

LIDAR

Mapping the world in 3D

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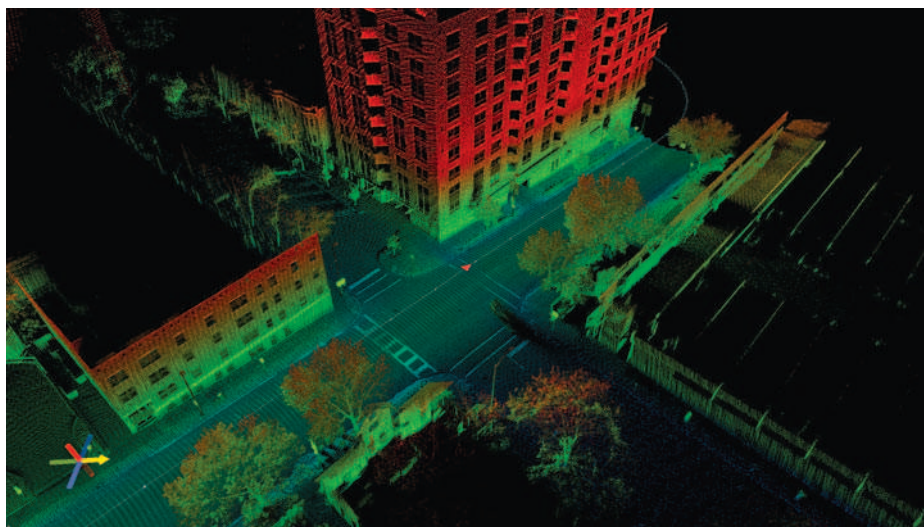
A high-definition LIDAR system with a rotating sensor head containing 64 semiconductor lasers allows the efficient generation of 3D environment maps at unprecedented levels of detail.

Recent progress in the cartography market can only be described as radical. The time-consuming days of mapping by hand seem numbered, as geographic information system (GIS) experts, professional land surveyors (PLS) and others within the field of cartography awaken to the advantages of integrating light detecting and ranging (LIDAR) into their mobile mapping systems.

LIDAR is similar to radar, except that the sensor sends out and receives pulses of light instead of radiowaves. As cartographers continue their relentless pursuit of new technology, a few organizations have identified one particular LIDAR sensor technology to be ideal for mobile mapping systems.

Whereas most LIDAR systems have a single laser that fires onto a rotating mirror, the high-definition LIDAR sensor from Velodyne uses a rotating head featuring 64 semiconductor lasers, each firing up to twenty-thousand times per second. This allows the sensor to achieve data collection rates that are an order of magnitude higher than most conventional designs. Each of the 64 lasers has its own dedicated detector, and each laser-detector pair is precisely aligned at predetermined vertical angles to give a 28.6° vertical field-of-view. By spinning the entire unit at speeds of up to 900 rpm (15 Hz) around its vertical axis, a 360° field-of-view is generated. Over 1.3 million data points are generated each second, independent of the spin rate. The resulting point cloud of distance and intensity information is so dense that computer programs can identify objects such as street curbs and overhead wires at distances of over 100 m.

This technology was originally designed to compete in the Defense Advanced Research Project Agency's (DARPA) "Grand Challenge" — a competition sponsored by the United States' Department of Defense to spur technological innovation in the field of unmanned ground vehicles. The competition required contestants to



A typical ultrahigh-resolution mapping image of an urban environment obtained by Velodyne's high-definition LIDAR technology. The system is capable of capturing features as small as street curbs and overhead wires at distances of over 100 m.

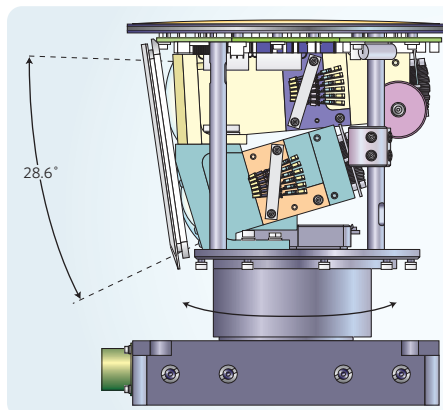
develop autonomous vehicles that could navigate across desert terrain. DARPA later sponsored a third race in 2007 that required unmanned ground vehicles to navigate through an urban environment while adhering to street markings, avoiding traffic and obeying motor laws. Although contestants exploited sensors from many different companies, high-definition LIDAR, with its spinning head design and large vertical field-of-view, was used by five of the six finishing teams, including those in first and second place; the sensor's performance allowed the teams to integrate the inputs from several different sensors, enabling them to produce a cohesive digital view of the surrounding terrain.

The performance of state-of-the-art high-definition LIDAR allows the navigation system of a vehicle travelling at 65 km h^{-1} to automatically identify a 15-cm-sized object at a distance of 50 m and still have sufficient time to navigate around it. The sensor utilizes commercial off-the-shelf 905 nm wavelength lasers to

keep costs low. Commercial off-the-shelf lasers are also beneficial for their low power consumption, class 1 eye safety and the availability of corresponding sensors for calibration and product quality testing.

Although originally developed for the autonomous vehicle market, high-definition LIDAR has now expanded into many other industries thanks in part to Mandli Communications, an industry leader in the design of field data collection systems and operational methodologies. As a proof-of-principle experiment, Mandli mounted a high-definition LIDAR sensor horizontally onto one of its mobile mapping system vehicles. The sensor generated a point cloud of measurements so dense that the company was able to develop new methods for identifying and extracting GIS features, thus dramatically reducing the labour required to create digital terrain models.

Although conventional LIDAR sensors that utilize spinning mirrors are capable of collecting dense point clouds, their low data



Internal (left) and external (right) views of Velodyne's high-definition LIDAR. The sensor features a total of 64 semiconductor lasers and matched detectors, arranged into two sets (upper and lower) of linear arrays. The sensor head is spun at high speed during data collection to give the LIDAR system a complete 360° field-of-view.

collection rates restrict vehicle speeds. In addition, most conventional LIDAR sensors were originally created for use in indoor industrial applications. Users must therefore restrict these sensors to operating in mild climates during periods of good weather. High-definition LIDAR doesn't have any of these restrictions, and at one third of the cost, the sensor is also more economical for price-sensitive GIS professionals.

One of the significant attributes of LIDAR data points is their distance measurement information. For the past ten years cartographers have been using airborne LIDAR sensors that typically collect a couple of data points per square metre, which was already a significant improvement over the traditional approach of extrapolating distance measurements and extracting GIS feature information from photographs.

During that time, software companies developed computer algorithms that could semi-automatically connect a series of LIDAR points to identify and extract linear features on large objects such as building rooflines, roads or railroad tracks. These applications generated a tremendous improvement in productivity. The feature identification and extraction step is by far the most laborious, time-consuming and expensive in the entire workflow process. By automating this step, cartographers were able to focus on other higher-value activities while also reducing costs.

Unfortunately, aerial surveying sensor arrays struggle to observe some ground-based objects. For example, objects located on vertical planes are difficult to observe, and many objects are either too small for airborne LIDAR sensors to identify or are located under hard surfaces that LIDAR sensors can't penetrate. By merging LIDAR

point cloud datasets from both airborne and mobile mapping systems, cartographers are able to create three-dimensional models of tunnels, bridges and other objects.

It is also worth noting that many customers require high-accuracy geographic information such as height data for tunnels, wires and bridges, or precise location data for pipe valves, cable boxes and fire hydrants. These customers have historically been contracted by civil engineering firms to collect the required field data. This work is very demanding, often requiring a measurement precision of less than 2 cm.

To achieve such accuracy, PLSs must often occupy a location (a 'point') with a survey-grade global positioning system (GPS) receiver for several minutes to collect a GPS coordinate. Because it takes so long to collect this information, PLSs often require road closures for their safety.

As the scope of each project is limited to a few GPS points collected on predefined objects or boundaries, the usefulness of the field data is generally restricted to the contracting customer. There is a relentless drive by civil engineering firms to reduce costs, and subsequently many of these firms are early adopters of new technology that promises to bring financial savings.

Instead of collecting only a few GPS coordinates an hour, a PLS using appropriate ground control points and a mobile mapping system can collect hundreds of millions of LIDAR points, all to an accuracy of under 2 cm. Mobile mapping systems are enabling the 'industrialization' of field data collection, and represent a paradigm shift for cartographers.

Uptake of this technology has not been immediate. For example, some PLSs argue that mobile mapping systems are not accurate enough for survey-grade work,

while others are unsure how to integrate mobile mapping systems into their digital terrain model workflow. However, what is clear is that early adopters are gaining critical knowledge that will give them a substantial advantage over their competitors.

Because mobile mapping system point clouds contain such rich information about all scanned objects, civil engineering firms and GIS professionals can repurpose their LIDAR point cloud datasets and extract different features to satisfy new customer requirements without the added expense of undertaking new field collection missions. This provides an additional cost advantage when bidding for mapping projects from ever-more price-sensitive customers. As software companies develop new applications that are able to extract even more value from LIDAR point cloud datasets, the gap between the old and new methods of cartography will expand even more.

Velodyne's vision for its LIDAR technology is simple: to market it wherever sophisticated 3D understanding or visualization of the environment is required. High-definition LIDAR has applications in robotics, map capturing, surveying, autonomous navigation, security, manufacturing and automotive safety systems. The day may come when this sensor technology is deployed on every vehicle in the world. Traditional LIDAR sensors have relied on fixed electronics and rotating mirrors to deliver a 3D terrain map, but the rotation of an entire array of multiple fixed lasers arranged to cover a long vertical axis has proven to be an enormous leap forward in sensing technology. Thanks to LIDAR, it is now possible for autonomous machines to have enough data about their immediate environment to identify and react to obstacles and threats in sufficient time, making new classes of such vehicles practical to deploy. This technology is also making it feasible to replace humans with robots in many extremely hazardous tasks such as fire fighting, landmine removal and perimeter security.

Automotive safety groups are now studying different ways of incorporating high-definition LIDAR sensors into their safety systems, with the long-term aim of developing completely unmanned commercial vehicles. High-definition LIDAR is changing the field of sensing, and helping to make the world a safer place. □

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Correction

In the Technology Focus Industry Perspective 'LIDAR: Mapping the world in 3D' (*Nature Photon.* **4**, 429–430; 2010), the credit for the image on page 429 was incorrectly given to Velodyne. The image was courtesy of Mandli Communications, and should have been credited as such.

Similarly, in the Technology Focus Editorial 'A sense of diversity' (*Nature Photon.* **4**, 423; 2010), credit for the Technology Focus cover image should have been given to Mandli Communications. The HTML and PDF versions of both texts are correct.