienced its pain 15-20 years ago, when it began in GPS/IMU, so it has extensive experience. It wants to bring more capabilities to its customers, through better products at lower prices, while continuing to innovate. The scientists communicate energetically, using academic journals[4] as well as vehicles such as *LIDAR Magazine*. Indeed, they have a blog site (https://geodetics/why-geodetics/blog/) to encourage the two-way communications. Bock emphasized, "We want our customers to feed back, so we can accommodate them." Fayman referred to the dichotomy of

Figure 3: Geo-MMS LiDAR product mounted on DJI M600 UAV. Clearly visible is the two-meter carbon fiber boom of the dual-antenna interferometer for estimation of heading, with GNSS antennae mounted on each end. Above the aircraft are three more GNSS antennae. Below the aircraft is the Velodyne VLP-16 lidar sensor (Geodetics can supply other sensors according to customer requirements), behind which is the cuboid shape of Geodetics's Navigator system.

4 For example: Moafipoor, S., L. Bock and J.A. Fayman, 2017, Autonomous UAV navigation based on point-pixel matching, *ION Pacific PNT Conference, The Institute of Navigation, Honolulu, Hawaii, May 1-4*, unpaginated CD.

Figure 5: Point&Pixel, which includes both lidar and camera. This close-up view shows, from left to right, the two-rail system with clamps to accommodate the boom of the dual-antenna interferometer; the Navigator system mounted rigidly to the rails; Velodyne VLP-16 lidar sensor, mainly hidden behind the Navigator; and Sony camera in vertical position. Point&Pixel is also available with a multi-spectral option.

Figure 4: GeoPhotomap. In this view, the Sony camera, mounted below the Navigator system, is pointing horizontally for tower inspection, but the user can rotate it to the vertical for nadir scanning in seconds.

defense and commercial development cycles, the former needing innovation continuously and the latter, rather slower. He quipped, "In the commercial market, if it's shipping it's obsolete. In defense, if it's in initial design review, it's obsolete." The Geodetics team enjoys defense business, with its interesting applications and the sense of supporting the nation's military, but conceded that the commercial UAV business is fresh and stimulating, full of potential.

Geodetics, furthermore, has discovered local synergies. There is a manufacturer of multispectral sensors across the street from Geodetics, as well as two AV companies. Geodetics feels some excitement about automotive applications, for which the company's special skills position it very well. We talked about creative market players such as Cepton, Ouster, Quanergy and Velodyne LiDAR. Solid-state lidar is central in automotive applications and is coming to UAVs. Geodetics admires the capabilities of these companies as well as mainstream sensor suppliers such as SICK, FARO, RIEGL and Teledyne Optech. Moafipoor added, "We like all these laser companies and one of our jobs is, every day, just checking out their sensors." Geodetics was disappointed not to be involved in the DARPA Challenge events more than 10 years ago, which were such a catalyst in the development of lidar for automotive purposes and, as a result, for more efficacious TLS and MMS applications. Fayman reiterated, "It's changing all the time and all the companies are getting better every day."

Geodetics uses Velodyne lidar sensors (**Figure 3**), which it regards as providing a good value for the company's target markets and is currently adding several new LiDAR sensors to its product

line including Quanergy and Optech. Numerous GNSS and IMU components are available for consideration for each project or product, the range being all the greater because Geodetics uses the GNSS sensors as measurement engines and process the raw data with its own GNSS/Inertial algorithms. One of Geodetics's recent additions is the use of dual-antenna interferometers for the estimation of heading on its Geo-MMS product range. Cameras are a relatively new addition and the product range reflects this with the addition of Geo-Photomap (**Figure 4**) and Point&Pixel (**Figure 5**). The rationale is to use precise positioning to reduce the need for ground control points and large overlaps, i.e. to make the UAV data acquisition mission more economical in terms of greater coverage per battery. MSI imagery is used to colorize the lidar point cloud or generate orthophotos. Geodetics has found a company that offers an MSI lens for existing cameras that they already sell with RGB. "Everything is modular now," explained Bock. Much as Geodetics has been proselytizing its off-the-shelf Geo-MMS product line, the company builds to order if that is what the customer requires. They received many requests for MSI and colorized point clouds, so it was natural to add these features. "We're bringing these particular capabilities to a market that's just opening up—drones," confirmed Fayman. "The applications are just going to continue to grow and we will continue to add capabilities." Since they start closer to the sensor and write their own software, they are well placed to be flexible. "We've found our niche here in San Diego and we enjoy what we do," enthused Fayman. "We are a very happy company," agreed Bock. "We don't have debt."

> "We've found our niche here in San Diego and we enjoy what we do. We are a very happy company."

The geodetics team reflected fondly on their mid-air refueling triumphs. There are applications in both commercial and defense. Autonomous ship-board landing is but a step further. They continue to supply products to their military customers for all sorts of applications. They write complex proposals. Often they participate by responding to RFPs from prime contractors. "We have our feet in both realms," said Fayman. As noted above, the applications are growing in number and are becoming more and more interesting. The company's revenue stream encompasses both defense and commercial. The balance or mix changes through time. "Both markets are expanding and the boundary between them is gray—they are really converging, these two markets," said Bock. "Defense is moving to using our commercial products." This also ensures more rapid development.

One of the reasons Geodetics located in San Diego was a wish to work with UCSD. The company also collaborates with San Diego State University (SDSU), where its work with Professors Allen Gontz and Tom Rockwell in the university's Department of Geological Sciences department has earned considerable publicity[5]. SDSU contacted Geodetics, not far from the campus, for help in applying geodesy to earth sciences. The area of interest was the San Andreas Fault and the goal was to identify precursors of earthquakes. Geodetics went out with the university team and performed a precise lidar survey at the very end of the Fault, in the area of Mecca, California, on the northern shore of the Salton Sea. Geodetics has consequently been invited to do further work in several countries.

The products today

The Assured PNT family is Geodetics' commercially available product line for defense. It includes multiple GNSS/IMU solutions focused on particular applications, for example Geo-APNT, Geo-iNAV, Geo-RelNAV, Geo-hNAV, Geo-Pointer and Geo-TRX (**Figure 6**). Geodetics offers them to defense

5 https://www.businesswire.com/news/home/20180620005279/en/San-Diego-State-University-Researchers-Track-San

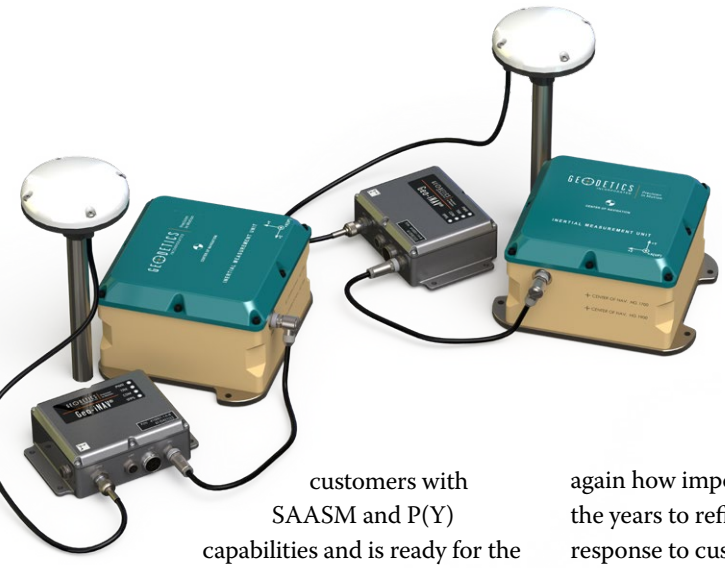


Figure 6: Members of the PNT Assured family of commercially available products for defense customers. Clockwise from lower left: Geo-APNT, Geo-RelNAV, Geo-hNAV, Geo-Pointer and Geo-TRX.

customers with SAASM and P(Y) capabilities and is ready for the forthcoming military (M-code) GPS. On the commercial side the product offering is the Geo-MMS family, i.e. mobile mapping, consisting of Geo-MMS LiDAR, Geo-Photomap, and Point&Pixel (**Figures 3, 4 and 5**). This family is growing, of course, since its main market is UAVs.

The company also offers a number of software products, such as RTD-Pro, the current incarnation of the CR-NET mentioned at the beginning of this article.

A support engineer at Geodetics brought some products into the room for me to admire. Moafipoor showed me Geo-MMS LiDAR, emphasizing again how important it had been over the years to refine the products in response to customers' feedback. They call their electronics box the Geo-MMS Navigator. It contains the GNSS receivers, IMU, radio and various subsystems. "The difference," Jeff reminded me, "is that we build the electronics that go into it—we don't buy them from a GNSS/IMU supplier." The goal is easy data collection. The system weighs 5-6 lbs. including two-meter boom, mounting assembly, Geo-MMS Navigator, lidar and camera, so they use the DJI M600 Pro UAV and other high lift capacity drones are available. Moafipoor, pithily referring to the output as "image with attitude", described the system as a "piece of art", a brilliant combination of components, beautifully integrated with the UAV. Data are downloaded to a MicroSD card and can be ready for use 20 minutes after flight. Geodetics also has a real-time capability: they download what they regard to be of greatest value to the user, i.e. a point density map, showing the density of lidar collection as it varies across the project area. The user sees this being built up as the UAV flies, assesses whether the mission goal has been accomplished, or decides on a further flight while still in the field. Geo-MMS includes its own mission planning software, so there is no need for their users to purchase licenses for third-party products. There are no annual license fees, because Geodetics develops the software and doesn't have

to pay third parties. Geo-MMS starts below $50K, surely economical given the expertise embodied in it.

Fayman mentioned calibration of the Kalman filters, but they have eliminated most of that via by the dual antenna interferometer. This involves a 2 m folding boom, made of carbon fiber, fixed to the UAV at any direction relative to the flightline. The GNSS antennae at its ends, plus the software, enable the UAV's heading to be estimated very accurately indeed, starting before take-off. The Geodetics team was adamant that the system does not change after factory calibration. Thus the customer has minimal need of special flight patterns for calibration purposes. The UAV has two rails, the relationship of which to the UAV is calibrated in the manufacturing stage (**Figure 7**). This is like determining the lever arm and boresighting of the rails, all in the factory with little for the user to do. The payload is rigidly attached to the mounting assembly, which in turn is rigidly attached to the calibrated rails. Hence the payload can be changed but, owing to the rigid connectivities, the calibration will not change. Geodetics has is proud of this intriguing feature, the culmination of many years of intense work. Fixing the boom to the UAV is very simple (**Figure 5**). The user can switch the UAV's camera from horizontal to vertical in seconds. The UAV just takes off and the Kalman filters work! Indeed, Geodetics uses the same rail system on its vehicle mount, so the same principles extend to data acquired on the ground. It is possible, therefore, to remove a payload from a UAV and attach it almost instantly to a vehicle. Geodetics flies UAVs over a calibrated test field near its office and has confirmed the constant state of the calibration—the firm has the courage of its conviction that is has found the ideal mechanical solution, so that the relationships between the navigation system, the lidar and the camera stay the same.

Altogether the system has five GNSS antennae (**Figure 3**). The Geodetics solution is autonomous with respect to the aircraft's autopilot, not reliant on the UAV manufacturer or the GNSS being used to control the UAV. The latter flies way points—that's all. Geodetics uses its own high-end dual-antenna interferometer and high-end IMU. Fayman reiterated the advantages of the boom: heading known before take-off and known calibration mean minimal need to turn Kalman filters in flight, saving precious minutes of battery life. This independence of the Geodetics solution from the UAV means they can easily fit their system to US-built UAVs as well as those from China.

Geodetics—the future

The firm's future directions include further innovation and more UAV markets, both defense and commercial. The UAV revolution provides opportunities to address new applications as well as provide more economical solutions for existing ones. As UAVs proliferate, Geodetics will endeavor to remain in the forefront. The scientists will exploit new technologies and inventions. They will continue to demonstrate their class by publishing academic papers. The company anticipates an exciting future.

Dr. A. Stewart Walker is the Managing Editor of the magazine. He holds MA, MScE and PhD degrees in geography and geomatics from the universities of Glasgow, New Brunswick and Bristol, and an MBA from Heriot-Watt. He is an ASPRS-certified photogrammetrist.

Figure 7: The two-rail system that enables the Geo-MMS systems to be rigidly mounted on either a UAV or a ground vehicle.

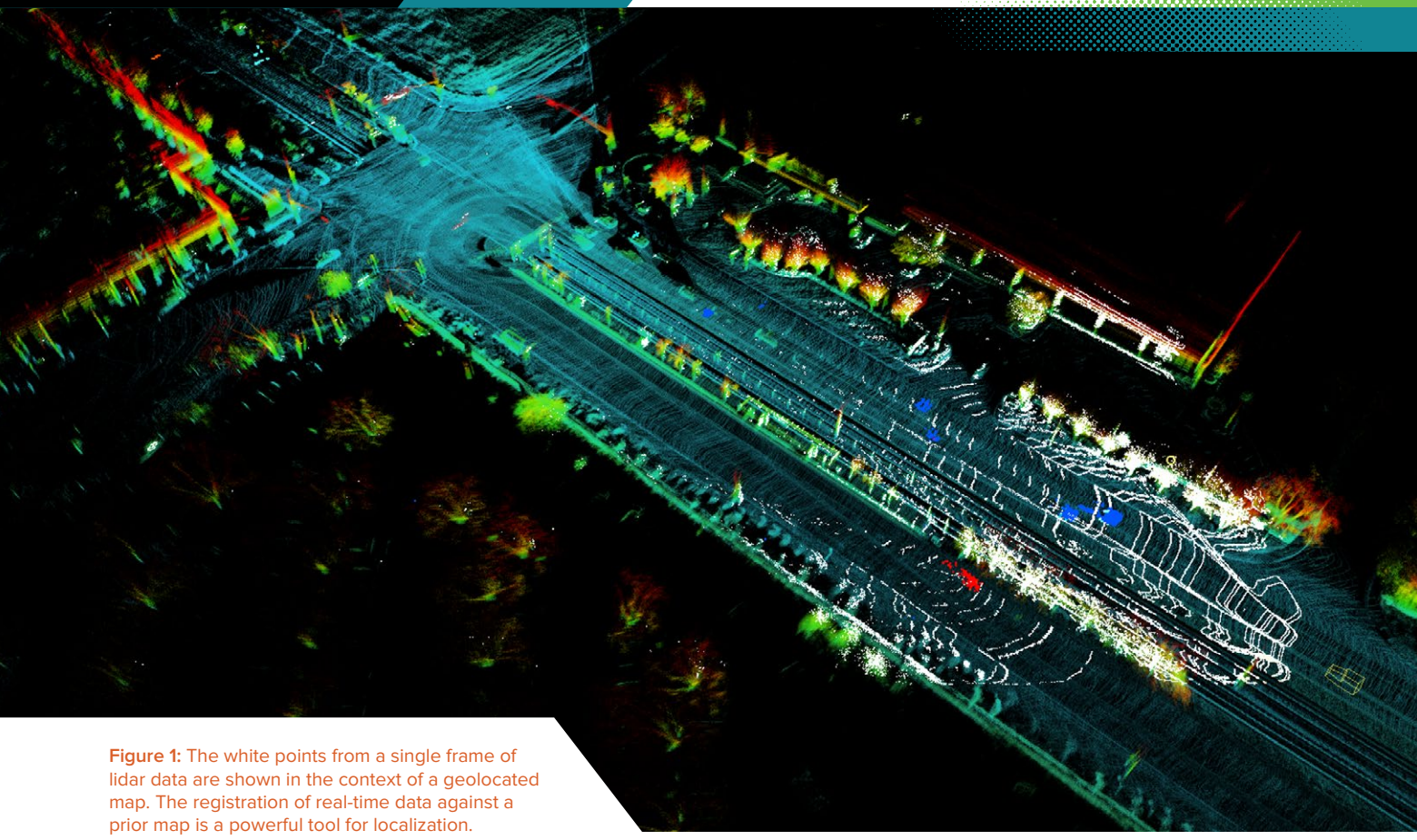


Figure 1: The white points from a single frame of lidar data are shown in the context of a geolocated map. The registration of real-time data against a prior map is a powerful tool for localization.

Blackmore leads the way with FM lidar for AV applications

Measuring velocity on every data point

Perception for any robotics task involves both the inference and prediction of reality from a set of imperfect sensors. All sensors seek to measure that reality to inform perception. Cameras, for example, produce densely sampled data in angular coordinates. At the individual pixel level, however, the data is nearly meaningless, so computer vision algorithms operate on patches of pixels to accumulate meaning. Radar provides a different slice of reality by directly measuring range and velocity, but with very coarse angular resolution. To complete this puzzle, lidar's three-dimensional acuity is widely recognized as indispensable for safe autonomous navigation. Localization against pre-existing maps is a standard use-case for lidar data (**Figure 1**). However, due to its limited range, lidar has not been more widely adopted for broader perception tasks such as object detection and tracking. The unique advantages of FM lidar for object detection and tracking is poised to expand how lidar is utilized.

Frequency modulated, continuous wave (FMCW) lidar relies on coherent detection, or the detection of

BY STEPHEN CROUCH

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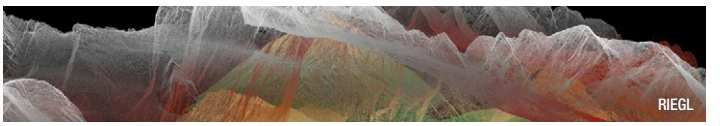

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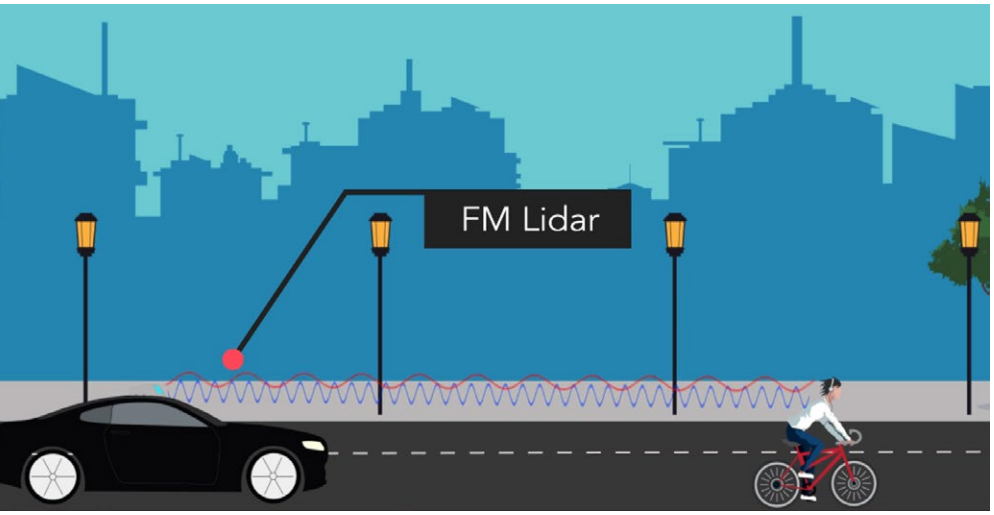


Figure 2: An FM lidar transmits continuous wave (CW) light to a target (red). The backscattered light (blue) may be Doppler-shifted depending on relative motion between the sensor and an object such as the cyclist. The shift is measured in a handful of microseconds and exists as a unique velocity measurement on every single point in the point cloud.

backscattered laser radiation, via the optical interference of that signal with a local copy of the optical source (**Figure 2**). Coherent detection offers both interference immunity (solar and lidar-to-lidar) and single-photon sensitivity. This combination enables operation to distances beyond 200 m within the optical power constraints of integrated photonics platforms. Perhaps the most compelling attribute of coherent detection is that Doppler shifts of the reflected signal can used as high fidelity estimates of radial velocity.

In the context of autonomous vehicle (AV) sensor packages, radial velocity measurement has hitherto been limited to radar platforms. Typical automotive radar carrier frequencies (24 or 77 GHz) lead to Doppler shifts in the kilohertz frequency range. To measure these frequency shifts, radar signals must be processed over tens of millisecond intervals to achieve adequate frequency resolution. While the range resolution of such radar signals can be a few centimeters, practical phased array apertures, even with MIMO (multiple-input and multiple-output) techniques, limit angular resolution.

FMCW lidar operating at 1550 nm is essentially a radar system operating at a 193 THz carrier frequency. This carrier frequency allows very high angular resolution—the laser beam divergence can be <0.01 degrees—as well as an extreme sensitivity to the Doppler effect. In fact, it's possible to achieve velocity

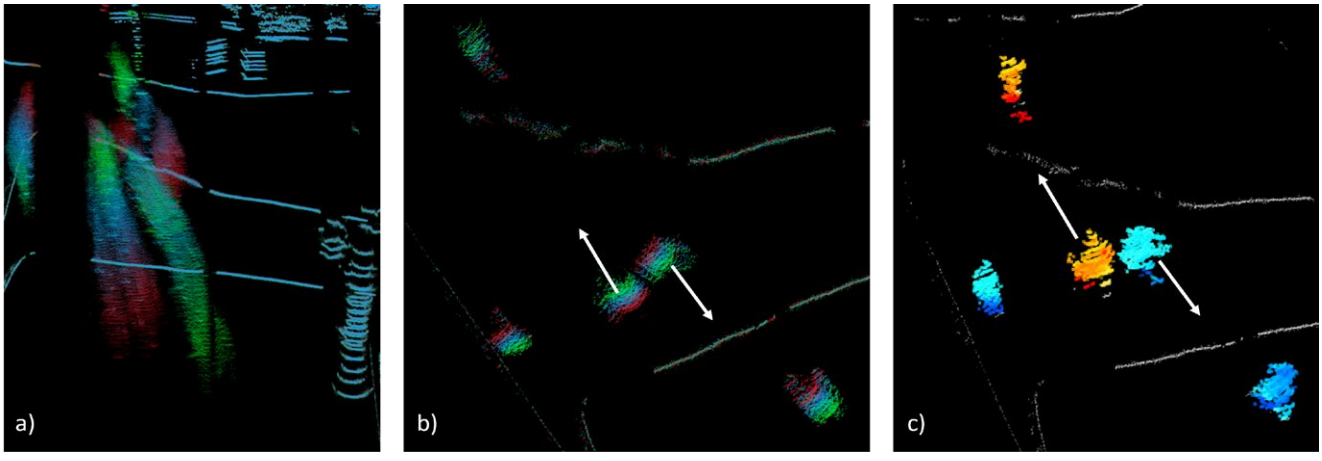


Figure 3:
a) Data from Blackmore's LDP lidar product. A set of points colored by 'age' demonstrate pedestrian tracks in an intersection. Red is older, green is newer.

b) An overhead view of age-colored points shows two pedestrians passing. Velocity derivation of the pedestrians requires comparison of the points over time to infer motion.

c) Doppler colored points of a single FM lidar frame clearly show pedestrian velocity on each data point. Furthermore, limbs and torso motion are delineated.

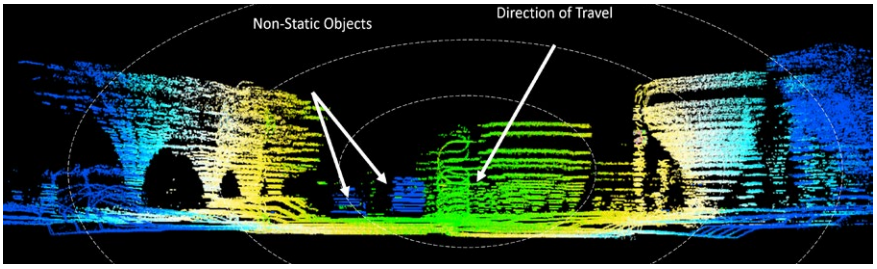


Figure 4: The color displayed in a single frame of Blackmore FM lidar data is determined by raw velocity. Green indicates the fastest approaching velocity with dark blue the slowest. The fastest relative velocities are shown in the center of the frame in the direction of travel. Away from the center, the relative velocity decreases as the projection of the true velocity on the beam direction. Some moving cars in the scene show different velocities. Such data sets can be fit to measure true global velocity independent of other sensors.

resolution comparable to automotive radar at processing intervals of only a few microseconds. The combination of these effects leads to a much higher resolution data product with much lower latency. The result is a high resolution, velocity-enhanced point cloud—a sort of 'radar on steroids.'

FM lidar improves the usefulness of conventional lidar data and streamlines the automation of general AV data annotation. By fusing velocity-enhanced lidar data with camera and radar data, moving objects are more accurately resolved at finer time scales and longer ranges. Offline, this reduces the need for manual annotation of data sets—an expensive and unscalable process that will fail to keep pace with (and extract value from) AV data produced by large fleet operations. For online perception, the fused data product has a multiplicative effect on signal confidence. Single-frame observations, poor visibility, or cluttered scenes all benefit from FM lidar. For example, when several pedestrians are crossing paths, it can be very challenging to predict their separate and distinct paths. FM lidar helps to maintain distinct object tracks, and prediction confidence in cluttered environments (**Figure 3**).

In automotive scenarios, FM lidar point clouds include millions of independent measurements of velocity across the sensors' field of view (**Figure 4**). These data are used to produce an accurate estimate of vehicle velocity that are independent of INS solutions, wheelspin readings, or localization routines. This is achieved with remarkable efficiency, and without requiring additional analysis such as frame-to-frame point association, feature extraction, or surface normal estimates. Velocity state estimation from FM lidar data improves SLAM routines and can also reduce INS hardware or high-definition map requirements. The same velocity estimate can help refine high-resolution mapping products and allow for extremely cost-effective removal of transient objects from the map data. Both online and offline, FM lidar addresses several localization challenges.

Many have asked if lidar (especially FM lidar) will one day replace radar. Indeed, the velocity measurement of FM lidar is much lower latency than radar. Furthermore, the angular accuracy of FM lidar makes it an ideal reference

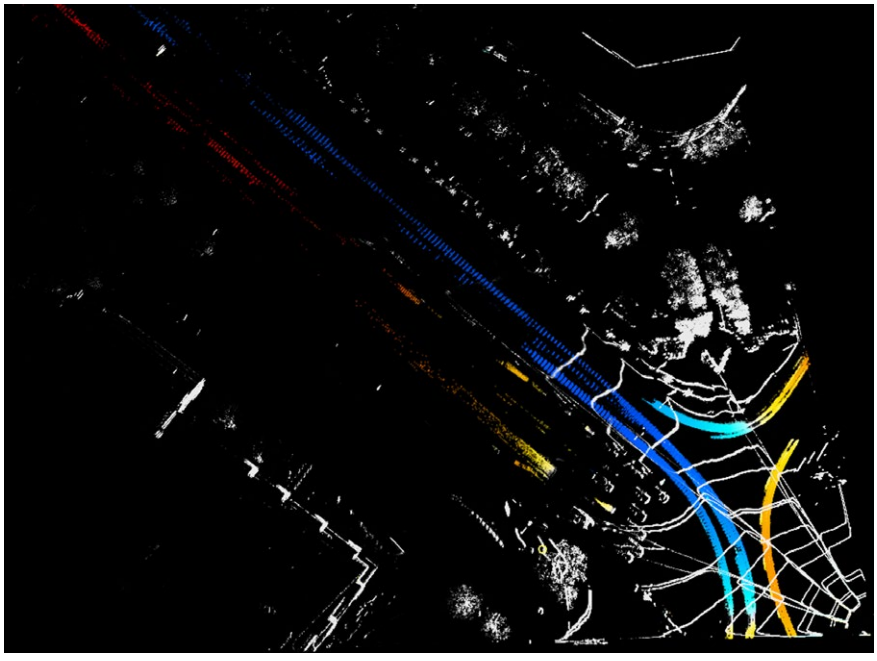


Figure 5: An overhead, Doppler-colored view of several seconds of data at a busy intersection in San Jose, California clearly shows traffic patterns. Cross-referencing this data greatly improves the ground truthing of radar sensors and streamlines the development of angle-of-arrival algorithms for such sensors.

Figure 6: Blackmore's Autonomous Fleet Doppler Lidar (above) and Lidar Development Platform (right) support customers in broader autonomy space with real-time, FMCW lidar. See *blackmoreinc.com* for more details.

sensor for the verification and testing of automotive radar detection and tracking algorithms (**Figure 5**). However, radar retains performance advantages in bad weather and sensor blockage. For personal vehicle safety, we don't have to choose between an airbag and a seatbelt. For autonomous driving perception, FM lidar and radar provide the same complementary benefits; why would you choose just one?

About Blackmore

Blackmore Sensors and Analytics was founded in 2016 with the mission of commercializing FMCW lidar technology and associated data products. The founding team has worked together on coherent lidar, primarily for U.S. DoD applications, for over 10 years and has contributed several academic papers in the field of coherent imaging. Today, the Blackmore team consists of over 75 multidisciplinary engineers and scientists to cover the broad needs of well-developed lidar products (**Figure 6**). Blackmore is based in Bozeman, Montana.

Stephen Crouch, co-founder and CTO for Blackmore Sensors and Analytics, Inc., has a decade of experience in coherent lidar and radar. Stephen completed his thesis, "Synthetic aperture LADAR techniques," at Montana State University; he also has a bachelor's in physics and a master's in microelectronics and photonics from Stevens Institute of Technology. He began his career as a radar systems engineer at Delphi Automotive.

Mandli, *continued from page 64*

We discovered several opportunities where the 3D Map was going to have an important role. In Advanced Driver Assistance Systems (ADAS), the Map would be a guide, giving vehicles a sense of place.

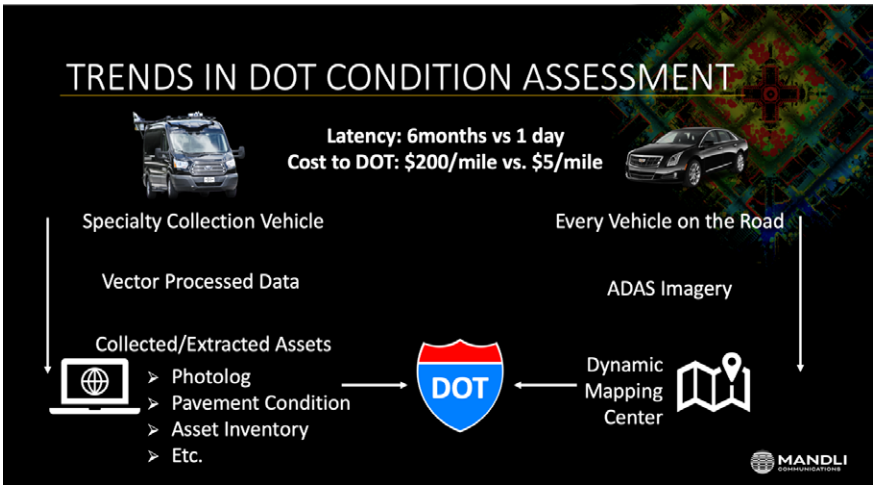
We specialize in 3D infrastructure and asset maps which can be used to describe the complications and other options that an ADAS system would need to consider outside of just driving a straight line. The data would also assist in the design and modification of infrastructure with new technologies and more relevant safety features.

The next step was to find a way to take the output from existing collection efforts and distill it into known formats like Autoware and OpenDRIVE. We also believe the Map can carry other relevant information related to safety and fuel efficiency. For example, a roughness index, the coefficient of friction and a safety confidence rating can be included in it. The knowledge of fiduciary signs that help give guidance and accuracy to location are another piece of the puzzle to be embedded in the Map for autonomous vehicles.

Do we have this figured out? To a degree. It gives us a revenue stream that should keep the company around for another five years. But, with great vision comes great understanding . . . of the next transition. This one is going to change our whole way of doing business. Again.

The Dynamic Map of the Future

The path to the Map is going to see major disruptions. It will become dynamic. It will update in real time. Those updates will come from the output of lane-keep sensor packages that actually use the Map. This is what companies like Mobileye have in mind, and with millions of systems already



> "With great vision comes great understanding... of the next transition. This one is going to change our whole way of doing business. Again."

in place, the writing is on the wall. Many of the automobile companies understand this methodology and are preparing by working with companies that can create sensor packages that keep a car in its designated place and update the Map instantly.

This will create a dilemma for companies that do cradle to grave transportation maps and asset inventory for government agencies. The need for direct-to-drive collection will diminish except for special projects.

For a DOT, instead of putting out a bid to have asset and pavement data collection done, and waiting six to twelve months for the results, they will have daily, if not hourly, updates on infrastructure performance and the cost will drop considerably. Most of the data will come from cars and trucks moving down the roadways.

As a company, we are adjusting to this new reality by learning to source data from many different origins including current competitors. There are attempts to control disparate datasets by hoarding and housing them in secure cloud environments to limit access. Our hope is that all public data can remain accessible and be used to create a new and enhanced understanding of resources needed for mobility.

In the end, there is still a lot of opportunity to distill pertinent information and knowledge from the data that is used outside of the logistics of the New Mobility ecosystem. Initiatives are being implemented to understand how the capacity of infrastructure can be maximized and monetized. One of my favorite examples comes from a white paper titled "*An action plan to realize the visions outlined in the Urban Mobility for a Digital Age and Great Streets for Los Angeles: 2018-2020 Strategic Plan*".[1]

LA County has basically defined how they will "Code the Curb" as a means to determine pricing for the use of public infrastructure. Geospatial data will become the cornerstone to the Mobility Data Specification (MDS).

It's a plan designed to deliver digital services and information to mobility providers at all levels. Any municipality could implement the features of this document to address the burdens and growth of the New Mobility. The study includes a look at Micro Mobility—scooters and bikes, Shared Mobility—ride sharing services, Mobility Hubs—Seamless Trips from Transit to last mile, and Transportation Happiness.

As dollars from parking and permitting continue to decline, this model will give a municipality a way to understand how they can monetize their infrastructure to produce new revenue streams.

The good news here is that there is a lot of curb to be coded and that will be a good source of work for my company well into the future. But it will be an evolution.

Ray Mandli is the President of Mandli Communications. Based in Madison, Wisconsin, Mandli is an industry leader in specialized highway data collection and the integration of 3D pavement technology, mobile lidar, and geospatial data collection equipment for various Departments of Transportation throughout the United States. Together with a suite of supporting GIS software and services, Mandli has enabled their clients to design, manage and maintain safe and efficient transportation infrastructure networks. Since 1983, Mandli has worked with over 30 states across the country, and has brought technology solutions to several nations outside of the U.S. Mandli functions exclusively from the Wisconsin office, and all data is processed and reduced in-house.

[1] http://bit.ly/Urban-Mobility-Action-Plan

Relevancy in the Age of Change

Recently I heard someone describe my organization as a 36 year-old startup company. That is a pretty good way to define what is going on here.

When someone new joins our team, I give them this advice: Find a way to remain relevant. Search for ways to explore your true potential. Push past the barriers that are limiting your current level of experience and understanding. In other words, try everything, fear nothing.

Today more than ever, remaining relevant has become the proverbial "drinking from a fire hose." The pace of innovation has surpassed anything that I have seen in my almost four decades in the Geospatial Data Industry. We are experiencing rapid change on a daily basis. New companies, new sensors, new ways to visualize, new markets and new delivery mechanisms. The need for the most current knowledge and understanding can sometimes become one of the biggest obstacles to starting a new project. One has to consider specializing in a single methodology and becoming an expert in it, while at the same time fearing that a chosen path could lead to obsolescence in just a few years. Change is a given.

The Ancient Art of Mobile Data Collection

When we added lidar to our mobile platform in 2007 and took on an incredibly large 90,000-mile project in early 2008, by default it put us on the map as a leader in this realm. There were very few practical solutions or tools available to us at the time. We had to innovate and build the collection vehicle, write the reduction platform software, and create a delivery mechanism for the 3D data.

Our organization grew by a factor of 5 in just six months. The experience nearly killed us. But what came out on the other side was an industry juggernaut. Since that early experience, we have gone on to collect and reduce hundreds of thousands of miles of 3D data for more than 30 state and local departments of transportation across the North American continent.

> "Our organization grew by a factor of 5 in just six months. The experience nearly killed us. But what came out on the other side was an industry juggernaut."

With the evolution and increased consumption of 3D data across the globe, other companies decided to capitalize on its value and joined the fray. Collectors like Google, Navteq/Nokia/Here, TomTom, Microsoft, Apple etc., advanced their platforms with the addition of lidar, and 3D data quickly became a commodity. To remain relevant, we had to look at raising the bar and finding a niche. The position we held in the DOT market turned out to be our best bet.

Fast forward to today. With hundreds of thousands of miles of processed 3D data in hand from large network-level DOT projects, we asked ourselves: could there be other ways to create value from such a large reservoir of data?

We had inquiries from the AI community. They were looking for large, quantified 3D datasets of roadways to test their automated analysis algorithms. It was obvious that most of this research was coming from people who were trying to make their mark in the arena of self-driving vehicles. We knew our role was never going to lead us to building an automated vehicle platform, but it became apparent that there was something new on the horizon. A need for a certain type of fuel that we had an abundance of: 3D Maps!

The opportunity opened our eyes to a plethora of new relationships and strengthened our established partnerships. But to remain relevant, we had to pick up our pace. Innovation in this sector was happening at breakneck speed and we found ourselves standing in the middle of several intersections. The only way to sort and absorb the massive knowledge stream was to find the common threads and stick to things to which we could add value.

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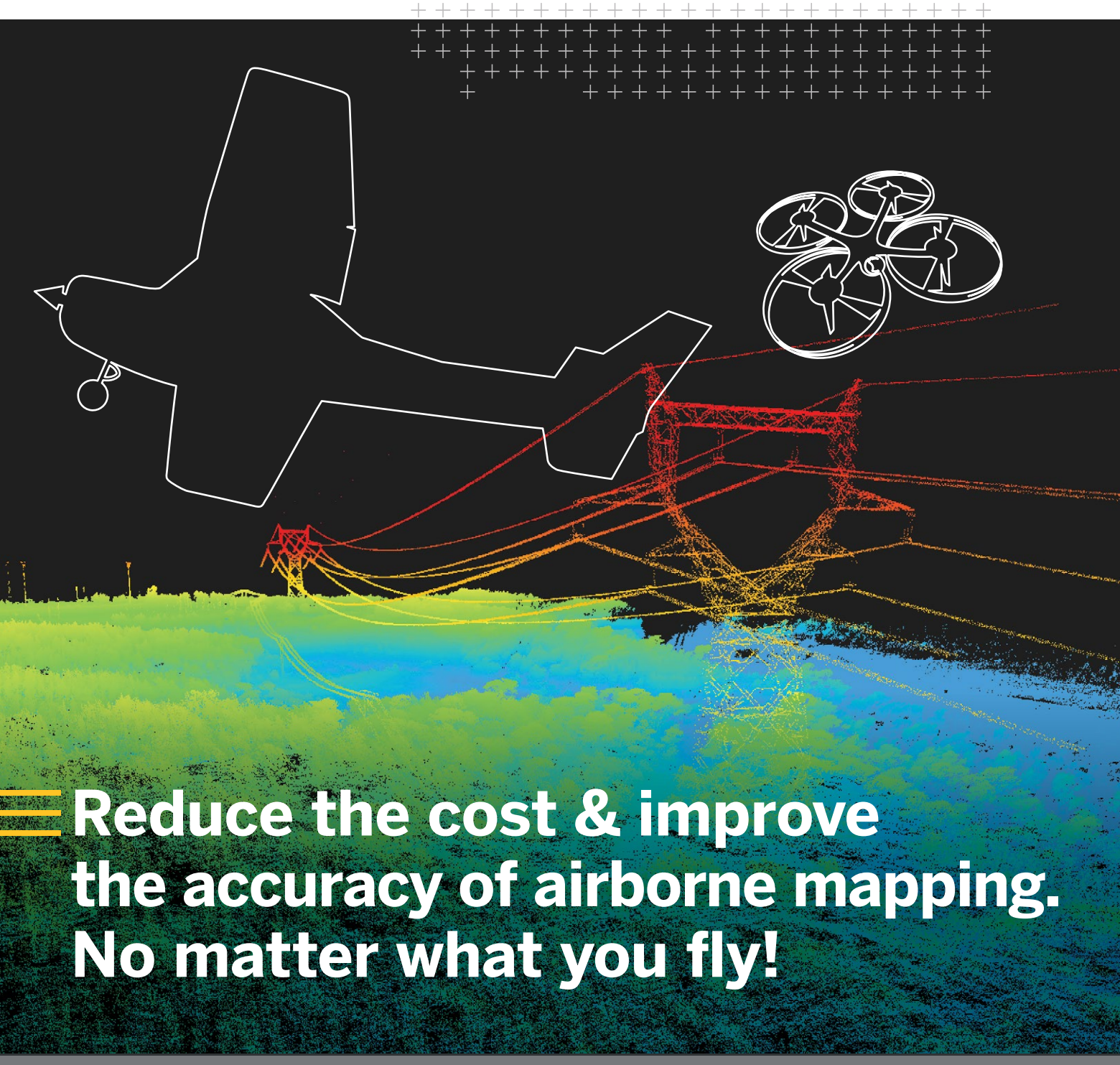

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