Cepton Technologies

The Silicon Valley Approach to Lidar Sensor Development

Cepton CEO Dr. Jun Pei outside the company's new facility in San José, December 2017.

Managing Editor Stewart Walker visited Cepton Technologies in San José, California, in December 2017, to find out why a lidar sensor supplier is located in Silicon Valley and how they bring new thinking to sensor development.

Cepton Technologies, Inc. is a fast-growing startup, founded in July 2016 to provide high-performance, high-resolution 3D lidar solutions for automotive, industrial and mapping applications. It produces four lidar sensors, the HR80T, HR80W and the brand new Vista for ground-based, primarily automotive applications, and the SORA 200 for UAV-based airborne use. Cepton stresses that its sensing principle has no rotation and thus no friction. CEO Dr Jun Pei and senior director business development, Wei Wei, met *LIDAR Magazine*'s publisher, Allen Cheves, and managing editor, Stewart Walker, during the Commercial UAV Expo in Las Vegas in October 2017 and proposed a visit to their facility in San Jose. Here is what Stewart discovered.

Cepton was founded by Jun Pei, Mark McCord and Jun Ye. There can be no doubt about the principals' intellectual acumen—all have PhDs from Stanford and Jun Pei met Mark while they were student and professor respectively. Mark

BY DR. A. STEWART **WALKER**

Figure 1: Cepton Vista sensor for automotive applications.

Figure 2: Cepton SORA 200 sensor for airborne UAV applications.

is now VP Engineering and Ye is a member of the Board. The founders provide massive expertise in optics, systems, algorithms and automotive applications. Both a serial entrepreneur and an expert in AI algorithms, Ye runs Sentieon Technologies, his third company, having successfully sold his first two, Brion Technologies (to ASML) and Founton Technologies (to Alibaba). Jun Pei consulted with Baidu in 2015 and concluded that no lidar delivered better performance than what had been available 10 years previously. Ye challenged Jun to do something different and better. He did, by forging a team handpicked for excellence. Not all are Stanford alumni, though: software VP Dongyi Liao has a PhD in nuclear engineering from MIT and worked at NVIDIA before moving to a startup then to Cepton.

At the time of my visit, Cepton was proudly awaiting the completion of its new building, less than a mile north of its first facility. The company moved in during February 2018. Triple the space of the old, the new facility will enable Cepton to run small-scale pilot manufacturing up to 10K sensors per year. Furthermore, Cepton is currently evaluating three large contract manufacturers for automotive volume production. This number sounds incredible to those of us with a background in traditional airborne lidar, where suppliers sell tens of systems annually, but doesn't sound so massive if one considers Cepton's primary market, automotive, where the units can be used in both autonomous vehicles and vehicles with drivers and advanced driver-assistance systems (ADAS). When I visited the company, headcount stood at 44, poised to expand. In the afternoon, Jun drove me to their new facility. He had planned the layout himself and the internal partitions and cubicles were awaiting assembly, all carefully thought out and incorporating expectations of dramatic growth.

During our initial conversation, Wei drew a comparison with Tesla and made an important point: success lies in speed of development and system-level innovation through making best use of mature materials and off-the-shelf (OTS) components, then adding smart packaging and control. Silicon Valley is not known for every breakthrough in fundamental sciences, but for bringing new solutions that solve meaningful, viable problems at scale. He modestly described his colleagues as hackers who bring their different culture and perspective, and apply their skills

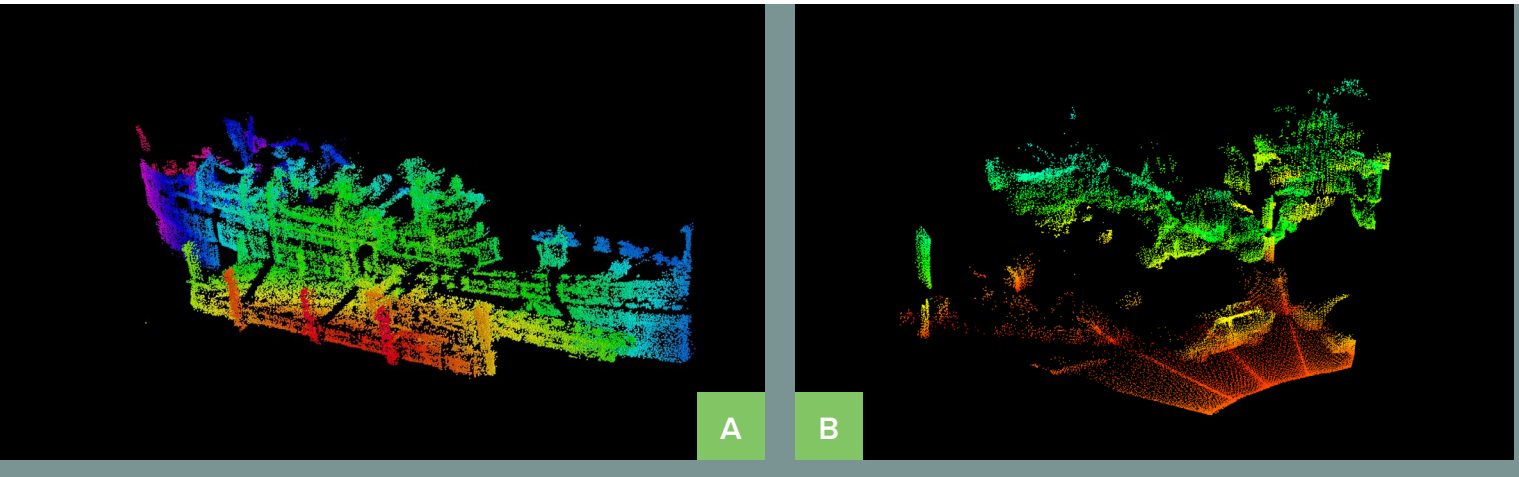
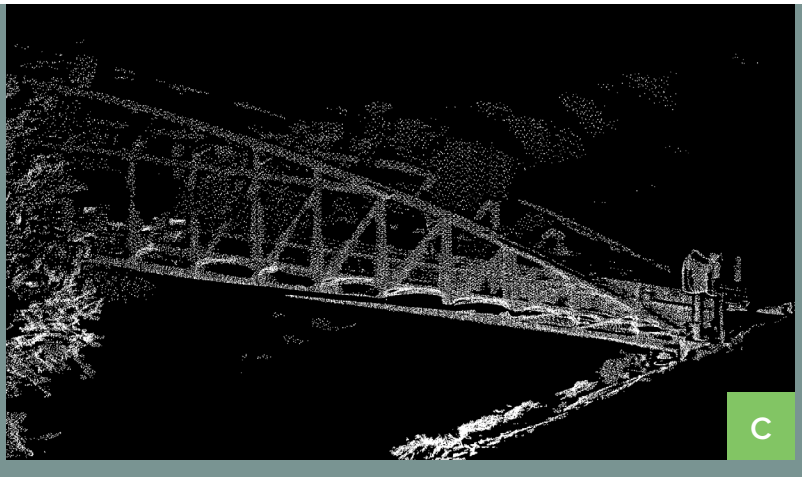


Figure 3: Examples of point clouds measured with Cepton sensors: (a) HR80T; (b) HR80W; (c) and (d) SORA 200.

to *what is available today*. They are ingenious, however, and not reluctant to tackle fresh problems. He described them as the "opposite of the Swiss watch industry", where craftspeople take a traditional approach, dedicated, persistent, creating art over generations. Striving to reveal the uniqueness of Silicon Valley as observed in both Tesla and Cepton, Wei elaborated, "We are 'hackers', trying to find out what would make the most impact and maximize the potential of every component to the limits of our knowledge, then integrate them together from different perspectives and make it happen in days, quite different from other places". Velodyne originally grew from that spirit. There were rangefinders in the early days of automotive lidar and the German company Sick AG built a single-layer rotating scanner. Then Velodyne created a multi-layer rotating scanner that provided more resolution and really helped the first generation autonomous vehicles. Nevertheless, they had to work hard to remain innovative. Wei elaborated, "But now lidar is evolving, people want higher and higher resolution, resulting in camera-like images—how do you do that?" For autonomous vehicles, the consensus is that rotating lidar sensor(s) with 360-degree coverage (or field of view—FOV) is not a desirable technology. Seamless integration into the vehicle body is difficult and there are many wasted pixels. At the same time, the rotating motor is known for low reliability. All the new lidar technologies are evolving towards a confined FOV, higher resolution, no rotating motor and smaller size for deep vehicle integration. The goal for the coming mass-produced autonomous vehicles is not to have lidar as a protruding element any more. Suppliers need to move to higher resolution at lower cost—and design accordingly. Yet they cannot allow the number of laser trackers to scale directly with the required resolution.

The underlying principle of Cepton sensors is that there is a proprietary, sparse laser emission and sensing array that delivers high performance and resolution at low cost. The HR80 and Vista (**Figure 1**) models are designed for automotive and area imaging applications: the sensors output a grid of pixels, whereas the SORA 200 (**Figure 2**) model for airborne UAVs—Jun explained that "sora" is the Japanese word for sky—has two scanning lines of 300 pixels, perpendicular to the direction of flight and 18° apart. This approach facilitates a very fast frame rate beyond 200 Hz. The solution is not entirely solid-state, but the required movements are tiny and frictionless. Though there are very few lasers, dense point clouds are produced through scanning. The SORA 200 platform is very flexible and can be customized for wider FOV and higher resolution through different optics. To put this in context, Wei noted, one competitor offers 0.2° operating at 20 Hz. Cepton could have put more pixels in each line, or they could add a third line. They even thought of using only one, but decided that two would increase canopy penetration. The pulsed lasers are off-the-shelf and have a wavelength of 905 nm. Some mapping companies have requested 1550 nm, but that needs more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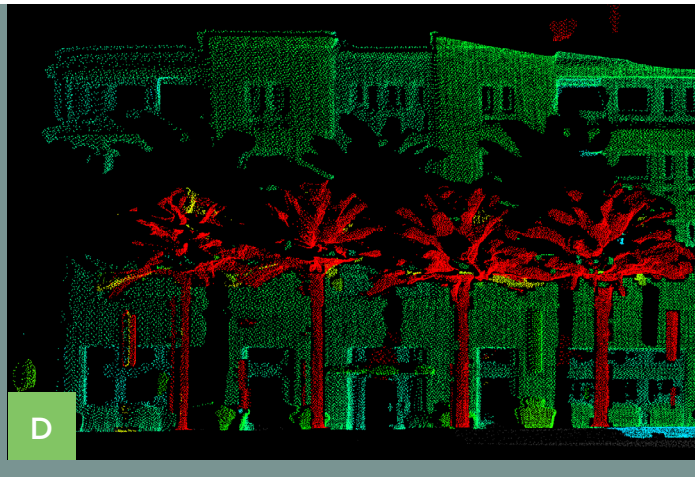
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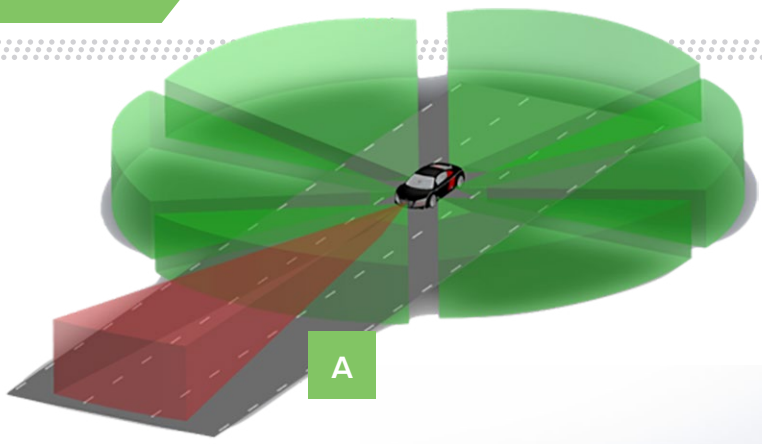

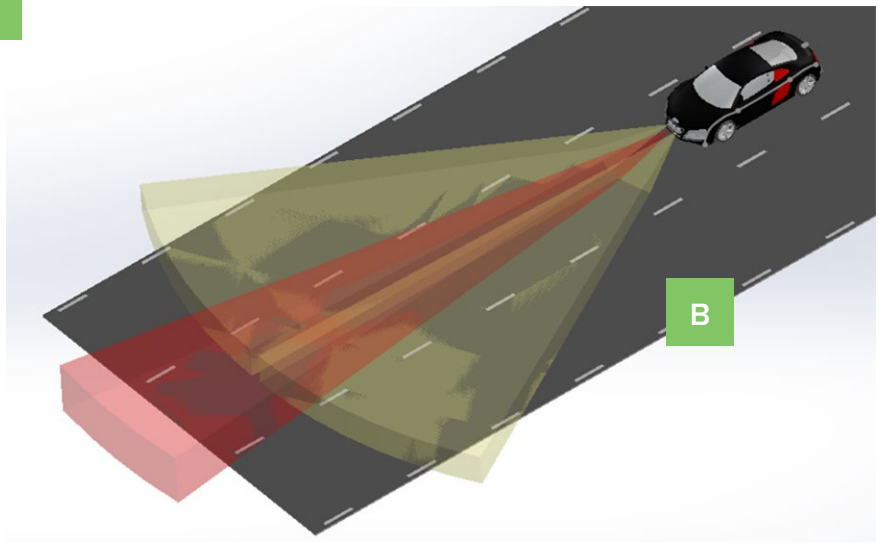

Figure 4. Cepton's concept of automotive lidar: (a) system consists of multiple HR80Ws and one, forward-pointing HR80T; (b) combination of sensors in the forward view reduces error by a squared function.

power and 905 nm provides sufficient range. The biggest problem of 1550 nm technology is cost, which will make the sensor more than 10 times more expensive than 905 nm. Also, water has much more absorption at 1550 nm than 905 nm, which can devastate sensor performance in bad weather.

Cepton's focus on size, weight, power and cost (SWaP-C in defense jargon) is obvious: the SORA 200, for example, measures 90 x 60 x 100 mm, weighs 550 g and draws 9 W. The HR80 comes in two models, the HR80T telephoto and HR80W wide angle. Examples of point clouds captured by these sensors are shown in **Figure 3**. Cepton's concept is that a car should be equipped with half a dozen HR80Ws, giving full 360° field of view, plus an HR80T looking forwards (**Figure 6a**). With both an HR80W and an HR80T looking forwards, there are more pixels in the crucial central area and the probability that an object critical to car safety is missed is minimized (**Figure 4b**; also look for Cepton on Vimeo for some informative video clips showing the system in operation). Development has been exceedingly fast: there was an alpha demo of the HR80T in November 2016, only four months after Cepton was founded; this was followed by a beta release in February 2017 and market introduction in June 2017—with worthwhile improvements between milestones. The HR80W was also released into the market in June 2017. The SORA 200 was announced at the Commercial UAS Expo in Las Vegas in October 2017. A new model, Vista, launched at NVIDIA's GTC event in March 2018, offers the same field of view as the HR80W, but with significant improvements to range, angular resolution, frequency and SWaP-C.

Cepton has worked closely with LiDAR USA to integrate the SORA 200 into UAV mapping systems and perform field tests (**Figure 5**). LiDAR USA has begun shipping these systems to its customers globally. Other customers and system integrators will work with Cepton in the UAV space. The automotive market will take two years to reach volume, but UAVs are flying today. Cepton anticipates a market for all its sensors of exceeding ten thousand units over the next two years, with significant growth thereafter. Talking to Jun and Mark in the afternoon, I asked provocatively about the manned aircraft market. Cepton admitted that this ambition would be premature for them, but from a technical point of view it's not impossible. Mark said that if enough customers ask for this product, the Cepton team will make it happen!

Wei identified an important similarity between the automotive and UAV airborne markets: both require long range and high accuracy; low cost is ideal too. Cepton is strong as far as range is concerned. Warehouse robots moving at 2 m/sec need a range of only 10-20 m: there are many low-cost technology solutions for this, making it a solved problem. UAVs will become totally

Figure 5: Cepton SORA 200 integrated on to UAV lidar system by LiDAR USA.

autonomous and perception capabilities will be necessary. Cepton can be quick to market with appropriate solutions. They are confident of their speed and expertise in the long-range, high-resolution niche. He summarized, "Cepton is working on a variety of applications where traditional lidar was too expensive but our low-cost solution becomes applicable."

Highly automated driving will be the main opportunity for lidar in the automotive market for the next three to five years. This is called Level 3—automated driving, whereby the driver's hands need not be on the steering wheel in certain scenarios: the system alerts the human driver to take over. This could become a standard offering in vehicles in 2020-23. Level 4 means hands off the steering wheel, all the time in some areas, and Level 5 means no need for a steering wheel, i.e. totally autonomous. The official explanation, for those of us less *au fait* with automotive applications, is at https://en.wikipedia.org/wiki/Autonomous_car. Current systems are not so sophisticated, of course: for example, the bleeps as a car reverses near a wall or other obstacle are often a response to simple ultrasonic measurements. Many cars have more advanced systems, with a rear-view camera and graticule superimposed on a screen to help the drive to maneuver. "Highway pilot", to drive the vehicle between freeway entrances, exits or toll booths, including lane changes, and automatic emergency braking (AEB) are the goals of car manufacturers today. This is the market that's driving Cepton and it's huge—global sales of new cars now exceed 80 million units *per annum*!

Cepton thinks that many UAV applications have hardly begun. Mapping is important today, but in the near future there will be autonomous delivery of goods and people and again drones will require perception capabilities. Detailed mapping, argued Wei, is challenging, but autonomous flight, even more so. The market for UAVs for deliveries will be enormous. The market for repeat mapping of construction sites using UAVs, moreover, has barely been captured. Precision agriculture is exciting too: imagery is essential for plant health, of course, but lidar can measure the physical sizes of plants and trees. These applications are not economical for manned aircraft or helicopters: UAVs are revolutionizing these markets and causing them to expand.

Wei ended the morning with some comments on the business side. Cepton already has a large number of customers in the automotive market and is proud of how far it has come in eighteen months. Prospects in the mapping market are numerous. Mobile mapping systems could be created with multiple HR80, Vista or SORA 200 sensors. MMS companies are moving away from expensive, single-line scanners, since

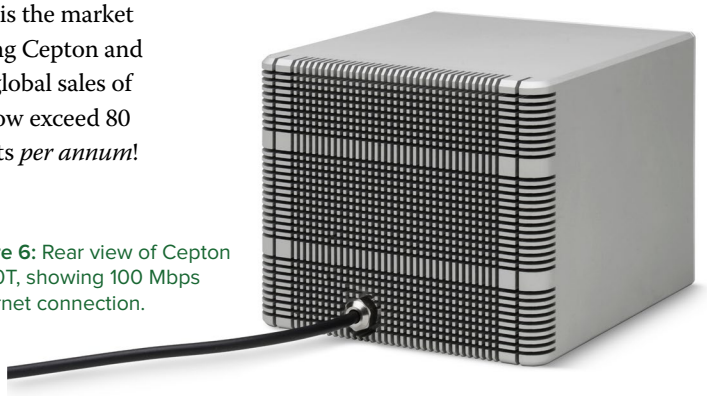

Figure 6: Rear view of Cepton HR80T, showing 100 Mbps Ethernet connection.

customers want laser beams to reflect off objects at different angles, so Cepton's array approach is promising. The prices of the HR80 or SORA 200 starter kits are a few thousand dollars for one sensor and Cepton software development kit (SDK), with big reductions anticipated for volume purchases. Cepton's plan for MMS is embryonic, but it envisages a price under $20K including multiple lidar sensors and GNSS/IMU, which will be a "game changer". They want to disrupt the market. They want to pluck "low-hanging fruit". City asset management is a potential market at these lower price points. Between automotive and airborne, Cepton has no doubt that it will sell sensors in large numbers. The company has a low burn rate and foresees profitability quite soon. Wei repeated the benefits of using OTS components and avoiding exotic materials. They focus on the core—the *lidar sensor*—and don't stray into GNSS, IMU or SfM.

In the afternoon session, Jun and Mark made clear that they didn't want to share the technical details of the inside of their box, since the market is ruthlessly competitive. With the high-volume demand of automotive lidar, there are many lidar companies in the race to get into mass-production vehicles. Competitors are proud of their intellectual property and guard it assiduously. Joked Jun, "Light goes out and comes back in!" But they *do want* to be less uninformative: they have to be convincing in the market-place. Companies such as Teledyne Optech and Hexagon can describe their technology in detail because the manned aircraft market is small and their customers expect some insight.

There are around two dozen companies currently aiming at autonomous vehicles. They have an idea, make sure it works,

Figure 7: Cepton HR80W mounted on Clearpath Husky warehouse robot.

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think of a few buzz words round the technology, ask for VC money, build a prototype, ask for a second round of money—the cycle is well known and Cepton has followed it to some degree. It's a replay of history, a selection process. Stars or survivors emerge, including some superstars such as Hewlett-Packard. The Cepton principals are *old* for Silicon Valley companies. They adopt what's there. This is a more practical approach—a traditional business model: make and sell a real product at a profit. Therefore there is a rhythm in business developments. This philosophy determines the technology approach. Cepton is not developing fancy technology without revenue—this doesn't give cash flow. The goal is to bring real products to solve meaningful market problems today. The velocity of innovation can be measured by milestones in every quarter. These milestones *must* be met. Whereas an approach dependent on research grade, immature technology and/or materials may not be successful, Cepton's technology-based approach enables it to control its own destiny and be able to make an impact today. Jun mentioned the analogy of Tesla—it didn't invent the battery but innovated at packaging and system level. Cepton invests effort in system design, packaging, optics and signal processing. Packaging matters, especially for autonomous vehicles. Performance, cost and reliability are all key.

Jun thought that the UAV market is easier to enter. October 2017, the launch of the SORA 200, was only 15 months after the company was founded. Cepton's ambition is based on the business model described above. Nevertheless, the automotive market is the big one. Cepton is planning its own manufacturing for small volume and will leverage contract manufacturing for high volume production runs.

Jun identified a market gap in spatial resolution and distance. Cepton positioned itself to be top-end, >300 m range and 0.1-0.2° resolution. There are four key areas and they have made advances in all of them: optics; electronics; mechanics; signal processing (algorithms in firmware and software). They use custom optics. They invested heavily in the electronics for best signal-to-noise ratio. The mechanics are not solid-state: the micro-motion scanning array designed in-house—indeed, Cepton coined the term—has moving parts, is innovative, and is the heart and soul of the Cepton solution, according to Jun. Most mechanical systems have motors, or the entire unit spins. The result is friction, causing wear and tear on the shaft and bearings. Cepton has eliminated that. Thus these critical components have infinite life expectancies. Micro-motion, by definition, provides small movements. Mark explained, "Our sensors are not pure solid state—like voice coils in speakers: they have moving parts and they are in every car." Mark added that the technology can scale to higher resolution and longer distance in future revisions, and that the Cepton approach is simpler and less expensive than other lidar solutions: Cepton's goal is to reach DSLR weight and pricing. Jun pointed out that Cepton *excels in engineering*. "Our team has a vertically integrated skill set from optics, electronics, mechanics, to machine learning and computer vision." Jun added that Cepton has an admirable portfolio of patents, but its biggest asset is a group of people. For its size, it has a big engineering team.

The sensor does not record data but pumps out a continuous stream of measured points with coordinates, distances and intensities (**Figure 6**). Cepton has created a SDK that provides parsed and assembled point cloud data as well as diagnostic information. The SDK supports Windows, Linux, Robot Operating System, Mac OS and Native Python Bindings. If Cepton makes a firmware upgrade to the sensor, the SDK will still be compatible with user's existing software.

"Cepton has an admirable portfolio of patents, but its biggest asset is a group of people. For its size, it has a big engineering team."

Figure 8: Cepton HR80W mounted on May Mobility autonomous vehicle.

We compared the automotive and UAV lidar markets. Eighteen months ago the market in Cepton's sights was almost entirely automotive. Jun thought UAVs were toys. Wei insisted, however, that a new commercial drone market was emerging, with scope for a competitively

CEO Dr. Jun Pei relaxing with music before pursuing Cepton's next milestone.

priced sensor offering high performance. I asked why Cepton had chosen the Commercial UAS Expo event for the SORA 200 launch. Jun admitted some shyness on his company's part—they are not natural marketers. Since they had shipped only a handful of the SORA 200 units at that time, they preferred a highly technical event, where they could expect intelligent questions from visitors. When I visited, however, Cepton was in the midst of preparation for the huge Consumer Electronics Show in Las Vegas in January 2018, an entirely different prospect.

Cepton units accommodate two returns per pulse as well as intensity. More features are in the planning stage. They have deliberately designed the SORA 200 with a detection range of 200 m, for targets with 50% reflectivity, because this easily covers the 400-foot ceiling for UAVs specified in current US regulations. Indeed, the US is more generous in this respect than some other countries.

I asked about distribution. Cepton has developed a strong partner network, especially on the automotive side, including a number of start-ups. Other distributor application areas include robotics, mapping, agriculture, railways and mining. In particular, we talked about Clearpath Robotics, located in Kitchener, Ontario, Canada. It has a robotics division specializing in warehouse robots and is a reseller of sensors and components related to robotics (**Figure 7**). The global market is certainly on Cepton's radar, with plans in place for 2018.

Jun perceives the short-term prospect for autonomous cars as successful operation on defined campuses. Therefore initial sales of sensors will be small fleets of robotaxis and people movers in last-mile transportation (**Figure 8**). The lidar sensors can provide centimeter-level distance accuracy and spatial resolution, to be fused with radar and camera sensors to provide extra redundancy and reliability. For high volume production vehicles, the car companies are looking into seamless integration of lidar into the vehicle body. Behind the fascia or in the headlamps could be satisfactory positions for lidar sensors and Cepton is actively working with Tier 1 suppliers on this front.

I ended by asking Jun some questions about himself. He likes wrist watches. He built model boats and flew model planes when he was growing up. He plays the piano expertly and almost went to music academy, but preferred boats and planes for his profession, while not losing touch with music. He has a Steinway grand piano at home and an electronic upright in his office, to which he listens, as he plays, through headphones so as not to disturb colleagues as they apply their various remarkable talents to the Cepton sensors that he hopes will transform the automotive, UAVs and perhaps other lidar markets. The company's strapline, "3D lidar for smart machines" hits the spot.

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