VOLUME 11 ISSUE 3

# LIDAR MAGAZINE

FALL 2021

## SPECIAL ISSUE

# SENSOR SPOTLIGHT

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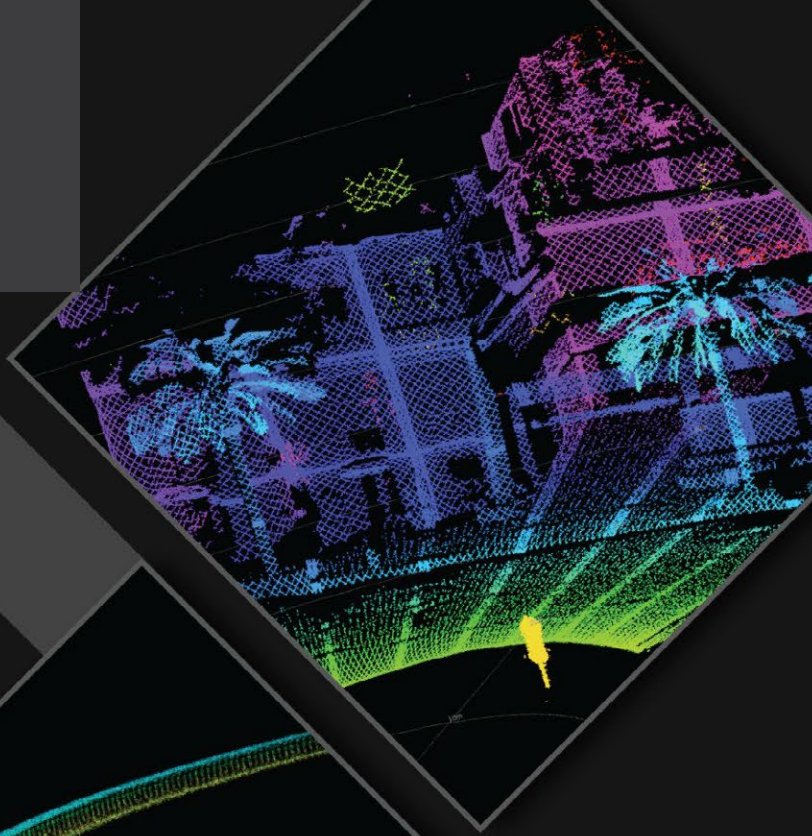

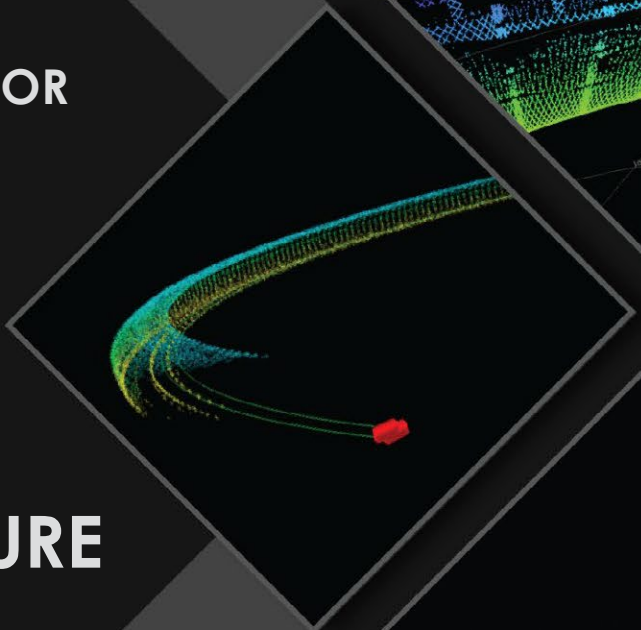


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LIDAR MAGAZINE




# IN THIS ISSUE



## COLUMNS



◀ ON THE COVER

*Lumotive, featured in this edition (page 6), utilizes innovative Liquid Crystal Metasurfaces™ (LCMs) manufactured in CMOS semiconductor processes to meet performance, cost and size requirements across a range of industries.*

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DR. A. STEWART WALKER

# At B.1.617.2's Mercy

## Covid regroups; lidar is SPAC to the future

We had hoped by now to have returned from the pandemic to normal life and the hot summer. Delta, however, has scuppered that and we are battening down the hatches again. There are some face-to-face and hybrid events, but it takes resolution not to become depressed. Wimbledon was OK, but the Tokyo Olympics seemed rather sad. Usually I write enthusiastically about the top-quality online events that have been a wonderful substitute for the real thing, but my memory of one of those is the most depressing of all. The Esri User Conference took place remotely in July and was as beautifully orchestrated as always. I've commented on our website about the remarkable financial performance that Esri was able to report despite the drawbacks—the company's success is simply indisputable. After quoting E O Wilson, Jack ended the opening plenary with the words, "It's late in the day, but it's not dark yet." Finally, experts are accepting that our planet is probably slipping through our fingers. Billionaires bopping just above the Kármán line isn't quite the solution we had in mind … and COP26 in Glasgow in November 2021 may be the last train, though the city in the winter may not be ideal for nurturing serious debtates about heat and drought. On the cover of its *Heights 2021* supplement, *xyHt* asks, "Can airborne lidar save the planet?", but the article being referenced is about making a digital twin of Earth[1], which is a tool but not a solution. We, the geospatial community, can help manage the fight against the effects of environmental degradation, for example managing wildfires, and we can provide base data for designing solutions, for example reforestation and the maintenance of infrastructure—but we cannot on our own create the will, on the part of the citizenry of the whole planet, to change.

While writing this, I had to dash to Home Depot for an infusion of *tradescantia pallida*. At one of the excessively numerous stop lights in our city, the pedestrian light was on and a lady with her dog passed in front of me. They arrived safely on the other side with 21 seconds still to elapse. The wait seemed interminable and, of course, there were several seconds more, after the clock had ticked down, before the lights themselves changed in my favor. How could the programming of the lights be improved, while safety for pedestrians, even those who make mistakes while in mid-crossing, is

1 Fisher, C., 2021. Creating Earth's digital twin, *Heights 2021* (delivered with *xyHt*, 8(7), August 2021), 10-13.

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maintained? This very question arose in a webinar organized by Seoul Robotics, "Is there a blueprint for smart cities?" The speakers were William Muller (VP BD, Seoul Robotics), Richard Hardiman (CEO, RanMarine Technology) and Kevin Komstock (Director, City of Chattanooga). Stop lights came up many times in the conversation and the City of Chattanooga turns out to be adventurous, forward-looking yet responsible to its citizenry as it adopts new technology. Seoul Robotics's CEO, HanBin Lee, has already been interviewed by the magazine[2] and we'll be speaking with him again soon.

Shortly before the webinar, a Seoul Robotics press release on a new perception software product, Voyage, included the following argument, "The lidar market, which is on track to reach more than $3 billion by 2025, has become crowded over the past several years as the technology became synonymous with autonomous vehicles. The marketplace is flooded with lidar companies producing sensors to fuel the demand of this industry, but most sensors on the market are sold without any intelligence." Users of Voyage include BMW, Mercedes-Benz and—wait for it—Chattanooga Department of Transportation. I noted the Vision Spectra conference on our website recently and I've been listening to some of the presentations. Artificial intelligence, usually in the form of deep learning, is becoming indispensable in machine vision.

Those of us on the geospatial side may be tiring of the financial news that often overshadows technology breakthroughs in the lidar world at present. It's all about SPACs (special-purpose acquisition companies), which provide a route to a lidar company going public without a traditional IPO, while obtaining access to capital less arduously than would have been the case on the conventional venture capital route. It seems, however, that the private equity people, who've typically been less generous in valuing target companies than SPACs, may be bouncing back with their own SPAC vehicles[3]. For those who inhabit this world, it's wildly exciting! We've seen SPAC deals with Aeva, AEye, Innoviz, Luminar Technologies, Ouster, Quanergy Systems and Velodyne Lidar in the last year; while this editorial was being written Cepton Technologies SPAC deal was finalized. We've already spoken to Velodyne[4] and in this issue we have an interview with Innoviz co-founder and CBO Oren Rosenzweig.

Despite these deals hitting the headlines, technology has not hidden its light under a bushel. Quanergy is mounting a charge based on its optical phased array technology, reported in this issue by co-founder and CTO Dr. Tianyue Yu. This really makes a difference and the firm expects soon to announce an increase in range to 200 m. Meanwhile, Quanergy realizes that the autonomous vehicle is probably some years from widespread adoption, so in the shorter term it is diversifying markets. While automotive remains prime, the firm is pursuing what it calls the "internet of things market", which includes verticals that Seoul Robotics has been talking about. Quanergy will use some of its SPAC-related capital to invest in sales as well as R&D. We're trying to understand why one firm's SPAC is better than another's, but even if they're all rather similar, easier access to capital will guarantee a rising tide and our geospatial world will be blessed with more robust, precise sensors at price points that would have been unimaginable even three years ago.

We also have an article by Dr. Gleb Axelrod, co-founder and CTO of Lumotive. I don't have the electronic nous to differentiate competently between this and Dr. Yu's piece. Suffice it to say that, in pursuit of miniaturization of lidar sensors, Lumotive seems to be following some similar paths. The demand is there. Just as I finished writing this, an article about robots for loading and unloading trucks arrived in my mailbox[5]. It described a robot arm as "festooned with sensors".

In contrast to these firms, which are primarily producers of sensors and related software, Neural Propulsion Systems (NPS), another Silicon Valley start-up, has developed a complete system, NPS 500, designed for the automotive market, including its own lidar, radar and other sensors, integrated, packaged and accompanied by software. We include both an article about the NPS 500 and an interview with co-founder and CEO Dr. Behrooz Rezvani.

2 Walker, A.S., 2021. Seoul Robotics makes lidar Discovery, *LIDAR Magazine*, 11(2): 30-35.

3 Anon, 2021. Frenemies: the uneasy partnership between private equity and SPACs, *The Economist*, 440(9253): 68, 10 July 2021.

4 Walker, A.S., 2020. Velodyne's journey: lidar drives the autonomous revolution, *LIDAR Magazine*, 10(4): 14-24.

5 Anon, 2021. Automatic goods handling: heave ho!, *The Economist*, 440(9257): 66, 7 August 2021.

Thus the lidar suppliers from the automotive world have other markets in their sights, while their newly deep pockets facilitate R&D in both the sensors themselves and the necessary software. The geospatial world will surely benefit, while the specialist, "traditional" lidar suppliers will continue to hold sway for both low-noise, precise data from UAVs and MMSs as well as lidar acquisition from crewed aircraft and helicopters. In a very welcome development, Teledyne Optech have made several appealing webinars available on demand at *teledyneoptech.com/en/events/webinars/*. I'm going to make time for "Introducing the game changer: new AI software for efficiencies in lidar noise classification". The whole lidar ecosystem is moving forwards at speed. Is it too speculative to wonder whether, with its experience of this measurement technology and the related data processing, geospatial firms can find a special role in the new but non-automotive applications, such as queue management at airports, stoplight control at intersections, and automation of ports, becoming involved in design, installation, data management and data analysis?

Indeed, we have two fascinating geospatial articles in this issue. The first is from Moncton, New Brunswick, Canada. The city needed a quick way to monitor vegetation above streets and sidewalks, making use of its existing staff and vehicles. It reached out to the local Trimble distributor, which proved resourceful and imaginative. The resulting low-cost, easy-to-use system is reinforcing Moncton's twenty-first century civic pride. The other is from photogrammetrist Riadh Munjy, a doyen for decades at California State University Fresno, his student Jacob Lopez, and Chris Thornton from Caltrans. They report on practical tests, based on two very precise test fields, of UAV-lidar systems. This is a fine complement to the recent, popular article by Mark Meade and Kyle King[6]. Properly executed UAV-lidar missions provide accuracies high enough for almost all purposes[7]. We've seen other evidence of this in the many beautifully prepared webinars by Lewis Graham and Martin Flood of GeoCue. Geospatial expertise combined with the availability of first-class platforms and sensors at reasonable prices enriches our profession as we delight our customers.

Last but not least, we've included an "exit interview" of sorts with Lisa Murray, well known to many as the former geospatial lead at Diversified Communications, the Maine-based group responsible for Commercial UAV Expo, the International LIDAR Mapping Forum and more. As of January, Lisa has moved on to a new career in counseling but she gracefully took time to share insights gleaned from years spent developing collaboration amongst geospatial professionals. I must note that we collaborate closely with Lisa's former group on our LIDAR Leaders Award Program, soon to be announced in its third iteration; Lisa was a driving force in the development of these awards.

We conclude on a light note. Recently I finished the third volume of Henry Kissinger's memoirs of his years in the White House. This tome was centered on his service to President Ford, but of course there were inevitable references back to the Nixon years. Who should pop up but Donald Rumsfeld. All of us have, perhaps unkindly, enjoyed the craic wherein one matches his known knowns, known unknowns, unknown knowns and unknown unknowns to the constants, parameters, systematic errors and random errors of the mathematical model underlying least-squares estimation. Kissinger himself, however, penned the following gem, after an unsatisfactory briefing to the National Security Council by Director of Central Intelligence William Colby about the impounding of the *SS Mayaguez* by the Cambodians in 1975: "Some confusion was expected; totally inaccurate precision is harder to explain—indeed, I do not understand to this day what the basis for it was."[8] This is another gift to geospatial raconteurs and we can only wonder whether there could be some *coup de grâce* still to be divulged. Perhaps John Dean will reveal something about deep learning…

A. Stewart Walker // Managing Editor

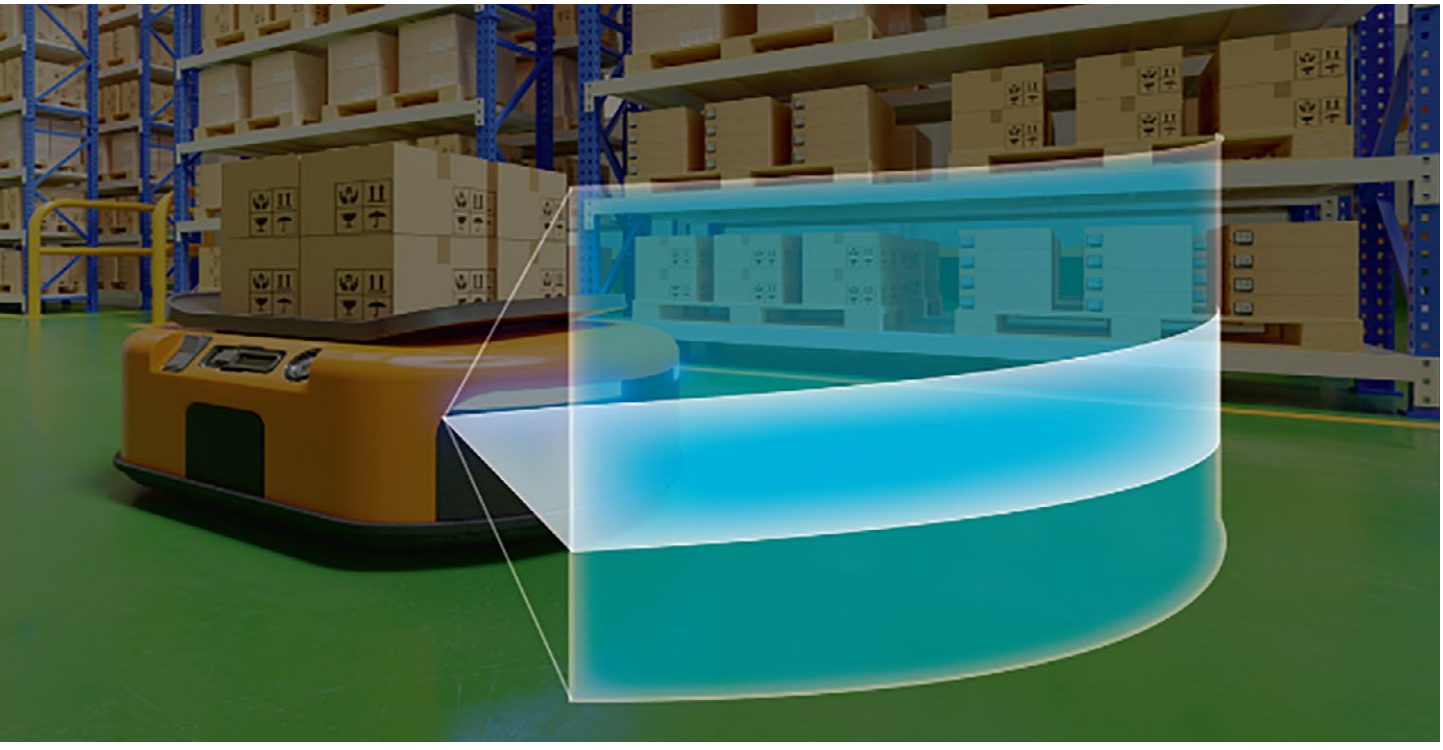
6 Meade, M. and K. King, 2021. Accuracies amaze the experts, *LIDAR Magazine*, 10(6): 6-12.

7 Lidar is also one of many tools in new approaches to UAV safety: see Anon, 2021. Uncrewed aerial vehicles: drones off the least, *The Economist*, 439(9250): 73-74, 19 June 2021.

8 Kissinger, H., 1999. *Years of Renewal*, Simon & Schuster, New York, 1151 pp: p552.

# Short-Range Lidar: Opportunities and Challenges

## Innovation revolutionizes sensor size



Most people associate lidar with long-range applications: aerial mapping, or those domes atop experimental autonomous vehicles. But lidar's most exciting story may come from short-range (10-20 m) applications and small form factors. The same benefits that have revolutionized airborne surface mapping and vehicle navigation are spilling out a cornucopia of new uses. The value of lidar is just as compelling at 2 m as at 200 m: piercing complex and ambiguous lighting to find physical surfaces, and attaching correct distance data to each point in a scene. Together these abilities all but eliminate catastrophic errors and vastly reduce computation for the software that must

**Figure 1:** Small, low-power, and short-range lidar modules can create a cocoon of visibility around robots and vehicles to enhance safety and enable new capability, such as a self-parking feature.

BY GLEB AKSELROD

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Small, low-power, and short-range lidar modules can strengthen active safety and improve mapping and navigation for industrial machinery, robots, and drones (**Figure 1**). If small enough, they can vastly improve augmented reality apps for smartphones. For proof, see the iPhone 12 Pro.

## Range, size, power

Small systems can benefit greatly from lidar, but they can't support the size, weight, power consumption, or cost of today's big, long-range systems. Fortunately, all four of these factors can be improved by reducing the required operating range to much less than automotive lidar's 250 m.

Reduce the range to, say, 20 m for ADAS or industrial/robotics use, and you can use a lower-power laser, less expensive optics, and a package the size of a golf ball. Reduce a bit more, and you can make a lidar in the size and power range of a smartphone camera module (**Figure 2**). But both of these reductions depend on one critical—and non-trivial—technical feat: eliminating the moving-mirror assembly that steers the laser beam to illuminate the field of view, and that, with its mirrors, bearings, and positioners, stubbornly refuses to scale down.

## Doing it without mirrors

It *is* possible to eliminate the moving-mirror subsystem. The easiest approach is called flash illumination. Like a camera flash gun, the lidar in a flash system illuminates the entire field of view with a single pulse. A lens focuses an image of the scene on a 2D time-of-flight (ToF) sensor, and each pixel in the sensor records the phase difference between the flash and the arrival of reflections from the scene. From these phase differences, the system can determine the distance from the lidar unit to each point imaged in the field of view.

The system is mechanically simple but has serious challenges. The energy of the flash is spread across the entire field of view, so the reflected pulse at any one point has little energy, and is easily lost in the glare of sunlight. In bright sunlight, it takes a heroic flash to give the sensor anything at all to detect. This is why the flash lidar in the Microsoft Kinect works well in dimly lit rooms, but is essentially blind in daylight.

Nor is ambient light the only issue. Multipath—when the flood of light can take more than one path from the flash illuminator to a point in the scene and back to the sensor—can cause spurious range measurements, distorting the shape and distance of objects. This artefact is especially problematic in a scene with reflective surfaces. And interference—when multiple lidar units operate in the same area, as in a warehouse with multiple robots or in a multiplayer game—can also cause incorrect range readings.

## Modified flash

Cleverness can help. For example, Apple engineers refined the flash approach for the iPhone 12 Pro by adding an optical element in front of the flash unit that shapes the light from the VCSEL[1] not into a flood, but into a 24 x 24 array of discrete beams spread evenly across the field of view. Hence more energy strikes each illuminated point in the scene, overcoming the ambient light so the system can function outdoors. The discrete beams also help, but do not eliminate, the multipath and interference problems. But with this architecture, the limited number of beams—576—produces a very low-resolution depth image. Such coarse resolution can distort the shape of irregular objects, and can miss smaller objects altogether, even if they are critical to the application.


**Figure 2:** The Lumotive LCM solid-state beam-steering technology allows lidars to be scaled from short-range, tiny modules for smartphones, to golf-ball-sized lidars for short-range automotive and industrial applications, and all the way to high-performance, long-range lidar for self-driving applications.

## Solid-state beam steering

Moving-mirror systems overcome the ambient light and other issues of flash by concentrating all of the VCSEL energy in a single beam, but they are nearly impossible to scale. Flash systems can scale to small sizes and lower power, but

1 Vertical cavity surface emitting laser.

they struggle with ambient light, resolution, and other accuracy issues. However, a remarkable application of physical optics using conventional liquid-crystal technology allows an escape from this dilemma. The trick is a solid-state device—a CMOS chip—that provides motionless beam steering.

The heart of this architecture is that chip, which Lumotive[2] calls a liquid-crystal metasurface (LCM). Envision a small CMOS integrated circuit overlaid with a thin array of tiny liquid-crystal cells—so tiny that they can be spaced on a ¼-wavelength pitch. At this size, the cells can act like a huge array of tiny optical antennae—reflecting an incoming beam of light at an angle determined by the voltage signals applied to the cells. In this way, a fixed LCM can sweep a beam of light across the field of view under software control.

In a Lumotive lidar module (**Figure 3**), a row of VCSELs illuminates the surface of the LCM. The LCM then sweeps the reflected row of light across the field of view. A lens focuses light reflected from the scene on to a 2D ToF sensor, which detects the laser illumination returning from the scene. After each sweep—requiring about 50 ms—the ToF sensor provides a 640 x 480 array of range data.

This approach has significant advantages. Because each point in the field of view gets a significant portion of the energy from the VCSEL row, the LCM lidar can reduce the power of the lasers about 10X compared with what a flash approach would require, or the LCM lidar can offer two to three times the effective range at similar ambient light conditions. Resolution is limited by the ToF sensor, not the illumination, providing more accurate shapes for surfaces in the scene and catching far smaller objects. Because only a stripe across the field of view is illuminated at any one time, multipath and interference are significantly reduced as well. Another key advantage is that because LCM beam steering doesn't have any mechanical inertia, the beam can be steered in any order across the field view, all under software control. For example, an application can switch from a uniform scan of the entire field of view to a narrower, faster scan of a limited area to collect more data on an object of interest.

Equally important from a system vendor's point of view, the materials and processes used are familiar and mature—in fact, all the base technologies are already used in smartphones. So Lumotive can scale the lidar to golf-ball or camera-module size at commercial volumes.

We have seen that a small, low-power, inexpensive lidar would open new vistas of compelling applications. But moving-mirror beam won't scale. Moreover, flash approaches that eliminate the moving mirrors suffer from significant performance challenges. Lumotive offers a scalable architecture based on our proprietary solid-state beam-steering LCM chip, shattering the dilemma and opening new worlds of compelling applications.

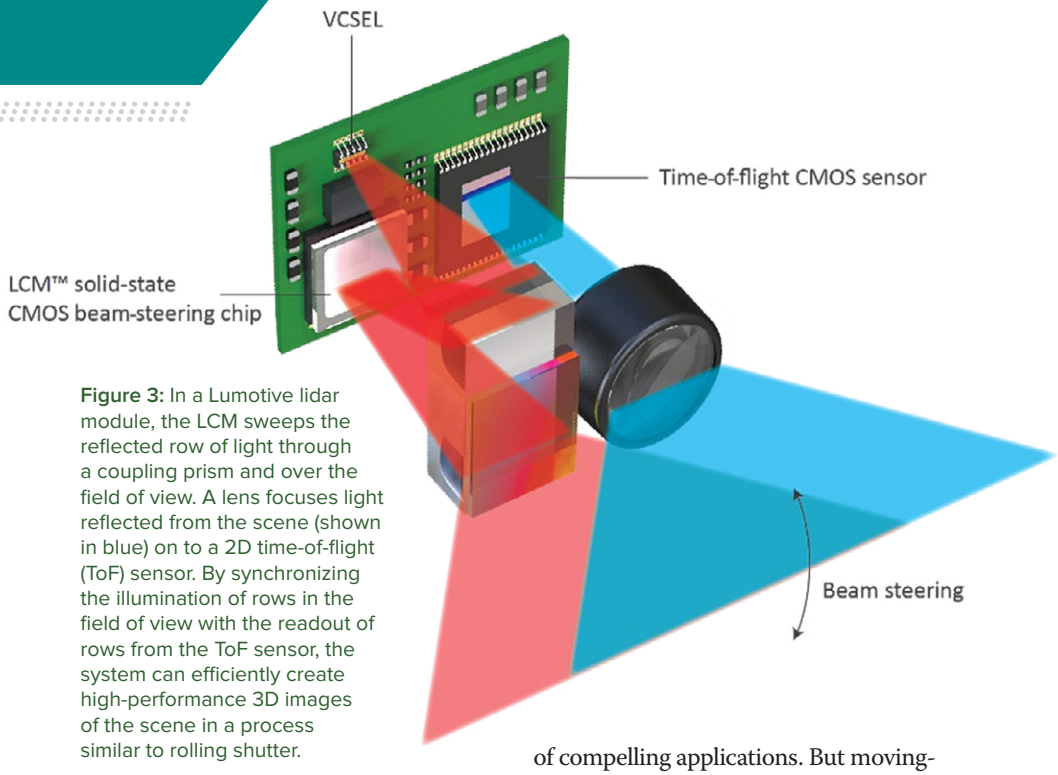


**Figure 3:** In a Lumotive lidar module, the LCM sweeps the reflected row of light through a coupling prism and over the field of view. A lens focuses light reflected from the scene (shown in blue) on to a 2D time-of-flight (ToF) sensor. By synchronizing the illumination of rows in the field of view with the readout of rows from the ToF sensor, the system can efficiently create high-performance 3D images of the scene in a process similar to rolling shutter.

2 www.lumotive.com.

Lumotive CTO and co-founder **Gleb Akselrod** has more than 10 years' experience in photonics and optoelectronics. Prior to Lumotive he was the Director for Optical Technologies at Intellectual Ventures in Bellevue, Washington, where he led a program on the commercialization of optical metamaterial and nanophotonic technologies. Before that, he was a postdoctoral fellow in the Center for Metamaterials and Integrated Plasmonics at Duke University, where his work focused on plasmonic nanoantennas and metasurfaces. He completed his PhD in 2013 at MIT, where he was a Hertz Foundation Fellow and an NSF Graduate Fellow. For his dissertation, he studied the transport and coherence of excitons in materials used in solar cells and OLEDs. Prior to MIT, Gleb was at Landauer, Inc. where he developed and patented a fluorescent radiation sensor that is currently being used by over 100,000 soldiers in the US Army. He holds 5 US patents and has published over 25 scientific articles. Gleb received his BS in engineering physics from the University of Illinois at Urbana-Champaign.

# New Multi-Sensor/Software Combo Poised for Autonomous Driving Market

## Neural Propulsion Systems proclaims promising innovation

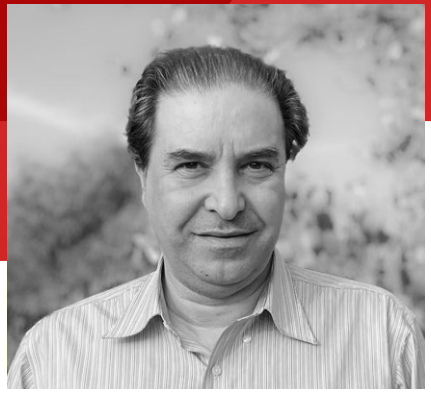

**Figure 1:** Top leadership at Neural Propulsion Systems: Dr. Behrooz Rezvani (founder and CEO; right), Professor Babak Hassibi (co-founder and CTO; center) and Heinrich Woebcken (executive adviser; left).

On 30 January 2021, a draft press release from Bay Area start-up Neural Propulsion Systems (NPS) hit the magazine's inbox[1]. The fledgling company had a product called NPS 500 that combined cameras, lidar, radar, computer hardware and software into a single offering that it claimed would transform the AV market. We were intrigued and made an approach. The result was an interview with, then a presentation from, founder and CEO Dr. Behrooz Rezvani. We've put the gist of his presentation below and the interview responses in a sidebar. Also in attendance was Alysson Do, VP operations and administration, NPS. The start-up is based in Pleasanton, California and has an office in Pasadena, California, close to the California Institute of Technology (Caltech). Already it has more than 40 employees, a few of whom are in Europe.

Behrooz started by commenting that a lot of money has been invested in technology to advance the dream of autonomous vehicles. It is still early days because the technology and go-to-market have to advance significantly before AV vehicles will be commercialized and farther still before there is wide consumer adoption.

Behrooz's significant insight into this market was that customers will have to believe that AVs are dramatically safer than today's cars before they will even

1 https://lidarmag.com/2021/02/24/neural-propulsion-systems-revolutionizes-l4-l5-autonomous-driving-with-next-generation-zero-accidents-sensing-platform/.

BY STEWART WALKER

consider giving over control of a vehicle to an automated system. That means a future of zero accidents. This "zero accidents vision" became the motivation behind all the innovation that NPS has just announced.

Both investors and national and local governments are intensely interested in AV because there is so much at stake and it will transform transportation as we know it.

Two categories of companies are emerging. One makes sensor systems and the other is focused on the perception engine software and navigation, etc. Many problems still persist in the former area and no frontrunner has established itself. That's where NPS comes into the picture, he explained. As part of his due diligence, he met with a range of potential customers and their enthusiastic responses brooked no other course.

Behrooz emphasized that NPS is focusing on level four/level five autonomy with a sensing system that will enable the company to solve some of the key issues that have held back this nascent industry. The NPS 500 is a very compact system of lidar, radar and cameras with a range of more than 500 m, packaged together and delivered to customers as a complete unit that is ready to be integrated into the vehicle's computer system.

Behrooz recalled that he had previously started companies that set the bar in their particular fields. For example, Ikanos Communications achieved 100 Mbps over-copper technology, when 6 Mbps was the norm. Quantenna Communications did the first 4x4 and 8x8 MIMOs[2]. He has assembled a strong team at NPS (**Figure 1**), including CTO Babak Hassibi, professor of electrical engineering and computing and mathematical science at Caltech, and executive adviser Heinrich Woebcken, formerly CEO of Volkswagen North American and SVP at BMW, to ensure that NPS focuses on what's really important to automakers.

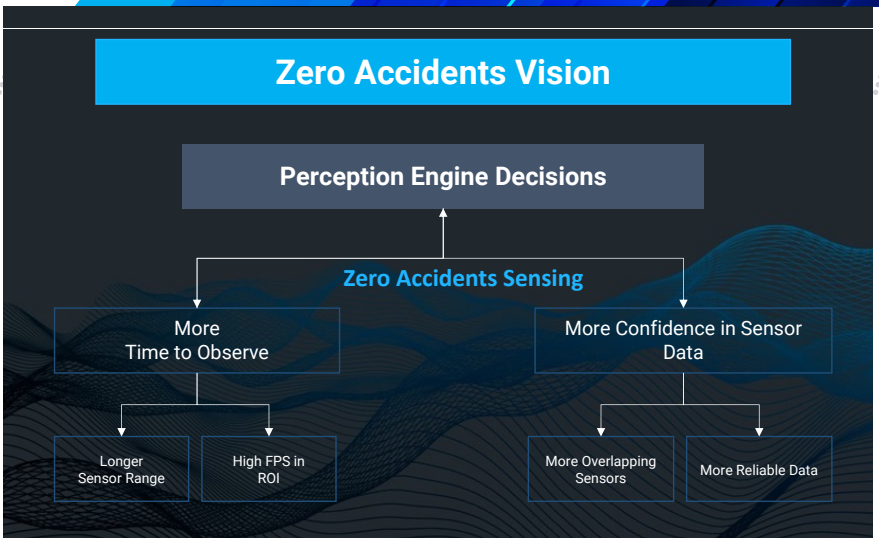


**Figure 2:** In order to attain the zero-accidents goal, the sensing components provide the perception engine with highly reliable data and more time to do its work.

The company was founded in late 2017 in California, and its work, he emphasized, has involved considerable innovation. To be successful, the company must deliver on this innovation while also developing for the large volume that will be critical to grow at scale.

Behrooz believes that the zero accidents vision should be adopted by the industry as a reset to the negative publicity that has surrounded early AV accidents. Over 18,000 articles were written on Uber's accident in Arizona and 8000 on Tesla's autopilot death[3]. Serious, negative publicity is also usually followed by lengthy NHTSA[4] inquiries. Behrooz further pointed out that, while society at large accepts human errors because we're all human and we all make mistakes, people don't like to see technology failures. The airline industry is also driven by public opinion issues. Airline safety has increased so dramatically over the past 25 years that few people think about the issue (737 Max aside). For large-scale AV adoption, and to dampen negative publicity and lawsuits, the goal must be less than 100 fatalities per year.

## How do we accomplish the vision of zero accidents?

The solution emanates from the two elements he had mentioned earlier, the sensing and the perception engine, the latter being the brain that navigates through the "tough spot" and has to make the right decision. What is the sensing system supposed to do for the perception engine? Logically, the former has to give the latter enough time to interpret the results and navigate properly (**Figure 2**). It must also provide more confidence in the sensor data.

2 Multiple-input and multiple-output components, for wifi in this case.

3 Behrooz was referring to the 2018 accident in Mountain View, California, but another accident involving a Tesla car, in Houston, Texas, on 17 April 2021, took place while this article was being completed and is generating its own cloud of articles and reports.

4 National Highway Transportation Safety Administration.

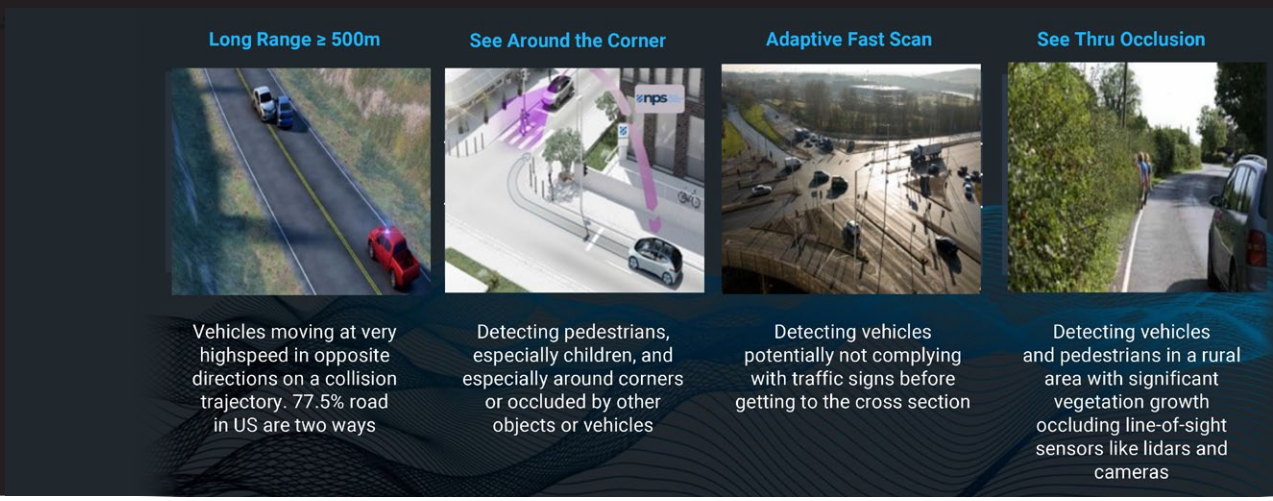


**Figure 3:** Sensor requirements for zero-accident goal.

There are two ways to get more time. The system has to deliver data from a longer range and needs to be able to operate at very high frame rates in the congested fields in the short ranges. That's similar to watching sports on TV: if you want to look at sudden movements, take the frame rate really high—television can show frame-by-frame what happened. Furthermore, all the sensors have to be tightly overlapped. Finally, the data must be so reliable that the perception engine trusts it. This is the zero-accident sensing platform.

How does that translate into requirements? Close to 80% of US roads are two-way, i.e. one lane each way with no separator (**Figure 3**), maybe more in other countries. Many perception engines need seven or more seconds in order to properly navigate. Today, the typical range is 250 m, which translates to two cars approaching each other at 35 mph. That's not what happens on the majority of roads, where the figure is closer to 70-75 mph. Thus NPS estimates that at least 500 m range is needed to reach the goal.

In an AV study by AAA, cars turning a corner at 15 miles per hour, all with ADAS systems, without exception hit a pedestrian. Thus two things are important from the NPS perspective. One is to be able to detect a pedestrian before reaching a corner (**Figure 3**). The other is being able to detect cars moving through a cross-section. Whether there are signals or stop signs or not is irrelevant, because some drivers may miss or not comply with them. These are key elements of what Behrooz considers a zero-accident platform. The other piece is being highly adaptive and able to scan fast in a congested cross-section so that subtle movements are picked up. NPS has concluded that it's essential to pick up these movements in order to be able to prevent accidents. Finally, while many sensor technologies such as lidar and cameras are line-of-sight systems, there are many situations where line-of-sight is not sufficient. Systems must be able to penetrate through vegetation, for example, to capture what may be missing (**Figure 3**).

**Figure 4:** NPS 500 components for installation on vehicle roof.

The NPS 500 is designed to be a solution for any car anywhere. It is based on the company's internal development of light and lidar technology, which it calls solid-state MIMO lidar. It is a super-resolution system with a range of 500 m. Complementary radar technology is integrated into the platform, with a resolution 10 times better than what's generally available. NPS radar has 360° simultaneous detection and, critically, it is resilient against other radar technologies. NPS claims that it performs 70 times better than other radar technology. Resilience in the presence of other sensors is important as people are going to put more and more of these on the road, which could become a problem.

**Figure 5:** Front, side and rear views of NPS 500 mounted on Jaguar i-Pace. The product is also available in black, blue and white.

There are nine cameras on the NPS 500. Behrooz proudly exclaimed, "We have our own silicon at the edge, in aggregate multiple silicons networked tightly together with a processing power of approximately 650 terabits per second. To put that into perspective, that's roughly twice as much as the supercollider in CERN that is processing particle detection. We've also put together the software necessary to detect and see round the corner for the first time. These are the highlights of our sensor technology."

How does it look? It's a two-piece 360° system installed on the roof (**Figures 4 and 5**). The outward appearance and dimensions are not yet finalized, but the product will closely resemble these renderings. The system is scheduled to become available in the fourth quarter of 2021. The components are summarized in **Figure 6**. On the left side of the schema (**Figure 7**) is the perception engine and navigation control of any third party or any OEM and on the right is the NPS integrated platform with simple connections to the perception engine, system control and vehicle data. NPS provides point-cloud data and fused data, and a 12V cable from the battery.

Asked to make comparisons with competitors, Behrooz quicky acknowledged that there are clearly many good lidar companies, such as Luminar and Velodyne Lidar. In terms of range, however, he claimed that NPS out-performs them by a factor of two; in terms of resolution, at least 10% better than the best resolution published. "We believe the kind of lidar technology that we are bringing with AI and silicon, it's really a class by itself," he elaborated. "I think you will find that most experts on the electro-mechanical-scanning lidar technology are talking 250 m, and even less on solid state—closer to 200 m. And the best resolution that we've seen is 0.1°. We're obviously better than that. We do a statistical method of computation of point clouds and we have been able to measure up to 0.01°." He thought that Luminar has claimed around 0.07° by 0.03° and that Ouster has 0.1° x 0.1°. Indeed, 0.1° is typically considered the standard goal. "And, based on our average results, we're better than 0.05°." We explored the lidar technology a little further, though Behrooz was reluctant to give too much away. "NPS does not have a moving lidar," he said. "We execute many small flashes, that collaborate and cooperate. That's why there's no dead space between any beams. All currently developed lidars, with the exception of a few that have a limited range, are flash types. They follow a similar concept to the electro-mechanical scanning. Ours is all solid-state."

Behrooz also claimed a significant competitive advantage on the radar side over, for example, ZF, Continental or Bosch. The radar is multiband: one of the biggest breakthroughs is that NPS uses four bands scanning simultaneously. This is a huge advantage because the typical frequency used in AV radar today is millimeter-wave at 77 GHz. In order to penetrate material, NPS has to

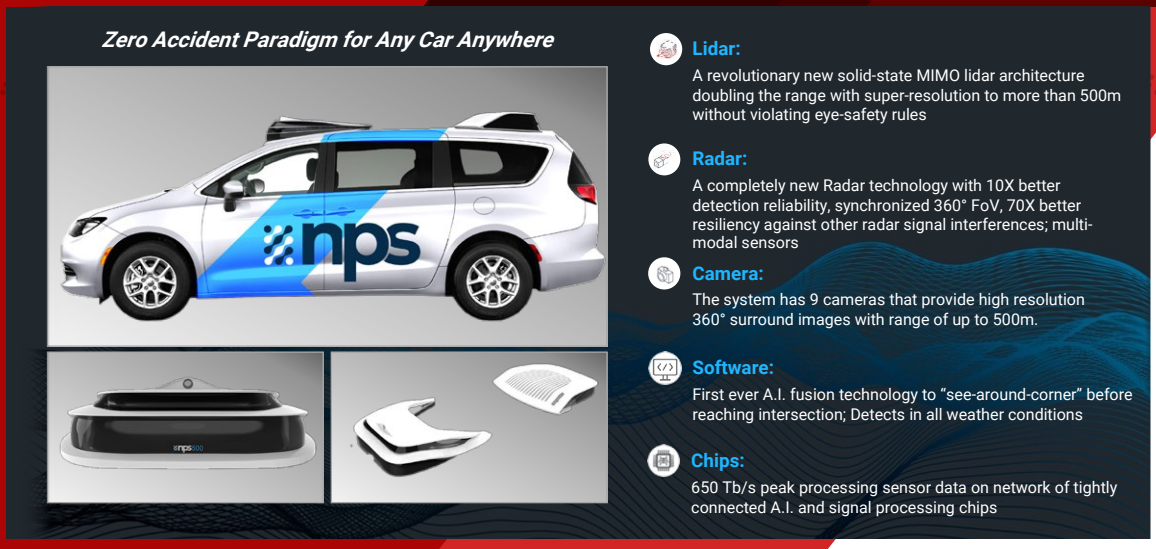


**Figure 6:** Components of NPS 500.

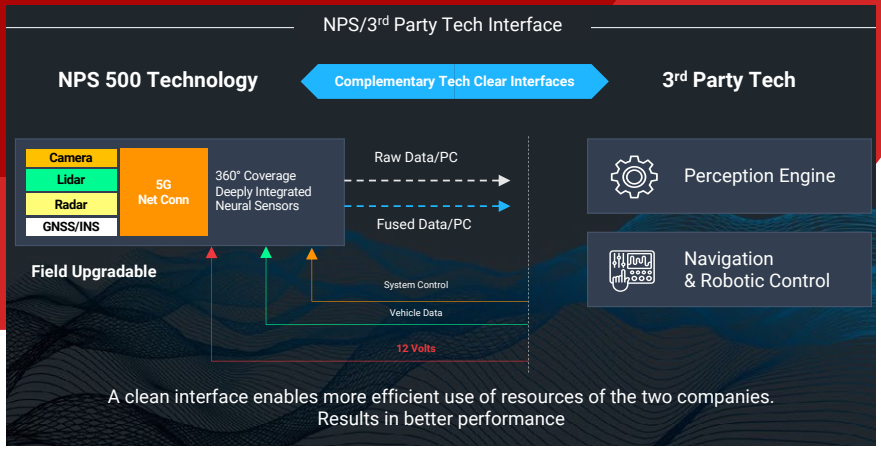


**Figure 7:** Schematic of NPS 500, with third-party components on left and NPS components on right.

go to much lower bands in order to see through occlusions and the like.

Yet the most apt comparison is against other fully integrated sensor systems that are level four or level five, and these are built by a handful of companies such as Waymo and Argo AI. NPS judges that Waymo is the farthest ahead amongst these integrated sensor systems. **Figure 8** gives a comparison.

| Parameters | Radar | | | Lidar | | |
|---|---|---|---|---|---|---|
| | Commercial Spec | NPS 500 Performance | | Commercial Spec | NPS 500 Performance | |
| Range: [max ] (meters) | ≈ 250 m | ≈ 1000 m | 4X | ≈ 250 m | ≈ 500 m | 2X |
| Angular Resolution | ≈ 1° | ≈ 0.1° | 10X | 300pt/deg² ≈ 0.06° | 400pt/deg²≈ 0.05° | 10% |
| Range Resolution [radar]<br>Range Accuracy [lidar] | AoAs equal: 12cm<br>AoAs not equal: 12cm | 12 cm<br>< 1cm | 1X<br>12X | 10 cm | ≈ 5 mm | 20X |
| Frame update rate | 1-15 Hz | 1-30 Hz | 2X | 1-30 Hz | 1-100 Hz | 3.3X |
| Single Point of Failure | probable | No | ✓ | Yes | No | ✓ |
| Reliability | No moving parts | No moving parts | ✓ | Moving parts | No moving parts | ✓ |
| Vulnerability to Interference/ jamming | Sometimes (FMCW) | No (multiband) | ✓ | Yes (with single aper) | No (multi-aper) | ✓ |
| Product readiness | Samples shipping ✓ | Sample 1Q 2022 | ✓ | Low volume shipping ✓ | Sample 1Q 2022 | ✓ |

**Figure 8:** Performance requirements of level 4/level 5 integrated system, with NPS 500 statistics in columns 3 and 5, against typical existing products in columns 2 and 4.

Behrooz anticipates at least two times better reaction time than the current sensors used by Waymo. He expects, based on the mathematical algorithms and test results, to be, "… orders of magnitude better—we believe at least five times better than our nearest competitor." Waymo, Argo AI and some of their competitors, Behrooz admitted, fully integrate with the perception engine, i.e. the whole sensor system is designed as it should be—the sensors are potentially fully redundant and share full coverage with each other. In that category, however, Behrooz contended that NPS is probably 10 times better than its nearest competitor. He made a comparison with the sensors in the Waymo Gen 5 fifth-generation system that came out in April 2020.

NPS does not use the sort of high-resolution, high-definition map database that most AV developers who are making use of lidar and other sensors require. Rather, the NPS 500 provides fused information, such as GNSS position and target classification, but NPS leaves it to the perception engine software to do the map.

Behrooz summarized. NPS, he claims, is the first of its kind as a sensor system company that has integrated cameras, lidar and radar, in a fully redundant way. Its ultra-long range has significant amounts of AI and silicon in it. "Essentially, we set new goals or standards for getting to the vision, which I think we all should shoot for—getting close to zero accidents."

**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.

## After the pitch, the interview …

### Behrooz Rezvani reveals more about himself

I put some questions to Behrooz that are less product-focused, to try to learn more about him as a person and, from that, discover what sort of company he has created.

**LM:** Behrooz, you've had a remarkable, highly distinguished career, which continues on a steep, upward trajectory. You have undergraduate degrees from Hamline and North Dakota State, an MS from the University of North Dakota and a PhD from Marquette. You have multiple patents and innovation awards. After graduating, you worked in various leading-edge companies and in more recent years you've been a founder and c-level executive in several of them. Could you please summarize your life and career, and also indicate the drivers that caused you to make the various changes of direction along the way? Looking back through the years, do you see any relationship between your PhD work and today's lidar sensors?
**BR:** Wow—this is a very deep question. To explain why I started NPS, I have to say a few words about how my internal compass works and guides me. I get really excited about solving a new problem that requires a complex solution—but efforts to date have not been all that successful in L4/L5 autonomous driving. The solution must also give back to society and impact our lives. So those are the necessary conditions for me to take on a new challenge.

In a way, everything I have done in my career prior to NPS prepared me to understand one of the most challenging engineering tasks of our time. Autonomous driving/transportation is one of the biggest challenges today and will certainly profoundly impact everyone on the planet.

From a technology perspective, the sensing problem is quite complex, especially when focusing on the zero accidents vision. We are detecting many different kinds of objects with different material composition under adverse weather and road conditions, all while minimizing the potential for error.

When one examines this problem at a deeper level, we have many issues to address. Some of the big ones are: the many aspects of the physics of propagation; EM wave interaction with material provides boundaries where information theory, mutual information and causality are involved; and we need custom chips to do supercomputing at the edge.

At General Electric, my first full-time job in industry, while pursuing my Ph.D., was in the NMR group (nuclear magnetic resonance; now known as MRI—magnetic resonance imaging). I learned a lot about how radio waves interact with the human body.

**LM:** Please tell us about the founding of NPS. Why did you choose Pleasanton, California?
**BR:** I wanted to be close to 680/580 interstate crossing. Those familiar with the San Francsico Bay Area will understand that this location is close to UC Berkeley, Lawrence Livermore Lab and San Jose, giving NPS the


ability to attract talent with expertise in optics, chip design and computer vision. However, our first office is near Caltech/JPL in Pasadena.

**LM:** Can you say anything about your leadership team and how you found the people? You gave some information in your presentation about yourself, the professor from Caltech and the top manager from the automobile industry. As to the other members of your leadership team, it's interesting how folk in Silicon Valley get together. You're all highly able, very highly qualified. How do you get a leadership team together? What makes them different?

**BR:** My goal when we start a company is to make sure we are going to be the best in the world. That's really the only way to go forward. I remember my first job at GE Medical. I was working MRI prototypes, and Jack Welch had a saying that, "You're either number one or number two in your market or I close you down." Number one is a big, big thing. So then I ask, who are the number ones, you know, the top 0.1% of the class, then I search for people. Some I may not be able to convince, but in that 0.1% a chemistry is developed, and a good leadership team emerges. One of our team members, Amin Kashi, was a vice president of the electric vehicle company NIO. Quite a diverse but complementary team!

**LM:** I've seen a draft of your press release about the NPS 500 and it includes the words, "Neural Propulsion Systems (NPS), a pioneer in autonomous driving sensor solutions, today emerged from stealth to launch NPS 500™, the safest and most reliable autonomous vehicle driving system that enables the industry to reach zero accidents vision." Wow! Before we talk about the technology, can you please explain the words "emerged from stealth"?

**BR:** "Stealth" is used a lot in the start-up world of Silicon Valley. There are good reasons. Small companies don't talk about what they are planning, because they don't want the attention of direct or indirect competitors. So for that reason we did not have a website until a few weeks ago, to coincide with our product launch.

**LM:** Now tell us about the NPS 500. From the press release, I understand that it's a lot more than lidar—it combines lidar sensor(s), radar sensor(s), chips and AI fusion software. Perhaps it also accepts inputs from cameras. Does this mean that you provide a complete solution for the autonomous vehicle (AV) developer? In particular, I'd like to know more about your claim, "World's first capability to see around corners and full sensor coverage in excess of 500 meters."

**BR:** That's correct. It's a complete solution and it's the world's first all-in-one deeply integrated multi-modal sensor system focused on level 4/5 autonomy. It's a new sensor-fused system that precisely interconnects the NPS revolutionary solid-state MIMO LiDAR™, super-resolution SWAM™ radar and cameras to cooperatively detect and process 360° high-resolution data, giving vehicles the ability to prevent all accidents. The densely integrated sensor system enables vehicles to see around corners and over 500 meters of range with ultra-resolution accuracy together with highly adaptive frame rate. The NPS 500 breakthrough capabilities make it 10x more reliable than currently announced sensor solutions.

From a super high level:

- Cameras provide high-resolution images, but lack depth information and depend on lighting conditions
- Lidar provides super-precise depth information, but its performance and reliability degrade in adverse weather and light conditions, and it can get occluded fairly easily
- Radar measures velocity with great precision, but has lower resolution than lidar and is vulnerable to interference from other radars.

**LM:** Can you please tell us about the solid-state MIMO lidar and SWAM radar sensors that are components of NPS 500? Did you develop these? Do you foresee any of your technology working with other suppliers' lidar and radar sensors in some sort of hybrid solution? Having both lidar and radar avoids the energetic debate about which is better in AV applications—that's good—but what about cameras?
**BR:** Our solid-state MIMO lidar is a revolutionary new concept that is composed of many small flash lidars. Working cooperatively together in a precise combination of time and space, they illuminate many fields of views (FoV) independently. The optical receivers are distributed spatially across the wide aperture of NPS 500 and are precisely timed to sample the FoV of interest, hence the name MIMO lidar. Because of this architecture we can have a very large group of independent laser beams that independently track hundreds of targets at up to 100 fps (frames per second), necessary for the zero accidents vision that the industry seeks.

We also developed super-resolution SWAM radar, which is a new class of radar technology with 10x better detection reliability, simultaneous, multi-band 360° field of view and 70x better against other radar signal interference.

**LM:** Does NPS do its own manufacturing or do you outsource?
**BR:** We can easily work with Tier 1s and ODMs[1].

**LM:** Are your customers the AV developers? What is your distribution chain, i.e. do you work directly with your customers in the AV world or do you have distributors?
**BR:** We are currently working with AV developers and other customers.

**LM:** May I please ask something that's of particular interest to the readers of *LIDAR Magazine*? Do you envisage your solutions being used in any applications other than road vehicles, e.g. UAVs?
**BR:** Absolutely. We are really about a zero-accidents platform in any transportation. And obviously, our sensing platform can lend itself to many other applications.

**LM:** Bringing NPS 500 to market is clearly an enormous, daunting technological achievement. You are fully committed to it. Nevertheless, I would like to ask, what do you see happening in the remainder of 2021 and beyond? What other huge innovations is NPS working on?
**BR:** Obviously NPS 500 is the first product in a family of products we are working on and I hope to discuss them in the near future.

**LM:** Behrooz Rezvani, thank you very much indeed for taking time to talk to *LIDAR Magazine* and for explaining Neural Propulsion Systems' remarkable technology. We wish you well in your endeavors.

1 Original design manufacturers.

# SPONSORED LISTING INDEX

The following pages provide an overview of key service provider, sensor hardware, software and component part manufacturers, in addition to system integrators. Visit the online directory at *www.lidarmag.com* for additional listings.

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# Lumotive

## APPLICATIONS

- SMARTPHONE
- GEOSPATIAL
- ROBOTIC
- AUTONOMOUS
- WEARABLES
- DRONES


## COMPANY PROFILE

Led by veteran technologists and serial entrepreneurs, Lumotive is making innovative, cost-effective 3D-sensing solutions accessible in fast-growing markets. Our highly-scalable lidar platform leverages unique beam-steering technology based on patented Liquid Crystal Metasurfaces™ to deliver an unprecedented combination of high performance and readiness for mass adoption as measured by cost, reliability and small form factor. Unlike traditional lidar offerings, Lumotive's solutions are scalable—from ultra-small form factor and low-cost solutions needed for smartphones, to high-performance and long-range solutions demanded by the automotive industry.

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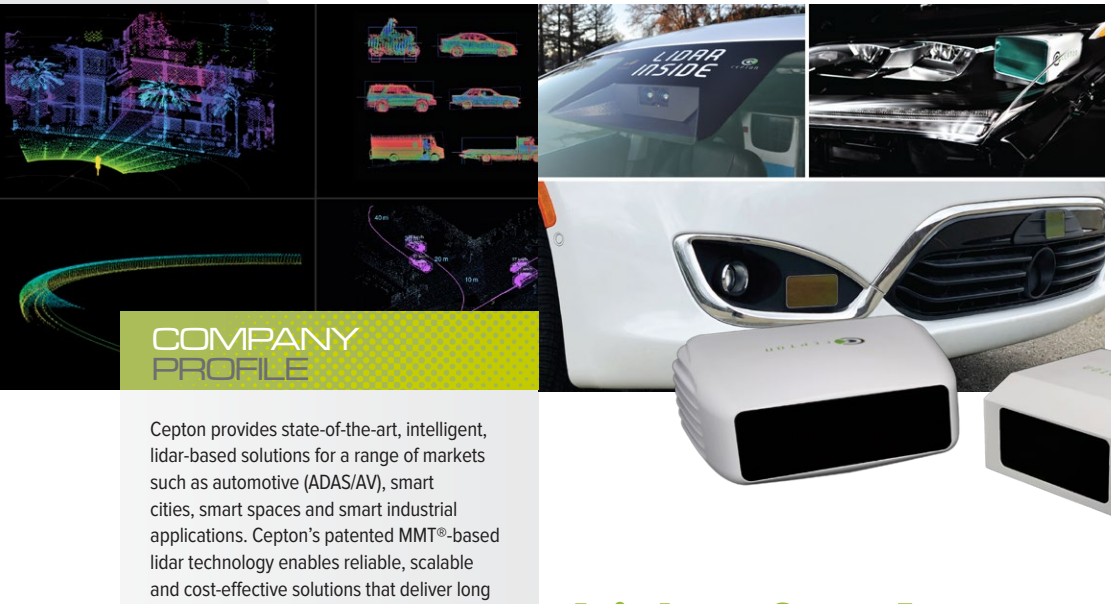
# CEPTON




## APPLICATIONS

- ADAS
- AV
- SMART CITIES
- E-TOLLING
- SECURITY
- CROWD ANALYTICS
- SMART INDUSTRIALS
- AGV

## COMPANY PROFILE

Cepton provides state-of-the-art, intelligent, lidar-based solutions for a range of markets such as automotive (ADAS/AV), smart cities, smart spaces and smart industrial applications. Cepton's patented MMT®-based lidar technology enables reliable, scalable and cost-effective solutions that deliver long range, high resolution 3D perception for smart applications.

Founded in 2016 and led by industry veterans with over two decades of collective experience across a wide range of advanced lidar and imaging technologies, Cepton is focused on the mass market commercialization of high performance, high quality lidar solutions. Cepton is headquartered in San Jose, California, with a presence in North America, Germany, Japan, India and China, to serve a fast-growing global customer base.

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**Nova** is an award-winning, miniature, wide field of view (FOV), near-range lidar intended to address major gaps in proximity detection of objects with current sensor technologies. Nova offers an unprecedented combination of compactness, FOV coverage and affordability. It is ideally suited for advanced driver assistance systems (ADAS), autonomous vehicles (AVs), autonomous ground vehicles (AGVs) and beyond.

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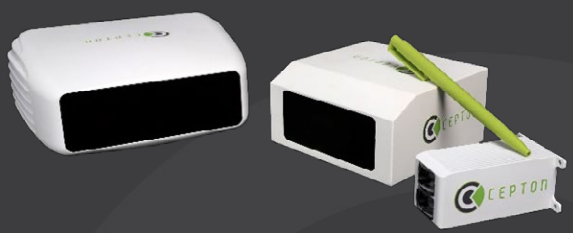

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# RIEGL

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


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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 VMX-2HA

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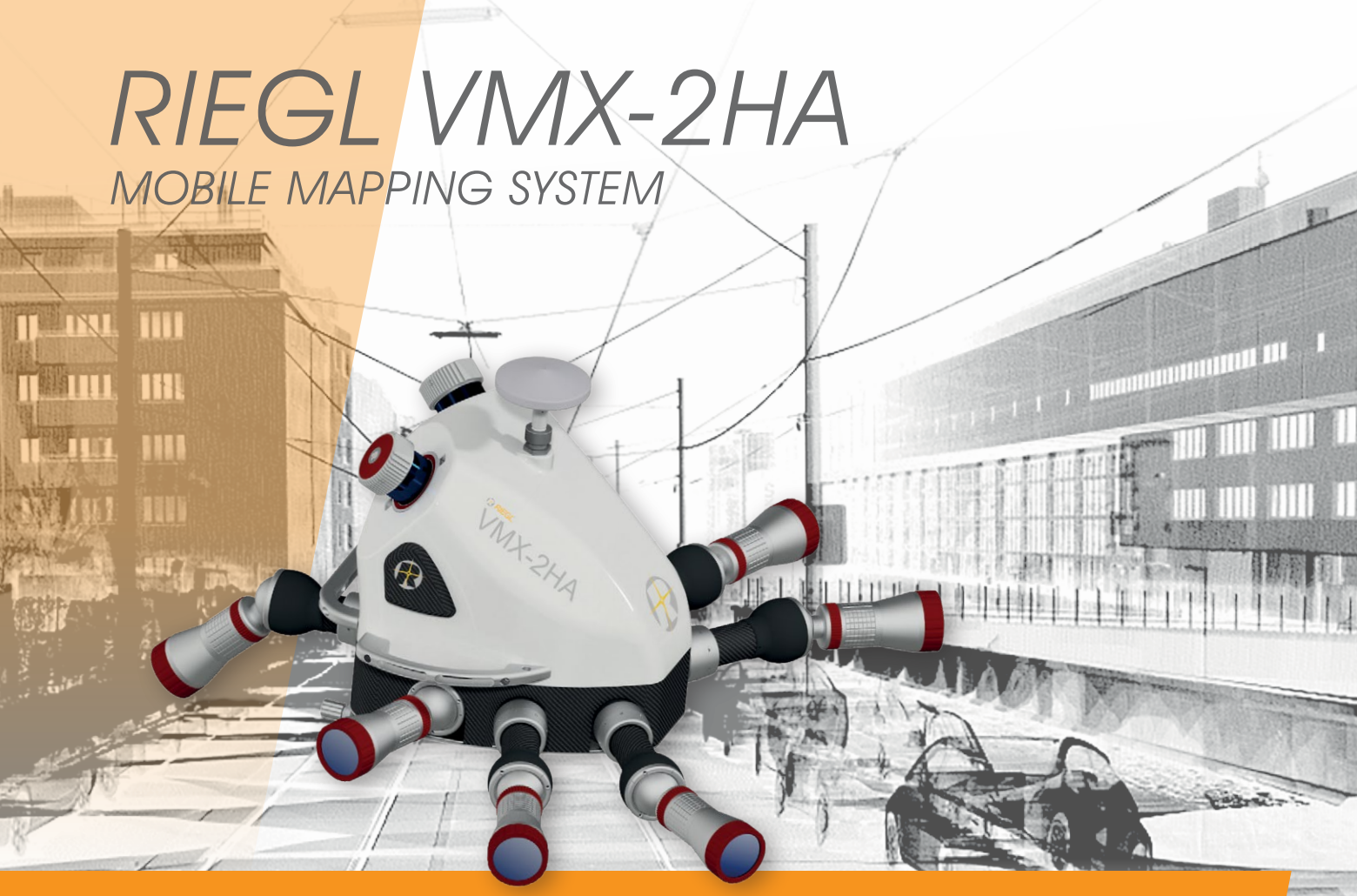


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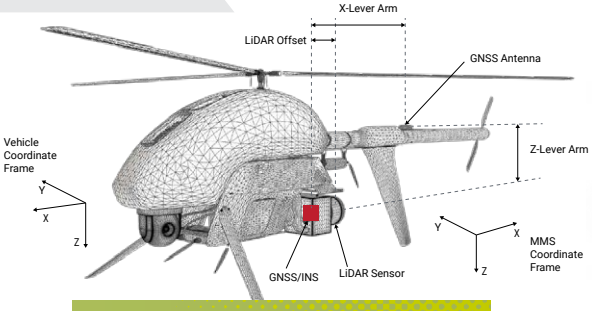
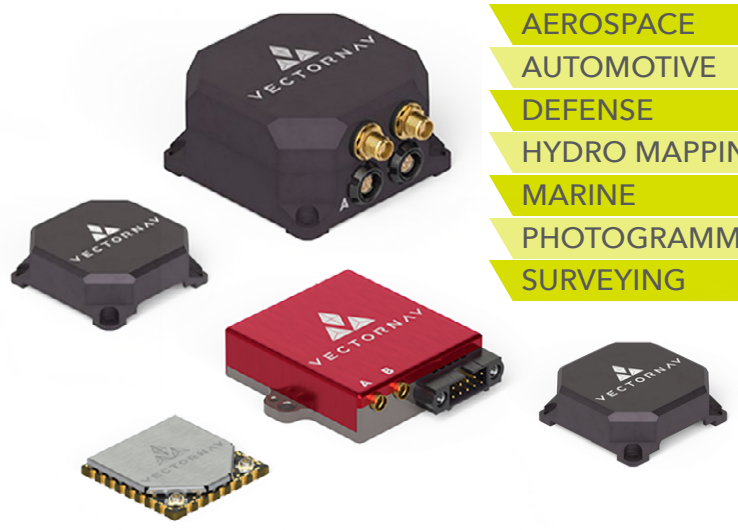
# VectorNav Technologies




## APPLICATIONS

- AEROSPACE
- AUTOMOTIVE
- DEFENSE
- HYDRO MAPPING
- MARINE
- PHOTOGRAMMETRY
- SURVEYING



## COMPANY PROFILE

VectorNav Technologies is the worldwide leader in embedded navigation solutions. Since its founding in 2008, VectorNav has been providing systems integrators in the military, aerospace, marine, and robotics industries worldwide with SWaP-C optimized, high-performance navigation systems. VectorNav applies digital filtering and sensor calibration techniques that have decades of heritage in aerospace applications to the state-of-the-art in inertial sensors and GNSS, redefining possible in today's inertial navigation technology. From the deep sea to remote deserts and beyond the stratosphere, VectorNav solutions enable UAVs and ROVs to circumnavigate the globe, defense systems to radically evolve, and world records to be broken. With more than 40,000 inertial systems deployed in a broad range of defense and commercial applications, its expertise you can count on.

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# High-performance inertial navigation solutions

VectorNav offers a range of Industrial- and Tactical-Grade inertial navigation solutions for direct geo-referencing applications. Combining temperature calibrated accelerometers, gyros, and magnetometers, along with GNSS receivers, VectorNav products provide IMU/AHRS, GNSS-Aided INS and GNSS-Compass functionality.

### Tactical Grade Inertial Sensors with Multi-Frequency GNSS and RTK/PPK Capability

Weighing only 15 grams, VectorNav's Tactical Embedded is the only product on the market to offer mrad-level attitude performance and centimeter-level positioning capabilities in a board-mount package. It is designed to enable dramatic reductions in size, weight, power and cost for the world's most demanding aerial direct georeferencing applications.

For marine and defense applications where size, weight and power are less critical, VectorNav's Tactical Series provides Tactical-Grade performance in IP68 rated enclosures certified to MIL-STD and DO-160G standards.

For applications requiring Industrial-Grade performance, VectorNav's VN-100 IMU/AHRS, VN-200 GNSS/INS and VN-300 Dual Antenna GNSS/INS offer the market's most proven, miniature and cost-effective inertial solutions.

### Inertial Navigation Library

Whether you are new to inertial navigation or looking for details on a specific topic, VectorNav's Inertial Navigation Primer is packed with industry expertise and best practices to help your project along. Explore topics ranging from basic terminology and explanation of specifications to advanced topics like INS error budgets and nonlinear Kalman Filters.

### LiDAR Mapping & Photogrammetry Application Notes

VectorNav provides deep technical content offering information on how to successfully integrate inertial sensors and GPS/GNSS into a variety of applications, including LiDAR Mapping, Photogrammetry, and more.

VECTORNAV

# UNPRECEDENTED PERFORMANCE AT YOUR FINGERTIPS

Introducing the all new Tactical Embedded line.
The best just got smaller.

Heading: **0.05°-0.1°**
Pitch/Roll: **0.015°**
GNSS: **L1/L2/E1/E5b**
with **RTK/PPK**


vectornav.com
**+1.512.772.3615**

# SBG SYSTEMS

## APPLICATIONS

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

## 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 Santa Anna, CA, and in Asia with its subsidiary in Singapore. 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***

# New Ellipse Series:

## Smallest High-end INS/GNSS with Qinertia Post-Processing

SBG Systems renewed its popular line of miniature inertial sensors with high-end functionalities and RTK. The 3rd generation of the Ellipse Series benefits from a 64-bit architecture allowing high-precision signal processing. All the INS/GNSS now embed a dual-frequency, quad constellations GNSS receiver for centimetric position, and higher orientation accuracy.

### New Ellipse-D: The Smallest Dual-Antenna and Dual-Frequency GNSS/INS

The Ellipse-D embeds a dual-antenna RTK GNSS, allowing heading in a few seconds, in all dynamic conditions, and even in challenging GNSS conditions. This high-end inertial sensor provides unmatched precise performance in attitude (0.05°) and heading (0.2°). All these features are made possible either in the 17-gram OEM version or the IP68 box version.

It is also compatible with SBG Systems' in-house post-processing software: Qinertia. Post-processing allows even higher accuracy for delivering more precise maps after data collection.

### INS/GNSS Post-Processing for all Applications with Qinertia

This full-featured software gives access to offline RTK corrections and processes inertial and GNSS raw data to further enhance accuracy and secures the survey, thus enhancing SBG Inertial Navigation Systems' performance.

Qinertia now supports third-party IMUs and all GNSS receivers and covers all surveyors' projects with its new GNSS license to post-process both static and kinematic GNSS data.

It now includes a brand-new Virtual Base Stations (VBS) feature to ensure a maximized, homogeneous, and robust position accuracy. With its new features for UAV Photogrammetry, such as image geotagging and specific outputs, Qinertia can dramatically reduce the need of GCP and maximize ROI with an optimal workflow.

SBG SYSTEMS


**0.05°** ATTITUDE | **0.02°** HEADING | **1 cm** POSITION

## The Smallest RTK GNSS/ INS for Robust Real-Time Navigation

# NEW ELLIPSE-D

- Quad constellations and Dual-frequency
- Fusion with Pulse or CAN OBDII Odometer
- Fast Initialization

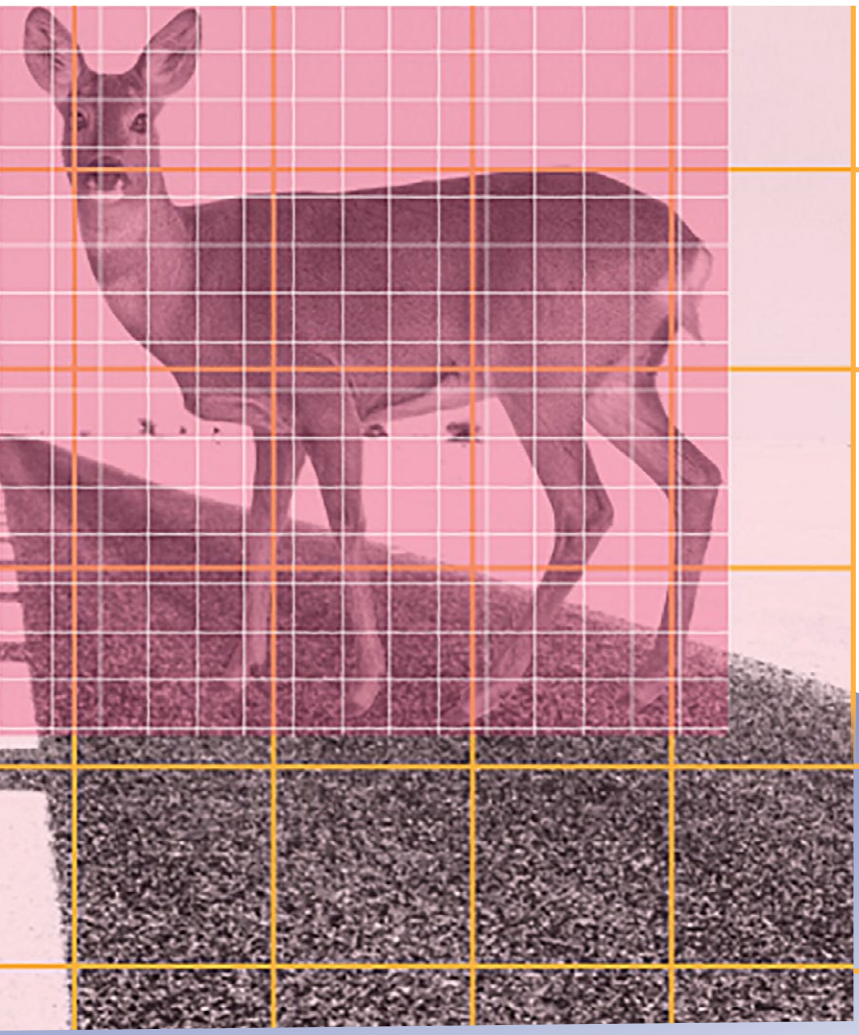
**Ellipse-D**
RTK Dual Antenna

**Ellipse-N**
RTK Single Antenna

**OEM**
RTK Best-in-class SWaP-C

Visit our website: **www.sbg-systems.com**

# Why Optical Phased Array is the Future of Lidar for Autonomous Vehicles



*Optical phased array (OPA) technology is an innovative approach to lidar that is rapidly emerging to meet performance and cost requirements for the autonomous vehice (AV) market. This exciting new lidar architecture is specifically designed for low-cost, high-volume, automotive-grade manufacturing. Learn how OPA-based lidar works, its advantages over traditional mechanical lidar, and why it is the technology to watch for autonomous vehicles.*

BY TIANYUE YU

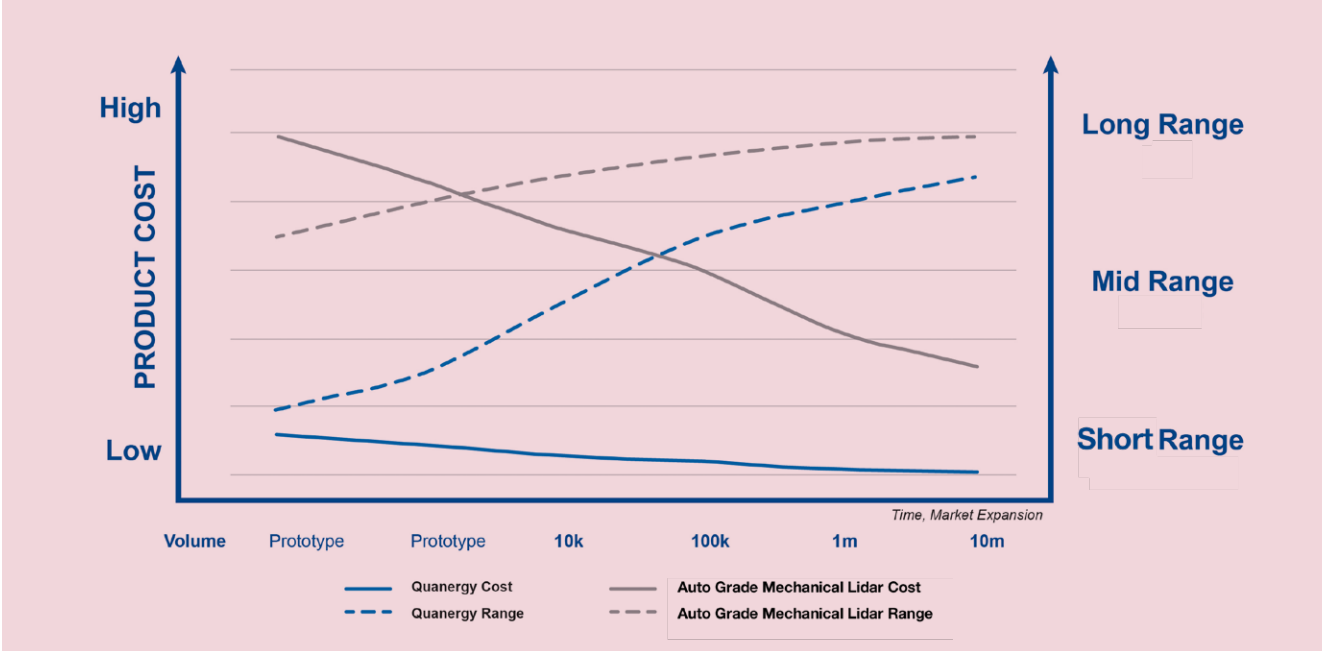



Figure 1: Quanergy's high-level architecture philosophy for automotive lidar hinges on a low-cost base technology platform. As the development takes its course, the detection-range performance increases and the cost further decreases with expanding applications and manufacturing scale.

Lidar enables the future of AVs—it is a key technology that will help make self-driving cars safe, efficient, and reliable. Until recently, however, the lidar market has been dominated by high-cost mechanical lidar sensors. While those costs *are* decreasing, most automotive lidar contenders simply cannot meet a <$500 per unit threshold *and* maintain the performance and reliability needed for consumer vehicles.

A next-generation technological approach to lidar leverages solid-state devices and OPA sensing technology to meet performance and cost requirements for the AV market. As OPA-based lidar continues to evolve and mature, it will emerge as a cost-effective, high-performing technology with advanced situational awareness for AV navigation and collision avoidance—that can be manufactured at scale. This target architecture of choice has been evidenced in the proliferation of automotive phased-array radar during the past two decades, as the industry has embraced phased-array architectures with shipment volumes of automotive radar already exceeding 20 million annually.

While OPA-based lidar is still relatively new compared to traditional mechanical lidar, it is making such rapid advances that solid-state lidar with OPA technology will begin to achieve relevancy to the transportation industry by 2022. **Figure 1** explains Quanergy's high-level architecture philosophy for automotive lidar. Although performance specifications are important, the most crucial aspects of lidar deployment in the transportation industry are low cost and high reliability.

A conscious architecture choice was made to use a silicon complementary metal-oxide semiconductor (Si CMOS) process for all critical components in OPA-based solid-state lidar. The motivation is to ride the mature semiconductor process to support a low-cost, high-volume manufacturing cost structure. Quanergy understood that this technology development path would be more challenging and time-consuming; however, the company pursued this route, eschewing any shortcuts that could compromise the long-term cost and reliability metrics—the ultimate determining factors for lidar democratization.

In this article, we explain what OPA is and why it is the technology of choice for autonomous vehicles.

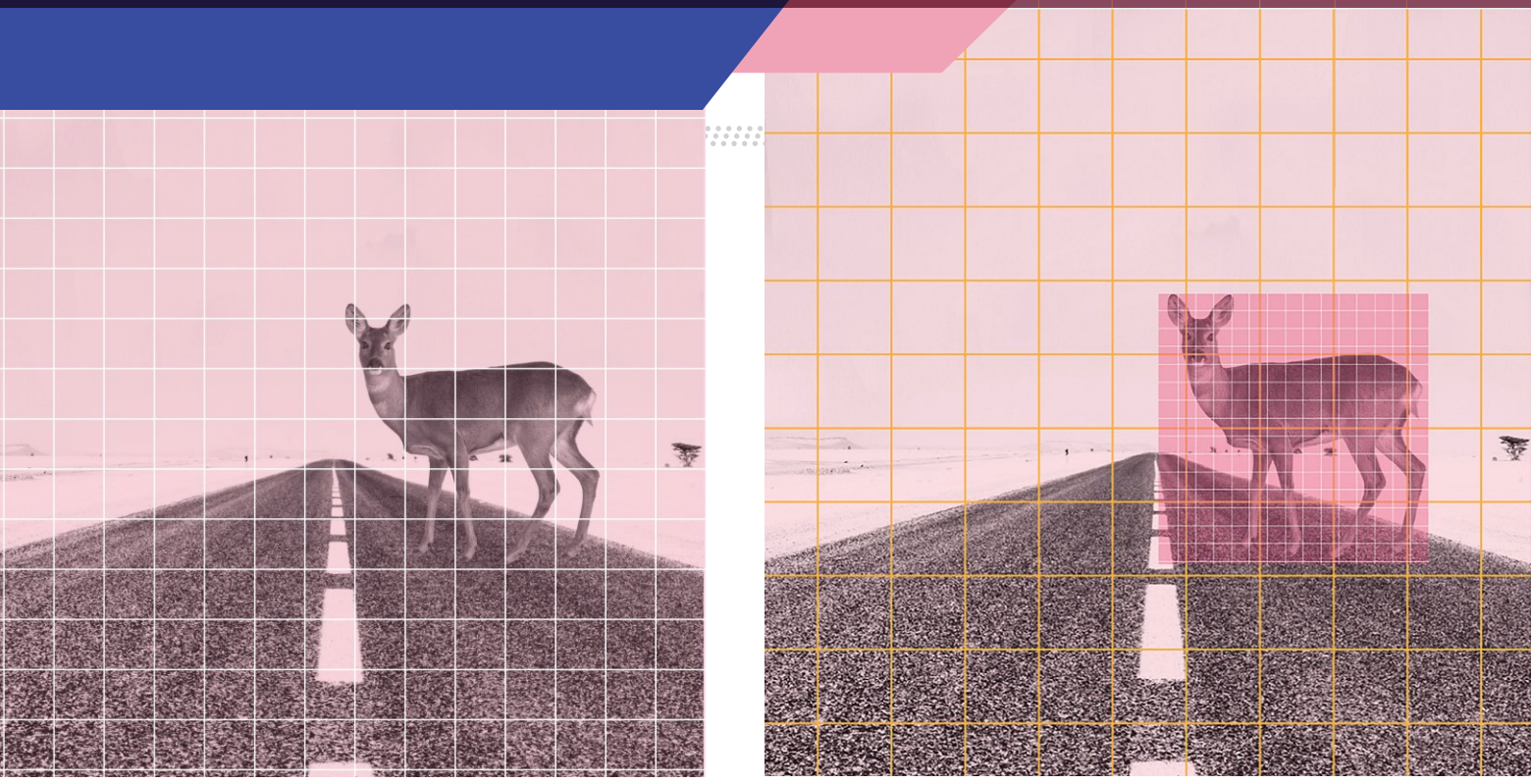


Figure 2: The principle of Quanergy smart zooming: an object, in this case a deer in the headlights, is detected in the coarse view (left), so the lidar sensor zooms in on this to provide the fine view (right), yet the system remains conscious of the broader field of view.

## The challenges of traditional mechanical lidar

3D lidar can be achieved with either solid-state scanning or mechanical motion. Despite many lidar vendors claiming solid-state capabilities, most lidar sensors on the market today operate using either micro- or macro-scale mechanical motion. These lidar sensors typically use either spinning or oscillating mechanisms, or MEMS (micro-electro-mechanical systems) mirrors, to achieve the mechanical scanning function.

While lidar sensors that operate with mechanical motion are used in some industries and applications, they have their limitations for the automotive market. For example, spinning or oscillating lidar sensors are relatively large and bulky to accommodate the scanning mechanisms. In addition, mechanical lidar sensors are more expensive to manufacture compared to newer types of lidar. Both factors make mechanical lidar impractical for widespread deployment in autonomous consumer vehicles.

Mechanical scanning also means there are many moving parts that are more likely to wear prematurely or become misaligned when exposed to shock or vibration. The mechanical scanning also limits the sensor's ability to respond respond adaptively to rapidly changing situations—like driving. Considerable engineering effort is being invested to bring macro- or micro-mechanical lidars to automotive grade compliance.

## What is OPA?

OPA is the optical analog of phased-array radar. A phased array has multiple antenna elements that are fed equal-intensity coherent signals and use variable phase or time-delay control at each element to generate an arbitrary far-field radiation pattern and sweep it in space.

Quanergy's solid-state lidar[1] uses OPAs fabricated using a CMOS-compatible silicon photonic integrated circuits (PICs) process. Laser beams are steered electronically, sweeping the view angle of the sensor with no moving parts. Solid-state lidar further reduces costs with a silicon CMOS detector solution, providing a path to commoditization for lidar sensors.

## Common misconceptions about OPA

While OPA lidar technology may sound new, it is based on decades of research. Furthermore, the electronics and software solutions developed for the spinning lidar products are also applicable in solid-state lidar. This helps accelerate the pace of commercialization. As with any emerging technology, however, there remain important

1 Currently the S Series products: https://quanergy.com/products/s3/.

developments in OPA-based lidar that will continue to improve the technology and make it more broadly applicable and cost-effective in the coming years. For example, though the first commercial product was released into short-range flow-management applications, Quanergy's OPA-based sensors are now rapidly extending their performance levels to higher scanning rates and longer detection ranges of 100 meters or more under outdoor conditions with bright sunlight and 10% reflectivity targets. This evolution is expected as the technology matures and positions OPA as not just a contender—but a winning solution—for the AV market.

## Unique capabilities enabled by OPA

OPA technology conveys many benefits that cannot be achieved by other methods of lidar scanning, including intelligent and adaptive situational awareness, high reliability for daily use in consumer vehicles, low-profile form factors that integrate seamlessly within the vehicle design, and low-cost production at high volumes.

As has been the case in many industries (for example, communications, computers, medical sensors), hardware is typically commoditized over time by semiconductor technology at one end and software technology at the other. The OPA architecture inherits both semiconductor cost trajectory and software scaling and follows this natural trend to enable scalable volume deployment.

Four of the advantages of OPA that are crucial to the AV market are explored further below.

### 1. Adaptive smart zoom

Electronic scanning enables a more adaptive approach to scanning and zooming into areas of interest. The sensor can adjust its laser beam movement dynamically depending on the *changing* environment. For example, Quanergy's solid-state lidar sensors feature smart zooming, which can zoom in and out dynamically to provide coarse or fine view (**Figure 2**), without losing sight of the broader field of view. This software-controlled beam formation and steering brings intelligence into the sensor hardware and puts the beam precisely where the light is needed.

### 2. Unmatched reliability

OPA-based lidar is a true 100% solid-state lidar with zero moving parts. This provides immunity to shock and vibration, with over 100,000 hours of mean time between failure (MTBF). The unmatched reliability and longevity of these sensors makes them ideal for use in consumer vehicles.

### 3. Low-cost, high-volume production

Quanergy's OPA-based solid-state lidar uses mature CMOS silicon production processes, which can support extremely high-volume production at scale for an exceptionally low cost compared to competing lidar sensors.

### 4. Seamless integration in vehicle design

The compact, lightweight OPA-based lidar sensors can be seamlessly integrated into the design of vehicles and provide rich data for object detection, tracking and classification, and the support of a variety of functions including truck platooning, ADAS functions (lane departure/change warnings and forward/reverse collision warnings), autonomous valet parking, and self-navigation in geo-fenced areas.

## Conclusion

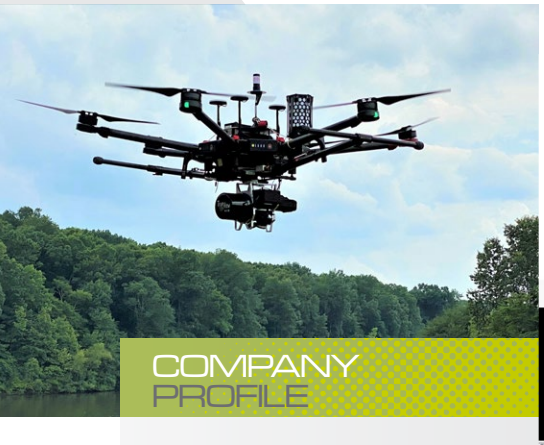
After many years of being perfected for lidar, OPA technology is quickly coming up to speed to intersect with the growing need for intelligent sensing in the automotive industry. It's another way lidar is improving the quality of life for people around the world—and, ultimately, making our world a safer, better, more efficient place.

**Dr. Tianyue Yu** founded Quanergy[2] and has served as Chief Development Officer since February 2020, steering the organization toward commercialization. Prior to that, she served as Chief Technology Officer (2018-20) and Vice President of Products (2014-18). She has extensive experience in high-resolution imaging, 3D laser scanning and microfabrication, high-throughput sensing, nanotechnology and advanced electronics materials. She oversees the company's technology architecture, product design and engineering to advance technology innovation and ensure successful implementation of the product roadmaps. Prior to founding Quanergy, she held various roles at established technology companies as well as startups, from principal scientist to leadership positions building cross-functional teams and driving technology development and commercialization. She started her career at Affymetrix on sensor miniaturization and high-resolution imaging. She holds more than 15 patents in sensing, nanotechnology, and system design. Dr. Yu earned a PhD from Cornell University with concentration on nanomaterials and nanotechnology and a BS in chemical physics from University of Science and Technology of China.

2 For more information go to www.quanergy.com.

LIDAR LEADER AWARDS
OUTSTANDING INNOVATION

# GEOCUE GROUP INC.



## COMPANY PROFILE

GeoCue is the largest supplier of kinematic lidar processing tools in North America and LP360 is one of the world's most widely used tool for exploiting point cloud data. In 2014, GeoCue Group started a division focused on using small Unmanned Aerial Systems for high accuracy mapping. 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® Drone LIDAR/Imagery fusion sensors.

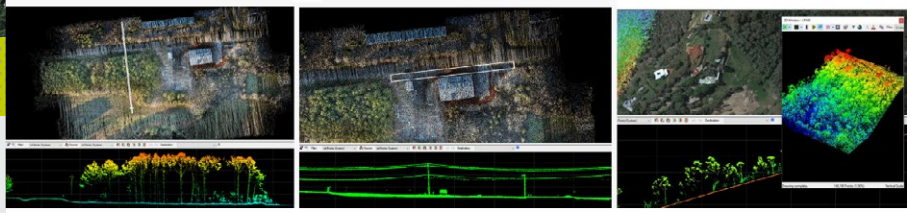
GeoCue Group

Founded 2003
11-50 Employees
520 6th Street Madison, AL 35756

***geocue.com***

## APPLICATIONS

- MAPPING
- PROCESSING
- SURVEYING
- UNMANNED
- AERIAL
- CONSULTING

# True View 3D Imaging Sensors

Powerful LIDAR + Dual Camera Sensor integrations, post processing software and data management for high accuracy drone mapping applications.

### Fly, Process, Deliver— All in One Solution

GeoCue's True View 3D Imaging Sensors offer an innovative drone mapping solution supporting LIDAR, photogrammetry, and direction geo-referencing solutions integrated in lightweight payloads. GeoCue focuses on offering full solutions rather than individual parts. Unlike other drone LIDAR providers, GeoCue includes post-processing software and a data management portal to provide users with a complete solution from flight to post-processing and data delivery.

### Utility-Grade to Survey-Grade 3D Imaging

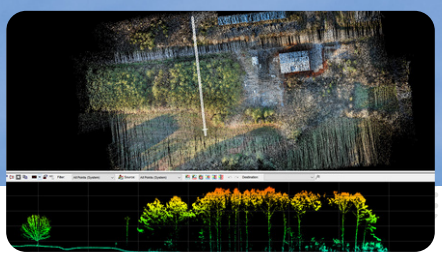
GeoCue offers a series of True View 3DIS systems ranging from utility grade to survey grade ensuring successful drone mapping projects no matter the application. The True View 3DIS includes all the components and software necessary to collect LIDAR and RGB image data and process these data to a 3D colorized point cloud in LAS format. True View systems use Applanix POS for best-in-class position and orientation accuracy.

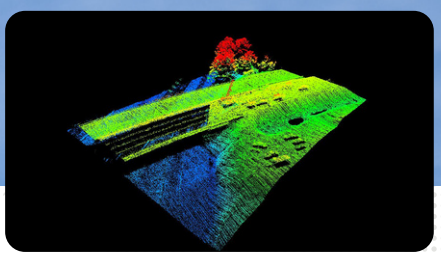
### Drone LIDAR Sensor Subscription Offering

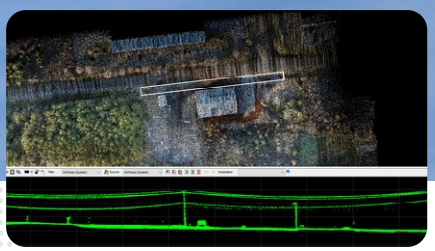
Explore drone LIDAR at low risk and low cost. This unique business model that allows customers to acquire a True View 410/515 3DIS under a subscription model for periods as short as ONE MONTH! This is an excellent model for seasonal use and surge capacity.

TrueView
GeoCue

Innovate.
Integrate.
Elevate.







# 3D IMAGING SENSORS

## Drone LIDAR + Photogrammetry Integration

### Data Collection

Collect LIDAR and Photogrammetry in a single flight. True View 3DIS can be mounted on just about any UAV platform.

### Data Processing

True View EVO software is bundled with every 3DIS. EVO generates a 3D LIDAR point cloud in LAS format, colorizes the point cloud and geotags the collected images.

### Data Management

Manage True View Points and sensor calibration files along with hosting your True View Data in our Reckon Portal.

www.geocue.com/trueview info@geocue.com

GeoCue Group

# 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.

In Uncertain Times Productivity is Important

# Special 0% Financing for 36 Months

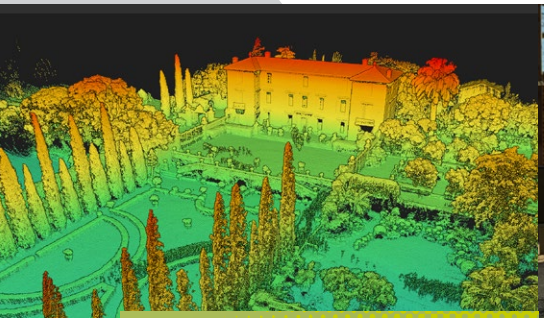
Support American Made - LiDAR and Drone Manufactured in the USA

20 YEARS ANNIVERSARY CELEBRATION

LiDAR USA

Fagerman Technologies Inc.

# Yellowscan



COMPANY PROFILE

**APPLICATIONS:**

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

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.

# Cities Branch out to Trim Trees

## New workflow tames hazardous vegetation

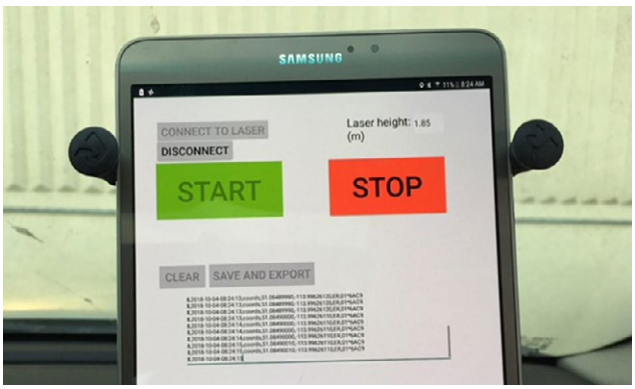
Trees growing in a pedestrianized area of Moncton.

Dan Hicks, director of operations for the Parks Department in Moncton, New Brunswick, Canada, oversees several city assets from arenas to forestry. Every municipality has standard operating procedures, and when elements of these processes are automated, efficiency and reliability grow. Hicks and his team correctly predicted that a certain routine maintenance task—identifying and recording low-hanging tree branches—was ripe for automation. A hazard to vehicles and pedestrians alike, low-hanging tree branches require continual identification and removal to ensure people can safely navigate the city. In the city of Moncton, tree branches must be 15 feet (4.6 m) above street level and 8 feet (2.4 m) above sidewalks.

When Hicks described the traditional method of recording low-hanging tree branch locations, the opportunity for improvement became evident. "We did it before by driving past, jotting down addresses and identifying low-hanging branches by eye," said Hicks. "It's time-consuming when you do it that way, using pen and paper and driving. Drive, stop, write it down. Drive, stop, write it down." Hicks and his team knew a more automated solution was possible. They presented the challenge to the team at Cansel, their Trimble distributor, who assured Hicks that they could figure something out.

BY GORDON WILSON

LaserTech TrueSense S230 mounted to front passenger window of car; Trimble Catalyst DA1 antenna mounted to car roof; mounting by suction cup in both cases.




Samsung Android tablet in use while connected to LaserTech TrueSense S230.

Cansel provided them with a simplified mobile scanning device made up of three basic elements. Attached to a company vehicle, a small lidar unit—a LaserTech TrueSense S230—measures the clearance to the nearest solid overhead structure while a Trimble Catalyst DA1 antenna defines the vehicle's horizontal location to sub-meter accuracy. A Samsung tablet with a customized software application developed by Cansel handles the data from these two elements and delivers the output file.

Catalyst, Trimble's subscription-based GNSS service for Android, turns the Samsung tablet into a fully functioning GNSS receiver, providing positioning at sub-meter accuracy without the expense of traditional GNSS equipment. Using a tablet (or smartphone) as a GNSS receiver makes this setup more approachable for employees who have no experience using survey equipment. Anyone familiar with a smartphone can navigate the software on their Android device. The small DA1 antenna and lidar unit are mounted by suction cups, making the setup easily transferable between company vehicles. "You can put it on a golf cart and measure clearances on sidewalks," Hicks said. "You can mount it to just about any type of vehicle." Currently, the setup is attached to the truck of a foreman who gathers the tree data as a supplemental task to his normal duties.

When the drive is over, the customized application exports a comma-separated-values (CSV) point file to the city's GIS technicians, who upload the data to a city map in Esri® ArcGIS®. Hicks and his team review the map, then filter and sort the conflict areas as high-, medium- and low-risk sites. The GIS map allows them to assess and schedule the maintenance of these conflict areas most efficiently, so they can attend to high-risk sites before they become a problem for motorists.

Hicks and his team are enthusiastic about the prospects of this new solution. Its simplicity allows employees without GNSS expertise or forestry knowledge to use it, which means purposeful, non-specialized work is available to more people. "You're looking at a municipality with 650 employees, and at any given time some of them are on modified duty," Hicks said. "They might be able to drive a truck but not lift a chain saw, so we need productive work for them to do." The ease of use makes this a task that any employee capable of reading a tape measure and driving can perform successfully.

The subscription-based GNSS capability provided by Catalyst also allows flexibility in planning when gathering data, without a substantial investment upfront.

"One could collect data several kilometers per day," Hicks said. It's a clever upgrade that will benefit both the employees of Moncton and the citizens they serve.

**Gordon Wilson** is a professional land surveyor and writer living in Portland, Oregon.

# Seiler Instrument Geospatial


## APPLICATIONS

- MOBILE MAPPING
- GIS
- SURVEY
- SOLUTIONS
- GNSS
- LIDAR
- TRAINING
- RENTAL

## COMPANY PROFILE

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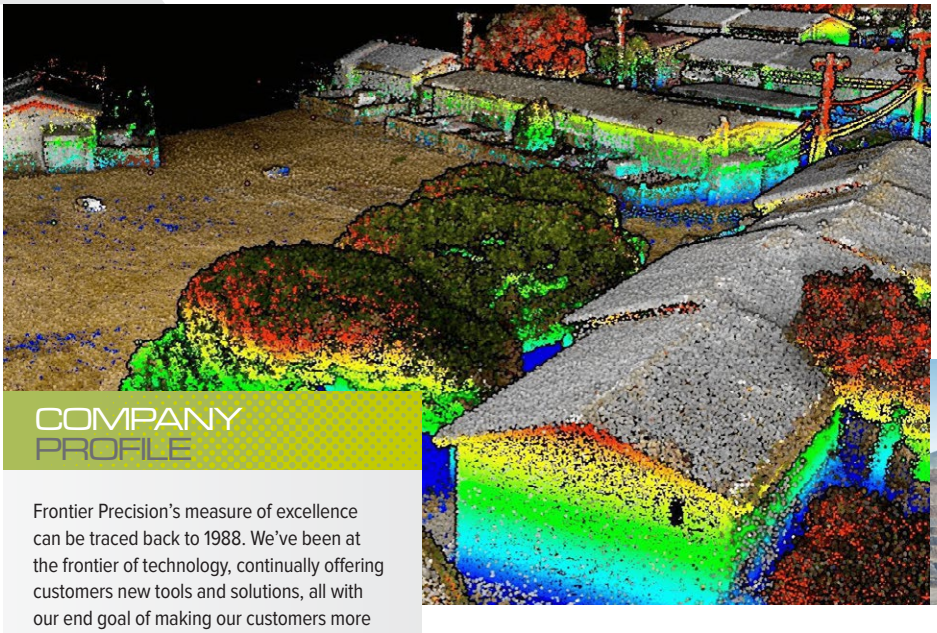

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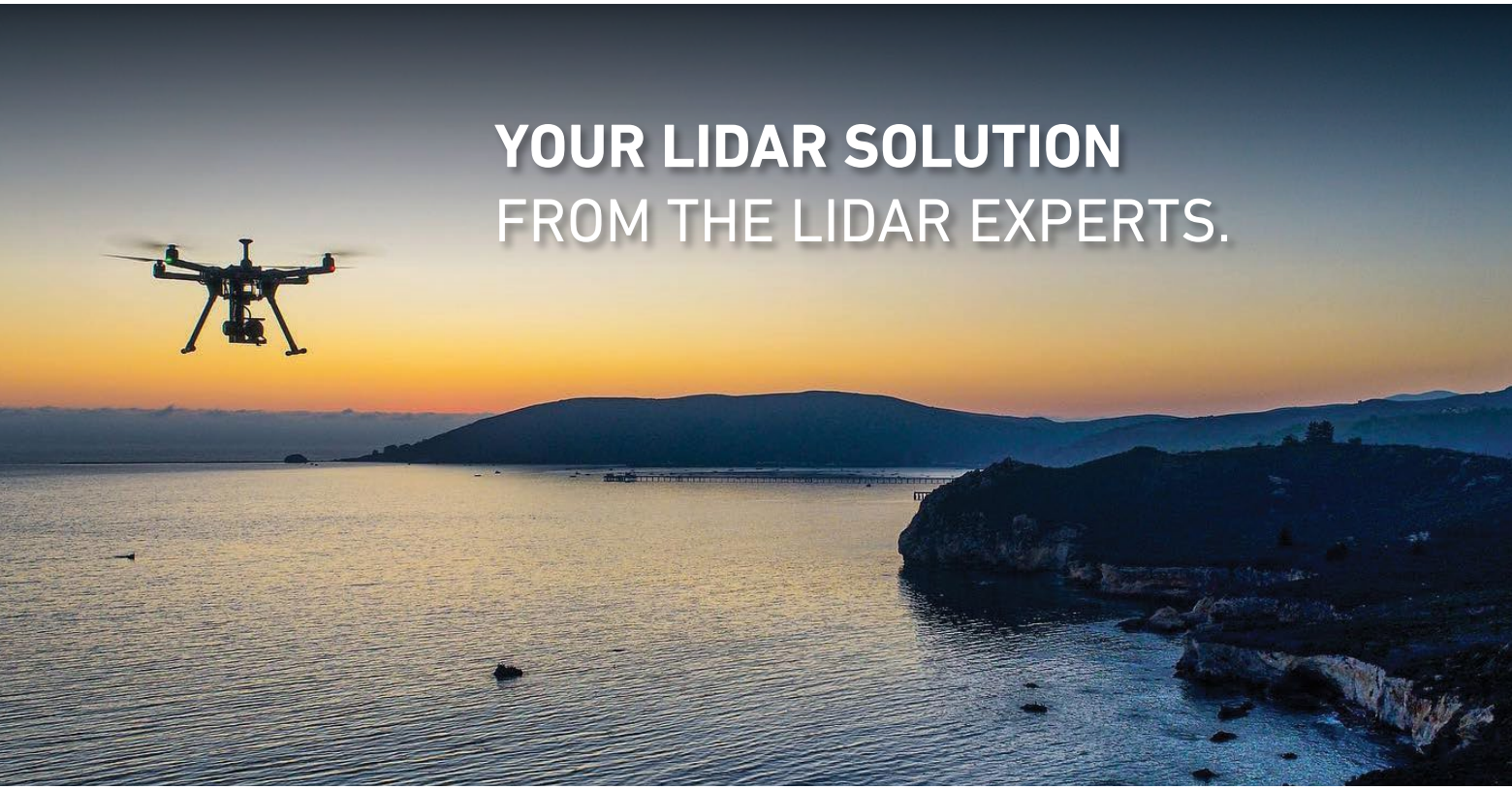

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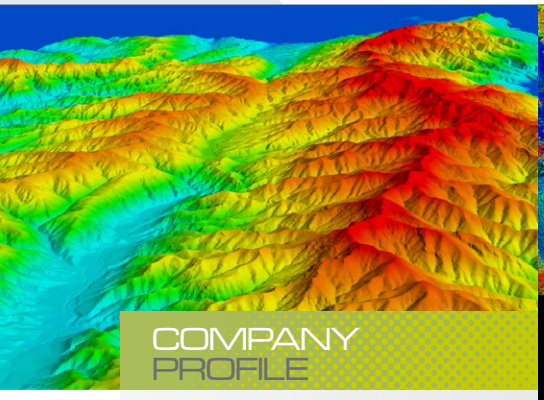

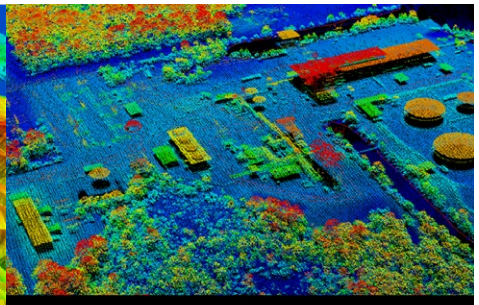

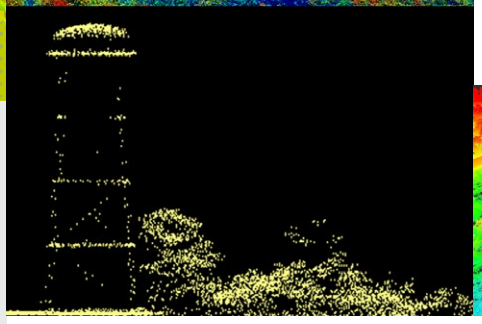

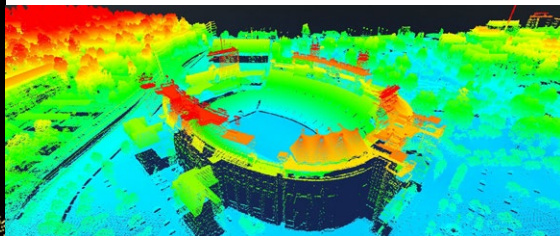

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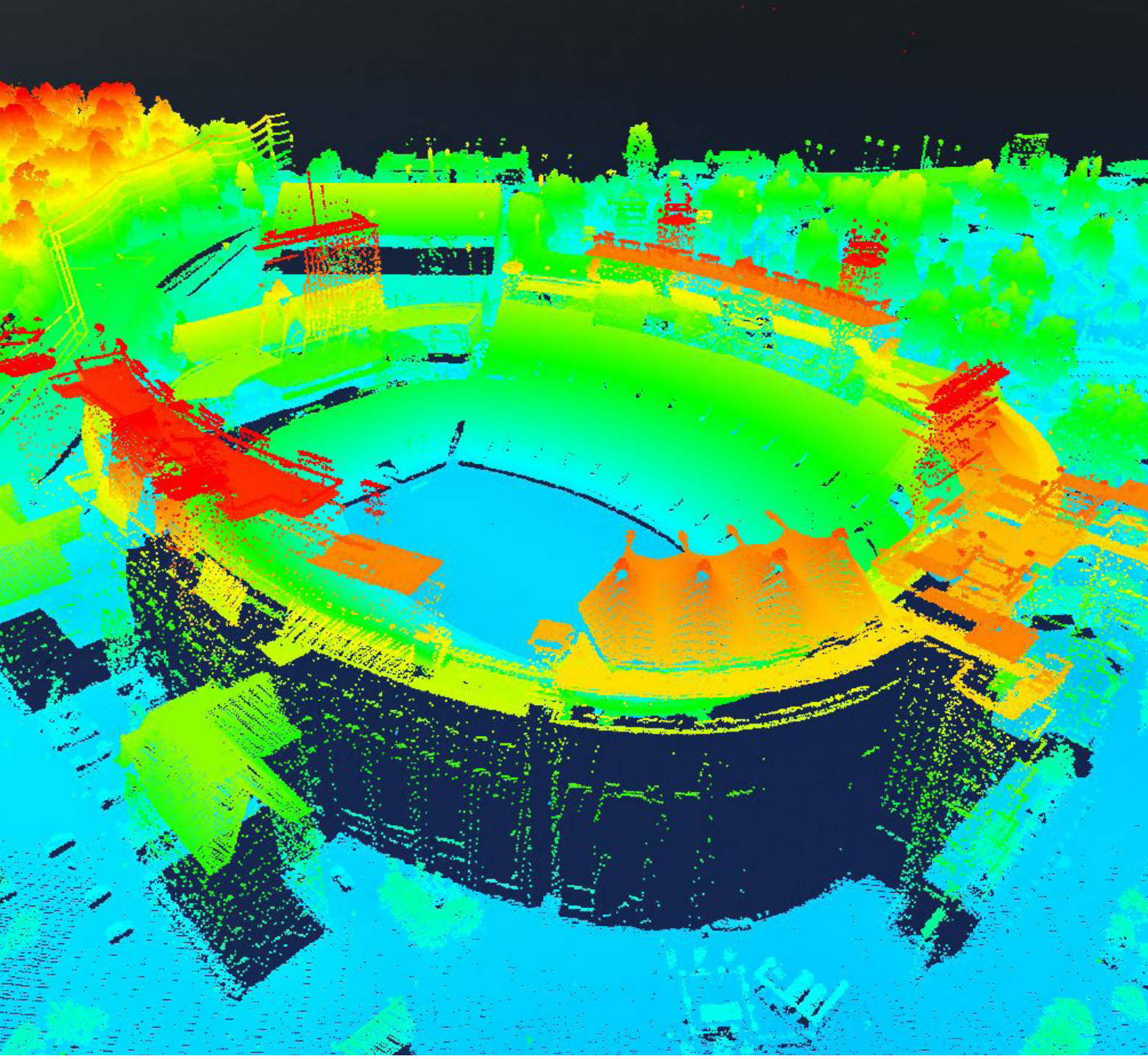
The firm's solid performance processes in geospatial technologies and corporate IT services led to it being appraised at Level 3 of the CMMI Institute's Capability Maturity Model Integration (CMMI) in Services and Development Models. In 2020, Dewberry also received the International Lidar Mapping Forum (ILMF) and Lidar Magazine's 2020 Outstanding Enterprise Achievement in Lidar award.

Dewberry works seamlessly to provide geospatial mapping and technology services across various market segments. With more than 30 years' experience, the firm is dedicated to understanding and applying the latest tools, trends, and technologies in support of its clients' program goals and objectives. Dewberry employs the latest GIS software and database platforms, including the full suite of ESRI products, and it was awarded the 2019 ESRI partner award for maximizing ArcGIS in service offerings. The firm's products and services include application, web, and cloud-based development; system integration; database design mapping; data fusion; and mobile solutions.



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# Accuracy Assessment of the Microdrones mdLiDAR3000DL

## Testing sUAS-lidar system for large-scale mapping

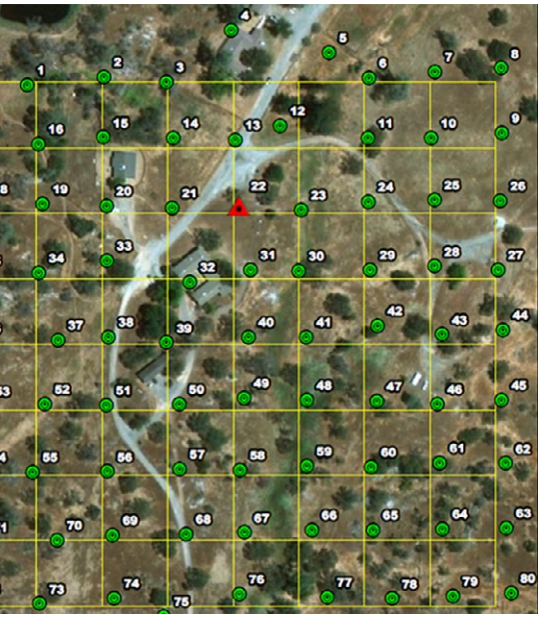

Figure 1: SJER test site.

Lidar systems based on small unmanned aerial systems (sUAS) are rapidly advancing. This research investigates a Microdrones mdLiDAR3000DL sUAS-based lidar system. Accuracy analysis of data is acquired for two different sites. These sites have dense ground control fields established using high-accuracy ground surveying methods. A lidar point cloud acquired from a manned helicopter was utilized to evaluate the mdLiDAR3000DL performance on paved roads, unpaved roads, and roof tops.

### Standards and test fields

The *American Society for Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data*[1] were used to validate the mdLiDAR3000DL accuracy (**Table 1**). Two test sites with high-precision control points were established to test the technology. The first, San Joaquin Experimental Range (SJER), has 81 control points in a grid-like pattern with estimated accuracies of 1 cm $RMSE_{XY}$ horizontally using static GNSS and 0.5 cm $RMSE_{Z}$ vertically using digital leveling (**Figure 1**). The second

1 American Society for Photogrammetry and Remote Sensing (ASPRS), 2015. Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0. November, 2014), *Photogrammetric Engineering & Remote Sensing*, 81(3): A1-A26, March 2015. https://www.asprs.org/wp-content/uploads/2015/01/ASPRS_Positional_Accuracy_Standar-ds_Edition1_Version100_November2014.pdf.

BY RIADH **MUNJY**, JACOB **LOPEZ** AND CHRIS **THORNTON**


Figure 2: Cal Fire test site.

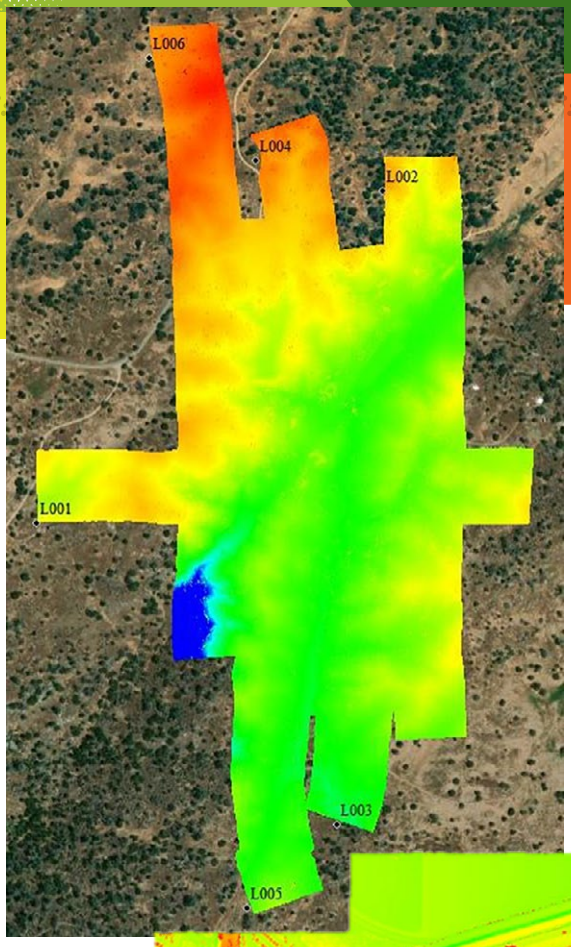


Figure 3: Flights of manned helicopter over SJER test site.

| Table 1: ASPRS 2014 Vertical Accuracy | | | |
|---|---|---|---|
| **Absolute Accuracy** | | | |
| Vertical Accuracy Class (cm) | $RMSE_Z$ Non-Vegetated (cm) | NVA at 95% Confidence Level (cm) | VVA at 95% (cm) |
| 9.3 | 9.3 | 18.2 | 27.8 |

site (Cal Fire) has 30 control points with 0.5 cm $RMSE_{XY}$ horizontally and 0.5 cm $RMSE_Z$ vertically (**Figure 2**). Both test sites are remarkable, given the large number of control points with such a high degree of precision and accuracy. To validate the point clouds generated with this technology, both control sites were scanned using a high-precision lidar system flown on a manned helicopter, with 1 cm $RMSE_Z$ vertically and 120 points/m$^2$ density (**Figures 3 and 4**).

## Microdrones sUAS-lidar

The Microdrones mdLiDAR3000DL is based on a md4-3000 quadcopter with a takeoff weight 14.8 kg (**Figure 5**). The payload consists of a Sony RX1R II RGB camera (not used in this research), Riegl miniVUX-1DL lidar system and Applanix APX-20 UAV PPK GNSS/IMU system.

The GNSS/IMU system has dual-frequency GNSS (L1 and L2) and IMU at 200 Hz with 0.025° heading accuracy and 0.015° roll and pitch accuracy. The expected accuracy specified by the manufacturer is 1-3 cm $RMSE_{XY}$ horizontally and 2-4 cm $RMSE_Z$ vertically.

The Riegl miniVUX-1DL builds upon the miniature UAV laser scanner Riegl miniVUX-1UAV. "DL" refers to "downward-looking", indicating special design parameters for corridor mapping (downward-looking, optimized field of view of 46°, small size, 2.4 kg). The sensor is capable of five returns per laser shot. With a scan rate of 150 Hz, it can produce 100K laser pulses per second[2].

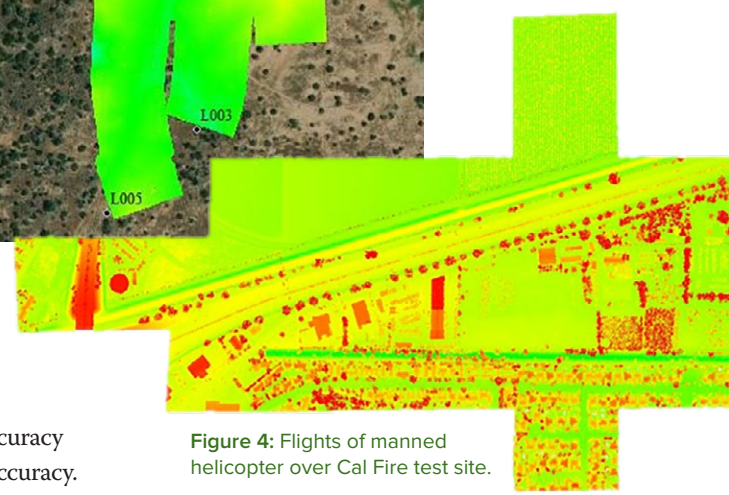

Figure 4: Flights of manned helicopter over Cal Fire test site.

Figure 5: Microdrone sUAS.

2 http://www.riegl.com/products/unmanned-scanning/riegl-minivux-1dl/.

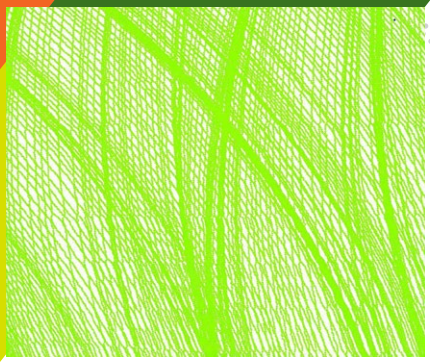

Figure 6: Scan pattern generated by Microdrones mdLiDAR3000DL with Riegl miniVUX-1DL.

The following mapping parameters were used at each test site: SJER - flying height 75 m AGL, flight speed 5 m/s, 50% sidelap; Cal Fire—80 m AGL, 5 m/s, 50%. The downward-looking, forward/backward-looking, rotating cone wedge pattern generates a well-distributed, circular scan with a point density of 270 points/m$^2$ (**Figure 6**).

## Vertical accuracy

### Check points

Using the lidar point cloud, a 5 cm grid digital elevation model (DEM) was generated for both test sites. The check-point elevations were interpolated from the DEM and compared to the ground elevations obtained from digital leveling. The statistical results of this comparison are shown in **Table 2**. The vertical RMSE$_z$ for SJER and Cal Fire test sites are 1.8 cm and 1.4 cm respectively, with less than 1 cm bias. The noise ranged between 6 and 9 cm. The vertical error contour maps for both test sites are shown in **Figures 7 and 8**. These maps show no doming effect or large noise in the check point results.

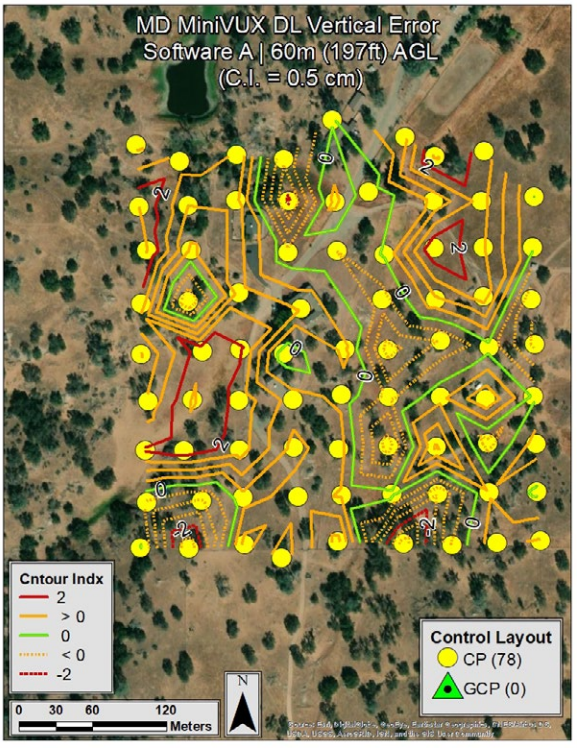


Figure 7: Error contour map for SJER test site.


Figure 8: Error contour map for Cal Fire test site.

**Table 2: Results at Check Points**

| Site | Date | RMSE$_z$ (cm) | St. Err. Z | Avg Z(cm) | Range Z(cm) | No. of Strips |
|---|---|---|---|---|---|---|
| **Cal Fire** | 9-24-2019 | 1.4 | 1.4 | -0.3 | 6.4 | 6 |
| **SJER** | 10-27-2020 | 1.8 | 1.8 | 0.5 | 9.3 | 13 |

**Table 3: Differences Between Profiles Derived From sUAS and Helicopter Point Clouds (cm)**

| SJER B1-1 | | SJER B1-2 | | SJER Driveway | | SJER Road1 | |
|---|---|---|---|---|---|---|---|
| **Avg Z** | **RMSE$_z$** | **Avg Z** | **RMSE$_z$** | **Avg Z** | **RMSE$_z$** | **Avg Z** | **RMSE$_z$** |
| 0.6 | 0.9 | 0.3 | 0.9 | 0.4 | 0.7 | -0.0 | 1.0 |
| **CAL FIRE-B1-1** | | **CAL FIRE B1-2** | | **CAL FIRE PAD 1** | | **CAL FIRE Road2** | |
| **Avg Z** | **RMSE$_z$** | **Avg Z** | **RMSE$_z$** | **Avg Z** | **RMSE$_z$** | **Avg Z** | **RMSE$_z$** |
| -1.5 | 1.7 | 1.3 | 1.6 | -0.8 | 1.3 | -1.8 | 2.1 |


**Figure 9:** Profiles at SJER test site.

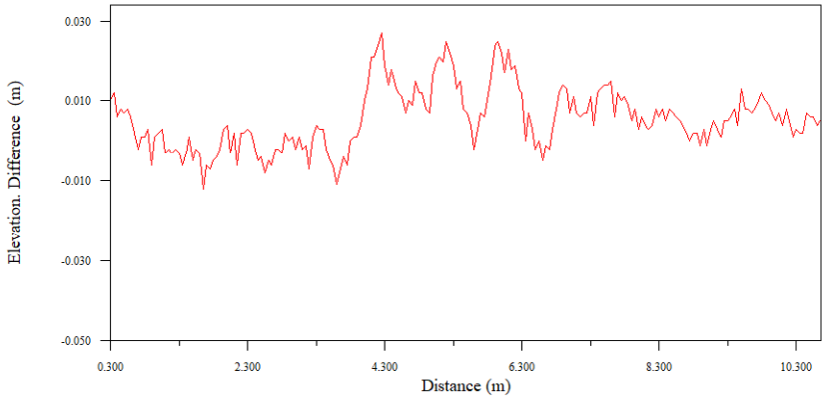


**Figure 11:** BLDG 1-2 profile difference at SJER test site.

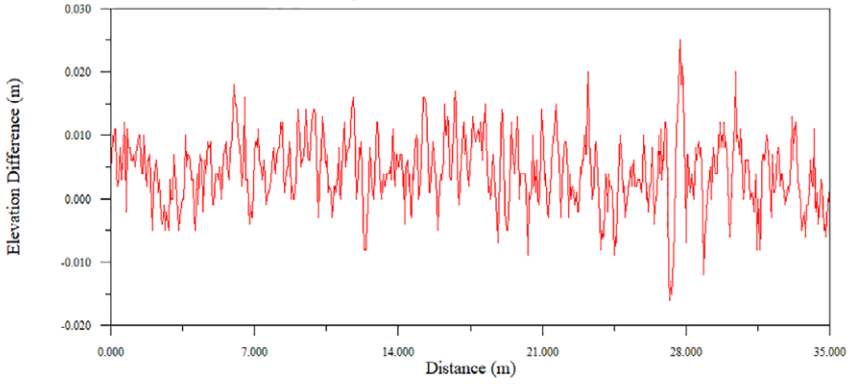


**Figure 12:** Asphalt Driveway profile difference at SJER test site.

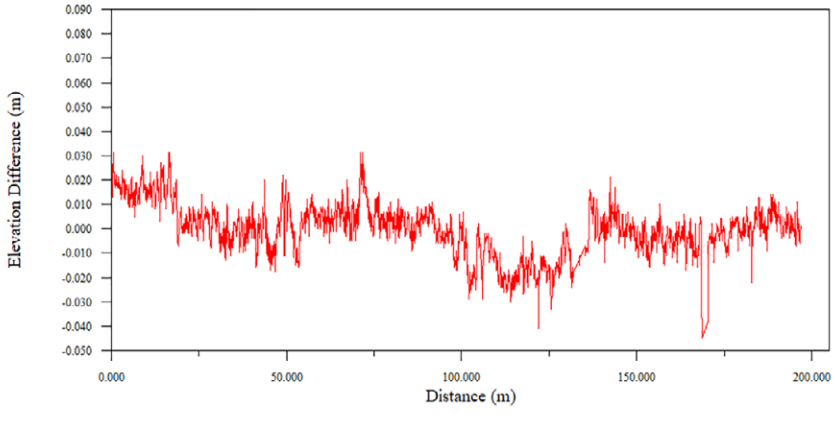


**Figure 13:** Unpaved Road 2 profile difference at SJER test site.

**Figure 10:** Profiles at Cal Fire test site.

## Profiles

Using the airborne helicopter laser point cloud from both sites, a profile analysis was conducted with Microdrones software for point-cloud comparison. Several profiles on different surfaces were generated as shown in **Figures 9 and 10**. Selected profile differences for the SJER and Cal Fire test sites are shown in **Figures 11–13** and **Figures 14–16** respectively. These are within the accuracy of the point cloud acquired from the manned helicopter. The noise is larger on dirt road surfaces, which is possibly due to a small planimetric shift between the sUAS and helicopter point clouds. **Table 3** shows the profile difference results with vertical $RMSE_Z$ ranges of 0.7-2.1 cm.

## Conclusions

This study demonstrates the potential capability of an sUAS equipped with lidar (Microdrones mdLiDAR3000DL) to meet large-scale mapping specifications with a factor of safety. Site-specific

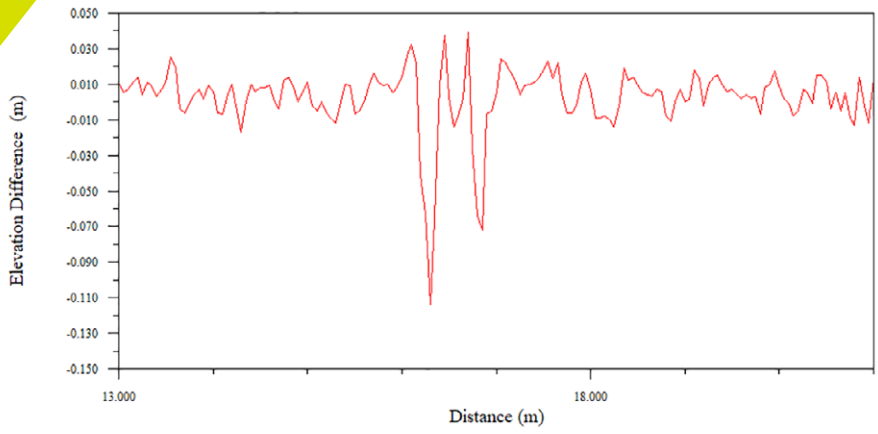


**Figure 14:** Overhang profile difference at Cal Fire test site.

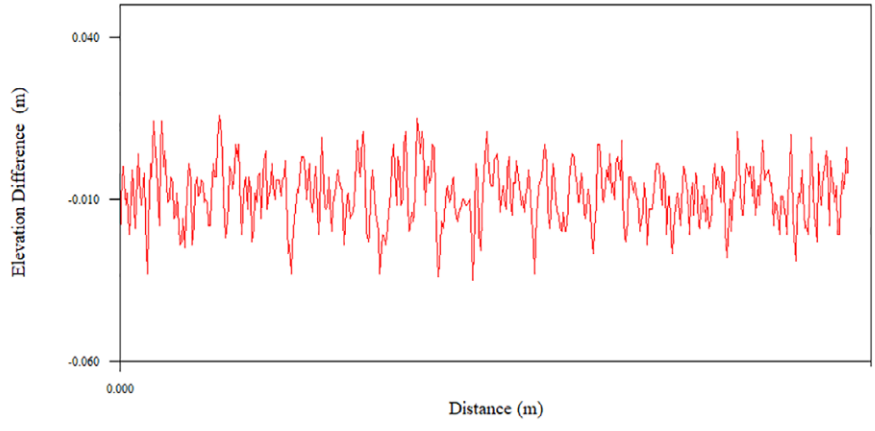


**Figure 15:** Concrete Pad 1 profile difference at Cal Fire test site.

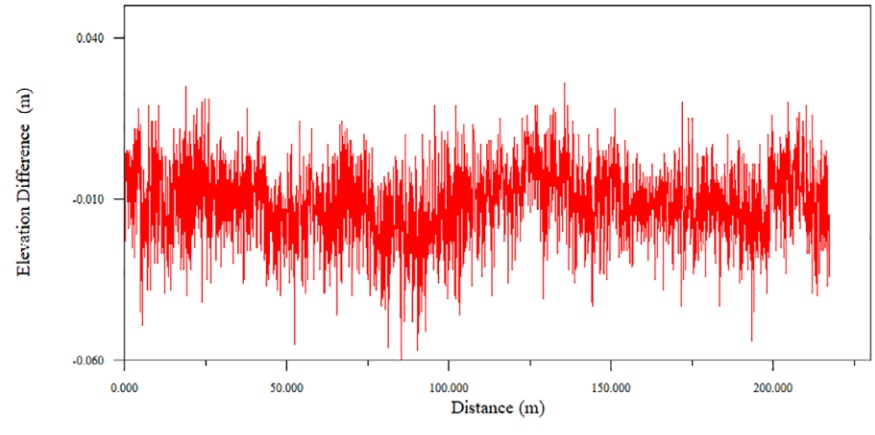


**Figure 16:** Unpaved Road 1 profile difference at Cal Fire test site.

considerations include extent of area of interest, terrain relief, vegetation coverage, surface variability, GNSS requirements, system specifications, flight-planning parameters, and site control requirements. These factors must be considered on an individual basis when evaluating system and site suitability and resulting accuracies.

Based on the test site conditions and system parameters, the test shows the system repeatability at two different test sites with varying height differences and land cover. It also validates the manufacturer's vertical accuracy specification of 2-4 cm $RMSE_z$ for these test sites.

## Acknowledgement

The research reported herein was performed by the Department of Civil and Geomatics Engineering at California State University, Fresno (CSUF) for the Division of Research, Innovation and System Information (DRISI) at California Department of Transportation.

The contents of this study reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein.

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**Chris Thornton, PLS** is Chief—New Technology Systems Advanced Technology, Office of Land Surveys North Region Office of Surveyors, California Department of Transportation, Sacramento, California.

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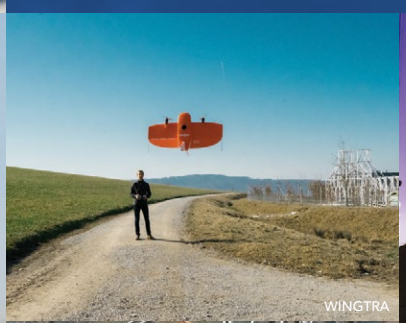




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# Lisa Murray, Lidar Impressario: Reflections on Collaboration

## Diversified Communications' geospatial lead moves on

Most readers of *LIDAR Magazine* have attended a Diversified Communications (DC) event, International LiDAR Mapping Forum (ILMF) being the best known. Many of us have had the privilege to spend time with DC's Group Director, Lisa Murray. She not only directed the trade shows and conferences that we attended and enjoyed, but she was instrumental in creating the Lidar Leader Awards, a joint initiative of DC and *LIDAR Magazine*. On 22 December 2020, DC announced that Lisa would leave the company—her last day was 15 January 2021—for a new career in counseling. Since she has made such a difference to the events landscape in our geospatial world, *LIDAR Magazine* contacted Lisa before she left and she agreed to give this "exit interview".

Lisa Murray, who left Diversified Communications on 15 January 2021 having masterminded the growth of the company's geospatial events for many years.

**LIDAR:** Lisa, it was with sadness that we learned of your decision to leave DC. You have made such a difference to the geospatial world. Although most of our readers are familiar with DC events, not so many know you as an individual. Can you please tell us something about yourself? When did you join DC and why? What has been your career path with the company? How does your geospatial brief fit into DC as a whole? DC seems to have more offices in the UK than the US, but it's a US company, isn't it?

**MURRAY:** DC is a third-generation privately-owned communications company based in Portland, Maine with offices in the UK, Australia and Hong Kong. DC produces over 120 events annually and a vast array of digital products for a range of industries worldwide. The full portfolio can be seen at *divcom.com/portfolio-products-services*.

I joined DC in 1993 as a sales rep, brought in to help launch the European Seafood Exposition, which went on to become the world's largest seafood show and DC's largest event. After seven years on that product, I took three and a half years off to stay at home with my two young children. I was hired back to run an organic food and beverage show which DC had acquired and eventually sold. I then pivoted to manage sales for SPAR International, a laser scanning technology conference and expo acquired by DC in 2010. I eventually became event director for SPAR.

**LIDAR:** Prior to the pandemic, in-person events (at least those that you hosted) seemed to enjoy a renaissance, expanding both individually and as a group. What dynamics were at play here? Can you speak to what your exhibitors and attendees sought when attending your shows?

**MURRAY:** 2019 was a banner year of growth for the technology portfolio, but it started back in 2010 with the acquisition of SPAR. The vision was always to grow and acquire events with complementary technologies that could eventually come together as one larger,

BY ALLEN **CHEVES** & STEWART **WALKER**


Artwork in support of Diversified Communications' rebranding of Geo Week for 2022.
*Courtesy of Diversified Communications.*

overarching event covering end-to-end precision measurement technologies across myriad industries. Our timing was good: in a market where "data is the new oil", our customers were at the forefront of innovation, providing technologies critical to the new data economy. We saw an opportunity to integrate them but the market was not yet ready. Instead, we focused on strengthening each individual event.

We listened carefully to our customers, who found a welcome platform in our tech events and digital channels to share knowledge and expand adoption. We focused on raising the quality and quantity of attendees to ensure we were delivering qualified leads and we researched additional exhibit categories to expand exhibits on offer in a way that made sense for the buyers. There was a concerted effort to refine our content, attracting compelling keynotes and next-gen content while barring sales pitches from the program. At every turn, we considered the attendee perspective, finding ways to attract more and better-quality attendees. When you do this, exhibit growth takes care of itself. Everyone wants to be where the buyers are; bellwethers expand their investment and new entrants to market join to get access to key decision makers. Again, it all comes down to having the right people in the room and then it grows from there.

**LIDAR:** Your experience with the "geotech" community is unparalleled in some respects. What have you learned about the various sectors that may not be apparent to the everyday "bystander"? Alternately, what is most memorable, looking back?

**MURRAY:** There is often a perception that vertically-integrated events (industry-specific) are better than horizontally-integrated events (multiple industry sectors converging around common technologies.) Our management team never bought into this. Our experience was the opposite—that there was much to be gained by attendees from various industries coming together at one event focused around a certain technology or technologies. I think it's more intuitive for people to gravitate toward an industry event, be it focused on mining, transportation or any industry. What they miss, however, is a deep dive on new technology tools and the opportunity to see how other sectors are using the technology. Often the best connections and the most out-of-the-box thinking comes from horizontally oriented events where, for example, thousands of users of laser scanning technology solutions can gain broader insight as to how the technology is used universally rather than the potentially limited use unique to their sector.

Diversified Communications' event team captured at Geo Week in 2019. Lisa Murray is on the far right.
*Courtesy of Diversified Communications.*

Lisa Murray opens the 2019 Geo Week conferences.
*Courtesy of Diversified Communications.*

**LIDAR:** You've brought several member organizations into the fold, such as ASPRS, GITA, MAPPS and USIBD. Is colocation a hard trend and, if so, what do you believe is driving this? What do you think about the future of professional events?

**MURRAY:** I remember being struck in the beginning by the fragmentation in the industry and the proliferation of small events. Vendors were frustrated that there was no one event they could go to that met all their needs. This was unlike any other industry in which I had worked. So, from the beginning, my goal was to bring groups together in a more collaborative way for the common purpose of promoting related technology solutions. It took over seven years from the start of those conversations to the colocation of ILMF, ASPRS and MAPPS in 2018. I think everyone was pleasantly surprised by the results and that success drove the growth from there.

Regarding the future of live events, one upside of not having events in 2020 is that people realized how much they missed them and the value of face-to-face interaction. As live events come back, I believe they will be even stronger. We are already seeing this yearning to return to and invest in events as we come back online with Commercial UAV Expo Americas, in September in Las Vegas, and Geo Week 2022, already well along in the sales process and taking place in Denver in February 2022.

**LIDAR:** Is there anything you'd have liked to accomplish that you weren't able to? Is there something you believe could or should happen within the industry that hasn't?

**MURRAY:** Absolutely. I wish I could have stayed on for the first colocation of Geo Week that includes the integration of SPAR 3D and AEC Next. This is the first time that stakeholders across the geospatial industry and the built environment will come together. In my opinion, this is the beginning of something big. I have total confidence in the tech team and our advisors to deliver an excellent event. I only wish I could be there to raise a glass to their success and to watch the event develop into the powerhouse I know it will be.

**LIDAR:** Please tell us something about your new career. How and why did you become interested in counseling? What are your goals for this next phase of your career?

**MURRAY:** Good question. To most, being a therapist probably seems really different from being an event director. I guess I have always been interested in human behavior and the way I approached our events was to form strong bonds with customers, listening to their needs, finding out where they think the market is headed and probing about what their biggest challenges were. That's really not so different from being a therapist and helping someone figure out where they are, where they are going and what obstacles might be in their way.

**LIDAR:** Owing to the pandemic, 2020 was a terrible year for conferences and trade shows, with most face-to-face events being canceled or postponed—how did DC navigate the tumult? How did it change its business model to suit the circumstances? Did it survive the year without sustaining major damage?

**MURRAY:** It's true that the events business was heavily impacted by the pandemic. Fortunately, DC had numerous online products in place. These channels enabled customers to stay connected to their audiences, launch new products and collect leads via webinars, reports, product spotlights, interviews and other online forums. Our editorial, sales and marketing teams pivoted quickly and served up an unprecedented amount of online content in 2020. This shift forced many companies to up their online game. Once they saw the results of their digital media efforts, they have continued to invest in 2021. This ramped up digital avenues quickly, but I think those channels are here to stay, even as DC returns to its core business of producing live events.

**LIDAR:** We mentioned ILMF at the beginning of this interview, but this is only one of a portfolio of events for which you were responsible. Can you please describe how this portfolio evolved?

**MURRAY:** The tech portfolio started with the acquisition of SPAR Point Group in 2010 from Tom Greaves, including the SPAR International event and the SPAR3D.com website. DC then acquired ILMF and European Lidar Mapping Forum (ELMF) from Intelligent Events in the UK, to further expand into the technology space. AEC Next was a DC launch, paired as a colocation with the SPAR3D Expo & Conference to build on the AEC sector in that space. The idea was to put them together for an overall "geospatial meets built world"

event, but the market was not ready for that integration at the time. In an effort to listen to the market, we ran these events separately and instead focused on making each event stronger.

In 2014, our UK office launched GEO Business, an overarching geospatial event based in London that largely replaced the need for ELMF.

In 2015, our team launched Commercial UAV Expo Americas in response to customer requests for a dedicated drone show addressing the integration of drones into the precision measurement space. In 2017, we launched Commercial UAV Expo Europe to serve the unique needs of the European market and establish DC as a global platform for drone education and integration. In 2020, we announced a partnership with Amsterdam Drone Week to partner with Commercial UAV Expo Europe. The first instance of that event will be in January 2022. All the above developments came from listening closely to customers and what they wanted as well as spotting trends and staying close to technology developments.

Indeed, three commercial drone shows were launched in 2015 with the same vision of focusing on sUAS technology in North America (among many other drone shows all over the globe). DC acquired Drone World Expo from JD Events in 2018 and integrated it into Commercial UAV Expo Americas. Commercial UAV Expo has always been the leading drone event for commercial users and the cancellation of Interdrone in 2021 further solidifies UAV Expo's bright prospects as drone leaders now have a single event on which to focus their energy and investment.

**LIDAR:** ILMF evolved to become co-located with ASPRS's annual conference and, indeed, other organizations such as MAPPS joined in. Then you introduced the name Geo Week to encompass all these components. This year DC is rebranding Geo Week and you have big plans for 2022. Can you please tell us about this?

**MURRAY:** In the age of interconnected data, it is our exhibitors and attendees who are at the forefront, developing and integrating technologies that are changing our world. I think this event has a unique opportunity as the leading geospatial event in North America to become the go-to platform for information exchange of core precision measurement technologies across critical industry segments such as infrastructure, transportation, engineering, construction, and many others. I couldn't put it better than the way DC's current Event Director, Lee Corkhill stated: "The event represents a continuum, with individuals and organizations from all corners of industry at differing levels of adoption. Geo Week will support a future vision, in which professionals and organizations that understand the full spectrum of data needs, work processes, software integration, and standards in both geospatial and BIM will be tomorrow's technology leaders."

Lisa Murray, thank you very much indeed for these fascinating answers. You have made a substantial difference to the lidar world and it is clear that DC's role is going to grow. Your new position will ensure that the imaginative, cooperative approach that you have taken, always with a view to growth, will continue. *LIDAR Magazine* wishes you every success in your new career as a counsellor.

**Allen Cheves** is Publisher of the magazine.

**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.

Packed, rapt audience at Geo Week 2019.

*Innoviz, continued from page 64*

Oren Rosenzweig, chief business officer, Innoviz Technologies.

One such supplier is the Israeli start-up Innoviz Technologies[1]. Its marketing pitch goes:

*Innoviz is a leading manufacturer of high-performance, solid-state lidar sensors and perception software that bring vision to nearly any scenario.*

*The company's commercially available, solid-state lidar sensors and perception software enable safe autonomy by bringing unparalleled optics, seamless design and cutting-edge software to market. Going beyond cameras or radar, Innoviz's lidar provides a comprehensive 3D image of a scene.*

*The company was founded in January 2016 and is backed by top-tier strategic partners and investors, including Magna International, Samsung, Aptiv, Magma Venture Partners, Vertex Ventures, SoftBank Ventures Asia, China Merchants Capital, 360 Capital Partners, Glory Ventures, Naver and others.*[2]

Innoviz announced on 6 April 2021 that it had gone public through a merger with special-purpose acquisition company (SPAC[3]) Collective Growth Corporation and had raised $371 million. For a lidar start-up, this is a significant sum, so we approached the company for further comment. The result was an interview with Oren Rosenzweig (**OR**), co-founder and chief business officer.

The Zoom call was hosted by Chelsea Lauber of New York PR firm Antenna Group. Eric Lachter, VP brand marketing at Innoviz, was also on the line—he's a marketing executive, based in Marin County.

Oren was speaking from Innoviz's office in Rosh Ha-ayin, Israel. Here's what he said.

**LM:** Oren, please tell us about yourself and explain how you came from your early years and your MBA into Innoviz.
**OR:** My background is similar to that of the other founders of the company. We spent seven years together in the Israeli Defense Forces (IDF), specifically in the Intelligence Corps doing R&D for advanced electro-optics systems. I worked a couple of years with Anobit Technologies, which was acquired by Apple and is now Apple's biggest R&D center outside Cupertino. Then I spent a couple of years in business school in Chicago [Booth School of Business, University of Chicago], then consulting for BCG [Boston Consulting Group] in New York. While I was there, I was working with Omer [Keilaf; now CEO of Innoviz], one of my co-founders and a good friend of mine from many years in the military. To cut a long story short,

1 www.innoviz.tech

2 Supplied by Innoviz amongst the company-related materials provided in support of this interview.

3 The SPAC route is proving an increasingly popular alternative to the traditional IPO (initial public offering). Velodyne Lidar chose this approach in July 2020 and we attempted to give some background in a related article, https://lidarmag.com/wp-content/uploads/PDF/LIDARMagazine_Walker-Velodyne_Vol10No4.pdf.

Group shot of Innoviz work force. Oren and his dog Winston can be seen front center.


The founders of Innoviz Technologies: Oren Rosenzweig (left), chief business officer; Omer Keilaf (center), CEO; and Oren Buskila (right), chief R&D officer. The three met while serving in the elite technological unit of IDF's Intelligence Corps. The model in the foreground underlines the importance of Innoviz's BMW customer.

we started working on Innoviz, then we raised a series A [venture capital] at the beginning of 2016. So I moved back to Israel after that. Since 2016, I've been in Innoviz leading the product and sales, with the title Chief Business Officer. So there's the technical side and the sales side—we have sales teams in the US, Germany and China, and we're hiring in Japan.

**LM:** How many people does Innoviz have at the moment?
**OR:** Just over 300. We grew quickly. We were four founders back at the beginning of 2016. We just recently went public through a merger with a SPAC, and just a few weeks ago started trading on the NASDAQ under the ticker INVZ.

**LM:** Your shares have gone up more than 10% since you launched?
**OR:** We're not very focused on the short term. The idea was to raise a significant amount of money for the company in pretty short order, which this transaction allowed us to do—we raised over $370m this way, much quicker than an IPO would do and, I think, quicker than a private round would be at this stage of the company. Now we have the money to execute on everything we need—getting the product to customers like BMW, and many other things that we're doing. It's very exciting now.

**LM:** When I finished my MBA 17 years ago, the financial instruments weren't the same. But it seems that, just viewing the lidar world, you can get a lot more money by joining with a SPAC than in a normal venture capital round—some of the lidar companies were talking of rounds in the single digits or tens of millions of dollars, but not hundreds of millions.
**OR:** Yes, it opens up the door to additional types of investors who can write bigger checks. It offers a lot of predictability in terms of valuations. There's a nice mix of the private and the public side too. We did a lot of marketing to the PIPE[4] investors, and you can get a lot of visibility from going through that type of transaction in terms of raising the SPAC and PIPE funds, and, following it, when you start trading on the public exchange.

**LM:** Going back to the beginnings, the founding of Innoviz, did you and the other members of the management team who were in that elite unit in the IDF, did you meet there or did you meet afterwards?
**OR:** We worked together there. Omer is the CEO. He and I were in the same team for five years. We've been very close friends for 20 years now. We worked very closely together on the same projects. At some point we split, I went to the US, then we joined forces again to start Innoviz.

**LM:** I have another question, trying to understand how high-tech companies like yours work. You've recently announced an expansion of your board of directors, but you've got an incredibly talented management team already, so what's that about?
**OR:** It's part of transitioning from private to public. Part of it is that we had to comply with different SEC rules in having independent directors, but in addition, we brought strong talent, specifically of people who were on the boards of public companies. On the financial side, we had to staff the Audit Committee with people who had CFO-type experience in public companies. Our previous board was mostly venture capitalists who invested in us in earlier stages. We wanted to bring in new people, who would be independent directors as the SEC requires, and also would bring us value for the coming years.

**LM:** Let's move on, then, to the products. You do both hardware and software. Would you like simply to give a description of your product line?
**OR:** We're very focused on lidar and in addition to that the perception software that analyzes the point cloud. With respect to the target markets, it's primarily automotive for us, but we're starting to diversify into other applications. The first product, which is now ramping up to series production, is called the InnovizOne. The lead customer for that is BMW, but we actually sell it through Magna[5], which is the biggest automotive tier 1 company in North America. We also work with other tier 1s, such as HiRain in China, Harman and Aptiv.

We just recently announced the InnovizTwo. The focus is primarily cost reduction, but we're also improving the performance by quite a lot. But the focus is really on cost reduction. As you know, the expectation of lidar in automotive is a bit different from some

4 Private investment in public equity.

5 Magna International: www.magna.com.

The sensors: InnovizOne (left and center) and InnovizTwo (right). Both sensors use a 905 nm laser. The InnovizOne measures 45 x 110 x 95 mm and weights 515 g. It offers a resolution of 0.1 x 0.1° with maximum range of 200 m at 50% reflectivity, or 0.2 x 0.2° with 250 m at 10%. The InnovizTwo features numerous improvements over the InnovizOne, for example the range increases to 300 m, the field of view to 125x40° and the resolution to 0.07x0.05°. Innoviz claims a 30x improvement in performance and a 70% price reduction compared to InnovizOne— the price point is in the $500-$1000 range (https://www.prnewswire.com/newsreleases/innoviz-announces-another-breakthrough-in-lidar-technology--30x-performanceimprovement-and-embedded-perception-software-301267408.html).

of the applications that you guys look at, e.g. geospatial. In automotive, the price tag that the customers are looking for is more in the $500-$1000 range and that's even going to go down. They can't afford the lidars in the thousands, tens of thousands or even hundreds of thousands that are used in some of those mapping applications.

**LM:** When I first became involved in lidar at the end of the last century, we were talking about airborne lidars costing $1m or even $1.5m. The specialist lidar companies do make first-class, lightweight units for drones, but they're still expensive. It's the automotive companies like yourselves who are transforming the geospatial world, not the other way round.
**OR:** Yes, if you're familiar with Clay Christensen's work on disruption[6], it's a classic case of low-end disruption: something comes in at the bottom range of acceptable performance but with a price that's completely disruptive—with volume it gets just good enough to replace some of the high-end applications. That's what you're seeing in the geospatial world. Today they've got better range and accuracy, but it's hard to compete with the volumes of the automotive space and with the investments of the automobile OEMs, the tier 1s and companies like us. Then eventually the product improves, so it becomes *both* better and cheaper.

**LM:** One of those specifications I couldn't find in your website is the weight of InnovizTwo?
**OR:** It's just over 500 grams—530 or so.

**LM:** Well, at that weight and at that price point I would have thought geospatial folks would be attracted. It's typically integration companies that put all this stuff on to a drone—the lidar, the camera, the GNSS receiver and the IMU. They're going to be salivating at that price point, and I think the range is plenty—you're 250 m on InnovizOne and 300 m on InnovizTwo. You've put your finger on it, that there may or may not be an accuracy issue, because with automotive you're trying to identify whether objects are there or not that could be a danger; with mapping you're trying to get information about every pixel, if you will. The other point, typically, automotive-grade lidars are just noisier than the specialist ones. But at $500 you can put two of them on a drone!
**OR:** Right. The thing is that they're getting better, much faster than the specialist lidars because of the investments and the volumes. The accuracy we have today is not as high as those lidars used by geospatial applications. They get 20-30 mm accuracy and we're more like 50-100, but we're getting better. So, yes, we're getting to the same kind of accuracy, and we don't necessarily need to get the same range. They've got some units that can measure from 3 kilometers high. We don't get there, but with some of the lighter drones you don't need that. So maybe we're not doing as wide a scan as they do, not necessarily, but I think that there are plenty of applications where what we do is actually good enough for drone-based mapping and just to prove that we recently started working with a few of those integrators that you mentioned. I can't mention any names yet, but I hope that we will be able do some announcements soon on those collaborations.

**LM:** That's exciting for our geospatial readers who—under my editorship, at least—are having to read more and more automotive stuff!

They need to know what's leading edge, but if those integrators you've just mentioned are in the US, then we probably know them, so that's exciting and we

6 Christensen, C.M., 2000. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, HarperCollins, New York, 320 pp. This is one of many editions of this work. Christensen has authored several other books on the same theme.

will look forward to that. I wouldn't worry about range because the altitude of drones is governed by regulations in the US. It's 400 feet, so you're easily beyond that. That's exciting, but let's not spend the time talking about geospatial, because that's not why you're here! One of the specific technical questions that I had about the InnovizTwo is that it's really good at working in poor weather conditions. Is there something specific about that, some technical development, so that it makes a particularly good job of that?

**OR:** It's a mix. I think that probably the most important feature is to be able to detect multiple reflections. So even with the partially covered pixels, or if you get few returns in the same direction of shooting the laser, we can get up to three returns and they can be the three strongest—it could be the first, last and strongest or different configurations of those, but that allows you to go through fog or snow. Typically rain is not as bad as some of the other things. Dust is especially difficult.

**LM:** Strangely enough, one of the lidar companies I talked to early on in their development even had problems with very strong sunlight, but I think they've got through that.

**OR:** Well, that's actually quite common. You're shooting lasers at either 905 or 1550 nm and there's a lot of noise from the sun at those wavelengths. So if you're trying to identify the pulse that you sent out after it returned from an object, the noise that you're trying to extract this from is sunlight noise. So if you don't have sunlight, then it's easier to detect returns, so typically lidars may work 20%, 30% better in terms of range at night versus at day.

**LM:** Your ISO 26262 compliance: I'm not too familiar with that, is that something that puts you ahead of the competition?

**OR:** Yes, that's a distinguishing factor. ISO 26262 is a Functional Safety standard that's used in automotive. It's required if you're designing a piece of hardware or software that's somehow related to the safety of the vehicle. The automotive OEMs require that and it's something you must do from the early stages of the design of the product. It's being audited by the OEMs and, specifically in our case, also by the tier 1 companies like Magna. It definitely gets you to better safety and quality, but adds a lot of overhead to the development process. There are different levels in the standard: they're called ASILs[7]—A, B, C and D. Our level is B of D, which means that we're level B out of a D system. That's difficult to achieve. I would say that almost none of our competitors meets that, and the reason we are able to do it, is because we've been working with Magna and BMW for more than three years now. Some of the other lidar companies that don't have design wins for series production automotive programs haven't started working on that.

**LM:** My next question is about the perception software. This is the Automotive Perception Platform InnovizAPP?

**OR:** Yes.

**LM:** So is that hardware and software?

**OR:** It's both. It will be built into the InnovizTwo, so it's going to run on a chip. It's primarily implemented in software, but it can also run outside of the InnovizTwo. So in some cases, especially when some customers actually want to work with multiple lidars, they would typically take the raw data, the point clouds from all the lidars, and run the perception software in the central computer ECU[8]—so it depends on the architecture of the vehicle that the lidar is being used on. It either runs on the edge, which means it is running

7 Automotive Safety Integrity Levels.

8 Electronic control unit.

In this example, there was a problem with bright sunlight (left), yet the data obtained using an InnovizOne (right) was not compromised and remained useful for vehicle navigation.


Innoviz CEO Omer Keilaf holding an InnovizOne sensor astride the hood of one of the company's R&D vehicles.

on the lidar, or it can run centrally on a separate computer, in which case we supply the software.

**LM:** Is that using deep learning or some other form of AI?
**OR:** Yes, a lot of the innovation in that field is in terms of functions like object detection and especially classification, trying to classify whether, for example, it's a pedestrian or a car or truck or motorcycle or bicycle. Deep-learning algorithms have much improved and offer better performance than the traditional algorithms. We collect a lot of data and we also leverage our partners, such as Magna—they have vehicles in different countries since things look different in different countries. For example, lane markings look different, or you've got different cars, so they collect the data and they send us the data and then we train the algorithms. We also use separate datasets to validate the KPIs[9] of those algorithms to see that we meet the requirements by BMW and then translate those into the software that's running in real time in the vehicle.

**LM:** You said that you were implementing this partly inside the InnovizTwo. Typically people who work in this area have got some quite big hardware from Nvidia. You're not going to fit that inside InnovizTwo!
**OR:** We actually have a partnership that we announced with Nvidia, for running our perception software in cases where it's being used in the central ECU, but when it's running inside the lidar, it's actually using a chip from a different vendor, a lower power chip than those central compute chips.

9 Key performance indicators.

**LM:** That's pretty amazing though. You've got at least one, and maybe several inside different lidar sensors on a vehicle. That's incredible progress in certainly less than 10 years, maybe even less than five. We start to take things for granted, particularly when we're close to the technology, but if you sit back for a minute and think about it, that's remarkable.
**OR:** I agree, generally in terms of the progress that AI made, and then, just specifically what's going on in automotive. This industry has gone through such a tremendous change in the last few years in terms of electrification and autonomy, much more than it has gone through in the last 120 years.

**LM:** Absolutely right! It's a very exciting time to be involved. The next question is do you use anything else? You focus very much on lidar and those are the exciting things you're doing, but do you also use cameras, radar?
**OR:** We're very focused. At least as of now, we develop lidars and we developed a perception software that's running on the point cloud—we are not processing any image data or radar data.

**LM:** We've been through one or two stages in the geospatial world where some real enthusiasts said for a while, to make a map, you only need lidar, you don't need photos anymore. I think, for the topography and so on, that's true. For getting the real detail on a map, maybe not, but you don't need that—you're looking for different things. I don't disagree with you. It's quite interesting: you're the opposite of Mr. Musk, who doesn't use lidar!
**OR:** Let me just clarify. We're not saying that you don't need cameras and radars. We're part of a system, for example, BMW uses our lidar and perception software. They fuse the raw data and they also fuse the high-level data, the object-level data from us, together with data that comes from the cameras and is being processed by companies like Mobileye, and data from the radars as well, so we strongly believe in sensor fusion. We think it's necessary and we don't believe that we're competing with cameras and radars. We think that for achieving the level of functional safety that's needed for autonomous driving, you must have the different modalities. We do the lidar parts.

**LM:** That makes sense. I'm talking to another company that just launched a unit that contains lidar and radar and cameras and they make the lidar and the radar themselves. They have a lot of stuff to develop and we'll see how it goes. That gets me on to the next question, which is trying to understand the market.

On the one hand, you get lidar sensor providers, people like Velodyne, Cepton and Quanergy, who basically make sensors, maybe an SDK and perhaps they're starting to get into perception software. Then you get the people like DeepRoute in China, where they make a unit that basically sits on top of the car with cameras and lidars and they do some software. You do lidar, but you've got some very high-performance specialist hardware, firmware and software. How do you see that spectrum and where does Innoviz sit on it?

**OR:** We went up the stack ourselves. We do lidars, but we also went up to the level of perception software. We offer a very rich development toolkit, including drivers and SDKs. In order to use the lidar, we provide simulation software in partnership with Cognata. That's the scope today. It is possible that in the future we will actually offer more software products and I mentioned sensor fusion earlier that we don't do today, but we may do in the future.

**LM:** I see that and I also see the fact from what your announcements say, you're actually manufacturing or you soon will be manufacturing at scale. And I know from talking to other lidar companies, that's almost as big a challenge as designing the lidar in the first place.

**OR:** Even bigger. I didn't really mention them as a product, but we also provide the manufacturing machines—we design the key machines that are used in the manufacturing of the lidar, which is completely automated. You could say that that's part of the product. I think designing an automated production line is probably even harder than designing a lidar. People very often underestimate the difficulty. In high volume manufacturing, you want to keep the yields up and the costs down—that's a lot of the focus now. We also leverage some good partners. We've been working with Jabil in Jena, Germany, for a few years now and in the last few months we've finished the ramp-up of a production line with one of our tier 1 partners.

**LM:** You have a production line in Michigan?

**OR:** One of our tier 1 partners has ramped up a high-volume manufacturing line.

**LM:** If we step back for a moment, the fully automated, the level 4 and level 5, hasn't come yet in the sense that it's not readily available, but there's a lot of ADAS. Is that important at the moment to you as a kind of stepping stone?

**OR:** I think it's very important. We're also relevant for level 2+ autonomy systems, which you could call ADAS, because you still need the driver to supervise the driving. We don't only go after the level 3 or 4 systems. The BMW system, for example, is level 3 and we work with some of the robotaxi and trucking companies that do level 4 systems. But there are also companies doing level 2+ systems. InnovizTwo, because of the cost reduction, is very relevant for level 2+.

**LM:** I think you've already answered the second to last question. Just the fact that you've already got a deal with BMW and several tier 1s means you're ahead of some of your competitors. They're getting into that situation, but they're not as far forward as you are.

**OR:** Thanks. I would say so. I think we're ahead of the pack, on a few dimensions. One is partnerships with tier 1s—the main competitors, jointly, have three partnerships and we have four major ones ourselves. We have the biggest and first design win for a level 3 system, the one with BMW.

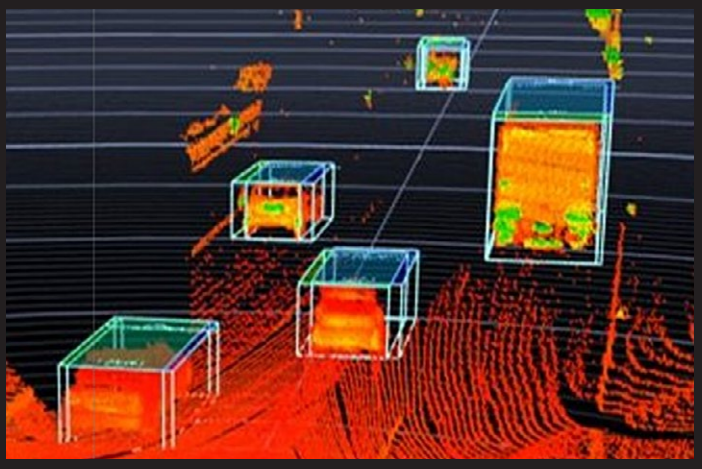
**LM:** I think you've already given me more time than we agreed, so let's finish with the last question. You've got InnovizOne and the perception software scheduled for production this year and InnovizTwo for this year. That's a lot. How do you see your plans for the next couple of years or beyond?

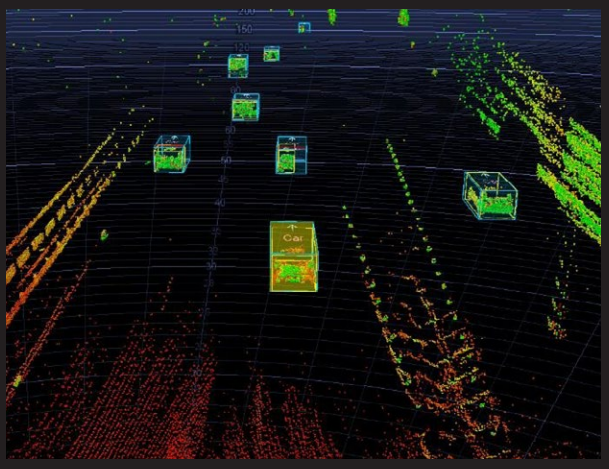
**OR:** We're ramping up very quickly now. Or I should say, continuing to ramp up quickly. We have teams here in Israel and also sales people globally. One big activity is to get InnovizOne into series production on the BMW cars, so we're in the final stages of testing and integration. That would be a very major milestone—getting on the road in the BMW cars with InnovizOne—but at the same time we're working on getting the first samples of InnovizTwo to customers by the end of this year. This will enable development based on InnovizTwo. I would say those are the main goals—getting InnovizOne into series production starting with BMW, then with others, and starting the engagements with customers around InnovizTwo later this year.

**LM:** That's a challenge in itself. You've got a lot on your plate, but you've definitely got the team that's going to be able to attack this. I'm very grateful for your frank answers and for being so ready to come and talk to us.

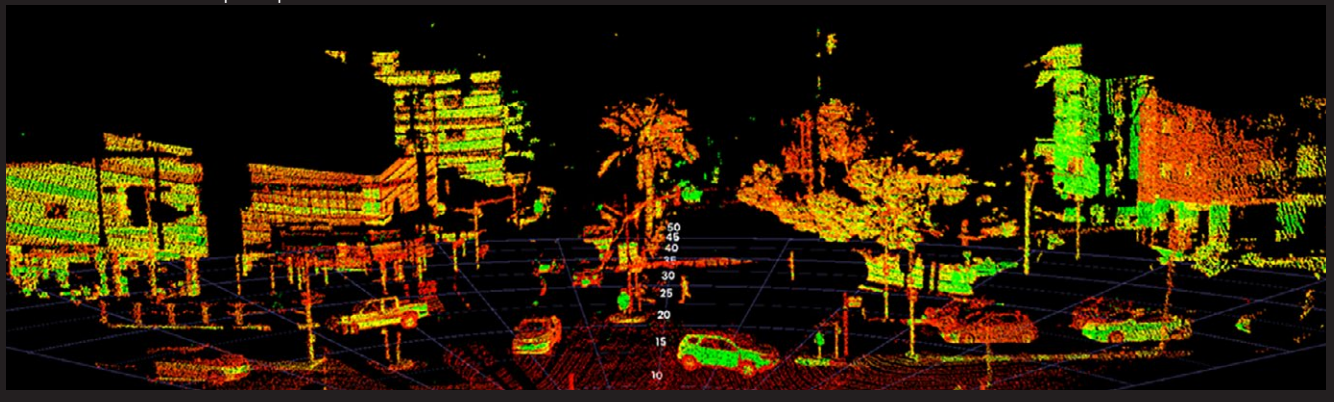
**OR:** Thank you very much.

**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.





Screenshots of Innoviz perception software at work.



InnovizOne point cloud of street intersection.

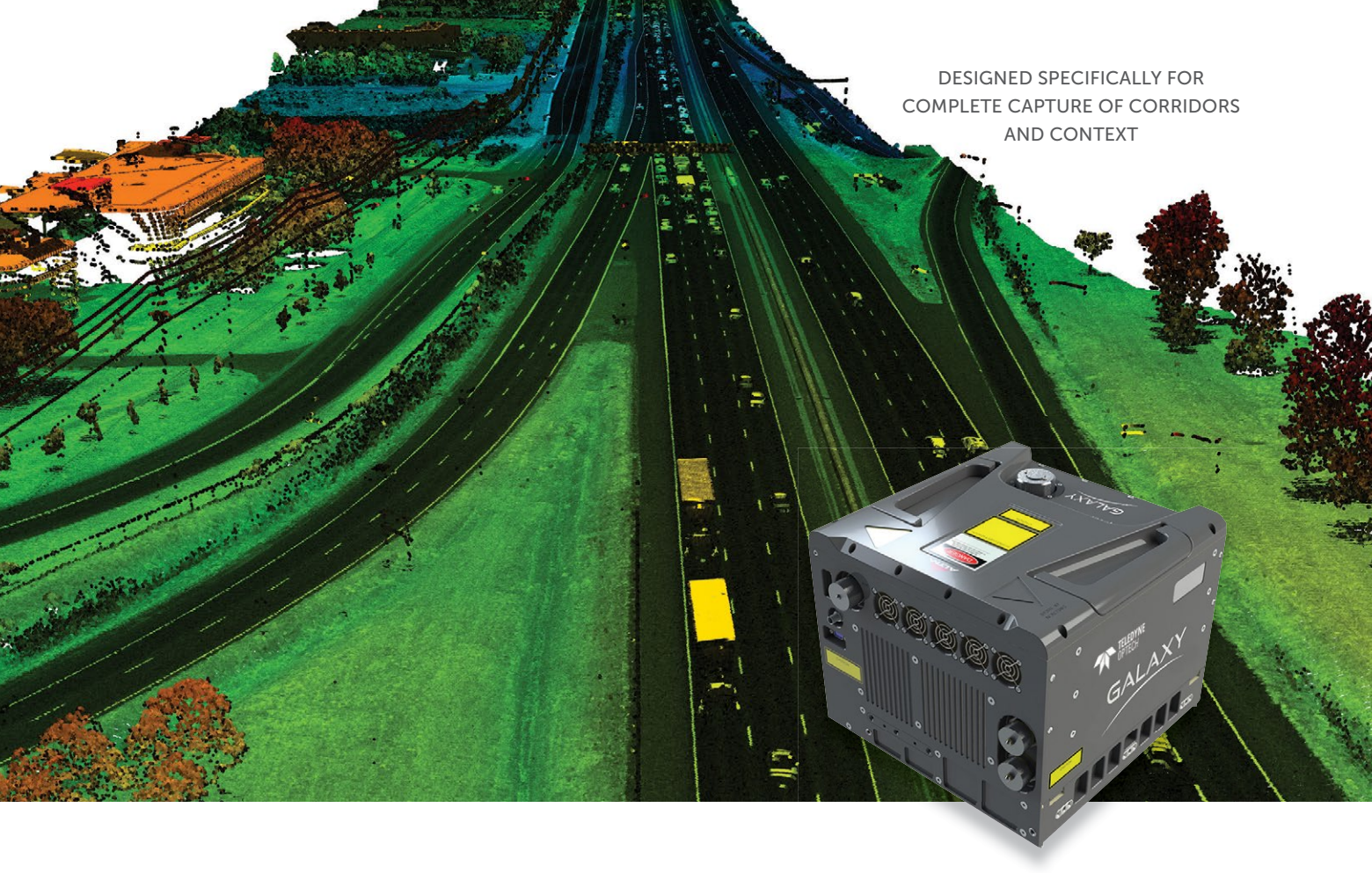
# Israeli Automotive Lidar Supplier Leapfrogs into Sight

## Innoviz lidar's price point must raise geospatial eyebrows

BY STEWART WALKER

We have often acknowledged in these pages the difference that lidar suppliers focused on the automotive sector, on both ADAS (advanced driver assistance systems—available now) and autonomous vehicles (AVs, which will surely transform our lives in the next decade), have made to the geospatial world. In particular, their lightweight, economical lidar sensors have made UAV-lidar popular and some of the resulting integrated systems have appeared also on vehicle-based mobile mapping systems.

*continued on page 58*

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