Heavy Vehicle Sensing Strategies

Understanding the benefits of High Density LIDAR in heavy vehicle, industrial and constructing applications.

SciVestor Research Paper: Analysis by Jonas Lamis

Summary

Sensing strategies for the heavy vehicle marketplace are evolving to take advantage of powerful capabilities that have emerged post DAPRA Grand Challenge. As these newer sensors prove themselves reliable in field endurance scenarios, we expect an accelerating adoption among industrial, construction, and heavy-vehicle fleet operators.

Background

In 2004, DARPA (The Defense Advanced Research Products Agency) launched the “Grand Challenge” competition series to foster the development of autonomous robotic ground vehicle technology to save lives on the battlefield. This research is driven by a Congressional mandate that one-third of all military vehicles be unmanned by 2015. Across three events, teams from industry, academia and hobbyists worked to create autonomous vehicle platforms that could traverse uncertain desert and urban driving conditions.

From 2004 – 2007, Grand Challenge teams realized the DARPA vision by evolving hardware and software technologies, culminating in the Urban Challenge win by Carnegie Mellon’s Boss Vehicle. The finalists sported an array of sensors including powerful new products such as the ibeo LUX sensor and the Velodyne HDL-64E.

In parallel, the DOD and other organizations have funded autonomous vehicle development projects, most notably the UPI program at Carnegie Mellon’s National Robotics Engineering Center (NREC), and

Hierarchy of Autonomy Needs

- Business Logic
- Navigation
- Sensory Enablement

Sensors are required to provide a representation of the world to the vehicle. Effective sensory enablement can turn vehicle autonomy into a software challenge – focused on navigation strategies and use case specific business process development.

During the Grand Challenge series, the emergence of high-density LIDAR sensors provided an enablement breakthrough.
made advances through the efforts of the membership of AUVSI.

Today, the technology has matured to a point where broader commercial use cases become viable.

**Understanding the Technology**

At its core, high density LIDAR builds upon proven LIDAR technologies sold by vendors such as SICK and Optech for more than a decade. A pulse of laser light is bounced off an object, and the flight-time of the light is captured. The round-trip time provides a distance while reflectivity measurements can indicate the type of material struck by the laser. Actuating and pulsing the laser hundreds or thousands of times per second creates a “point cloud” that can define the shape and movement of items in the path ahead.

With its compact size, polished design and lack of any external moving parts, the ibeo Lux sensor is pushing hard to become a standard platform for consumer automotive applications. The ibeo Lux sensor has four lasers configured vertically to cover a vertical field of 3.2° that is swept across a 100° angle identifying obstacles up to 200 meters away. With a 3.2° vertical scan, the Lux has effectively increased the thickness of the planar scan of its parent company’s (SICK) flagship scanning products.

HDL (High Density Lidar) is an extension of this capability. Rather than one laser being used to create the point cloud, HDL systems use multiple beams. More lasers, more layers, and more pulses result in more data.

In the case of Velodyne, a pioneer in this segment, their HDL-64E uses 64 discrete lasers aligned over a 27 degree vertical field. These lasers are further mounted in a spinning turret configuration. Together, these augmentations to standard LIDAR produce an extremely dense 3-D point cloud of data surrounding the vehicle of more than 1.3 million data points per second over a full 360 degree rotation.

**State of Technology Maturity**

HDL systems have been in field trials since early 2006 and have experienced increasingly stringent environmental qualifications over the past two years.

Velodyne, for example has HDL-64E sensors in trials with all major automotive vendors, defense departments and contractors, and has built a successful OEM customer in Mandli Communications.

Mandli is an example of a company that has focused on automating the business logic of their industry while letting other companies solve the sensing problem. Mandli has mounted the sensors of their work vehicles in a rear mounted horizontal
configuration so they scan the world vertically around the back of the vehicle. They use this data to measure information about critical infrastructure like overpasses and bridges, widths of roads, wires and stoplights, and sell this information to municipalities.

Ibeo has likewise been in automotive field trials over the past year culminating with an anticipated limited passenger vehicle rollout in 2010-2012 model years.

**Automating Navigation**

The Heavy Vehicle industry balances the three drivers of productivity, cost and safety with each product iteration and use case. Vendors such as Caterpillar and John Deere are constantly innovating to drive out operational costs while improving safe operating environments for the humans working in the vicinity of their vehicles.

Operating in dirty, difficult and dangerous conditions with large, slow moving vehicles is a ready-made scenario for high-density lidar.

Return on investment calculations can now be made for several areas of potential return:

- Replacement of expensive cab operators.
- Elimination of in vehicle worker injury.
- Reduced risk of equipment and infrastructure damage.
- Enhanced coordination planning between multiple vehicles used on master tasks.

While the ability to determine and ROI for sensing technologies relies on specific costs, configurations and use cases, the following framework may be used as a starting point to analyze potential areas for documenting returns. The following scenario models a 100 heavy vehicle deployment with an HD Lidar configuration. Detailed calculations are available in the companion ROI model spreadsheet.
**Investment Cost** $5,250,000

<table>
<thead>
<tr>
<th>Potential Return Areas</th>
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<tr>
<td>Replacement of operators</td>
<td>$5,000,000</td>
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<tr>
<td>Elimination of worker injury</td>
<td>$500,000</td>
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<tr>
<td>Reduction of equipment damage</td>
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<tr>
<td>Enhanced coordination</td>
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<td><strong>Total Potential Return</strong></td>
<td><strong>$11,000,000</strong></td>
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<td><strong>Return on Investment</strong></td>
<td><strong>210%</strong></td>
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**Use Case 2 – As Built Analysis**

Use cases that require high-density coverage of a space are well matched with large point cloud LIDAR. Consequently, a second strong use case for the Heavy Vehicle Industry is the application of HDL to the analysis of construction, earth movement and agricultural activities.

HDL sensing can provide sub-inch accuracy reporting, and can be used to validate a physical environment compared to an engineered plan. This yields a strong ROI for calculating as-built analysis.

As-built analysis and record keeping for roads, bridges and construction sites is a service for both the mapping marketplace and the construction auditing market. In both cases, the return on investment calculated by automating the as-built analysis process versus traditional manual data collection and management is superior.

**Use Case 3 – Change Analysis**

The ability to rapidly scan large areas of geography and conduct a time series comparison of “what has changed” poses an interesting set of potential use cases:

- For traditional GIS roadside data: Identify potential road hazards (pothole depths, guardrail damage), identify changes in infrastructure (bridges, signs, pipelines), and identify other hazards like branches hanging over power lines.
- Road Construction progress auditing: High resolution LIDAR sensors can be used to detect differences in road bed coverage, answering questions like how much pavement was applied over a given timeframe.
- Jobsite construction auditing: Being able to rapidly scan and assess how much progress has been done at a construction job site could accelerate the construction audit process.
• Battlefield Change Analysis: Autonomous or remote-controlled vehicles equipped with LIDAR can make multiple passes across a battlefield and identify “what has changed” including the potential identification of roadside bombs and other hazards.

These use cases offer significant ROI models over their traditional manual counterparts. Savings are driven from an increase in speed, a reduction in manpower, and an elimination of risk.

**Vendor Summary: Velodyne**

Velodyne is a Morgan Hill, CA based manufacturer of high-end audio equipment and LIDAR systems. Velodyne was founded by Dave Hall who has been involved in the robotics community for a number of years. Dave and his brother Bruce entered the 2004 and 2005 Grand Challenges as Team DAD. In 2005 they pilot tested their prototype LIDAR sensor. In 2007, their HDL was used by 7 of the 11 DARPA Urban Challenge finalist teams and was the primary sensor for the 1st and 2nd placed teams. Following this success, they have formed a new company, Velodyne LIDAR Inc to accelerate the commercialization of their sensor.

The HDL-64E sensor creates the most dense point cloud of technologies we have researched. Up to 2.3 million points per second – and can be throttled down to a level that available hardware can process successfully.

The company has a broad following of leaders in the autonomous vehicle industry. SciVestor spoke with Sebastian Thrun, head of Stanford Racing about Velodyne. Stanford’s vehicle was the champion in 2005 and runner up in 2007. They had a menagerie of every possible sensor you could think of on their vehicle including the Velodyne in 2007. We asked Dr. Thrun, if he had the Velodyne, why did he need all these other sensors. He commented to us that when he bought the Velodyne, it rendered all the other sensors superfluous.
Vendor Summary: Ibeo LUX

The primary differentiator between the Ibeo Lux and other mobile laser scanning systems is the software system architecture that builds on the primitive data returned by the sensor. The sensor merely provides a list of points within the sensor’s angular field of view. Ibeo has built on this information to provide higher levels of abstraction to application developers.

The first software incarnation of the sensor is the data it returns which represents a set of points—each an indicator of the distance and angle from the sensor as was reflected by an object. Darker objects return a weaker signal while brighter or more reflective objects yield stronger signals. It is this principle that allows the software to identify stripes in the road. Ibeo has an algorithm that evaluates four measurements per sample in order to “see through” rain, fog, or dust.

The second layer is an object recognition layer. This layer clusters points returned by the sensor and identifies types of objects such as other vehicles or pedestrians. Beyond that is an object tracking layer that monitors up to 64 objects and their location, direction, and speed.

The highest layer is the application layer which leverages the foundation layers to implement high-level behaviors such as Adaptive Cruise Control (ACC), Pedestrian Avoidance, Stop and Go, and other driver-assisting applications.

The Ibeo Lux is currently in field trials. Ibeo expects to produce approximately 3,000 units a year at a little over € 9,000 EUR or about $ 13,132 USD. Once the product hits mass production the unit cost is expected to drop to € 180 EUR according to Marketing Director Tanja Veeser.
Recommendations

High density LIDAR technology has matured to a state where early adopter companies and military applications will be well along field trials in 2009. Mainstream vendors of heavy vehicles run the risk of missing application launch windows over the 2010-2014 timeframe if they are not investing in HDL research and field trial projects this year.

In particular, SciVestor remains positive on the high-density data generation capabilities of the Velodyne HDL-64E. Companies with novel applications should develop a strategy for testing their applications with Velodyne technology. Plan to invest substantial resources on the software side of the equation. The challenge of interpreting the data generated by the HDL-64E, especially in novel applications, will require substantial programming sophistication.

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