FALL 2020 MAGAZINE

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Today's geospatial reality involves a world awash with sensors. As developers seek to embed lidar technology in ever smaller, increasingly mobile installations, the importance of sensor encasement grows. None of this is new to German glass manufacturer Schott, which is part of the Carl Zeiss Stiftung, the foundation that includes also the famous Carl Zeiss company. Schott is well known in the geospatial community, because its glass has been widely used in lenses for surveying and photogrammetric instruments.

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18 Velodyne's Journey

We arranged to interview Velodyne Lidar's new CEO, Dr. Anand Gopalan, in mid-January 2020—only ten days after Anand was promoted and founder David Hall moved up to chairman—but a family emergency cut short the trip. An in-person interview was precluded by covid-19, so we did it remotely. Anand was in his factory in San José, California, in the heart of Silicon Valley. While this article was being finalized for publication, Velodyne made a major announcement about combining with Graf Industrial Corporation, which we've addressed herein. INTERVIEW BY DR. A. STEWART WALKER

44 Intel Makes Lidar Too

As part of our series on lidar players in Silicon Valley, we were keen to talk to Intel Corporation. Our curiosity about the semiconductor giant's lidar activities was piqued in December 2019, when the company announced its Intel[®] RealSense[™] LiDAR Camera L515. The L515 seemed to us to bear similarities to the lidar sensor in Apple's new iPad Pro. We were fortunate to be able to put our questions to Sagi Ben Moshe, corporate vice president and general manager of Intel's Emerging Growth and Incubation (EGI) group. INTERVIEW BY DR. A. STEWART WALKER

66 Intelligence at the Speed of Light

LIDAR Magazine last visited Cepton Technologies in San Jose at the end of 2017. Fresh off a new round of venture funding, the firm was prime for an update. Managing editor Stewart Walker and publisher Allen Cheves were welcomed by Cepton's executive team and briefed on everything from the status of the market to recent product announcements. Unable to cast aside our fascination with Silicon Valley's secrets, we tried to focus on the firm and the people rather than the technology. Here is what we learned. INTERVIEW BY DR. A. STEWART WALKER

80 Technology Helps Combat Covid-19

LIDAR Magazine attended a webinar that noted how various enterprises were exploring the use of UAVs to assist in the fight against covid-19. When we received a release from a Californian company, iinside, that it was using lidar with similar intentions, we wanted to learn more. LIDAR Magazine is very familiar with Quanergy Systems, which is active in the geospatial world and whose lidar sensors have been successful and economical when integrated on to UAVs. We don't know so much, however, about iinside, so we decided to learn more. INTERVIEW BY DR. A. STEWART WALKER

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ON THE COVER

An illustration of the various fields of view of multiple lidar sensors fitted to a vehicle with autonomous navigation capabilities. Image courtesy of Velodyne Lidar.

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FROM THE PUBLISHER

ALLEN E. CHEVES

Winds of Change

ver the last nine months, many aspects of industry development have been blown about thanks to the volatility that (so far) seems to sum up 2020.

It's not hard to describe the "change" brought about by extreme events, something you can feel as well as see—when likened to weather, market flux is similar to the remarkable instability that results from cold and warm air engrossed in a colossal struggle for balance.

Our intention with this year's "Sensor Integration Spotlight" remains addressing where and how successful innovation is occurring, especially at the point of integration. As we shared last year, more than 100 firms are currently developing close to 50 flavors of next-gen lidar solutions.

This year, downward pressure on sensor price in advance of mass adoption (of lidar) has led to storm clouds for start-ups lacking established sales channels. Automotive remains the main growth driver but increased price pressure coupled with a transportation industry recoiling from covid-19 has only served to complicate matters. Firms with fragile margins and/or unproven means are likely to struggle.

Complex systems are weakened, even killed, when deprived of stressors.

Doubling down, industry bellwethers Velodyne and Luminar have recently "gone public" via the ever-clever "reverse merger", ensuring unfettered access to liquidity—read more about Velodyne's developments on page 14. Somewhere, Gordon Gekko is gazing out a penthouse window, pondering the efficiencies yet to come!

For this issue, we've gone to the front lines again, peering into the crystal ball with the world-class teams at Schott, Intel, nimble start-ups such as Cepton, iinside and of course, Velodyne. Look to the website for additional interviews with firms such as Quanergy, Insight, DeepRoute and more. In addition to this year's magazine previews, we've added a simple research component to our website called the "LIDAR Directory" (directory.lidarmag.com), highlighting the wares and contact details of those on the bleeding edge.

Last but not least, our friends at Yole have released an updated guide with heavily pored over estimations of market growth between now and 2025¹. See page 4 for details.

1 Lidar for Automotive and Industrial Applications report, Yole: bit.ly/Yole-Report-2020



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MARKET REPORT

Lidar faces headwinds in evolving markets

KEY TAKEAWAYS:

Yole expects 3.2% of personal cars to adopt lidar technology by 2025 The covid-19 crisis has placed pressure on the automotive segment Emission requirements have shifted investments toward electrification

Editor's Note: Just how big are the "lidar markets"? Each Year, the French firm Yole publishes an exhaustive review of activities across various industries. Previous estimates of a 2024 marketplace as large as \$6 billion (USD) have been revised downward.

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

he price drop in lidar in the past three years has been massive," asserts Pierrick Boulay, Technology & Market Analyst, at Yole Développement (Yole). "Indeed, it is the result of strategies by different companies and not due to the result of mass-production. Volumes have not evolved significantly in these three years and mass adoption of lidar The price drop over the past three years has been massive... It is the result of strategies and not due to the result of mass-production.

still has to happen. However, this price drop of lidar has a significant impact on market forecast. At Yole, we expect that the unit price of lidar will continue to decline, and large volumes will be needed in order to maintain the market."

In this complex and rapidly evolving environment, Yole's analysts predict that the lidar market for automotive and industrial applications will be US\$1.7 billion in 2020. Growth is expected to be 19%. Yole's forecast is a revenue of US\$3.8 billion in 2025. Automotive applications are expected to be the main driver for lidar in the next five years, providing US\$1.8 billion growth between 2019 and 2025. Yole expects 3.2% of personal cars to adopt lidar by 2025. On the other hand, the impact of robotic cars on lidar will be more modest due to lower deployment of robotic cars than once expected. lidar for personal cars could also be jeopardized.

The covid-19 crisis is putting financial pressure on car manufacturers. Regulations imposing reduced carbon emissions are pushing investments toward electrification. Finally, the ambition of Tesla to rapidly achieve autonomous cars without lidar could make lidar less essential in the coming years.

Alexis Debray, PhD., Technology & Market Analyst, MEMS, Sensors & Photonics at Yole asserts: "A new trend

in the lidar business appeared a few years ago, which might dramatically change the shape of the lidar market, namely dropping prices. Velodyne has announced a plan to reach an average unit price of US\$600 by 2024, from US\$17,900 in 2017". And the story does not stop here. Indeed, Chinese lidar companies, which usually have lidar unit prices one-fifth of that of other companies and usually below US\$1,000, are gaining market share and expanding their business. lidar with lower unit prices is expected to enter new industrial applications, including factory, logistics and security.

For more information, visit: http://bit.ly/Yole-Report-2020

LiDAR market 2019-2025 forecast by application



Schott at the Sharp Edge

Precision glass and glass-ceramics influence signal strength

oday's geospatial reality involves a world awash with sensors. As developers seek to embed lidar technology in ever smaller, increasingly



mobile installations, the importance of sensor encasement grows.

None of this is new to German glass manufacturer Schott, which is part of the Carl Zeiss Stiftung, the foundation that includes also the famous Carl Zeiss company.

Headquartered in Mainz, Germany, Schott AG specializes in the manufacture of glass and glass-ceramics. The company employs over 16,000 people in 34 countries, almost 40% of them in Germany. In 2019 it reported annual revenues of €2.2b, of which 87% was generated outside Germany. Schott is well known in the geospatial community, because its glass has been widely used in lenses for surveying and photogrammetric instruments. Publisher Allen Cheves and managing editor Stewart Walker, therefore, were delighted to receive an invitation to visit the Schott facility, a few kilometers from the spot where Johannes

BY ALLEN CHEVES & DR. A. STEWART WALKER



Gutenberg's movable-type printing press revolutionized the transmission of knowledge some 580 years prior.

Schott headquarters in Mainz

Our hosts were Christine Fuhr, innovation/technology communications manager, entering her 30th year with Schott, and Jonas Spitra, manager corporate and innovation communication. On entering the building, we admired the huge

stained-glass window, lit by the morning sun. We enjoyed a guided tour of the remarkable museum, marveling at the range of glass and glass-ceramic products created by the company since its foundation. Indeed, "museum" isn't quite the right word, as the extensive space includes superb displays of the latest Schott products and concepts. The innovation and ingenuity of Schott's top-class engineers have clearly endured throughout the company's more than 135-year history. We saw amazing technologies, such as glass with almost zero thermal expansion, glass that can be

moved from Jena after World War II.

bent and folded, and fiber optics. We marveled at the application areas, which Schott categorizes as home appliances, life sciences, astronomy, pharma, electronics and automotive.

The various technical developments for which Schott is renowned are too numerous to describe here, but there's a fine list on the website¹. While most

1 https://www.us.schott.com/english/ company/corporate_history/milestones. html#block166818





LIDAR Magazine readers are focused primarily on the geospatial, Schott's glass products are used in a myriad of applications. Kitchen stove tops, for example, are a gigantic market. There are, of course, other high-quality optical glass manufacturers, but products such as Schott's BK7 (now N-BK7) are recognized by almost anyone in the optical industry. Hexagon Geosystems, for example, uses BK7/N-BK7 in important components of several of its systems, for example optical windows. When it comes to focal optics, the designers have a large number of glass types to choose from. They use glass with specific characteristics for each individual lens in a system, balancing optical and mechanical characteristics with the particular prescription desired for the element to produce an optimal overall design. Companies such as Schott target specific characteristics, for example, transmission wavelength range, scattering and refractive index (among many others), in order to offer products that can ultimately be employed across the widest possible range of optical devices.

Enter lidar

Schott is interested in lidar. To learn more about Schott's lidar strategy and positions, we were joined for lunch by Boris Eichhorn, senior manager new ventures. Coming to Schott from Siemens in 2017, he had worked on Schott's initiatives in augmented reality before specializing in lidar. He explained that Schott has built a growth platform, which causes customers and prospective customers to come to the company, looking for solutions. Schott can play a proactive consultancy role, i.e. go beyond being a materials supplier. He



Boris Eichhorn, managing Schott's charge into lidar

Glass, glass-ceramic, and glass-to-metal sealed components protect lidar sensors, while maintaining a high optical performance. **

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mentioned glass solutions for protective windows as well as the optical paths and hermetic packaging for laser diodes, MEMS mirrors and photo diodes. As a result of its development path, Schott is able to occupy different positions in the value chains of companies,whether they are component and sensor providers, system integrators or tier 1s.

According to a market study by Yole Développement of Lyon, France, 70% of the lidar market will be automotive by 2025, characterized by high volume

and low price². Schott is extremely willing to become involved in lidar and can contribute a great deal in terms of materials and components, which Boris summarized in the message, "Glass, glass-ceramic, and glass-to-metal sealed components protect lidar sensors, while maintaining a high optical performance". This includes protective windows; filters, mirror substrates and lenses for the optical path; and hermetic packaging for harsh conditions. Schott explains much of this on its website, with a focus on automotive applications, though the company's interest extends beyond AVs to robotics and many other applications related to geological and industrial uses. In order to reach the mass market, however, manufacturers need components that meet exact performance standards economically.

High-quality protective windows must be tough to withstand unforgiving conditions. A lidar sensor has to function reliably at a high level to provide a continuous situational picture, so it needs protection from rain, temperature fluctuations and impacts from stones and other debris. Protective windows, moreover, must feature high transmission at lidar wavelengths that allows near infrared (NIR) to pass through, while attenuating visible ambient light.

For the optical path of a lidar system, filters, substrates and lenses must provide high performance. The precision of the interacting components is key, because the laser beam cannot afford any loss of photons. Lidar sensors must deliver long-lasting, high image quality regardless of temperature differences or aggressive climate conditions. High transmission and an athermal lens

2 http://www.yole.fr/Lidar_Market_Status.aspx



system design are typically taken into account. Overall, lidar sensors require superior imaging quality, while they must be compact and lightweight.

Hermetic packages protect and power lidar sensors to withstand demanding conditions like vibrations, shock, dust, moisture and extreme temperatures. The use of the best suited glass, for example, could ameliorate some of the problems lidar experiences in conditions such as snow and ice. Laser diodes, photo diodes and MEMS mirrors must be protected against internal condensation and challenging external elements of the driving environment in all types of lidar sensor devices. Schott believes that professional support and consulting is needed when it comes to product size, shape, materials, technology, and all-round R&D support as well as solutions optimized for competitive, high-volume manufacturing.

BOROFLOAT®33, a technical float glass from Schott, is gaining traction in lidar applications because of its excellent material properties at reasonable prices. The component quality has a tremendous impact on system performance.

Used as an entrance window, BOROFLOAT provides extremely high light transmission while remaining strong, lightweight, and resistant to potential corrosive environments or thermal changes. High transmission at the relevant laser wavelength is especially important as it ensures that light passes unimpeded through the entrance window, which serves as a protective cover for the components inside. If the entrance window impairs the lidar signal, it will not see its surroundings accurately. BOROFLOAT's high transmission properties stem from the use of extremely pure raw materials. It features greater than 92% light transmittance in the NIR wavelength range, outstanding colorless visual appearance, low auto-fluorescence, high resistance to solarization, and a low refractive index. BOROFLOAT also has a very strong microstructure, resulting in high material hardness, excellent abrasion resistance, and low degradation behavior during highintensity radiation exposure.



Fabrication of the 4.25 m diameter secondary mirror for the Extremely Large Telescope, the centerpiece of the European Southern Observatory in Chile. The material used was ZERODUR, which has proved efficacious in Schott's astronomy market.

Lidar systems use lasers of a specific wavelength, typically 905 or 1550 nm. BOROFLOAT has a long history as a substrate for narrow bandpass filters that reduce signal-to-noise ratio, allowing only the wavelength of interest to be transmitted or received. BOROFLOAT glass is often the substrate of choice for such coatings, as a high material transmission is key for exceptional filter properties.

The Schott Story



Otto Schott, 1851-1936, photographed here in 1884

The Carl Zeiss company earned a reputation across Europe for its microscopes, but these were hard to make, so in 1866 Zeiss recruited university physicist Dr. Ernst Abbe, who developed optical theories that revolutionized the manufacture of lenses. Abbe joined Zeiss as a partner in 1875.

Otto Schott was born in Witten in Westphalia in 1851. As a young boy, he was fascinated by his father's glassmaking business and so enthusiastic about the family tradition of glassmaking that he studied chemistry, mineralogy and physics in Aachen, Würzburg and Leipzig. In 1875, he wrote a dissertation, "Contributions to the theory and practice of glass fabrication", in Jena. In 1879 he began basic research on the melting,

glass-forming and crystallization behavior of many different chemical compounds. In 1882, he moved to Jena to facilitate a collaboration with Abbe and Zeiss. Two years later, these three, together with Roderich Zeiss, founded the Schott & Associates Glass Technology Laboratory. The Schott Villa, on Otto Schott Strasse in Jena, is open to the public, so visitors can see where he lived and worked as well as interesting exhibits. Schott developed specialized glasses with precisely defined properties for a wide variety of applications and turned his laboratory into an industrial company of international stature. With the development of entirely new types of glass and new production methods, Schott not only became the founder of modern glass science and glass technology, but also of the specialized glass industry.

Photogrammetrists know Abbe for his contributions later in his life, such as his comparator principle and his work with Carl Another interesting option, currently in testing for use in lidar applications, is the versatile glass ceramic NEXTREMA*: although its light transmission might not be as outstanding as BOROFLOAT, NEXTREMA shows strength in impact and thermal shock resistance.

Geospatial reflections on Schott's history

We've put Schott's history into a sidebar on this page and the previous one, but here we pause to reflect on Schott's role in geospatial products. Carl Zeiss was born in 1816 and set up his workshop in Jena in 1846, to make laboratory equipment for the local university. Kern & Co. in Aarau had been founded in 1819, i.e. it had also preceded Schott. Kern began with the manufacture of drawing instruments but quickly moved into surveying equipment. Founder Jakob Kern's sons, Adolf and Emil, joined the business in 1857 and Jakob retired in 1863. Heinrich Wild, on the other hand, was born in 1877. He was chief engineer for geodetic instruments at Carl Zeiss in Jena from 1907 until



Schott & Associates Glass Technology Laboratory, founded in Jena in 1884

The Schott factory in Jena, seen here in a 1925 painting

Pulfrich on stereoscopic instrumentation. but he found fame also as a social reformer. In 1889, the year after the death of Carl Zeiss, Abbe, with the help of Schott, founded the Carl Zeiss Stiftung, initially to provide corporate benefits that were way beyond their time. Two years later, the glassworks in Jena become a foundationowned enterprise. The Carl Zeiss Stiftung is now the sole shareholder in both Schott AG and Carl Zeiss AG. It uses dividends from its member firms to support research. By 1900, 50% of Schott revenue accrued from exports and in the period 1927-30 the first subsidiaries were set up. Otto's son, Erich, born in 1891, entered the business in 1917 after his older brother, Rolf, was killed in World War I. Erich took over the running of the business in 1928, eight years before the death of his father. After World War II, the

American occupying forces orchestrated the "odyssey of 41 glassmakers", whereby selected management and experts were moved from Jena to West Germany. Key Carl Zeiss employees were also moved to the west in the same operation. The factory in Jena was now in the Soviet-occupied zone and became a



The Schott Villa in Jena, where visitors can see where Otto Schott lived and worked

state-owned company. The Schott group re-established itself in Mainz, under Erich's direction, in 1952. When the first of two Bauhaus-style buildings was completed, it established its headquarters there. Erich lived in one of these buildings and introduced the tradition of giving presents to employees working on Christmas day. There followed gradual expansion as Schott grew into a multinational group, starting with production in Brazil in 1954. In 1989, the year Erich died, the Otto Schott Research Center was set up in Mainz. With the reunification of Germany, the Mainz headquarters assumed management of and integrated the old plant in Jena. In 2004, legal steps were taken to convert the foundation enterprise to the corporation Schott AG. Its sole shareholder is the Carl Zeiss Stiftung.

1921. He returned to Switzerland after World War I and founded Wild Heerbrugg. In the chronology, therefore, Schott, founded in 1884, came after Carl Zeiss and Kern, but before Wild Heerbrugg.

Schott glass, naturally, was used in Carl Zeiss instruments and, in due course, in the big lenses required by aerial film cameras. Carl Zeiss, however, was not the only supplier of photogrammetric equipment to purchase all its glass from Schott. Wild Heerbrugg, which evolved into Wild Leitz, Leica, Leica Geosystems and Hexagon Geosystems, also used Schott glass for its aerial cameras for decades, both the RC film models and the ADS digital series introduced in 2000³. The reason was that all big Wild lenses for photogrammetry were "braune Optik". 'Braun' was not meant politically but 'schmelzenabhängig' (dependent on the melt). Normally the refractive index n of glass is specified with a tolerance of 100 points where 1 point corresponds to $\delta(n) = 10^{-5}$. The big glass blocks for the UAGS lenses, however, needed tolerance values of 50 or 30 points, a requirement which only Schott was able to meet. They had to select the glass carefully and measure the optical data at five different positions with the accuracy the designers needed. So each objective had its unique glass components and, to avoid a wrong mixing in the factory, they were always packed in brown paper! Braune Optik is still needed today for

lenses where achromacy is important rather than resolution: resolution is handled by aspheres, but "color" needs different glasses. High-end optics needs glass material with a high refractive index near to 2, which traditionally was only possible using lead and arsenic as chemical components. When about 2000 'green' glasses, i.e. free of lead and

66 BOROFLOAT®33, a technical float glass from Schott, is gaining traction in lidar applications because of its excellent material properties at reasonable prices. **

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arsenic, were requested, Schott had to redesign its whole glass spectrum of more than 200 glasses, a complicated and very expensive transformation. In close cooperation with its main industry partners, Leica, Carl Zeiss, Schneider Kreuznach and Rodenstock, however, the glass spectrum could be reduced to about 100 types, a win/win situation for all parties. Remember also that geospatial system suppliers purchase optical components from specialist vendors, according to make-or-buy decisions; these may source their glass from Schott. Vexcel Imaging, for example, makes use of Schott glass in its UltraCam aerial cameras through the purchase of lenses from the Qioptiq Photonics⁴.

Endnote

We were privileged indeed to visit a leading world glass manufacturer and innovator with almost 140 years of experience and the most distinguished history. Much of Schott's involvement in our geospatial world is not well known, perhaps, but the crucial role of its high-end glass in the lenses for aerial cameras is widely acknowledged. Now the company is returning to our consciousness with its proactive approach to automotive lidar.

While returning home, one of the authors noticed, on a large information screen in the beautiful Franz Josef Strauss Airport in München, a short video about the SOFIA observatory, the renowned 747-borne NASA project. Schott enjoyed a serendipitous mention: the telescope's primary mirror, 2.7 m in diameter, was cut from a blank of ZERODUR[®], developed in Mainz and selected because it is a unique glass-ceramic material with zero thermal expansion.

³ Information on Wild Heerbrugg, Wild Leitz and Leica supplied by Dr. Bernhard Braunecker, Leica Research Fellow (retired); e-mail correspondence 1 May and 12 August 2020.

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.

⁴ Information on Vexcel Imaging supplied by Dr. Michael Gruber, Vexcel Imaging; e-mail correspondence 5 May 2020.



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Velodyne's Journey

Lidar Drives the Autonomous Revolution

e arranged to interview Velodyne Lidar's new CEO, Dr. Anand Gopalan, in mid-January 2020—only ten days after Anand was promoted and founder David Hall moved up to chairman—but a family emergency cut short the trip. An in-person interview was precluded by covid-19, so we did it remotely. Anand

was in his factory in San José, California, in the heart of Silicon Valley. While this article was being finalized for publication, Velodyne made a major announcement about combining with Graf Industrial Corporation. This is extremely important, so we have added a second, short piece to explain the news. First, the interview.

BE 551 KY

LM: Anand, thank you for talking to us today. Now you are six months into the CEO post. Your previous time with Velodyne was three and a half years as CTO. What brought you to the company? AG: I'd been in the Valley for a couple of

INTERVIEW BY DR. A. STEWART WALKER



decades, working on a variety of different technologies on optical transceiver products in many different spaces, such as automotive networking, and got a call out of the blue from Velodyne saying they were looking to start a research and development function. When I got started, it was three guys and myself in David's boatyard in Alameda, not a real office, no drywall. I am an electrical and electronics engineer by training and have spent all my career doing that. I like to tell the story that my grandfather was actually an automotive engineer, in the automotive business in India. He tried really hard to make me an automotive engineer. I refused and became an electrical engineer. Then, all these years later, I come to Velodyne and am working on technology that's finding a lot of applications in automotive. So it's my dad's turn to say he told me so! It's been really an interesting journey and that's how I came on board. I've spent the past four years working alongside David, developing incredible technology, then talking to our big customers and learning about them deploying it across all their different applications, automotive and non-automotive, seeing how the technology was impacting their applications and how the applications were impacting society. It's amazing to see your product on a vehicle as it drives.

David and I spent a lot of time thinking about technology strategy and



Velodyne's facility in San Jose

Lidar

55/

Dr. Anand Gopalan, Velodyne's new CEO

business strategy over these years, which enabled the transition to CEO. We are still, first and foremost, a technology company. But it's been a good transition and that's been my journey.

LM: Your PhD was from Rochester Institute of Technology, in the area of RF data?

AG: Right. We were building radio frequency transceivers for many different applications. Those days, Bluetooth was the new "in thing" and we were building Bluetooth transceivers. I came to the Valley and worked on many different products and projects. I worked a lot on optical transceiver technology. I think that's what attracted me to lidar, because essentially I'd been working on the communications side of things. Some of the first projects I worked on were such systems, bringing passive optical networking systems to the home. We were deploying the first fiber-to-thehome systems in Japan and Korea.

When I was called by Velodyne I looked at lidar—to some extent it's a free-space optical transceiver. From that perspective, it's been like coming full circle to the things that I had worked on before. We have taken some of the concepts and technologies that really made optical transceivers as ubiquitous as they are today and we've been able to apply them to mass produce lidar at scale, which is where we are as a company. There has been a natural progression to lidar, at least as far as I see it.

LM: That's an interesting challenge. We did an interview with Cepton Technologies—I suppose they compete with you—and one of the points that they discussed is this issue of production scale, what you do in-house, what you outsource, how you find good firms to outsource to.

AG: These are very interesting challenges, especially because lidar until very recently was new and emerging technology without that much expertise in mass manufacturing. We've not only had to develop the technology into products, but also develop some of the key manufacturing methods to be able to scale



it ourselves. Now we know that we have understood the manufacturing, we are better deployed with mass-manufacturing partners. I believe a lot of lidar in industrial and automotive segments is really a trade-off between high performance and manufacturability. You can build a very low-performance lidar that's very easy to manufacture. But a high-performance one is usually very difficult to manufacture. I think that Velodyne has really spent its time and investment to find that sweet spot where you can get high enough performance and solve for the manufacturability challenges. The optical transceivers stuff comes in handy for sure.

LM: Absolutely. But are you still making subwoofers?

AG: No, not anymore. Velodyne Lidar has been a standalone company since

2016. And the acoustics brand was sold off to another company in 2019. So now we are no longer making subwoofers.

LM: I don't want to spend much time on history, but I think you may have seen a book about the history of lidar by Todd Neff¹. David Hall and Velodyne get a good write-up in there. In particular, how David saw an opportunity in the DARPA Grand Challenge in 2004. He put some stuff on a Toyota pickup truck and the rest is history.

AG: It's the quintessential American inventor story. There's an incredible challenge. At first no one succeeded, then David went away to think about the problem and came up with a unique solution. Then he tackled the DARPA challenge, as is famously told in the book. Five of the six contestants who completed the urban challenge had David's lidar on them and it started off an autonomous revolution. It's incredible that, even today, a lot of the participants in that Grand Challenge are very much still in the autonomy industry, in fact, in leadership positions across most of our customers. And of

Neff, T., 2018. The Laser That's Changing the World, Prometheus Books, Amherst, New York, 314 pp.





From left to right Velodyne Alpha Prime, Ultra Puck and Puck



DARPA-ready: Toyota Tundra pickup truck with David Hall's invention in 2004

course, lidar has come a long way since then. It's a vast array of form factors and applications all the way from something as big as the wheel on the top of the car to now something that's tiny.

LM: It's quite remarkable. I suppose I got into that because I noticed when I was coming to visit you in January that you became CEO and David moved to chairman at almost the same time that Steve Berglund at Trimble moved to chairman and Rob Painter became CEO, and Dr. Eldada at Quanergy Systems moved to a sort of consultant role. I guess that's just private industry, isn't it, particularly in

Silicon Valley?

AG: Exactly. I think that's the nature of Silicon Valley. There's lots of incredible talent, technical talent, leadership talent. The autonomous

industry is a really dynamic industry. Even within the Valley, it's probably at the cutting edge where everyone wants to work. There's an incredible amount of talent in the space. We have been able to attract some great talent too. And so that's part of it. And I think David is still an inventor at heart. He's passionate about the technology, has a vision for the business and really wants to see his technology proliferate in all of these different applications. So as chairman he's very much still involved from a vision perspective. Our customers are transitioning and the business is transitioning from providing technology for research and development projects, to being able to provide mass market technology to all these different applications that are actually going out into the field. That transition as a business requires a set of people to manage it. And David's heart is inventing the technology and seeing the vision. So that's why he made that the



Fields of view of multiple lidar sensors fitted to a vehicle.

change [to chairman]. For some of the other companies in this space, it's been a challenging time as well. Obviously, you're seeing consolidation in the space. You're seeing many companies die on the vine as well, especially in the harsh economic conditions.

LM: Yes, indeed—the CEO of Cepton said very similar words to me. I come from the geospatial world and was with Leica in 2001 when it acquired a company that was making airborne lidar systems selling at more than one million dollars each. It's a different world. And so although that's where our magazine has its roots, it's interesting to report on automotive, because there's a lot happening, the R&D pockets are deeper and so on. Indeed, the geospatial world has been the beneficiary of the contact with companies like yours, because it turns out that because of the enormous investment in R&D, you've been building lidar sensors that have become smaller and lighter—both attractive in the geospatial world. In particular, the sensors have reached the point where



Velodyne Velabit: \$100 lidar breakthrough

they can be mounted on UAVs. AG: Three or four years ago lidar was really an autonomous vehicle and an automotive story, and automotive drove a lot of the initial investments in the space. But today, especially as form factors have gotten smaller, as ASPs [application service providers] have gotten much more accessible, you're seeing this whole array of applications that are exploding into the commercial space Today lidar is not just an automotive story for us by any means. You're seeing many different applications around small robotics, delivery systems, security systems, smart city applications, just moving into commercialization on the back of how

attractive this technology has become. And now they're as much volume drivers for our business as automotive. That's been the other sea change that's happened. The unfortunate situation with covid-19 has actually accelerated some of these applications, where many of our customers are creating cashless delivery systems, robotic systems that can help in communities, do things like disinfection, delivering medical supplies and so on. That whole trend has accelerated the acceptance of small robotics in society and lidar is playing a key role to make those systems successful. It started off with automotive investments driving the miniaturization of the technology, but today many different industries do so, including the geospatial world. All these other industries are benefiting and scaling quite rapidly today. We are very excited to see the growth not just in the automotive space, but actually far more in the small robotics space as well.

LM: I think there's a parallel there small integrators in the geospatial world, such as LiDAR USA, Phoenix LiDAR Systems or YellowScan, again full of very talented people. They've brought sensors like yours into the hands of UAV users, companies that offer UAV-lidar services. And I'm sure in these other applications that you're talking about, such as automated delivery systems, similarly, very impressive integrators have been leading the way. AG: Very much so. I think you're seeing some of the very big players in the space want to use these smart solutions developed by these integrators, incorporating lidar to solving some of their big delivery e-commerce challenges. Definitely that's a trend that's cutting to accelerate across the board for sure.

LM: So we come to the Velabit product, which you announced at a price point of one hundred dollars. As I said, I started in a world of million-dollar airborne sensors. So there's a bit of a difference four orders of magnitude. Tell us a little bit about that and about the technology, the miniaturization and then also the application of Velabit.

AG: Velabit is a culmination of a lot of work that we have done over the past four years around bill of materials, integration, miniaturization, and then just bringing efficiencies of scale. We have been developing our own lidar ASICs-application specific integrated circuits for lidar—for about four years. This has allowed us to collapse the entire bill of materials for lidar into a couple of pieces of silicon and drive huge benefits from a bill of materials, cost and reliability standpoint. The other thing driving miniaturization as well as automation is the act of putting a lidar together. There is a technology that we call the microlidar array, which is really an array of lidar elements that we're putting together in a fully automated fashion, effectively creating the ability to miniaturize multi-channel lidars and create form factors that are very persuasive. Just to give you a sense, what I'm holding in my hand is an eight-channel lidar element which has fixed lasers, detectors and our own ASICs. It's put together

in a completely automated fashion. These technology investments we have made over the past four years really have come to fruition. Within the development concept, it



Velodyne's microlidar array, an eight-channel lidar element with fixed lasers, detectors and ASICs developed in-house

was an attempt to say: if you wanted to build the smallest form factor, most affordable lidar that was still usable in outdoor, automotive-grade applications, what could you come up with? That's what we're going for! Velabit is compelling, with a tiny form factor. And then it has this microlidar array technology. It really has allowed us to break open of a variety of new applications around lidar.

There's many interesting conversations happening. In the context of automotive, up until now, we've gotten lidars to a few hundred dollars, where the automotive OEMs were thinking about lidar as still starting off in the luxury car segment. Think of a

highway autopilot, that kind of functionality enabled by lidar. And then eventually, as the prices

Velodyne VELARRAY: compact lidar for seamless integration within a vehicle's body or behind the windshield. come down, it makes its way into the big tier and the lower tier segment. But what we're able to do with something like Velabit is say—I've already jumped. I made the quantum leap to give you something that's so attractive from a cost-point perspective that you can afford to put a couple of hundred dollars of lidar plus compute content even in a mid-tier car. With this technology, in conjunction with our software, you're now able to get vastly improved functionality on something like pedestrian and bicycle collision avoidance. For example, there was interesting work by IIHS² and AAA³ last year. They were testing all the automatic emergency braking systems that are available across many different standard cars today. They found that, for many of the cars, the systems barely worked in daytime and did a very poor job of detecting pedestrians and bicyclists.



² Insurance Institute for Highway Safety: https://www.iihs.org/topics/advanceddriver-assistance.

³ American Automobile Association: https:// www.aaa.com/AAA/common/aar/files/ Research-Report-Pedestrian-Detection.pdf.



And they never worked in the night. And, you know, that means if you are driving around in the night, you have huge risk that the systems completely fail because they have no ability to detect in the night as they're all camerabased systems.

Now you have this massive, quantum leap in the robustness and reliability of the technology. So the interesting conversation we're starting to have in the automotive space, with many of our customers, is: think about the fact that you have one-hundred-dollar lidar content plus some compute and software. Can you imagine what you could do, even in a midtier car, to make the car much safer for the occupants as well as for the general public around them? Those very interesting conversations have started because of development. And then, of course, in non-automotive the possibilities are limitless. We are seeing customers come up with many applications we haven't even imagined because they are enabled by the contractor and the cost-point of the technology. So developments are seeing an explosion of interest and are driving lots of interesting discussions around new applications for lidar.

LM: I think that, in the geospatial world, there are still some companies reluctant to put lidar on UAVs because of the cost. Even your eight-thousand-dollar Puck is a little bit of a worry to put on a five-thousand-dollar UAV in case it crashes! You could put a couple of one-hundred-dollar lidars on and not worry about it. It could be that people like LiDAR USA will be on the phone to you quite soon and say, let's try some of these, because it's got a 100-meter range. That's easily good enough. That means that you can fly almost at the regulatory maximum height and that sensor will still work.

AG: Exactly. So we're definitely seeing a lot of interest from the UAV space, for that exact reason and also it's a very light sensor, so from a mass perspective and battery life perspective, it's pretty attractive.

LM: Yes. You don't need a five-thousanddollar DJI Matrix. You can go for something, maybe a thousand-dollar price-point. I think that will make a difference because nobody else has really got anything just there at the moment. Congratulations. So we covered Velabit then you touched on the VELARRAY. And that was going to be in my next question, how that fitted in. Now you've got software too, and I suppose in order to gain market share, because it's a very competitive world, as you said, you need to be able to offer solutions. Solutions require software. I



	(mid to long range)			Directional Sensors		Software
			Velodyne			
Sensor	Puck™	Ultra Puck™	Alpha Prime [™]	Velarray™	Velabit™	Vella™
Description	Power efficient Affordable and high performance Ideal for low speed autonomy, mapping and advanced driver assistance systems (ADAS)	Optimal power and high performace in a compact form factor High density, long range imaging	Optimal long range sensor for autonomous mobility Field-of-view, range, and image clarity for reliable and precise roadway detection	Compact form for seamless integration in a vehicle Robust directional image, day or night Faster object detection at higher speeds	Velodye's smallest sensor Versatile and affordable mid range lidar Highly configurable for a wide range of applications	Revolutionary ADAS software solution based on the Velarray Superior to existing camera + radar approaches Advancement of ADAS functionalities
Key Applications	Autonomous Drone/UAV	Autonomous ADAS Trucking Mapping Smart City	Autonomous Mapping	ADAS Delivery	Robotics Drone/UAV	Autonomous ADAS

Velodyne product range

see Cepton, Quanergy going that that way. I see SICK in Germany going that way. And you're doing the same. **AG:** There's two ways to think about the software itself. One is, of course, there are applications for lidar outside traditional automotive, where the customers are really looking for a hardware-software solution. They feel that the lidar provider can add much more value because they understand the output of the sensor much better. Even in the automotive context, especially for driver-assistance system applications, we are seeing customers want a more complete software solution, because we understand the lidar that much better. And we have the entire solution of how to drive intelligence and value from the lidar. We acquired the small software supplier mapper.ai in 2019. And that's allowed us to really accelerate and bring to market effectively a suite of software that's ready to go, this year. So definitely that's a key element. And obviously, as the leader in this space with the broadest installed base of our technology, we think we're well suited to leverage our software to be able to effectively increase our monetization of the technology. Software is a great addition to our hardware technology and gives us lots of growth.

LM: So we've talked then about the Velabit, the VELARRAY. You've now got quite a large, complex product line. I think you've got six pucks, two XDLs, VELARRAY and Velabit. Do you want to say something to put them in context? AG: The breadth of product portfolio is a key part of our strategy, because all the different applications we serve cannot be satisfied with a single technology. There are so many different types of lidar needed for so many different applications. As we try to solve all these different applications going into commercialization, we have come to the recognition that there is a need for a broad portfolio. Many of our customers are big, marquee, blue chip companies which have many different needs for lidar and our ability to have this breadth of the portfolio allows us to serve these customers across all the different applications. So if you see level four, level five autonomy, you still see the rotational 360° surround-view lidar, often roof-mounted, as being the reference architecture. So we continue to see traction for level four, level five systems. Now, if you look at small robotics or if you look at it ADAS [advanced driverassistance systems] applications for consumer vehicles, then of course the

solid-state directional lidar is preferable. Again, we have a broad portfolio going from the Velabit to the VELARRAY to cover that space very well. And then we have other architectures like the VelaDome for commercial vehicles and so on. The breadth of the portfolio has helped us and we leverage that to be able to serve our customers well across all the different lidar needs.

LM: It makes sense, but it's hard keeping all these products-the product management is a challenge. AG: That's definitely something that we continue to work on and think about a lot. There's a strategy to this: we have created a common core set of technologies that drive into all of these different product architectures. That's what allows us to be able to get economies of scale and leverage it. Imagine common base elements, common supply chain, even common manufacturing methods for a lot of the subsystems, common signal processing techniques and firmware, and common ASICs that work across all these different products-that's allowed us to create the breadth of the portfolio. These are not eight point-solutions that have been put together. It's actually one continuum of product architectures with common core technology elements that are across this entire family.

LM: Preparing for this conversation, I went through your website and there are numerous press releases of different kinds. But I want to home in on your strategy for sales, in other words, developing a sales channel as opposed to doing direct sales from the Valley. You talk about Emesent, which we know quite well in the geospatial world. There's the NavVis VLX, an indoor mobile mapping system.



There's your relationship with GeoSlam. So some of these are technical. And then some of them, for example, Agrointelli, are sales agreements. So maybe you could talk about your sales strategy and sales agreements. And then we'll talk about the Automated with Velodyne program. **AG:** The common thread is a series of industries that are at an inflection point, going from what I would call the research and development phase to the commercialization phase across many different applications. There's two things we want to do. We want to continue to seed our technology into new and emerging applications for the usage of lidar. That's what we have been doing for many years. And we continue to do that both directly in the case of some customers and through our sales distribution partners in many cases as well, on a worldwide basis. So we have both direct sales as well as distributor relationships in all major geographies. But a lot of this seeding activity over the past four or five years is now coming to fruition with many of these technologies effectively moving into the commercialization phase. And often there, as in the examples that you quoted, we are now establishing these direct long-term relationships with our customers. We are able to support them as they walk the walk towards mass-market adoption of their technology by providing them the

lidar and, in some cases, the software that allows them to scale this in the most cost-efficient manner. A key portion of the strategy is being able to create these long-term relationships with customers as they scale. That allows us to provide them the technology that scales with their application—at the right pricepoint, of course. Broadly speaking, that's how we do it. It's obviously true in North America, Europe and the Middle East as well as in Asia-Pacific.

LM: There's so much going on over and above the technology development, which I guess was where you came from, but there is clearly other expertise in Velodyne on the business side, looking at this relationship-building over the last five or 10 years.

AG: The company, of course, has been the first mover and the incumbent for over a decade and has very long-term relationships with many of these customers. And there's people in Velodyne who have built those relationships, for a decade plus. That is key because I think we have had a track record of being able to deliver this technology into these customer applications. That creates a very deep trust relationship with our customers, which allows them to have the confidence that, as we move to this next phase of lidar adoption, we will be able to continue to scale and meet their needs.



LM: On the technical side, then, as opposed to the sales and distribution side, you've introduced the Automated with Velodyne program⁴, announced in April this year.

AG: Broadly speaking, this dovetails into the strategy that I was just telling you about. We believe that when we're able to partner deeply with the customer, enable their end application, as we do with the Automated with Velodyne program, and then, in many cases, co-market that application and bring it to their end customer together, then we are able to drive adoption of the technology much faster. The co-marketing efforts, as well as the education efforts around the technology, increase and speed up societal acceptance of the customers and technology. The Automated with Velodyne program allows us to be able to deeply engage with our customers on these activities and accelerate the adoption of their end technology into their markets, which obviously is a great benefit to us as well.

LM: Yes, that will be an interesting program that will grow and grow as time passes.

AG: I am very excited about the fact that we already have a significant number of customers—more than 50, I think. We are seeing a lot of customers approach it with great enthusiasm and sign on to be part of it. It's created a very nice ecosystem around the lidar technology.

LM: Well, the next question, it's unfortunate that I have to ask this, is about covid-19. I attended a webinar run by the organizers of the Intergeo trade show and conference in Germany, about what various companies were doing to try to help the fight against covid-19. So I presume Velodyne is involved as well. AG: We are seeing a lot of our customers, especially in the small robotics space, develop and deploy solutions to help communities to deal with these issues. We have a customer developing disinfecting robots, as an example. We have many customers developing touchless delivery services so medicines, goods and groceries can be delivered into communities that are



affected. We have seen such applications in North America. We have seen such applications in China, when the pandemic first hit. It's been incredible to see how the customers-in some cases their technology was still in early R&D-were able to accelerate the march to production and deploy these technologies in many of these communities. As Velodyne is supplying the eyes of these machines, so to speak, I'm really proud to be part of that effort to help communities as best we can. So while it's been, of course, a challenging time for all businesses, including ours, this has kept us very passionate and motivated, seeing our customers coming to the forefront in many of these different applications. That's definitely the silver lining.

LM: Yes, indeed. I was impressed reading your your website, you're obviously intensely active, with expansion, growth in markets, growth in partnerships, growth in product range. How do you see things going for the rest of this year and then in the future? AG: Yes, we are we are seeing a tremendous growth in markets. We are seeing an ability to have this broad product portfolio and ship product at scale really help move our customers into a mass commercialization phase. I expect that trend to continue across many different applications, automotive and autonomous vehicles being just one of them. You will see many of these applications come to market around the usage of lidar and that's really driving a lot of growth for the business and a growth in the customer base. As this continues, it will be a very exciting, intense and busy time for us as a business. And I think we will continue to grow and serve a broad base of customers to the best of our ability.

⁴ Jon Barad, vice president of business development at Velodyne, pointed us to this blog for further information on the program: https://velodynelidar.com/blog/automatedwith-velodyne-ecosystem-video/.

Big News After The Interview: Velodyne SPACs more punch

Only two weeks after this interview took place, Velodyne made a dramatic announcement: the company is combining with Houstonbased Graf Industrial Corporation, a special purpose acquisition company (SPAC). The following excerpts from the press release¹ give the gist.

"The combined company will remain on the NYSE and trade under a new ticker symbol VLDR following the close of the business combination. The *pro forma* implied market capitalization of the combined company is expected to be approximately \$1.8 billion. The transaction is supported by a \$150 million committed PIPE² and is expected to leave Velodyne with approximately \$200 million of cash on its balance sheet. The net proceeds from the combination will primarily



David Hall, seen here receiving an Autos2050 award, will continue, after the Graf combination, to play a critical role as executive chairman of Velodyne. CEO Dr. Anand Gopalan and CFO Drew Hamer will lead and manage the business along with Mr. Hall. CMO Marta Hall will continue to support and elevate the brand.

remain on the balance sheet to enhance financial flexibility, support growth and fund selective acquisition opportunities to further expand market leadership."

"A SPAC is a company with no commercial operations that is formed strictly to raise capital through an initial public offering (IPO), with the purpose of "merging" with an existing company. This process is called a combination, though some finance experts have called it a "reverse merger". SPACs have been around for decades but have become more mainstream in recent years and more popular in the past few months. SPACs attract big-name underwriters and investors and raised a record amount of IPO money in 2019."³ Some SPACs are described as "blank check companies" and Graf uses this term in its own marketing material. For the less financially expert, *The Economist* has recently provided a pithy, more whimsical description of SPACs⁴. Readers who enjoy this sort of thing can find the small detail at *https://s24.q4cdn.com/384053642/files/doc_downloads/2020/07/GRAF-Velodyne-Investor-Presentation-Website. pdf*. This presentation also oozes with insider information about Velodyne–well worth a read because it both complements and confirms what Anand told me!

The bottom line is that Velodyne appears to be going from strength to strength, but with much deeper pockets, not only to support vibrant R&D activities, but also to facilitate scaling of production, which is essential, as the autonomous vehicle market explodes and Velodyne launches new sensors aimed at higher-volume lower-cost markets. The UAV and MMS user communities can only be enriched as a result.

- 1 https://velodynelidar.com/press-release/velodyne-lidar-and-graf-industrial-corpannounce-business-combination/
- 2 "Private investment in public equity (PIPE) is the buying of shares of publicly traded stock at a price below the current market value (CMV) per share. This buying method is a practice of investment firms, mutual funds, and other large, accredited investors. The purpose of a PIPE is for the issuer of the stock to raise capital for the public company. This financing technique is more efficient than secondary offerings, due to fewer regulatory issues with the Securities and Exchange Commission." (https://www.investopedia.com/terms/p/pipe.asp).
- 3 https://www.investopedia.com/terms/s/spac.asp
- 4 Anon, 2020. The SPAC hack, The Economist, 436(9205): 58, 1 August.

LM: Now, I completely understand that you don't want to answer any questions about your financial numbers because your company is privately held. Can you say anything at all about the number of employees?

AG: We have about 300 employees.

LM: 300 employees is big in the world of lidar! Your company is growing, so the number of employees is growing and the influence that you will be having on offshore companies to which you outsource manufacturing is growing. That's all good news.

AG: Yes, very much so. And I think we will continue to expand our footprint globally and impact both directly and indirectly all these different companies which are working with us, buying our product, manufacturing our product and supplying subsystems into our applications. So I think it's a pretty exciting time for the lidar business in general. And definitely we are seeing that also for ourselves.

LM: Well, congratulations on your accomplishments in the state of the company today. Thank you very much for giving so generously of your time. I really appreciate that. As I said, for a magazine such as ours to gain access to C-level executives in a leading company is much appreciated.

AG: Thank you very much for your thoughtful questions and for the conversation.

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.

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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.

We encourage you to visit our sponsors. Thanks to all that participated in this year's edition.

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HARDWAREPROFILE

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Cepton provides state-of-the-art, intelligent, lidar-based solutions for a range of markets such as autonomous driving, ADAS, intelligent traffic systems, security, crowd analytics, and industrial robotics. 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, USA, with presence in Germany, Canada, UK, Japan and India to serve a fast-growing global customer base.



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APPLICATIONS

AUTONOMOUS VEHICLES

ADAS

Intelligence at the Speed of Light

Cepton's Vista®-series lidars are optimized for automotive and AV applications, and along with the Sora[™]-series lidars, they are also widely used in automotive-adjacent and nonautomotive markets. In addition, the award-winning Helius[™] Smart Lidar solutions combine lidar with advanced perception to enable a whole range of applications such as smart traffic intersections, wrong-way driving detection, electronic tolling, rail crossing safety, rail obstruction detection, platform safety, perimeter and area security and crowd analytics.

The Helius-V Smart Lidar System is a groundbreaking solution using Cepton's high resolution, long range Vista-P lidar sensors. It provides accurate object detection, tracking and classification along with object velocities and dimensions. In networked applications, multiple lidars can be interconnected via POE+ and edge computing to provide stunning, anonymized 3D intelligence across extended areas for a variety of applications. The system provides sophisticated controls and options for zone management, map overlaps and more, is easy to install and can run 24/7.

The Helius-S Smart Lidar System combines high-fidelity, industry-leading, high frame rate Sora lidars and Al-based perception software to enable real-time, high-speed vehicle profiling applications, such as e-tolling. The system captures extremely detailed profiles of vehicles moving at highway speeds and provides information on vehicle shapes and dimensions, body/trailer bounding boxes, and axle counts. The Sora lidar is also ideal for container scanning and high accuracy industrial applications.



MARKET-LEADING

LIDAR SOLUTIONS FOR SMART TRANSPORTATION



Rail

ADAS/AV

Smart Cities

HARDWAREPROFILE

SICK AG



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

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SICK

Sensor Intelligence

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

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

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

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

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



LIDAR sensors from SICK: OUTDOOR IS OUR FOURTH DIMENSION THIS IS SICK

Sensor Intelligence.

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

HARDWAREPROFILE

RIEGL

COMPANY

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



Founded 1977 230+ Employees Horn, Austria Orlando, USA

Riegl.com



APPLICATIONS

AIRBORNE BATHYMETRIC MINING MOBILE INDUSTRIAL TERRESTRIAL UNMANNED WIDE-AREA



Innovation in 3D

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

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

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

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

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

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

RIEGL AIRBORNE LASER SCANNERS & SYSTEMS

RIEGL WAVEFORM LIDAR TECHNOLOGY for TOPOGRAPHY CHOOSE THE SCANNER EXACTLY RIGHT FOR YOUR SPECIFIC SURVEYING MISSION





Also explore RIEGL's proven LiDAR sensors for UAVs and for BATHYMETRY www.riegl.com



HARDWARE PROFILE

Acuity Technologies



Acuity Technologies has been developing and marketing time of flight rangefinding and lidar components since 1993. Acuity's first complete scanning lidar system had a 120 by 360 degree field of view with two-turn lock to lock rotation.

In 2017 Acuity introduced the AL-500, a next-generation lidar significantly smaller than earlier systems with unlimited turret rotation, improved accuracy, reduced laser pulse width, and smaller laser spot size.

Acuity's new single axis AL-500AIR is based on the AL-500, with significant upgrades including multi-return detection, time sync inputs, and lighter weight composite structural components.

Acuity can incorporate scanning components into systems that meet customer requirements for performance and form factor that cannot be met with its standard products.



3475 Edison Way, Building P Menlo Park, California 94025 877-659-3406 inquiries@acuitylidar.com

www.acuitylidar.com



APPLICATIONS

AIRBORNE MINING INDUSTRIAL AGRICULTURAL MOBILE TERRESTRIAL

UNMANNED

MAPPING



AL-500AIR: The Lightweight Heavyweight

The AL-500AIR is a lightweight single axis scanning lidar designed by Acuity for airborne mapping and continuous or batch industrial point cloud acquisition. Weighing only 1.3 Kg and consuming 6 to 50 watts, the AL-500 is well suited for small drones and UAS at altitudes up to 200 meters AGL.

The AL-500AIR features programmable laser pulse and line scan rates. Three versions with top pulse rates of 200,000, 400,000 and 800,000 offer different laser pulse power and maximum ranges of 300, 225, and 150 meters respectively. The AL-500AIR captures up to 4 returns per pulse up to 200,000 pulses per second and 2 returns up to 400,000 pps. The maximum line scan rate is 300 lines per second.

Scan rate, field of view, and laser pulse rate are controlled from the interactive host computer interface or through Acuity's PointWorks Application Programming Interface routines. Control and data communications use TCP-IP over a 100 Mb ethernet link.

For mobile systems, PPS and NMEA inputs are used to synchronize the AIR scan data with external time signals, allowing point-by-point transformation of scanner output to an inertial or ECEF frame of reference.

Acuity's PointWorks software is included with the AL-500 and AL-500AIR, with C++ source for control and data collection programming. Pointworks also provides interactive point cloud visualization and data export in standard file formats. For advanced processing, PointWorks' .LAS output can be used with any of several available point cloud manipulation and analysis packages.



AL-500 and AL-500AIR Lidar Systems

High speed scanning lidar systems for airborne and terrestrial surveying 15 to 300 scan lines per second Up to 4 returns per sample 333 to 6667 points per 120° scan line Three versions: 300, 225, or 150 meter maximum range at 200,000, 400,000 or 800,000 samples per second Range accuracy 8mm (1σ at 20 m). Angular accuracy 400µRad IMU/GNSS timing inputs for mobile applications Fully calibrated for signal strength, scanner geometry, temperature TCP-IP command/data interface



AL-500AIR

Airborne mapping, industrial process capture 11.49" (292mm) x 3.22" (82mm) x 4.74" (120 mm) Up to 150 meter flight altitude 9.5 Watts at 100 lines /sec 2.9 lb (1.3 Kg)

AL-500

Terrestrial and mobile scene capture 12.67" (322mm) x 3.22" (83mm) x 4.74" (120 mm) Two-axis scanning to 300 lines/sec and 10 rev/sec Precision tip-tilt sensing for automatic vertical rectification

Acuity PointWorks Software

API with source code for controlling the AL-500 and AL-500AIR Unlimited duration scan capture .LAS and text file export Point cloud visualization: Color coded distance, elevation, signal strength, nth return, and ambient light

4 4 2



www.acuitylidar.com

877-659-3406 Rangefinding and lidar systems since 1993 Designed and produced in the United States

HARDWAREPROFILE

SURESTAR LIDAR

APPLICATIONS:

AIRBORNE AUTONOMOUS MOBILE NAVIGATION ROBOTICS TRANSPORT UNMANNED

COMPANY PROFILE

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

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

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

SureStar

Founded 2005 200+ Employees Beijing, China

isurestar.com

Continuous Innovation

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

As one of most important lidar providers for both mapping and automotive applications, Surestar has distributed lidar sensors into USA, Europe, Russia, Australia, South Korea and South East Asia. The Fortune 500 clients of SureStar include several Chinese leaders in power and transportation, and many big names in autonomous driving. SureStar sensors were also seen in Malaysia's first self-driving car in which Prime Minister Tun Dr Mahathir Mohamad took a ride on April 2019. Mid-2019, SureStar was notified that it had met the requirements of IATF16949:2016. This international standard was published in 2016 by the International Automotive Task Force to supersede ISO/TS 19649. The standard is aimed at the development of a quality management system that provides for continual improvement, emphasizing defect prevention and the reduction of variation and waste in the automotive industry supply chain. SureStar's commitment to automotive lidar is clear, while it continues to offer products across the lidar spectrum, including the rapidly growing UAV-lidar market.
Tel : +86 10-58717175; +1-248-773-7768 Email : bkth@isurestar.com Website : www.isurestar.com





Mapping & Navigation LiDARS





Mini UAV LiDAR

- -- Weight below 1.2 kg
- -- Range beyond 200 m



HARDWAREPROFILE

TELEDYNE OPTECH

COMPANY

APPLICATIONS

UNMANNED

AIRBORNE MOBILE TERRESTRIAL INDUSTRIAL MINING SPACE

COMPANY

Teledyne Optech has led the world in the design and manufacture of advanced lidar instruments for more than 45 years. Widely recognized for its technological depth, the company has decades of experience in lidar, photogrammetry and in auxiliary technologies such as GPS integration and waveform digitization. Known globally for reliable and innovative products, Teledyne Optech offers standalone or fully integrated lidar and camera solutions to meet your airborne, mobile mapping, UAV and terrestrial laser scanning needs.

Visit www.teledyneoptech.com to see the latest solutions such as the ALTM Galaxy T2000 offering true 2MHz points on the ground and first time ever dual sensor mounting capability with the G2 Sensor System providing true 4MHz points on the ground or the innovative Compact Lidar suite of products featuring CL-360 with full 360 degree scanning and no blind spots.



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

Teledyneoptech.com

Hyper-Realistic Mapping With Galaxy G2 Sensor System And Galaxy T2000

THE GALAXY G2 SENSOR SYSTEM is a ground-breaking advance for Teledyne Optech. Integrating two advanced Galaxy T2000 or Galaxy PRIME on a single system, G2 operators can survey in high definition and capture more of their targets than ever before, while maintaining the flexibility to split the sensors and use them for separate projects.

TRUE 4-MHZ MAPPING The most obvious benefit of the G2 is its extremely high measurement rate. Using two 2-MHz GalaxyT2000s, the G2 paints the ground with 4 million true measurements per second, providing unprecedented point density. Notably, 4 MHz is the system's "real" on-the-ground measurement rate thanks to the Galaxy's oscillating scanner that keeps all of the points focused on the ground.

THE NEW GALAXY T2000 boasts a true 2 MHz ground sample rate with 100% of the points on the ground, extended range performance for increased productivity and faster scan rate to distribute points more efficiently. Teledyne Optech's signature SwathTrak with variable field of view provides more scanning efficiency over fixed field of view designs and PulseTrak enables continuous operating envelope for maximum collection efficiency regardless of terrain.

Increased energy density and vegetation penetration are realized through T2000's small beam divergence and data fidelity is increased for energy density and feature identification through 8 discrete returns with 8 intensity measures.

THE WORLD IN 360 DEGREES



Compact Lidar CL-360 Survey Grade Lidar for Mobile and UAV Applications



» True 360 degree survey grade scanning at up to 750 m

- » Maximize productivity from UAVs by collecting data at 120 m above ground level through vegetation
- Industry-leading maximum scan speed of 250 lines per second for even x-y point spacing
- » Available from leading lidar system integrators

And Introducing CL-360 Marine —



The First Survey Grade 360 Degree Laser Scanner for Marine Applications

Combine sea and land with CL-360M and get the whole picture
Plug and Play with all major hydrographic data acquisition software
IP67 marine grade protection – designed for salt environment



► TELEDYNE OPTECH Everywhereyoulook[™]

Part of the Teledyne Imaging Group

HARDWAREPROFILE

VectorNav Technologies



APPLICATIONS

AEROSPACE AUTOMOTIVE DEFENSE HYDRO MAPPING MARINE PHOTOGRAMMETRY SURVEYING

COMPANY

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, highperformance 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.



Founded in 2008 11-50 Employees Dallas, TX, USA Alton, Hampshire, UK 10501 Markison Road Dallas, Texas 75238, USA Tel: +1 512.772.3615 sales@vectornav.com

vectornav.com

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.



UNPRECEDENTED PERFORMANCE AT YOUR FINGERTIPS

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



Applanix Corporation

HARDWAREPROFILE

APPLICATIONS

AIRBORNE MAPPING MOBILE OEM SURVEYING INERTIAL/IMU UNMANNED

COMPANY PROFILE

Applanix and the Trimble Indoor Mobile Mapping Solution (TIMMS) for the fast creation of accurate representations of indoor spaces

Applanix Corporation, a wholly owned subsidiary of Trimble since 2003, builds, delivers, and supports TIMMS, a complete, all-in-one solution for high-productivity measuring, georeferencing and modeling interior spaces. All hardware and software of TIMMS is specifically designed and integrated to deliver full indoor mobile mapping scanning capability quickly and easily. Applanix expert customer support is also available for every project. TIMMS produces geo-located maps and point clouds—the real-world positions (latitude, longitude, elevation) of each area of the surveyed building and all of its contents are known.

Anywhere indoors, Trust Your Position with Applanix



Founded 1991 51-200 Employees Ontario, Canada

applanix.com

TIMMS

Easily operated and highly maneuverable, TIMMS accurately measures and models interior spaces without accessing GPS.

The Trimble Indoor Mobile Mapping Solution (TIMMS) is the optimal fusion of technologies for capturing spatial data of indoor and other GNSS-denied areas of all sizes and locations. It provides both LiDAR and spherical video, enabling the creation of accurate, real-life representations (maps, models) of an interior space and all of its contents; every object in the interior space, including desks, chairs, stairs, and doors appear in the plan.

And with TIMMS Spatial Processor (TSP), the operator has optimum control and visibility of the project in a single interface. With a simple click of a button, data is 3D registered in real world coordinates using TSP.

TIMMS produces geo-located maps and point clouds – the real-world positions (latitude, longitude, elevation) of each area of the surveyed building and all of its contents are known.

Because of its high efficiency and speed, TIMMS is very effective for as-built environments of all sizes, including very large spaces (even those extending over several city blocks), buildings with multiple rooms, and those with multiple floors. 3D indoor geospatial views of all kinds of infrastructure can be created including:

- Plant and factory facilities
- High-rise office, residential, and government buildings
- Airports, train stations and other transportation facilities
- Conference halls, theatres, auditoriums and other public event spaces
- Covered pedestrian concourses (above and below ground) with platforms, corridors, stair locations and ramps

The Trimble Indoor Mobile Mapping Solution (TIMMS)

is the optimal fusion of technologies for capturing spatial data of indoor and other GNSS denied areas.



Scan the QR code for more information

Anywhere indoors TRUST YOUR POSITION

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HARDWAREPROFILE

SBG SYSTEMS

APPLICATIONS

AIRBORME AUTOMOTIVE

- DEFENSE
- INERTIAL
- MAPPING
- MARINE
- SURVEYING
- UNMANNED

COMPANY

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



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

sbg-systems.com



High-end Inertial Navigation Technology in the Smallest Form Factor

This year, SBG Systems renewed its popular line of miniature inertial sensors with high-end functionalities and RTK called the Ellipse Series. The 3rd generation of this product line 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.

Qinertia GNSS-only License, an Addition to the Software now Open to Third-Party IMUs

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

Qinertia now covers all surveyors' projects by offering a license dedicated to GNSS postprocessing. This allows surveyors to post-process both static and kinematic GNSS data. Open to the world, Qinertia supports all major GNSS receivers and is now compatible with third-party IMUs.

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



Intel Makes Lidar Too

Renowned chip-maker launches low-cost lidar

s part of our series on lidar players in Silicon Valley, we were keen to talk to Intel Corporation. Our curiosity about the semiconductor giant's lidar activities was piqued in December 2019, when the company announced its Intel® RealSense[™] LiDAR Camera L515. The L515 seemed to us to bear similarities to the lidar sensor in Apple's new iPad Pro. We were fortunate to be able to put our questions to Sagi Ben Moshe, corporate vice president and general manager of Intel's Emerging Growth and Incubation (EGI) group, the mission of which is to identity, incubate and scale the next big business for Intel. Here is what he said.

LM: Intel is best known as the world's leading supplier of the microprocessors at the hearts of our desktops, laptops and servers. Why did it decide to get into lidar?

SBM: Over the last 50+ years of innovation, Intel has explored and developed many cutting-edge technologies. We recognized the importance of vision years ago, which led us to establish Intel RealSense. RealSense has more than ten years of expertise creating different types of depth cameras using various sensing technologies such as stereo and coded light. Our depth cameras are used worldwide across industries



The Intel RealSense LiDAR Camera L515 is a very small, power-efficient lidar sensor, suited for indoor use cases such as health, retail, logistics, robotics and measurement. Intel introduced L515 in December 2019. L515 offers consistently high accuracy over the supported range of 0.25 – 9.00 m. It provides over 23 million accurate depth pixels per second, with a depth resolution of 1024 x 768 at 30 frames per second. L515 has an internal vision processor, motion blur artifact reduction and short photon-to-depth latency. The lightweight L515 consumes less than 3.5 watts of power, enabling easy mounting on handheld devices with the flexibility of long battery life. L515 retains its depth accuracy throughout its lifespan without the need for calibration. It includes accelerometer, gyroscope and FHD [full high definition: 1080p, 1920 x 1080) RGB video camera. It uses the same open source Intel RealSense SDK 2.0 as the other RealSense devices. L515 is priced at \$349.

like robotics, drones, 3D scanning and more. Our RealSense LiDAR Camera L515 is a great addition to our broad portfolio of computer-vision hardware, as lidar rounds out the portfolio of vision technologies, and it offers our customers a full set of solutions depending on their application.

BY DR. A. STEWART WALKER

LM: Intel is a huge, well-structured company. Where does lidar fit into this overall structure? Is Intel RealSense a brand name, a subsidiary, a division or a business unit?

SBM: Intel RealSense is a business unit within EGI. Intel RealSense produces stereo, coded light and lidar depth cameras along with an SDK and software libraries to tie it all together. Each of these cameras comprises a number of advances in computer-vision algorithms, custom ASICs and hardware design.

LM: Please tell us about yourself and your history, before and since Intel. SBM: As well as the role of corporate vice president and general manager of EGI, I also serve as senior vice president of Sensor Technologies at Mobileye®, an Intel company. Intel's official description is: "Sagi demonstrated his strong entrepreneurial capabilities when he founded his first company at the age of sixteen. He later went on to establish seven more companies. Sagi successfully sold most of his ventures, with four of them going to Fortune 500 companies. Sagi initially joined Intel part-time in 2004, as a member of the design team for the first mobile version of the Intel Core[™] 2 processor. In 2009, Sagi left Intel to establish InVision Biometrics Ltd., a startup dedicated to innovative 3D technology. He rejoined Intel in 2012 with Intel's acquisition of InVision, where he served as CEO, and became general manager of the RealSense[™] group. Sagi served as a staff sergeant in Mamram, the Israel Defense Forces' central computing systems unit. He holds bachelor's and master's degrees in computer science, both earned at the Technion—Israel Institute of Technology. He is a Stanford Graduate School of Business alumnus



Sagi Ben Moshe, corporate vice president and general manager of Intel's Emerging Growth and Incubation Group

and has been granted multiple patents for his inventions."

LM: What is the market for the L515? It's about the size of a tennis ball and weighs 100 g. Is it for indoors only? The target markets include logistics, robotics, and 3D scanning, but are there others that seem to you to be particularly exciting? What do you think about the price point of \$349? Related to the question of markets for the L515, could you please explain your sales strategy, i.e. do you mix direct sales with OEMs, resellers etc.? SBM: I'll answer the multiple parts of the question with the following bullets:

- The first product in the new LiDAR Depth family, L515 is for indoor applications. It features unparalleled depth resolution and accuracy that make it perfect for use cases such as health and retail, logistics, robotics and measurement. This new addition to the Intel RealSense family works seamlessly with the same Intel RealSense SDK 2.0 as other RealSense devices, allowing users to develop once and deploy on any current or future Intel RealSense depth device.
- L515 produces a very accurate and high-resolution depth map and

there are many market segments that can take advantage of such information. Robot navigation, object detection/recognition, logistics, and object scanning are a few. We are seeing immediate, strong interest, in particular from automated pick and place robots using the camera for object detection and logistics companies using the camera for package dimensioning and inventory counting.

- L515 is the first product in our new LiDAR family of depth cameras. We are working on enhancements for the next generation to expand the family to enable outdoor uses cases.
- Intel RealSense cameras, including the L515, are available to purchase directly from our website (store. intelrealsense.com). This is the easiest way for customers to buy a camera for evaluation. At intelrealsense.com, you can find white papers, code examples, and video tutorials. Customers can also purchase L515 through any distributor that has a relationship with Intel—that's a large number of distributors worldwide. It won't be long before OEMs are selling products with the L515 built in.

LM: You've mentioned the software that will help developers work with the L515—the Intel RealSense SDK 2.0, which is open source. Would you like to comment further? SBM: Intel RealSense SDK 2.0 is a mature, open source SDK that customers have

been using with the Intel RealSense D400 stereo camera product line. The SDK also supports L515 at launch, which means that users have access to a full-featured SDK from the beginning and

any development work done previously with D400 cameras can easily be ported to the L515. The SDK is designed with preset configurations and simple APIs so developers can get started quickly. It provides programmability of the camera for customers who need a high degree of control for their particular application. There are several SDK wrappers available for developers used to working in a certain environment, such as Unity, Matlab, and ROS. An open source viewer tool is also available, allowing anyone to get started with the camera immediately even if they have no software background. L515 has a USB 3 type C connection and supports Windows, Linux and Android operating systems.

LM: The accuracy of the L515 is rangerelated, but is of the order of 1 cm, which is impressive. The L515 has a range of 9 meters, which is interesting, but is probably too little for many automotive applications and certainly too little for



UAV applications: UAV-borne lidar sensors typically have ranges between 100 and 200 m. Do you foresee the range being increased as time passes? SBM: I think the following covers your questions:

- The L515 is not targeted for automotive applications or UAVs. The underlying technology is capable of longer ranges and working outdoors, beyond what is supported on this first lidar product. The goal was to build a highly accurate and high-resolution depth camera that was small, lightweight, and power-efficient, making lidar technology practical for markets beyond automotive and bringing the advantage of lidar to industries where it was not considered in the past.
- L515 enables exciting new applications with its internal vision processor, motion blur artifact reduction and short photon-todepth latency. It features an onboard vision processor, which enables a processing rate of 23 million depth points per second, without requiring host depth-processing. This makes it perfect for "compute lite" edge devices. Motion blur artifact reduction is achieved by an exposure time of less than 100 nanoseconds, enabling use cases such as gesture recognition and hand tracking. Additionally, the 4-millisecond photon-to-depth latency allows real time applications such as autonomous indoor navigation.

LM: Your website information on L515 includes the language, "The L515 is a revolutionary solid-state lidar depth camera which uses a proprietary MEMS

mirror-scanning technology, enabling better laser power efficiency compared to other time-of-flight technologies. With less than 3.5W power consumption for depth streaming, the L515 is the world's most power-efficient high-resolution lidar camera." How does this differ from the technology used by automotive lidar suppliers on which LIDAR Magazine has reported, i.e. what is special about the technologies Intel uses in its lidar sensors? SBM: L515 is capable of creating a very dense and accurate depth point cloud compared to other lidar solutions focused on the automotive market. It is a very light device with a very small form factor. L515 can scan a person accurately enough for fitness assessments or custom tailoring. The technology that Intel has developed produces a very dense depth map using comparatively low power. Our technology utilizes a MEMS mirror for scanning and a very low input referred noise (IRN) receiver, enabling it to work in a very low SNR, which in turn allows the L515 to be a power-efficient, high-accuracy lidar system at a very high resolution of up to 23 million depth points per second. We believe that this is very disruptive technology that will enable many new markets.

LM: The L515 includes a camera and an IMU. It does not include a GNSS receiver, presumably because it is designed for indoor use. Is there an intention, therefore, to link the position and pose of each L515 data capture with algorithms such as SLAM, so that all the data can be merged into one dataset, for example for the inside of a building? SBM: We see the IMU used by customers in many ways like scanning applications and SLAM. Having the IMU data makes "localization"



much easier for SLAM, autonomous navigation for robotics, AR/VR applications and many other navigation use cases. Also, knowing how the camera moved as frames were captured allows software to orient and stitch the frames together more efficiently. Scanning applications may include scanning the inside of a building for a virtual tour or scanning an historical object for digital preservation.

LM: In addition to the L515, Intel RealSense offers a series of cameras that measure depth stereoscopically, the D400 series (and the earlier D300 series), all with prices below \$250. These are offered with AI, including the Intel Neural Compute Stick 2. There is also the T265 Tracking Camera. Although these are not lidar products, they are complementary, and LIDAR Magazine is interested. Could you say a little about this product line, please? **SBM:** RealSense products are not tied to any single technology-we focus on how to help our customers solve their problems, so they can bring value to their customers. We think that each depth camera technology has a lot of benefits and it really depends on the application's use case. We deliver the best solutions suited to meet a range of use cases. The D400 family provides quality depth at incredible value, and works both indoors and outdoors. The four camera options for various use cases can be used in the

same field of view without interference. The stereo line complements the lidar line, offering a choice for our customers. (You can find all our offerings at www. intelrealsense.com.)

LM: You've worked for Mobileye, an Israeli company that was founded in 1999 and acquired by Intel in 2017. Mobileye is a tier 2 automotive supplier, very active in the advanced driver-assistance systems (ADAS) space. Almost everyone agrees that lidar is an essential component of ADAS and AV systems, so I guess Mobileye has been working on lidar for a while. Could you please say more about this? I've read up a little on Mobileye and it seems to do some ADAS systems with imagery only, as well as others using lidar, radar and other sensors, so the two can be complementary. Please tell us about Mobileye and whether there is any relationship to the RealSense business area. SBM: Mobileye is the global leader in the development of vision technology for ADAS. Mobileye's system-on-chip (SoC)-the EyeQ[®] family¹-provides the processing power to support a comprehensive suite of ADAS functions based on a single camera sensor. We have significant experience within EGI of various sensing technologies including lidar and radar. We are always exploring new opportunities, including

1 https://www.mobileye.com/ourtechnology/evolution-eyeq-chip/ automotive sensing technologies, which have a lot of technical challenges to be solved and several interesting use cases.

LM: By exploring RealSense and Mobileye today, we hope that we have gained some insight into Intel's lidar activities. It's a huge company, however, so are there any other lidar activities that we've missed? **SBM:** Intel is committed to the development of industry-leading lidar and 3D computer-vision technology. The first applications of lidar technology have been developed within the RealSense team, but the R&D can be applied to applications across Intel as we move into new market segments and uses cases.

LM: Sagi, thank you very much indeed for answering all these questions from *LIDAR Magazine.* Is there any chance of a brief tour of the lidar part of your factory at some time in the future, or are the lidar sensors not made in Santa Clara? **SBM:** Our lidar sensors and cameras are not built in Santa Clara and, given the current covid-19 pandemic, we are limiting access to all Intel facilities for safety purposes. However, once things are safer, we will be happy to show you more details on the assembly process in person.

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.

INTEGRATORPROFILE

LiDAR USA



COMPANY

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.



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

LIDARUSA

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

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



One System. Dual Use. Yes, You Can Do <u>Both!</u>

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







IDAR US

INTEGRATORPROFILE

Geodetics

COMPANY PROFILE

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



Founded 1999 25–50 Employees San Diego, California

geodetics.com

APPLICATIONS:

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

State-of-the-Art Lidar and Photogrammetry Solutions

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

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

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



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

Geo-MMS Family of LiDAR & Photogrammetry Products

Offering the Best Price/Performance Value in the Market



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GEOCUE GROUP



COMPANY

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® lidar/ Imagery fusion sensors.



Founded 2003 11-50 Employees Huntsville, Alabama

geocue.com



APPLICATIONS:

MAPPING PROCESSING SURVEYING UNMANNED AERIAL CONSULTING

True View[®] 615/620

The True View® 615/620 is a compact, survey grade lidar/camera fusion platform designed from the ground up to generate high accuracy 3D colorized lidar point clouds using the new RIEGL miniVUX-2UAV. Featuring dual GeoCue Mapping Cameras, a RIEGL miniVUX-2UAV laser scanner and Applanix Position and Orientation System (POS), the result is a true 3D high accuracy imaging sensor (3DIS).

With its wide 120° fused field of view, the True View 615/620 provides high accuracy 3D color mapping with excellent vegetation penetration and wire detection in a payload package of 3-3.5 kg. Our own True View EVO software is included for point cloud generation, colorization and a myriad of post-processing data creation and analysis tools.

The True View 615 can be upgraded to the True View 620 configuration via the addition of the external IMU and an internal interface board.

True View UAS LIDAR/Imagery Sensor Fusion







True View 615/620

Get A Complete 3D Imaging System



GeoCue's True View sensors are the industry's first integrated LIDAR/camera 3D Imaging System (3DIS) designed from the ground up to generate high accuracy 3D colorized LIDAR point clouds. The True View 410 (general use) and 615/620 (survey grade) provide high efficiency 3D color mapping with vegetation penetration.



INTEGRATORPROFILE

Yellowscan

COMPANY PROFILE

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



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.

- APPLICATIONS:
- AIRBORNE CONSTRUCTION MAPPING MOBILE
- SURVEYING
- SURVETING
- INSPECTION
- TRANSPORT
- UNMANNED



Fly when you can, Drive when you must.

The YellowScan Fly & Drive is a versatile land vehicle-mounted or UAV-mounted mobile mapping system which combines high resolution laser scanning and precise positioning to collect georeferenced point clouds for a wide range of applications.



Car LiDAR Acquisition The Fly & Drive car pod can be mounted to any vehicle



Easy swap The swap between car and UAV takes less than 5 minutes



UAV LiDAR Acquisition The bracket allows smooth and quick mounting on DJI M600

HARDWARE PROFILE

RPMC Lasers

APPLICATIONS

AIRBORNE LIDAR TOPOGRAPHIC LIDAR BATHYMETRIC LIDAR TERRESTRIAL LIDAR 3D SCANNING DOPPLER LIDAR ATMOSPHERIC LIDAR

COMPANY

RPMC Lasers, the leading OEM laser distributor in North America, has nearly 25 years of experience supplying integrators in the LiDAR industry with:

- Solid State Lasers
- Fiber Lasers & Amplifiers
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RPMC Lasers, Inc. Founded 1996 636.272.7227

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Our LIDAR Expertise

- 20+ Years in the Industry
- Time-Tested & Reliable Solutions
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Bright Solutions Srl develops and manufactures state-of-the-art ns, sub-ns, rugged, DPSS laser systems, with 1,000s of units fielded.

- 23 Years in the Industry
- Rugged, Compact, Reliable, and Flexible Laser Solutions
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Bktel offers a wide range of Telcordia grade fiber lasers and amplifiers as the leading fiber manufacturer for LiDAR with 10,000s of units in the field.

- 24 Years in the Industry
- Low Cost, Ultra-Compact and Rugged Fiber Lasers and Amplifiers
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- Eye-Safe Wavelengths
- Proven Track Record

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Bktel has a proven track record as a leading fiber laser and amplifier manufacturer for LIDAR, with a host of Telcordia grade, low SWaP, maintenance-free, and reliable lasers.

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HARDWARE PROFILE

SCHOTT



APPLICATIONS

- NARROW BANDPASS FILTERS
- LIDAR MIRROR
- **BEAM SPLITTERS**
- MEMS-BASED SCANNING
- MULTISPHERICAL ASSEMBLIES
- MICROFLUIDICS

COMPANY PROFILE

SCHOTT is an international technology group with 130 years of experience in the areas of specialty glasses and materials. With our high-quality products, advanced technologies and intelligent solutions, we contribute to our customers' success and make SCHOTT part of everyone's life.

More than 20 years ago, SCHOTT set up the first microfloat production line for manufacturing what soon became one of the most influential specialty glass materials.

The long-standing international success of BOROFLOAT® drives us to continuously improve. We work closely with our customers to offer exceptional solutions that help unlock new markets and meet even the most technologically demanding material requirements.

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BOROFLOAT[®] 33 Precision in Motion

In the optical path for a LiDAR system, precision is a must. SCHOTT BOROFLOAT® 33 provides high transparency in the near infrared and ultraviolet range. The specialty glass is engineered to handle harsh road conditions, with mechanical qualities that help it resist cracks and scratches from stones.

BOROFLOAT® 33 is a floated borosilicate glass—the world's first—which stands out with its flat, mirror-like surface. The sum of its properties is what makes BOROFLOAT® truly unique:

• Outstanding thermal resistance

A particularly low coefficient of thermal expansion makes BOROFLOAT® remarkably resistant to high temperatures levels—and the ideal substrate for narrow bandpass filters.

 Exceptionally high transparency BOROFLOAT[®] offers exceptional high transparency in the near IR and UV range, making it a perfect solution for high precision components.

- High chemical durability
 Neither acids nor alkalis or other types
 of fluids can impair the performance of
 BOROFLOAT® glass.
- Excellent mechanical strength
 A study conducted by the renowned
 Fraunhofer Institute has proven that
 BOROFLOAT® has higher mechanical
 strength than other types of specialty
 glass—and is even lighter.*

SCHOTT consults with customers to develop inspiring solutions to tomorrow's challenges within the realm of LiDAR technology and beyond. See precisely how SCHOTT fits into your vision at **us.schott.com/lidar**.

*2007 Study. Fraunhofer Institute for Applied Optics and Precision Engineering: "Study and Analysis of the Scratch and Abrasion Resistance of Optical Glass Types".

SCHOTT BOROFLOAT[®] 33

Precision in motion

In the optical path for a LiDAR system, precision is a must. SCHOTT BOROFLOAT[®] 33 provides high transparency in the near infrared and ultraviolet range for LiDAR systems. The specialty glass is also engineered to handle harsh road conditions, with mechanical qualities that help it resist cracks and scratches from stones. See precisely why the sum of its properties makes it unique. Visit our website to learn more.

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SERVICE PROVIDER PROFIL

GPI Geospatial, Inc. (GPI)

APPLICATIONS

COMPANY	

GPI Geospatial, Inc. (GPI) has been a premier provider of geospatial solutions for 47 years. We are a trusted professional consultant delivering precision mapping, imagery, lidar, and surveying services within the transportation, energy, planning, design, construction, and government communities. GPI is committed to creating a tailored approach using state-of-the-art sensors and software to deliver accurate and complete information for design and planning purposes. We own and operate multiple aircraft and vehicles equipped with imagery and lidar sensors, including two RIEGL VQ-1560 II aerial lidar sensors. GPI strives to provide customized solutions for our clients from aerial, mobile, and terrestrial platforms.



Paul Badr, CP, PLS, PPS, SP, President 3051 E. Livingston St., Suite 300, Orlando, FL 32803 P. 704-251-8402 pbadr@gpinet.com

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MAPPING	
SURVEYING	
IMAGERY	
LIDAR	
GIS	
SCANNING	
3DEP	
MODELING	

Exceptional Geospatial Solutions

An established user of *RIEGL* airborne, mobile, and terrestrial sensors and systems, GPI has added the VQ-1560 II to our toolbox of advanced digital sensors to further expand our capabilities. As a highly progressive company that uses proven technologies to satisfy clients' needs, this cutting edge *RIEGL* airborne sensor will further allow us to provide advanced mapping solutions to meet and exceed our client's expectations.

The *RIEGL* VQ-1560 II is an ultra-high performance, dual channel waveform processing airborne lidar mapping system that is well-prepared to fulfill the challenging demands of complex airborne mapping missions. The fully integrated and calibrated system is equipped with a high performance IMU/GNSS system and a primary Phase One 150-megapixel RGB camera. Based on *RIEGL's* sophisticated Waveform-lidar technology, the system is capable of online waveform processing, as well as full and smart waveform recording, thus delivering highly information-rich scan data for post-processing.

GPI provides precise, accurate mapping products and solutions to our clients in applications, such as statewide and high altitude mapping, power transmission modeling, vegetation management, shoreline and environmental studies, transportation surveys, agriculture, forestry, and private development. We provide cutting edge remote sensing services utilizing our advanced *RIEGL* lidar sensors. The VQ-1560 II will enable us to fly at higher altitudes and deliver increased point cloud density.

GPI is also upgrading our existing 1560i to a 1560 II, resulting in our firm owning and operating two state-of-the-art 1560 II sensors. Our collection of advanced lidar and imagery sensors continues to expand, allowing us to provide exceptional geospatial solutions.

GPI

LiDAR | Photogrammetry | Asset Management

SENSOR ACQUISITION

RIEGL VQ-1560ii

- > Two waveform processing LiDAR channels
- > Up to 2.66 million pulses per second on the ground
- > High laser pulse repetition rate up to 4 MHz
- > Ultra-wide area / high altitude mapping
- > Mapping of complex urban environments

An established user of RIEGL airborne, mobile, and terrestrial sensors and systems, GPI has added the VQ-1560ii to our equipment toolbox. GPI will be upgrading our existing 1560i to a 1560ii, resulting in GPI owning and operating two state-of-the-art 1560ii sensors. Our collection of advanced LiDAR and imagery sensors continues to expand, allowing us to provide exceptional geospatial solutions.



www.gpinet.com/geospatial

RIEGL



OUTSTANDING ENTERPRISE ACHIEVEMENT

Dewberry

Dewberry is a leading, market-facing firm with a proven history of providing professional services to a wide variety of public- and private-sector clients. Recognized for combining unsurpassed commitment to client service with deep subject matter expertise, Dewberry is dedicated to solving clients' most complex challenges and transforming their communities. Established in 1956, Dewberry is headquartered in Fairfax, Virginia, and has more than 50 locations and 2,000+ professionals nationwide.

With comprehensive geospatial products and services, we help clients deliver mission success. We're a privately held, family-owned, full-service engineering firm committed to helping federal, state and local, and commercial clients serve communities nationwide. Our consulting team includes many of the most recognized and respected industry experts and thought leaders. We create, analyze, and build tools to share geospatial data, as well as help clients integrate these tools into their daily lives. We fuse multiple data sets together and provide clients with easy-to-use tools that simplify the use of information to allow for more effective and efficient decision making.

Our firm wrote the book on lidar—The *DEM Users Manual* 3rd Edition—which includes lidar standards, guidelines, and specifications for the 3D Elevation Program (3DEP). We developed lidar quality levels, widely used today, and authored the National Enhanced Elevation Assessment, which provides the blueprint for the 3DEP based on QL2 lidar or better for all states except Alaska. For Alaska, we were selected by USGS to acquire, process, and quality control airborne IFSAR data to meet QL5 specifications. Additionally, we authored the Florida Statewide Lidar Assessment that established higher-resolution QL1 topographic lidar and QL0B bathymetric lidar as the state's standards. Currently, we are acquiring and producing statewide QL1 lidar for Florida, except for Leon County, where we acquired QL0 lidar with RMSEz of 5-cm. We also specialize in topobathymetric lidar and the merger of topographic and bathymetric datasets as we did for USGS and NOAA in Puerto Rico and the California coastline.

Our national team of experts provide a variety of expertise across numerous services, including remote sensing data acquisition and processing, data analytics, digital orthophotography, emergency response, geospatial benefit-cost analysis, geographic information systems, hydrographic mapping, independent QA/QC, photogrammetric mapping, raster and vector products, survey and control, technology evaluations, and topographic mapping. We employ the latest GIS software and database platforms, including the full suite of Esri products and various open-source platforms. Our products and services include application, web, and cloud-based development; system integration; database design mapping; data fusion; and mobile solutions. Not owning or operating our own aerial sensors allows us to objectively review project specifications and outline sensor types that best fit specific project needs. Our flexibility with acquisition enables us to add subcontractors at the request of our clients or work jointly with other contractors responsible for data acquisition. Additionally, we can augment clients' staff by performing independent QA/QC of data provided by other contractors. We are dedicated to our clients and believe that flexibility and responsiveness leads to optimal solutions to their toughest challenges.





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SERVICE PROVIDER PROFILE

Woolpert

APPLICATIONS

UAS

PHOTOGRAMMETRY ORTHOIMAGERY BATHYMETRY HYDROGRAPHY ACOUSTIC SURVEY CLOUD

COMPANY

ASPRS PRESIDENT JEFF LOVIN

Woolpert Senior Vice President and Market Director Jeff Lovin, CP, PS, was named president of ASPRS this year. Lovin has been with Woolpert for 33 years and has had the privilege of leading and serving multiple industry organizations.

"ASPRS is the original geospatial organization. Founded in 1934, it is responsible for our national standards and our credentials," Lovin said. "I've been very fortunate in my career to be a part of several organizations, but being elected as president of ASPRS ranks near the top for me. There is so much history with ASPRS, and if I look at the list of past presidents, it is quite humbling and an honor to join that list. It is a highlight of my professional career."



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Leading Lidar Data, Solutions Provider

We were there at the beginning and we'll be there till the end. Woolpert celebrated 50 years of geospatial excellence in 2019 by acquiring international geospatial firms, adding global geospatial experts and augmenting its strategic geospatial service offerings. These include aerial lidar, terrestrial lidar, bathymetry, hydrography, traditional land-based survey, acoustic survey, aeronautical survey, photogrammetry, remote sensing, sonar, data processing, GIS, UAS, subsurface utility engineering, floodplain mapping, coastal resilience, etc.

We also know all the right people. Woolpert is an Esri Silver Partner with Release Ready and ArcGIS Online specialty designations. As a Premier Google Partner, we were named Google Maps Partner of the Year in 2018 and formed our Google Cloud division in 2019. We also launched STREAM:RASTER[™], a subscription software service to host and facilitate access to vast volumes of geospatial imagery in the cloud. Through these partnerships, we're able to bridge the high-level geographic science and software development of Esri with the ubiquitous client-facing expertise of Google.

And, oh yeah, we're also a full-service, 109-year-old architecture and engineering firm. How does that help our geospatial services? It provides a comprehensive, intimate understanding of those fundamental business needs and ensures we maintain successful, multifaceted relationships with local, state, federal, private and public customers around the world.

COLLECTING DATA AT THE SPEED OF LIGHT

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Intelligence at the Speed of Light

Silicon Valley lidar start-up enjoys automotive investment





IDAR Magazine last visited Cepton Technologies in San José at the end of 2017, just as the firm was preparing to move into its new facility¹. The build-out, designed by CEO Dr. Jun Pei, was under construction. The company's Sora[™] sensor had attracted interest in the UAV-lidar

 Walker, A.S., 2018. Cepton Technologies: the Silicon Valley approach to lidar sensor development, *LIDAR Magazine*, 8(2): 34-44, March/April. market. Dr. Pei recommended we talk to his customer May Mobility, which was making autonomous vehicles for use in limited, geofenced areas, so we visited its headquarters in Ann Arbor, Michigan, and its operations center in Detroit². Cepton has become a familiar presence at geospatial trade shows

2 Walker, A.S., 2018. Autonomous vehicles operational thanks to lidar, *LIDAR Magazine*, 8(5): 20-26, September/ October.

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and the products have been used by several UAV-lidar integrators. We asked if we could re-visit for an update. Managing editor Stewart Walker and publisher Allen Cheves were welcomed by marketing & communications manager Faithy Li, CEO Dr. Jun Pei (Jun) and EVP of Marketing Dr. T.R. Ramachandran (TR). Unable to cast aside our fascination with Silicon Valley's secrets, we tried to focus on the firm and the people rather than the technology. Here is what we learned.

We toured the new building. There were cubes full of parts, systems and

BY DR. A. STEWART WALKER



Dr. Jun Pei, co-founder and CEO, in the machine shop

instruments. We saw an area for calibration and Jun emphasized that Cepton does outdoor testing in bright sunlight, which can be tough for lidar. We returned inside, to an open area for production and testing. There was a mechanical lab, with a sensor under development, then an electrical lab, also for testing. But Jun showed his real joythe machine shop. All the equipment and cabinets used to be in his garage in Saratoga, except for some new machines. We saw test vehicles, then a production area, on a small scale, with people using their hands, on different stations for different parts of assembly. Behind this was optical alignment. And a ping pong table! On the way back to the conference room, there was a sensor mounted on a wall, with results on a monitor, where we could see people moving. Jun added that the takeaway was not so much the lidar image itself but the box around it and the tail behind each person, i.e. the tracking mechanism. The software could find people and track them anonymously. The user could define a zone and



Bob Brown, CFO

count people moving in and out, in a software-based solution: it was possible to measure the height of people, count how long they looked in the nearby display cabinet at the product, i.e. a lot more than just a dumb sensor.

We met Bob Brown, CFO, who joined Cepton in May 2019 from Velodyne LiDAR, where he had also been CFO. He's a University of Michigan man, which gave me a segue to refer to May Mobility. "We had May Mobility in our booth at CES," said Bob. "They got a good investment from Toyota recently³. They're one of the few companies actually to make revenue from this. But it's early days."

Before we continued to the main part of the interview, Jun quipped about Bob's high stature as a CFO, "Bob worked after grad school with a semiconductor company. When we were both in semiconductors I could not even make an appointment with him, yet now we are together working on something great." Jun continued, "Bob is a tremendous asset to the company. I don't know what we did right to get his interest -we were introduced through an investor friend, had a coffee, found common goal in life and agreed to do something together."

LM: Thank you for inviting us back. What's going on?

Jun: Good to see you guys. We are eager to provide updates, but I have become more nervous talking to the media. When we last met, Cepton had about 20 people, now we are approaching 100. We just got an investment from Koito Manufacturing Co., Ltd.⁴ When we started, much investment came from me and my family. You don't want to talk about family money, so for years I did not want to talk about how much we had raised-unlike other lidar companies! This time, we are doing so because Koito is a Japanese automotive tier 1 and world-leading provider of automotive lighting systems. It's a multi-billion dollar public company that supplies the majority of Japanese vehicle headlamps

³ https://www.autonews.com/mobilityreport/toyota-leads-50-million-fundinground-may-mobility

⁴ https://www.businesswire.com/news/ home/20200205005678/en/Cepton-Expands-50-Million-Investment-Koito.

and a dominant percentage of Japan's street lamps. So Koito had to disclose its investment in Cepton under the rules of the Japanese stock exchange. Then people would find out, so we issued a press release! Now, suddenly, I get pings from all over the world, all sectors, the technical end, the financial people, the marketing people, the media, everyone's trying to get an understanding. It's fascinating what one press release can do!

LM: You've said your total financing up to now is ~\$100 m—that's a lot of money. Jun: It is a lot of money and we've been shy to talk about it. The amount of warchest ammunition doesn't necessarily guarantee that you win the battle or the war, but it's a good thing. I'm an engineer by trade and I'm always shy of media attention. I remember my piano-playing picture in the last article and it was nice to get a chance to get a good review.

The biggest change, other than the build-up of the place and the expansion of the business, has been the congregation of great people. The landscape is changing in the lidar industry. I'm always grateful that I've lived in Silicon Valley, I came to Stanford in 1992 and never left. I just cannot decide to go anywhere else; this is the place for me-weather, career, marriage, everything is here, this is home. A great number of people with talent, with integrity, with a desire to do something great, they're all here. TR: Other cities in the world have tried to re-create Silicon Valley but haven't been successful. The blend of cultures, immigrants, universities, as well as of

LM: When we were here at the end of 2017, it was all about technology and

course the weather, is a nice mix that's

conducive.



Dr. T.R. Ramachandran, EVP of Marketing, photographed while bird-watching in Colombia

the focus was on product development, direct sales, just getting the product out the door, but now you're in a different world. You're in the solutions world and you've got partners. What's changed? Jun: I showed you the demo. Cepton is slowly growing from being just a simple sensor company to being more and more a solution company. It's no longer just having the raw point cloud. If I'm sitting beside you giving you driving directions, I can't just give you XYZ coordinates-that's a dot! I need to tell you that in front of you there's a tree, so make a left. Turning raw data into an abstract concept that everyone knows, e.g. a person crossing the perimeter, let's count him as one person, or a person over three feet tall crossing a perimeter, i.e. not a child, things of that nature are starting to materialize with our sensor and software solution. The company grew over the past couple of years and at the last CES we won two awards for the solution rather than just a simple sensor⁵.

The software solution brings more meaning to the applications of lidar. A supermarket wouldn't buy lidar but would buy a solution that counts the people coming through the door. Yes, we're building a product or a product series, but really we're building the company and the company is a lot more than just a product—it has the business engagement, facilities, fund-raising, money, but the most important of all is the building up of the people and that's where we shine amongst all the lidar companies. In the past three or four years, I would say, this has become a magnet of great people.

LM: You have a great management team, almost all with PhDs from Stanford. Jun: There's also an MIT camp and USC! This used to be an open space, then we built a big white wall to make a conference room, and we couldn't figure out what to put on it. So we decided on photos of people's schools, Stanford, MIT, then two Chinese universities-one is Tsinghua, one is Peking [both in Beijing]. We have five people from Tsinghua and two from Peking. The second to last in Princeton, where Mark [McCord, CTO] comes from. And I had the privilege of putting one more for myself, the very last one, that's Brandeis [where Jun did his undergrad]. As people such as TR and Bob join, we run out of space, but let's leave it the way it is. It's an incredible grouping of talents and just great people.

LM: I see your product family and trophies on the other side of the room! What is responsible, what do you think drives that?

Jun: On the top level, I really don't know. Then I do know. To me there's a more personal level. There's the natural grouping of people. I have my own close friends

⁵ https://www.businesswire.com/news/ home/20200106005357/en/Cepton-Showcase-Award-Winning-Lidar-Solutions-Multimarket-Collaborations

and, when we meet up, their personalities involve similar interests and similar passion for things. There's a natural grouping of people who just like to come and work together or be together. It could be on a personal or a professional level, but there is always a mix between the two, there is a natural attraction of this place. Cepton is pretty well known in the Valley, so toptalented lidar people, whether in business or in electronics, optics, finance, they just like to be part of this, and as people group together, we work and accomplish a little bit and that attracts more people. There's a positive cycle. Last time we met it was just Mark and I, but now I don't call the shots anymore-I'm just a facilitator for the company. Bob calls the shots in finance, TR in business and marketing, and Mark at the technical end. The bottom line is that I'm very slowly losing my job right now, but I'm not complaining!

LM: I was interested also in your own personality. You are the CEO and you have to be a technical expert—that's why you founded the company in the first place. You have to be good at giving pitches to customers, distributors, partners, venture capitalists, investors,



Co-founder and CTO Dr. Mark McCord presents Cepton's unique approach to lidar at technology conferences worldwide.





yet you have to be good at attracting a top team. But as you say, it also happened because you were friends. Jun: I think that, as a start-up company, when you grow from a few people, to a hundred people, it is really difficult to hire or work with someone who cannot be your friend, that's just not possible. In a 2000-person company, you just have to be colleagues, you don't have to be friends, that' s fine, but in a small company there has to be personality match first. Just this morning, a board member sent me a resumé, a young software engineer. I have to take this seriously, so the first thing I do is I send the kid an e-mail saying why don't we meet for coffee on Saturday afternoon, couple of hours, let's just feel each other out. I don't want to invest in a full interview process yet, but I want to feel whether he belongs in this group, do I see him working in this growth. So even for the lowest software job, it starts from me and I look for a personality match. I'm very technical, but I don't talk about technical things, I feel the pulses, I feel the temperature and assess whether the person would be a good fit to work in this group. A bunch of us want to jump on a bus and go somewhere, so we have to figure out whether we want this guy to get on the bus. Then we figure out where to go and how to get there. There's a huge emphasis from me, a self-imposed emphasis, to hire people right. An effect is that we have very few people leaving here. The attrition rate has been extraordinarily low.

LM: In recent weeks or months, the CEOs of Velodyne LiDAR, Trimble and Quanergy have left their positions, to be moved upstairs to chairman, or to an evangelical role. Can you comment on that? Will it happen in Cepton? Jun: What do you think?! I think there are different personalities of CEOs, so inevitably there's different personalities of company. The culture is very much set by the CEO. We don't want to say anything about our competitors that we're not supposed to know. I know Dave Hall very well. I know Louay [Eldada, former CEO of Quanergy Systems] reasonably well, we've met at conferences and shared insights into the industry. But it is public knowledge that the Bloomberg article exposed

Quanergy's issues in both technical path and management style. Start-ups are tricky-you always have to balance the project you want to do, the people you have to manage and the amount of money you have in the bank. It's hugely important to know how much ammunition you have left and whether you want to fight the next battle or whether you will die from hunger. So, these are tricky maneuvers, sometimes you have to adopt different strategies, you have to be nimble. You have to get to the next place. You have to change your generals to get there. Whether it is for financial, technical or morale reasons, there can be hundreds of factors that cause you to make a big change. I don't think we should publicly comment on these changes. They won't happen here-yet! The reason is that things here are going very well. We have delivered every product that we have promised. We have attracted the interest of Koito. They have vetted almost every lidar company and they chose us as their partner and invested hefty money into us to go on. So, from the product end, the technology end, the money and the partners, we are doing extremely well. We're probably one of the most well-positioned lidar companies right now. There are probably 50 or 60 out there and the vast majority are likely to struggle this year and by the end of next year I'm sure half of them won't actually exist. But we're in a very comfortable position and we're going to do betterwe have projects coming up that will make an even bigger impact than the people-tracking solution you saw in the hallway. So we're doing extremely well at a time when other companies are not doing so well or are struggling, so it's unlikely I'll be replaced.

That said, one of the goals as a business owner is to get yourself out of a job. For example, if you run an ice-cream shop, you don't go there every hour of the day. As a business owner, you want to make a self-sustaining, self-lubricating organization. As an engineer, I draw a parallel with making automated machine systems -you don't want to always have a screwdriver or a wrench in your hands, you want to press one button and take a nap. But with an organization it's a much taller order to accomplish that. I'm very much looking forward to the day when I can retire from my position, when it will just go by itself. I'll probably still go back to the lab or the machine shop... and continue with my hobby.

LM: The original benches!

Jun: Yes, I handmade them myself—also the drawers, where I made the runners able to carry a lot of weight. I don't have any of that stuff at home any more. The garage can hold cars!

LM: There seems to be intense movement of staff in Silicon Valley, i.e. a great deal of staff turnover. Some of this is from one competitor to another, e.g. between yourselves, Velodyne and Quanergy. What do you think about that—is it healthy? Is it ok for IP and good for health?

Jun: The movement is only one-way, other companies' great people moving into Cepton! I am not aware of anyone quitting here and joining a competitor. I get resumés from the competitors all the time and we do our due diligence to get the greatest people. They join and they stay here! It is the natural way for people to behave—they see we are doing the right things and they want to join a winning team. This is very, very
healthy. As for IP, I think that's a level of professionalism that people generally just observe. In addition, since last time you were here, we have quite a few patents already granted and more coming. The MMT^{*} (Micro Motion Technology) is unique, we are the only one in the industry with this patent. People come here to work on it, their work will be based on it, and it has zero overlap with Quanergy, Velodyne or any other competitors. Very few people know what we're doing or how we're doing it. This is another reason Koito, number of companies with small fleets who are doing development, testing, early trials etc. But let's think ahead to what is required to get AV fleets into the thousands and tens of thousands. What is required for passenger vehicles that are currently in SAE Driving Automation Level 2 to get closer to Level 3? If I set aside the software, AI etc., which is more typically owned by the OEM or the Tier 1, the lidar technology has to mature to the point where it is highly reliable for use in hundreds of thousands of vehicles. But

66 Lidar technology has to mature to the point where it is highly reliable for use in hundreds of thousands

of vehicles. But of the dozens of lidar companies, few can realistically achieve that goal.

after evaluating all the lidar companies, decided ours was the winning technology. So there's not only people from other companies joining us but also a concentration of attention from customers who realize what we do is the winning package. It's a healthy motion and it's one-way.

TR: If you think of the lidar industry, there are lots of start-ups, it's an exciting field. The excitement got built around the AV market and obviously Velodyne has been the leader for lidar sensors in that space for some time, so, with the excitement they created, now there are lots of companies in that field, trying to compete, trying to get some market share from them and some others. In the AV space you have a

of the dozens of lidar companies, few can realistically achieve that goal. For a small fleet you can hand tweak, but it's very difficult to scale to 100,000. If a customer is using 50 sensors from a supplier, that sensor or architecture may not be the right one when you need to deploy 100,000. For me, having spent time in the lidar space, it was very important to really be involved and bring to market a technology I felt had a high likelihood of scaling to that capability and when I saw the Cepton technology and the underlying MMT, it gave me confidence that that was one of the few technologies likely to succeed in the long-term. What is fascinating for me is that as we've talked to customers and partners under NDA and showed

them the technology, many agree. They're not shipping 100,000 yet but they've been in the market for 20-30 years and they have their own way of doing assessments, evaluating the risks, figuring out whether this is going to scale. I feel good that this architecture is likely to be positively viewed by customers and so far it's playing out very well. That's an important factor. Bob and I obviously came over and other people have approached us and said they really want to come and work here. So the success in building products with that sort of capability will continue to draw good talent in my opinion and the Koito announcement is another testament. Koito started working with us over a year and a half ago, they evaluated quite a few of our sensors, put them through testing, integration, proof of conceptso where we are today is evidence that, for a large company, the top automotive tier 1 for lighting, for them to feel this is a scalable architecture, so we're not just doing a technical partnership, they're going to invest, that's a big deal for us.

LM: Congratulations on your recent injection of capital from Koito. Clearly, you are still running on VC. At what point does a company like yours earn enough revenue and profit to plow back and ensure growth and sustainability without further injections? Where do you think you are in that process? Jun: Before this company, I had AEP Technology, a mom-and-pop shop, which was profitable from the first quarter-rather like ice cream, if you do it right you can be profitable from the first week. As a small-business owner, I'm very interested in profit. For lidar, especially lidar applications in the automobile industry, how often

do you get a new model of car? Every four years. So people are working right now on 2023 and 2024 models. Then you draw a profit out of it, but once you do it's a very solid business, as the stickiness of a sensor in a car, especially one that's there for safety, is very strong. Our business model is slightly different, it's not immediate profitability, more of a long-term engagement. Take Koito: when they started making headlamps for cars, it would be many years before they would start being profitable, because a headlamp was a low-margin piece, so they had to sell millions before becoming profitable. But Koito has had the vision to move from headlamps to headlamps with sensors and smart headlamps, so they're taking the lead, together with us. It just takes a little bit of time and patience to get to profitability. It's a completely new sensor in the automobile industry, but we have the people, patience, technology, and financial backing from a tier 1 supplier to get there. Even a year ago I would have still been uncomfortable thinking about what the future would be, but now we're on a solid footing. In this day and age, you have to be good but you also have to have good partners.

LM: I see you have opened an office in England. Why Derby? You also have offices in Germany and Canada. Could you comment on your distribution strategy? When I was here last time everything was based on direct sales. Jun: As I said earlier, it takes time. There is a huge automotive market and we are taking care of it through partners and a distribution channel. We identified two talented people interested in lidar and willing to work for us and they live near Derby—no underlying big reasons, just mere fact and convenience. Frankfurt and Munich are near automobile centers. We have an office in Ottawa with quite a number of people. We do development there too.

LM: In addition to opening your own offices, you've also formed partnerships, for example MechaSpin and CNL. Jun: I know the owner of CNL well. TR is the person responsible for forming these alliances!

TR: I'll start with a very basic point. We're still a small company, so we can't afford to have a massive sales and direct marketing team. We want to optimize where we focus and where there are partners who can help us to go to market.

The second part is identifying the right partners. They could come in different forms. Sometimes people think of a distribution partner or reseller or VAR. I use the word "ecosystem". We want to create an ecosystem of partners across the full life-cycle of our product delivery, from architecture and design, prototyping, validation, manufacturing, to integration at end-customer level and helping customers to deliver their own solutions. For this whole chain, we are trying to build partnerships. We invited a few partners and collaborators to come to the booth at CES and give presentations. An example is Dataspeed. They do drive-by-wire kits and build small autonomous vehicle fleets for their customers. That's a good example of a partner which can build an entire system using our sensors, demonstrate it to a customer and say, "This works just great. If you need help we can help you build a few vehicles with Cepton sensors." That takes a lot of work off our plate.

Autonomous Vehicle Technology gave Dataspeed and Cepton a 2020 ACES



Cepton's state-of-the-art Vista-X120 lidar has a 120° horizontal field of view, high angular resolution of 0.15° and long range of up to 200 m at 10%

Award Winner in the Autonomy | Sensors category⁶. Dataspeed was selected by the State of Michigan to build an autonomous fleet for the North American International Auto Show⁷, using Cepton sensors. This is the kind of thing we look for-it's win-win. There are other examples. The partner benefits, because they can achieve solutions with our sensors and we benefit because our partners bring us new customers and give us visibility. It's really not just about selling, but about where could we bring in the right partner to improve our product, our own solution, so that when we jointly go to market, it's an even better solution.

LM: When I last visited, you had the Sora and had just launched the Vista[°] and the second model of Vista was imminent. What has happened since then on the product side? Now you have Vista[°]-X120 and you've also been successful with the Helius[™] software. Please comment on both the hardware and on the software.

⁶ https://www.autonomousvehicletech. com/articles/2121-dataspeed-ceptonpartnership-speeds-av-rd-andintegrations

⁷ This was canceled owing to Covid-19. It is now planned for June 2021 in Detroit.



During CES 2020, Cepton showcased its award-winning Helius Smart Lidar System to track the booth traffic in real time. The installation had a Vista lidar sensor running behind the automotive windshield, with the Helius software-processed crowd tracking data overlaid onto live video imagery.

Does your product development path reflect any changes in your assessment of the different markets?

Jun: Yes, we still have Sora and Vista. We have made significant improvements in those sensors, which have come a long way after a couple of years of maturity. May Mobility is using dozens and dozens of them for their fleet deployment. We have exposure in many areas of the world with those sensors. I see as product progress the Helius™ Smart Lidar System, which enables solution deployment rather than just a sensor, which gives the company much bigger exposure in a variety of industries. If you go out in the street and say you have a 3D sensor called lidar, not many people would know about it. If you say, we have an anonymized people-tracking system that can be used to monitor how much time people spend in front of your counter, then

that's valuable. These are the things that we're slowly but surely merging into the product development, ultimately we have the interests of running our business. We are going one step beyond all the competitors. I hope we are very slowly eating into the market and will dominate with our complete solutions. Helius can run on different hardware platforms. We also provide Helius as a complete package including computer, such as the demo you saw. It's a generic perception solution.

LM: I've noticed that Audi claims its blind spot monitoring goes back 200'. Is it lidar?

TR: It's probably radar. The range is too long for ultrasonic. My wife drives a Lexus we bought over 13 years ago. It has "proximity detection" for when you're reversing or trying to park. Ultrasonic is very good for that application, but the challenge of trying to scale is false positives, the kind of resolution you need for autonomous navigation is more difficult, what if it's beeping too much or not enough? As we go further up the [SAE] levels, companies look at lidar.

A lot of customers ask for shortrange lidars with a wide FOV, that's increasingly of interest. We could do that. For us it's more a priority decision, we don't want to spread ourselves too thin, trying to build too many things at the same time, so at the moment we're trying to focus. If you look at our markets, automotive ADAS is big: these are front-looking, long-range sensors. That's a big focus and the Koito partnership is tied to that. But we've also seen that combined with our lidar we have the Helius Smart Lidar System, which has a full perception layer. That's becoming quite popular in markets adjacent to automotive, like intelligent transportation systems (ITS). It's becoming popular in the security market, anything that requires crowd analytics, of people and objects moving around in large spaces, like airports, theaters and stations. It turns out we don't need to do any customization of our core lidar for that application, so it's much less work for us, because we're just re-using an existing product in a different market, but in those markets we offer the software layer on top, which makes it easier for customers to adopt.

LM: Do you do offshore manufacturing or do everything here in this building? TR: We do manufacturing here in this building, but we call it a pilot line. Our intention is not that 100,000 units be built here, so we've actively been working on partnerships with contract manufacturers, essentially

to qualify them to build pieces of our product, which we call modules. Our manufacturing team has been actively doing that, getting them ready for scale. The announcement with Koito is an example where now we have an automotive tier 1 that's saying, "We're going to manufacture a sensor using Cepton's technology." It's not specific to headlamps, more for an automotive application. It depends what the customer needs and where they would want the sensor located.

LM: LIDAR Magazine is in the geospatial world, which has been the beneficiary of companies like yours and your competitors. Your primary market is automotive, in the sense of both ADAS and AVs, then you have security, smart cities etc. We're a very small market for you, but it just so happens that your sensors work very well in UAVs. I know, for example, that you've worked with Jeff Fagerman at LiDAR USA in Alabama and he'll have given you a testing time! Jun: Right. We'll continue to work with geospatial solution providers. They find that our point cloud is very dense and that we have specific scanning solutions that are different from others, so would be a good fit for some applications. We'll continue to work on that, though there's no specific case study I can share. We're a lidar company after all, and if there are opportunities out there, we tend to be engaged.

TR: We've found him [Jeff] very objective. He said that he's amazed by our sensor's performance, but if we could just make some improvements, then it would be game-changing. We value the feedback. That's one thing that I like about the culture here: it's a very responsive culture. We can't fix everything, but we try to improve the product on a continuous basis. Jun: We have already identified this technology; our path is defined. Even for smart cities there is another facet for real-time monitoring, intersections, car monitoring for speed, location, risk reduction. These are not for surveygrade equipment but low-cost, highreliability lidar units. We want to focus enough so that we actually become

successful. I see some issues with some of our competitors, too defocused, you run out of money very quickly, no more bullets to fire, then trouble.

LM: The last question is more whimsical. Larry Tesler, the inventor of copy and paste software, died recently. He did much of his work for Apple. In a 2012 interview with the BBC, he spoke of the culture at Silicon Valley, "There's almost a rite of passage. After you've made some money, you don't just retire, you spend your time funding other companies. There's a very strong element of excitement, of being able to share what you've learned with the next generation." What do you think? Might *you* say that in 10 years?

Jun: Yes, of course, this is very natural. There are a lot of people of this caliber. I may not belong to that high of a level, but I belong to a category of people that consider what we do not to be a job but a hobby, which is something that you do whether you are paid or not, to stimulate your mind. I expect that I will continue my interest in optics and acoustics, in the technology overall, if I have the resources to do it. Investing and helping other companies demands a different type of skill and I don't know whether I have it. I'm just at the age of 50 and my eyes are open.

LM: Dr. Pei, Dr. Ramachandran, *LIDAR Magazine* is enormously grateful for your time and insights. Thank you very much indeed.

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.



Cepton's in-house, pilot-line manufacturing capability

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Sam Kamel, CrowdVision's President for North America

CrowdVision, continued from page 80 ride-share information services to travel-planning solutions—that can forecast wait times and estimate 'time-to-gate'. Using our data, airports are better serving travelers, improving passenger satisfaction and creating new revenue opportunities.

The company has a unique background. Our core group was founded in 1999 by ex-NASA scientists who were instrumental in the creation of today's GPS framework. As experts in outside and inside positioning technologies, they brought with them patents for motion detection and queuing solutions, which have provided for the foundation of CrowdVision's ability to track, monitor and provide analytical insights into pedestrian movements. After several years of supplying human flow solutions for the tourism and retail segments, CrowdVision entered the airport industry in 2013.

CrowdVision currently serves a number of major airports around the U.S., including Charlotte Douglas International Airport (CLT), Indianapolis International Airport (IND), McCarran International Airport in Las Vegas (LAS), Baltimore-Washington International Airport (BWI), Miami International Airport (MIA), Jackson-Medgar Wiley Evers International Airport in Mississippi and Phoenix Sky Harbor. TripIt, the

popular online trip planning and itinerary management app owned by SAP Concur, also utilizes the CrowdVision API to issue wait-time alerts, as well as real-time queuing updates at several major U.S. airports. Based on CrowdVision data, TripIt helps travelers plan their trip and select the best departure time for the airport by letting them know projected wait times at security checkpoints.

CrowdVision North America is led by its CEO, Sam Kamel. Sam has experience as an entrepreneur, Fortune 100 executive, team builder, change agent, innovator, strategist and successful dealmaker. He has been at the center of some of the most disruptive changes in technology at companies such as Netscape, E-LOAN and Microsoft. Over the course of his career, he has raised more than \$75 million in funding, overseen multiple acquisitions, and played a pivotal role in two IPO events. He has also served as a decorated officer in the U.S. Navy. He studied electrical engineering at Cornell, earned his MBA from Harvard and started his professional career at McKinsey & Company.

LM: Can you say anything about number of employees, sales, profits, etc? Does CrowdVision generate sufficient revenue from sales, or is there still venture capital involved?

SK: CrowdVision's North America team includes 30 people—a mix of cuttingedge software engineers, IoT experts, airport industry gurus, customer service maestros, data analytics scientists and overall enthusiasts for applying technology to solve real-world complex problems. The company is privately funded and does not disclose its financial information. **LM:** Does CrowdVision supply products, services or both?

SK: CrowdVision delivers customers with the right mix of hardware, professional services and software that provides motion data analytics to meet their solution requirements. CrowdVision's iQueue technology utilizes a cloud-based software-as-aservice (SaaS) model to deliver action-



M8 lidar sensor without base from Quanergy Systems—the principal measurement element of CrowdVision's product line

able insights and data to venue and facility managers. Utilizing an intuitive dashboard, these venue and facility managers can monitor, identify and mitigate crowding and congestion.

iQueue utilizes lidar sensors and 3D perception software from Quanergy, a global leader in 3D lidar flow management solutions. Lidar sensors are placed throughout venues and facilities to capture the data necessary for iQueue to assess crowding and people flow.

LM: We know that several suppliers of lidars are working on people-counting and crowd-analytics, but CrowdVision's iQueue SafeDistance product is very focused on covid-19. It's gratifying to



Estimation of social distancing in downtown environment

see high-tech companies leveraging their expertise to make the return to some semblance of normal life less risky. Could you please tell us more about this new product?

SK: We recognize that the world will be a very different place once shelter-at-home mandates are lifted and public venues re-open. We wanted to do our part to help restore the public's confidence in going to the airport, a sports arena, or any other venue. When venue and facility managers have real-time crowd density information and predictive analytics, they can take immediate action to uphold proper social spacing. We also believe that making SafeDistance metrics available to the public will restore confidence in venues where indoor social distancing parameters are being properly maintained.

Built on top of CrowdVision's iQueue technology used for monitoring and analyzing passenger flows at airport security checkpoints, iQueue SafeDistance utilizes precise 3D lidar to help airport, venue and facility managers monitor and mitigate crowding and congestion, and maintain safe distancing within their venues.

Using iQueue SafeDistance, building and facility managers can access historical heat maps that highlight zones where crowd spacing falls below configurable parameters, or track real-time spacing between passengers, customers, employees or sports fans to help manage safe social distancing.

LM: You say in your press release that iQueue SafeDistance is being tried out at several large airports. How is this going? **SK:** The solution is operating as a beta test in MIA, BWI, IND and CLT. It has become available only recently, so it's still too early to arrive at any conclusions worthy of sharing-but I can tell you the preliminary results are showing accurate data and good social distancing insights. Additionally, the airports and other venues are genuinely interested in the offering. They are concerned about operating their facilities safely when crowds return-and are giving careful consideration as to how to manage it all.

LM: iQueue SafeDistance is your latest offering, but it is by no means your only one. Could you please say more about your iQueue and iFlow product families and how they have evolved? How mature would you say they are? SK: iFlow, introduced in September 2019, is a comprehensive motion analytics platform that provides airport operators valuable insights into passenger movement for improving service levels, increasing operational efficiencies and enhancing revenue. iFlow utilizes different sensor types in addition to lidar, such as Bluetooth, WiFi, infrared and other technologies.

My colleague Steve Moody, VP of Business Development for CrowdVision, put this well. "iFlow gives airports new insights they've never had before. For instance, the airport concessions director could compare a typical Delta passenger's travel habits to that of a typical Southwest or JetBlue passenger. iFlow will also offer aggregated insights into passenger dwell times, such as how long passengers spend in ticketing versus baggage claim, or versus the gate lounge—all without compromising individual passenger identities."

Initially, iFlow provides general insights into passenger movement. As CrowdVision continues to add new data sets, such as retail spending, and applies increasingly advanced analytics, the capability of iFlow scales quickly. As iFlow evolves, airport operators will be able to explore trends such as average spending habits of passengers flying to various locations or during different days of the week. For example, iFlow could help airports understand how much time passengers flying to Las Vegas spend in retail versus those flying to Des Moines or Shanghai.

LM: Please talk about Quanergy's relationship to CrowdVision and how Quanergy technology is used in iQueue SafeDistance and other CrowdVision products. How did your relationship with Quanergy begin? Is it a two-way street, i.e. your requirements influence their product development, while their new sensors and software give you ideas for new products and product improvements?

SK: CrowdVision and Quanergy have had a strong partnership for a number of years. CrowdVision started testing Quanergy's lidar technology in 2016 for the purpose of monitoring passenger movements and wait times in airport security checkpoints. We installed our first permanent solution in 2018 at LAS. We have since installed Quanergy lidar in seven additional airports. Quanergy's 3D AI-powered perception software Qortex provides the foundation for many of our analytics and applications. Our proprietary software then modifies and enhances Qortex's data to provide airport operational insights. Our software development teams work very closely in this regard.

LM: Are your products typically purchased and operated by the facilities themselves, for example airports? Or do they use sub-contractors? I'm looking for opportunities for geospatial service companies!

SK: Yes. Typically, airports purchase our solutions, which are then most frequently used by the airport and TSA. The solution can be procured either directly by the airport or through a third party. Purchasing policies differ from airport to airport, so there's no one consistent model. We welcome the chance to work with sub-contractors, value-added resellers and/or systems integrators in order to increase the speed and scope of our go-to-market plans and more rapidly bring the value of SafeDistance to more airports and other venue operators as well.

LM: Further to the role of geospatial service companies, do your products depend for their success on high-quality building models of the facilities where they are installed? Are these models usually available or are new or better ones required?

SK: No, our solution can be deployed independently of the building model.

LM: Over recent weeks I've seen a number of products, services or R&D directed at detection of covid-19 infections. For example, I recently attended a webinar where one of the speakers was from Draganfly, a UAV supplier, talking about flying drones over people to try to detect infections using a mixture of sensors and analysis to acquire heart and respiratory rates and temperature as well as body micromotions. In a recent issue of the Photonics Media newsletter, there is an article about how Amorph Systems and VANTIQ are working with hardware and development partners, including several camera vendors such as HikVision, to develop solutions for continuous detection and monitoring of infectious disease outbreaks inside buildings and facilities, including airports. Do you think that future products from CrowdVision could incorporate optical sensors as well as lidar? **SK:** Video technology is advancing quickly and we've seen new capabilities that could potentially be brought into our product development cycle. While we are primarily focused on maximizing

the utilization of lidar technology, future products could include the use of optical sensors. The potential is there, so it's something we're considering in order to better serve our customers.

LM: When the economy does restart, what do you see in the future for CrowdVision? What are you working on for 2021 and beyond?

SK: The introduction of iQueue SafeDistance opens up a range of applications outside of airports and our ability to measure and generate key performance indicators such as passenger counts, flow rates and wait times. With SafeDistance, there is an opportunity to serve stadiums, concert venues, warehouse facilities, and many more applications-in addition to airports. When the economy restarts, we expect building and facility operators to invest in technology that keeps people safe and gives them the confidence to return to work, go on vacation, go to a concert or cheer on their favorite football or soccer team. We expect that we're solving a problem that will address a global need and potentially deliver value and safety across the world.

LM: Sam, thank you very much for your time and your detailed answers to our questions. We wish you well with your short-term efforts with the pandemic, and your other solutions beyond that. As we travel through airports, we now understand the efforts being made to make the experience more pleasant.

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.

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Technology Helps Combat Covid-19

CrowdVision's Quanergy-based solutions monitor social distancing



Estimation of social distancing suitable for airport, downtown plaza, shopping mall or similar spaces

IDAR Magazine attended a webinar moderated by the organizers of the Intergeo trade show and noted how various enterprises were exploring the use of UAVs to assist in the fight against covid-19¹. When we received a release from CrowdVision, who acquired California-based iinside earlier this year, a team that was using lidar with similar intentions, we wanted to learn

1 https://lidarmag.com/2020/04/18/abroadthoughts-from-home/. more. Managing editor Stewart Walker interviewed CrowdVision's President for North America, Sam Kamel (SK).

LM: LIDAR Magazine is very familiar with Quanergy Systems, which is active in the geospatial world and whose lidar sensors have been successful and economical when integrated on to UAVs. We don't know so much, however, about CrowdVision. Please tell us something about the company: when, why and by whom it was founded; its leadership team; its location and the reason for it; and its funding.

SK: CrowdVision's North American operation is headquartered in Anaheim, California and is the leader in indoor motion analytics for airports and other large public venues. Its iQueue solution uses precise three-dimensional lidar data to generate business intelligence for analyzing and managing the indoor flow of people. The company's queue management solutions apply machine learning to help smart airports better manage passenger movements, reducing bottlenecks through real-time visibility and predictive analytics. CrowdVision distributes its information through its Travel Data Services API Platform, enabling a range of applications-from continued on page 76

BY DR. A. STEWART WALKER

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