LiDAR: Driving the Future of Autonomous Navigation

A Frost & Sullivan Exclusive Whitepaper For Analysis of LiDAR technology for advanced safety
Preface

Safety and its improvement is a concern paramount to all passenger vehicle manufacturers. The value proposition for driver, passenger and pedestrian safety has become equally important as engine performance and fuel economy. This paper addresses how light detection and range (LiDAR) technology will impact Advanced Driver Assistance Systems and explore the term, “autonomous driving intelligence.”

The paper will consider Lidar technology today and how it stands to capture a large market share of automotive sensor technology in the future. Lidar is poised to penetrate the market in 2016 as the lead technology in automotive safety and autonomous systems.

Three primary approaches to Lidar development are considered, including Hybrid Solid-State Lidar, MEMS Lidar, and Mechanical Mechanism Lidar. Mechanical mechanism Lidar is the oldest and most traditional technology. MEMS Lidar technology is in the beginning stage of development as a low cost Lidar solution for low level automotive safety. Solid-state Hybrid Lidar (SH Lidar) was introduced in 2005 as a result of the Darpa Robotic Car Races. The technology has been tested for autonomous safety over the years and the cost for SH Lidar dropped dramatically in 2015. With planned mass production to meet the growing demand for autonomous navigation and advanced safety, further dramatic cost reduction is expected in 2016 – 2017.

The development of Solid-State Hybrid Lidar (SH Lidar) was a break away from the traditional mechanical mechanism of single Lidar technology, and it is described in detail in this paper. The technology simplified what was previously a complex mechanical system of parts into one robust solid-state part. The solid-state developmental enabled faster data capture in 3D, capturing pictures instantaneously while moving in real-time at speeds of 30-40MPH. SH Lidar technology has matured from an extremely costly technology and large system to being affordable, smaller in size, and headed toward mass production. SH Lidar technology is poised to be commercialized in 2015-16 and radically change the way we move about in the world.

This paper looks at other sensor technology in use today in the automotive industry for safety. There are several type of sensors currently in use for ADAS (Advanced Driver Assistance Systems) levels 1 and 2 level, such as camera solutions, radar, and infrared sensors. We will look at how sensor technology systems will potentially affect the future of safety by improving what is currently offered and addressing safety levels of ADAS 3 and 4.
The paper compares SH LiDAR, proposed MEMS technology, camera systems, and suites of sensors as the various systems apply to ADAS, autonomous driving, and autonomous intelligence.

### Exhibit 01. Comparative Analysis of Various Automotive Technologies

<table>
<thead>
<tr>
<th></th>
<th>Short Range Radar 24GHz</th>
<th>Long Range Radar 77GHz</th>
<th>Ultrasonic</th>
<th>Vision</th>
<th>Infra Red</th>
<th>LIDAR</th>
<th>Implications for LIDAR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Short Range (0 to 2m)</strong></td>
<td>Very Good Low resolution</td>
<td>Barely satisfactory</td>
<td>Ideal solution</td>
<td>Barely satisfactory</td>
<td>Ideal solution</td>
<td>Very Good</td>
<td>LiDAR enables short range detection</td>
</tr>
<tr>
<td><strong>Nominal Range (2 to 30m)</strong></td>
<td>Very Good Low resolution</td>
<td>Very Good Low resolution</td>
<td>Barely satisfactory</td>
<td>Barely satisfactory</td>
<td>Ideal solution</td>
<td>Ideal solution</td>
<td>LiDAR enables high precision detection in real time with object detection and recognition. Radar provides no object detection.</td>
</tr>
<tr>
<td><strong>Long Range (30 to 100m)</strong></td>
<td>Barely satisfactory</td>
<td>Ideal solution Low resolution</td>
<td>Needs improvement</td>
<td>Barely satisfactory</td>
<td>Good</td>
<td>Ideal solution</td>
<td>Unique feature of ToF lasers in LiDAR is most accurate real time long range detection</td>
</tr>
<tr>
<td><strong>Narrow Vertical FOV &lt;10deg</strong></td>
<td>Good Speed only</td>
<td>Good</td>
<td>Needs improvement</td>
<td>Ideal solution</td>
<td>Ideal solution</td>
<td>Ideal solution</td>
<td>Except LiDAR &amp; NDIR, all other sensors are limited to &lt;10 degree range. LiDAR exhibits higher precision than NDIR</td>
</tr>
<tr>
<td><strong>Wide Vertical FOV &gt;30deg</strong></td>
<td>Barely satisfactory</td>
<td>Barely satisfactory</td>
<td>Very Good</td>
<td>Good</td>
<td>Very Good</td>
<td>Ideal solution</td>
<td>Multi-laser LiDAR eliminates flux &amp; is the only single sensor capable of narrow and wide range</td>
</tr>
<tr>
<td><strong>Angular resolution</strong></td>
<td>Barely satisfactory</td>
<td>Very Good</td>
<td>Needs improvement</td>
<td>Good</td>
<td>Very Good</td>
<td>Ideal solution</td>
<td>LiDAR is the only solution able to maintain high image resolution with utmost clarity</td>
</tr>
<tr>
<td><strong>Object speed measurement</strong></td>
<td>Ideal solution</td>
<td>Ideal solution</td>
<td>Very Good</td>
<td>Needs improvement</td>
<td>Needs improvement</td>
<td>Ideal Solution</td>
<td>LiDAR accurately measures speed of approaching objects in real time</td>
</tr>
<tr>
<td><strong>Bad weather operation</strong></td>
<td>Ideal solution</td>
<td>Good</td>
<td>Good</td>
<td>Barely satisfactory</td>
<td>Very Good</td>
<td>Very Good</td>
<td>LiDAR is not impacted by environmental &amp; ambient light conditions</td>
</tr>
<tr>
<td><strong>Blockage (impurity on sensor)</strong></td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Needs improvement</td>
<td>Good</td>
<td>Very Good</td>
<td>LiDAR rays are not impacted by changes in ambient light conditions</td>
</tr>
<tr>
<td><strong>Night operation</strong></td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Needs improvement</td>
<td>Ideal solution</td>
<td>Ideal solution</td>
<td>LiDAR is not impacted by light/ sound interference unlike Radar &amp; Sonar. Lidar is immune to background noise &amp; environmental changes unlike ultrasonic.</td>
</tr>
<tr>
<td><strong>Sensitivity to Light</strong></td>
<td>Barely satisfactory</td>
<td>Barely satisfactory</td>
<td>Good</td>
<td>Needs Improvement</td>
<td>Good</td>
<td>Ideal Solution</td>
<td>Mass production &amp; technology improvements will drive price of LiDAR down</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Very Good</td>
<td>Very Good</td>
<td>Ideal solution</td>
<td>Good</td>
<td>Barely satisfactory</td>
<td>Needs improvement</td>
<td></td>
</tr>
</tbody>
</table>

*Source: Frost & Sullivan*
This paper will examine the roadmap and future vision of Lidar sensor technology developers as the technology is poised to substantially increase vehicle safety across the industry.

“Lidar is the single best way of getting integral information about the world around you,” said Douglas Thornton, an engineer at Battelle Memorial Institute, who works on automotive Lidar applications.

- Nick Shchetko, Wall Street Journal, 2014

“The difference between a 64-beam LiDAR, and a $150 single-beam unit, underscores an important point: not all LiDAR is created equal. There are three primary levels of automotive applications—one for mapping; another for limited driver-assistance functions; and the more forward-looking fully self-driving vehicles.”

- 11-Feb-2015 Automotive Engineering Magazine

Source: http://articles.sae.org/13899/
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**LIDAR OVERVIEW**

**How LiDAR Works**

LiDAR is a tool to measure the shape and contour of the ground and environment. It bounces a laser pulse off a target and then measures the time (and distance) each pulse traveled. The science is based on the physics of light and optics, measuring wavelengths in nanoseconds. In a LiDAR system, light is emitted from a rapidly firing laser. LiDAR gathers its information by sending out laser light and gathering the light each laser beam generates. Laser light travels and reflects off points of things in the environment like buildings and tree branches. The reflected light energy then returns to the LiDAR sensor where it is recorded.

Time of Flight or TOF is the way Lidar measures the environment and it is the most viable and proven technique used for detecting target objects. Simultaneously, as the lasers fire, firmware within a Lidar system is analyzing and measuring the data. The optical receiving lens within the LiDAR system acts like a telescope gathering fragments of light photons returning from the environment. Lasers generate and fire out billions of photons, but for each 1M photons sent out, 1 photon returns. Lasers send out 1B photons to generate 1000 photons of returning information. The more laser beams used in a system, the more the information about the environment is gathered. Single laser Lidar systems and systems with 8 or fewer lasers are at a disadvantage because fewer photons are retrieved, thus less information compared to a multi-laser Lidar system equipped with 16 or more laser beams.

There are three basic methods developers have employed to make Lidar technology, all based on firing a single or multiple laser light into the environment and through different methods, determining the distance from the points it illuminates in the environment and reflects back. The distinct approaches to LiDAR technology are 1) solid-state hybrid technology invented in 2007, 2) MEMS technology (in development stage) and 3) mechanical mechanism technology. Solid-State Hybrid Lidar (SH LiDAR) defines Lidar used by Google over the past ten years and sold by Velodyne. Ibeo technology is also a hybrid using fewer laser beams. Quanergy is a start-up company exploring the use of semiconductor/MEMS for LiDAR, discussed later in this paper. Mechanical Mechanism LiDAR has been around for decades and it describes the technology of Leica, RiegI, and Sick Lidar, which are companies that play in the high-end industrial LiDAR market.
Solid-State Hybrid LiDAR and how it Works

Single laser LiDAR technology was invented more than fifty years ago and it took the invention of the Hybrid LiDAR to change the future of Lidar for real-time scanning and navigation. Single LiDAR technology is slow comparatively, not fast enough for a moving car to see in high resolution.

Solid State Hybrid LiDAR is a combination of a solid-state detector system within a spinning system taking advantage of a 360 degree view in order to gather data at a very fast speed. Using multiple laser beams, 16 to 64 lasers scan the environment at 1.2M points per second. The Hybrid design was break-through technology in 2007 because it vastly simplified what was previously a complex mechanical part into one solid-state part. Without the hybrid technical advance, multiple laser systems of 16 to 64 lasers at one time would be complicated and unmanageable.

As a solid-state central component, the detector system is consolidated into a robust part which can be spun, an excellent solution for incredibly fast data collection. It is hardened to resist laser and detector misalignment from vibration. It proves to be a reliable, strong, and practical as a method of 3D visualization for automotive navigation, while fast enough for computation in a real-time moving vehicle. The solid-state hybrid was patented as a radically efficient technology for fast data collection in real-time.

Specifically, SH LiDAR is a point-by-point measurement of distance and reflectivity in a horizontal field of view of 360° and a vertical field of view of up to 40°, updated up to 20 times per second. It’s a Time of Flight (TOF) measurement, where a pulse of light is emitted and the return trip to an object is measured and by using the speed of light, the exact distance can be determined. In the case of SH Lidar, multiple pulses of light from multiple lasers are simultaneously pulsing and measuring distances in nano-seconds. The calculation for measuring how far a returning light photon has travelled to and from an object is:

\[
\text{Distance} = (\text{Speed of Light} \times \text{Time of Flight})
\]

The speed at which images can be developed is affected by the speed at which it can be scanned into the system and create a high resolution picture. The calculations of the distance are processed instantaneously, measuring distances in nanoseconds. The speed of data calculation and measurement is critical because the faster the speed of the scanning process the more data points are collected. Abundant and accurate data produces the highest resolution, best 3D picture.
Multiple Points of Viewing (MPV) was invented with the development of SH Lidar. The intrinsic technology of the SH Lidar provides MPV, a radical 3D visualization feature which allows the computer-brain of the system to have greater “visibility” of the environment, seeing from multiple points of view simultaneously due to its 360 degree coverage. The Lidar brain and control center is able to take advantage of a million points of view, scanning the environment in nanoseconds. The 360 degree rotating view of the environment is able to assess the environment, “seeing” faster and more completely than the human brain, excelling beyond what the eyes, ears, and human brain can perceive from the driver’s seat of a moving vehicle. It can “see” emergencies in some cases before a human driver can because the system has the advantage of a million different points of view, directly centered on the moving vehicle, using the view from the driver’s seat, but not confined to this as a single point of view.

Viewing SH LiDAR data in real-time is akin to moving through computer-generated 3D scenery. The “view” can be shifted, choosing from a million views of the environment if you are looking at a computer screen. The computer sees the millions of views simultaneously. The views include multiple views from overhead, from different vantage points, or directly ahead like a conventional driver in a driver’s seat.

Every measured LiDAR point reflects full X, Y, Z reflectivity data over time, which means that the observer’s point of view can be selected at any location within the scene. With instantaneous visual information from multiple vantage points, the computer analyzes millions of points at speeds measured in nanoseconds, to assess conditions of the environment including the lay of the road, road conditions, foot traffic, approaching pedestrians, and vehicle traffic. XYZ points that move together are recognized as objects and, due to the high density of data, can be classified discretely as bicycles, pedestrians, cars, etc.

Multi-laser SH Lidar can produce data that include these qualities: 1) Abundant data for up-close, mid-range, and far range viewing. 2) Accurate data without false positives or false negative information. It is not blinded by sunlight and can “see,” well at night. 3) Lidar is durable and reliable in all kinds of weather, including snow, fog and rain. 4) It can “see” in 360 degrees. 5) It “sees” in measurements, so it is highly accurate and not confused by optical illusions, like cameras. Multi-laser SH Lidar can currently be purchased as small as a hockey puck.
Optics in 3D Visualization

In a complex SH LiDAR system, 3D visualization is made through mathematics calculating the speed of light waves. The nano-sized light waves are also analyzed for their characteristics using patented software, measuring the travel-time of light waves in nanoseconds, so the quality and size of the optical lens is critical.

The optical lens in a 3D viewing system for a vehicle system is comparable to the central nerve system of a human. It gathers information and serves as a vehicle’s eyes and ears, providing the entire perception system for a vehicle. The lens gathers accurate environmental information, measuring and analyzing at speeds of nano-seconds, feeding a computer and software system which will make critical decisions to navigate the vehicle. In a SH LiDAR system, 3D visualization is made through mathematics calculating the speed of light waves. The nano-sized light waves are also analyzed for their characteristics with software.

The SH Lidar technology involves measuring the travel-time of light waves in nanoseconds, so the quality and size of the optical lens is critical. The lens acts like a telescope gathering fragments of light returning. Lasers generate billions of photons, but for each 1M photons sent out, 1 photon returns. Lasers send out 1B photons to generate 1000 photons of information. The equipment required to measure this needs to operate extremely fast.

This highlights why a high quality lens is required to generate accurate, abundant environmental data. The importance of the size and quality of an optical lens within the Lidar system can be understood if you consider the lens of NASA Hubble’s telescope and other professional telescopes. The far reaching telescopes have large lenses, from 17-33’ in diameter to view far away planets and comets in space. There is a reason that NASA has not yet invented a telescope and method of viewing the universe that is as small as a matchbox. The limits of the physics of optics make it impossible. For a similar reason, SH LiDAR requires a quality lens for accuracy and abundance of data collection, essential for automotive safety. If the lens is reduced to less than 1” in a system, it could produce degraded data best suited for lower levels of ADAS for automotive safety.

The effective range of the Lidar device is in proportional to the diameter of the size of its optical lens. Like professional telescopes, the SH Lidar becomes degraded if it is miniaturized smaller than 1” in diameter. At this point, the viewing distance, resolution, and details becomes compromised. Miniaturization is possible to a certain degree, after which the results produce degraded and compromised data.
“The speed at which images can be developed (pictures of the environment created in order for a car to function and make decisions to drive autonomously,) is affected by the speed at which the data from the environment can be scanned into the system. A variety of scanning methods are available for different purposes such as azimuth and elevation, dual oscillating plane mirrors, dual axis scanner and polygonal mirrors. The type of optic system determines the resolution and range that can be detected by a system.”

- Source: http://www.lidar-uk.com/

Solid-State Hybrid LiDAR Summary

When combined with automated processing of data in real time, reflectivity measurements successfully identify street signs, lane-markings and license plates. SH Lidar excels at “seeing” lane markings.

The data capability of the SH LiDAR sets it apart from other sensor technologies, making it the solution for ADAS with the higher level requirements of safety, including levels 3, 4, and 5. Combining multiple laser beams and firing the laser pulses at extremely high repletion rates (20000Hz)--while rotating the laser sources and detectors up to 20 times per second -- allows for very effective 360° perception around a vehicle, in real time with up to 1.3M data points per second.

Multi-laser Solid-State Hybrid LiDAR produces optimal data with following details:

1) Abundant data for up-close, mid-range, and far range viewing.
2) Accurate data results without false positives or false negatives. The LiDAR is not blinded by sunlight and can “see,” perfectly at night.
3) SH Lidar is durable and reliable in all kinds of weather, including snow, fog and rain.
4) It can “see” in 360 degrees.
5) It “sees” in measurements, so it is highly accurate and not confused by optical illusions, like cameras. Multi-laser SH Lidar can currently be purchased as small as a hockey puck.

The History of Real-Time Lidar

LIDAR is an optical technology of environmental measurement, first used in the 1960s for remote sensing instruments including lunar laser ranging, satellite laser ranging, oceanographic and atmospheric research. Lidar developed slowly for 30 years, used by NASA for atmospheric and oceanographic study, space exploration, weaponry, and for topographic mapping applications. By the mid-1990s, laser scanner manufacturers were delivering Lidar sensors capable of 2,000 to 25,000 pulses per second to commercial customers for topographic mapping applications. In the 1990s, Lidar was used to create accurate maps of three dimensional terrains. Photography based systems and radar systems were less than ideal.
Lidar presented a fast, accurate, and direct (not inferential) method of generating 3-dimensional data.

Real-time Lidar technology has been developing over the past decade, as a direct result of the DARPA sponsored Grand Challenge Races of Robotic Vehicles. Ten years ago David Hall conceived of real-time Lidar in preparation for the second race. It was the first time multiple lasers were bundled into one unit, with an array of detectors to gather abundant data for navigation purposes, working in real-time from a moving vehicle. For the first race Hall had used stereovision but it did not have the accurate data needed for the computer to make critical navigational decisions. Even multiple cameras bundled together produced many false positives and flawed data. For the sophisticated decisions, Lidar was the answer for the second race. The third race held in 2007, Hall was asked to not race but further develop and produce Lidar for other teams. Subsequently, the real-time Lidar was used on six of the winning teams.

“The Urban Challenge introduced the concept of high-density LIDARs through a sensor developed by Velodyne. The new sensor had a spinning head that swept a set of 64 LIDAR emitters through space, generating over 1 million range measurements per second with relatively high angular resolution. This style of sensor enabled a new level of precision modeling that had until then been difficult, if not impossible, to achieve in real time.”

Source: https://www.nae.edu/

Since then, enthusiasm for the technology continued after the Darpa races as dozens of top universities and hundreds of engineers continued their research and development of software/Lidar solutions for autonomous cars. The interest and technology was quickly picked up by Google, Uber, and many other companies who are now developing and offering commercial products. The technology continues to develop and improve at lightning speed.
3. NHTSA AND AUTOMOTIVE SAFETY

Statistics provided by National Highway Traffic Safety Administration or NHTSA report 90 percent of accidents are due to human error. Common driving states which cause fatalities include Intoxication, driver distraction, and health emergencies. Current ADAS address situations with passive technology to prevent injuries, but not a large number of fatalities. ADAS safety levels 3 and 4 will address more dangerous situations with the potential to significantly decrease car and pedestrian fatalities.

In 2013 the NHTSA issued a Preliminary Statement of Policy Concerning Automated Vehicles. It stated, “America is at a historic turning point for automotive travel. Motor vehicles and drivers’ relationships with them are likely to change significantly in the next ten to twenty years, perhaps more than they have changed in the last one hundred years. Recent and continuing advances in automotive technology and current research on and testing of exciting vehicle innovations have created completely new possibilities for improving highway safety… in fact, many are inspired by the vision that the vehicles will do the driving for us…Recent and continuing advances in automotive technology and current research on and testing of exciting vehicle innovations have created completely new possibilities for improving highway safety preventing significant numbers of crashes.”

### Exhibit 02. Classification and Definition of Automated Driving

<table>
<thead>
<tr>
<th>Level of Autonomy</th>
<th>Type of Automated Driving</th>
<th>Description</th>
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<tbody>
<tr>
<td>Assisted (Level 1)</td>
<td>The driver is responsible for motion control while the vehicle provides advisory information and supportive actions when appropriate. Assistance systems include Blind Spot Detection (BSD), Lane Keeping Assist (LKA), Adaptive Cruise Control (ACC), and Autonomous Emergency Braking System (AEBS).</td>
<td></td>
</tr>
<tr>
<td>Automated</td>
<td>Semi-automated (Level 2)</td>
<td>ADAS functions take partial control of the vehicle under specific circumstances and at the driver's discretion. The function combines both longitudinal control (for speeding up or down) and lateral control for additional steering torque overlay or counter-steering based on driving conditions.</td>
</tr>
<tr>
<td></td>
<td>Conditional Automation (Level 3)</td>
<td>All aspects of dynamic driving tasks are automated. The human driver is prompted when to intervene actively as indicated by the system.</td>
</tr>
<tr>
<td>Fully Automated</td>
<td>Highly Automated (Level 4)</td>
<td>All aspects of dynamic driving tasks are automated. The system has the ability to override manual controls if the driver fails to respond timely to a system-generated warning based on information derived from the driving environment.</td>
</tr>
<tr>
<td></td>
<td>Fully Autonomous (Level 5)</td>
<td>The vehicle is capable of driving itself in all traffic conditions without the physical presence of a human driver. These vehicles need to have redundancy in critical systems, such as steering, braking, and power train, so that they can be fail operational.</td>
</tr>
</tbody>
</table>

Source: Frost & Sullivan; NHTSA; MIRA Ltd
Within the Statement, NHTSA published a chart of safety levels for ADAS automated vehicles. It included the complete range of vehicle automation, ranging from vehicles that do not have any of their control systems automated (level 0) through fully automated vehicles (level 4). The agency segmented vehicle automation into these five levels to clarify the level(s) of automation.

The distinct levels provide car makers and developers of sensors and systems for ADAS a language and way to categorize the new safety systems and the degree and features of driver assistance it provides.

**Exhibit 03. Roadmap to Automation- Driver Driven to Driverless Vehicles**

**LiDAR Covers All Levels of ADAS Automated Safety**

- **LEVEL 0**: No Intervening Vehicle System Active
- **LEVEL 1**: System Handles the Other Function
  - **Assisted Driving**: Driver Carries Out All Lane Holding and Lane Changes in a Special Application Case

- **LEVEL 2**: System Handles Lane Holding and Lane Changes in a Specific Application Case

- **LEVEL 3**: System Handles Lane Holding and Changing in a Specific Application Case: Detects Limits of System and Asks the Driver to Take Over With Sufficient Warning

- **LEVEL 4**: System Handles Lane System Can Handle All Situations Automatically in the Specific Application Case: Sufficient Warning

- **LEVEL 5**: System Can Handle All Solutions Automatically Throughout the Trip: No Driver Needed

**LiDAR is Essential Part for ADAS**

Source: Frost & Sullivan, VDA Automotive SYS Konferenz 2014

**Sensor Technologies for ADAS**

ADAS (Advanced Driver Assisted Systems) covers a wide variety of capabilities that make for easier and safer driving. Car makers are currently using an array of less expensive sensors to provide safety, when minimal data, 2D information, and low resolution data is helpful and acceptable.
In anticipation of the growing automotive automation market, the NHTSA released a ratings chart describing levels of safety, from 1 to 5 for Advanced Driver Assistance Systems (ADAS.) The paper will document current ADAS technology and the companies producing sensors addressing levels 1 and 2. Examples of level 1 and 2 are parking assist, backup safety, and warning lights for blind spot detection.

**Currently addressing levels ADAS safety levels 1 and 2:**
- Long and Short Range Radar,
- Short Range Lidar,
- Infrared Sensors,
- Single Laser Lidar,
- Flash Lidar,
- 4-8 Laser Lidar,
- Camera and Stereovision
- Sensor Suites, a combination of above sensors

The more advanced the automated driving features are, the greater the requirement for both data quantity and data quality. For Level 3 and Level 4 ADAS features -- where the computer assumes control from the human being, especially in emergency situations – rich, redundant data is essential. False positives are unacceptable, since bad data could well prompt the computer to brake for an object that doesn’t exist.

The NHTSA applauds the current features in ADAS; at the same time it calls for more measures by car makers to reduce highway and pedestrian fatalities. This would require addressing higher levels of safety, 3, and 4 of ADAS, with sophisticated technology to actively mitigate accidents. Developers of alternative technologies advocate for a suite of sensor technology stitched together and coordinated with complex software solutions.

The system should cover 360 degrees of the environment and not isolated, sliced sections of the environment in the front and rear of a vehicle. For levels 3 and 4 to be adequately addressed, a sensor system should be able to anticipate danger coming from the sides as well as front. Side views become important to mitigate accidents caused by lane changing, or vehicles entering from an on-ramp onto highway.

For a robotic technology to intervene and make an important decision such as to brake, it has to be accurately informed by the 3D visualization system in real-time. False positives, which are abundant in photographic-based sensor system, are unacceptable. The technology for level 3 and 4 requires brake functioning, steering, speed, and all other controls in place that are needed for autonomy.
To make tough decisions on critical maneuvers, the system should be equipped with sensors with high resolution for object detection, a 360 degree view and range up to at least 200 meters, and the system should produce accurate data without false positives.

ADAS systems which address levels 3 and 4 will reduce highway fatalities more dramatically because most fatalities are caused by complex road and driver conditions, at speeds over 15 MPH when changing lanes and while typically driving in the city and on the highway. Collision avoidance and crash prevention requires a more robust and sophisticated technology.

“Ford is road-testing a fleet of self-driving Ford Fusion Hybrids in Dearborn, Michigan, and hopes to expand beyond its hometown. What’s more, the company wants to offer a no-kidding, it’s-fully-autonomous car in five years. No middle ground, not half measures, just a headlong leap into robo-vehicles...to avoid one big problem with semi-autonomous technology.”

- Alex Davies in Wired Magazine comments about Ford’s plan for autonomy.


Ford is one automaker that is fast moving on its technology roadmap to have fully autonomous vehicle on road. Recently at CES they showcased their Level-4 autonomous vehicle which takes human totally out of the loop. Ford plans to introduce directly Level-4 safety compliant autonomous vehicles, closely working with Velodyne to achieve this using LiDAR. Ford plans to skip Level-3 and go directly to Level-4, assuming a high degree of autonomy is needed for level 3 because the engineers at Ford do not believe that a driver can be expected to recover control in matters of seconds. Ford wants to skip Level 3 because it presents the one of the biggest challenges with this technology: How to safely transfer control from the computer to the driver, particularly in an emergency.

A lot can happen in that time—a car traveling 60 mph covers 88 feet per second—and automakers have different ideas for solving this problem. Audi has an elegant, logical human machine interface. Volvo is creating its own HMI, and says it will accept full liability for its cars while in autonomous mode.”

Audi says its tests show it takes an average of 3 to 7 seconds, and as long as 10, for a driver to snap to attention and take control, even with flashing lights and verbal warnings.

Next Generation ADAS

Car makers have been testing and analyzing SH Lidar technology to address NHTSA safety levels 1, 2, 3 and 4 simultaneously. The technology has been developing over the past ten years and has reached a state of technical and product maturity.

The same technology developed for robotic autonomous driving is appropriate for the development of Forward Crash Avoidance and Mitigation (FCAM) systems with Automatic Emergency Braking (AEB) systems and Crash Imminent Braking (CIB.)

To explain the concept of providing the utmost in safety, Japanese Professor Masao Nagai called it Autonomous Intelligence, a term used by Nagai in a 2014, ADAS with autonomous intelligence for the future innovation of safety.

The professor points to the aging population in Japan and sees the need for a back-up safety system “to recover the situation from degraded performances of recognition, decision-making and operation for elderly drivers.” On the same hand, a robust Lidar safety system could recover an emergency situation for the disabled, distracted, tired, and intoxicated saving many lives.

The conversation within the consumer automotive market will likely shift from exclusively about autonomy to the safety it can provide. As the cost of the SH shrinks, car companies will likely offer cars with autonomous technology primarily used as safety back-up systems. The technology for advanced ADAS needs to be accurate and robust. The technology for level 3 and 4 requires brake functioning, steering, speed, and all other controls in place that are needed for autonomy. However, a Lidar system will likely be welcomed first because of its contribution to safety.

Exhibit 04. LiDAR Application and Technology Roadmap in Automotive

<table>
<thead>
<tr>
<th>Phase</th>
<th>Passive Safety</th>
<th>Semi and Highly Automated Driving</th>
<th>Fully Automated Driving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most Suited LiDAR</td>
<td>Flash and Simple Lidar</td>
<td>Solid-State Hybrid 360 Rotating Lidar</td>
<td>Solid-State Hybrid 360 Rotating Lidar</td>
</tr>
<tr>
<td>Resolution</td>
<td>Low to Moderate</td>
<td>High Resolution</td>
<td>High Resolution</td>
</tr>
<tr>
<td>Speed Range</td>
<td>Up to 50Km/hr</td>
<td>Up to 70Km/hr</td>
<td>Up to 150Km/hr</td>
</tr>
<tr>
<td>Operational Range</td>
<td>Short range close to 30m</td>
<td>Short to long range 200m</td>
<td>Short to long range 300m</td>
</tr>
<tr>
<td>Use case</td>
<td>Driving under limited uncertainties with driver alert all of the time</td>
<td>Driving needs 100 % backup from system</td>
<td>Driving needs 100 % backup from system</td>
</tr>
</tbody>
</table>

Source: Frost & Sullivan
NHTSA New Goals for Braking

ADAS Braking systems in play today employ low cost, single laser Lidar as well as radar, cameras, and infrared sensors. The enthusiasm for an automated (back up) safety braking system is high but the delivery on good braking systems in 2015 is low.

An analysis of the tests conducted in 2015 shows that though most car models drastically reduced their speed, but could not avoid the impact and nor brake as expected. This is evident in AUTOEVOLUTION, 11TH MAY 2015, 14:54 UTC HTTP://WWW.AUTOEVOLUTION.COM/NEWS/SHOCKING-MOST-PEDESTRIAN-EMERGENCY-BRAKING-SYSTEMS-FAIL-INDEPENDENT-TEST-VIDEO-95337.HTML

Automatic-braking systems may get scored during a future round of government safety tests. The NHTSA has submitted a proposal to test and rate this crash-avoidance technology to better differentiate the effectiveness of the systems currently on sale. In the future, the SH Lidar will be cost reduced and provide vehicles with a more complete and robust system of visualization for crash avoidance.

The National Highway Traffic Safety Administration plans to add two cutting-edge automatic emergency braking systems to the recommended advanced safety features included under its New Car Assessment Program (NCAP) – the latest step in a half-century of safety innovations.

The agency plans to continue to encourage development and commercialization of additional promising safety-related technologies of vehicle automation through its recommendation of two automatic emergency braking systems – crash imminent braking (CIB) and dynamic brake support (DBS).

**Automatic Emergency Braking (AEB)**

AEB system technologies are a subset of what NHTSA refers to as Forward Crash Avoidance and Mitigation (FCAM) systems. Whereas the FCAM designation includes systems that provide Forward Collision Warning (FCW) only, AEB systems such as Crash Imminent Braking (CIB) and Dynamic Brake Support (DBS) are specifically designed to help drivers avoid, or mitigate the severity of, rear-end crashes. CIB systems provide automatic braking when forward-looking sensors indicate that a crash is imminent and the driver has not braked, whereas DBS systems provide supplemental braking when sensors determine that driver-applied braking is insufficient to avoid an imminent crash.
According to NHTSA data, one-third of all police-reported crashes in 2013 involved a rear-end collision with another vehicle at the start of the crash. The agency also found that a large number of drivers involved in rear-end crashes either did not apply the brakes at all or did not apply the brakes fully prior to the crash. Crash imminent braking and dynamic brake support systems can intervene by automatically applying the vehicle’s brakes or supplementing the driver’s braking effort to mitigate the severity of the crash or to avoid it altogether. This would include the development of Forward Crash Avoidance and Mitigation (FCAM) systems with Automatic Emergency Braking (AEB) systems and Crash Imminent Braking (CIB.)
4. ALTERNATIVE SOLUTIONS TO SH LIDAR FOR AUTONOMY

We will consider whether it is realistic that Phased Array technology, MEMS technology, radar, stereovision, non-SH LiDAR, or other unseen technology in combination can replace SH LiDAR technology in advanced safety and autonomy in the future. We will look at alternative concepts for guiding autonomous vehicles and advanced safety.

Single-laser LiDAR

The historical approach of using a single laser beam rotating in a circle, or some fraction of a circle, results in measurement of a single plane (the difference between 2D and 3D data). Objects directly in front of the vehicle can be detected only if they are exactly within that plane. Objects that are slightly above or below the plane won’t be detected and so collision avoidance is almost impossible with a single laser.

Exhibit 05. Comparing Single-laser LiDAR and Multi-laser LiDAR

Implications for ADAS

Multi-Laser

- **Multi-laser Channels:** Velodyne employs up to 64 laser channels and a vertical field of view of 30-40°, depending on the model of LiDAR sensor, with spacing as tight as 0.3°
- **Enables Detection in harsh environment:** Design enables the scanner to direct multiple laser lines on an object, even at 100 meters range enabling detection even under harsh weather conditions.
- **High Resolution:** The tight spacing produces high special resolution good for object recognition and collision prevention. Combining high resolution and an extensive vertical field of view yields other significant benefits.
- **Real Time 360 Detection:** Velodyne’s real-time 3D LiDAR sensors can also be used for localization within the environment. The high spatial resolution supports feature recognition in a scene (a sidewalk, streetlamps, parked cars, etc.)
- **High Precision:** Comparing the real-time scenery to a pre-recorded map in order to determine an exact location beyond anything GPS can provide

Single-Laser

- **Sick AG offers a single plane, 2D scanner,**
- **For DARPA Grand Challenge multiple scanners used to achieve directional 3D perception.**
- **Alternatively, Challenge participants created “nodding” mechanisms whereby a motor would move the 2D sensor up and down, to extend the view beyond a singular plane.**
- **Acquiring 3D data through nodding does not lead to problem solving the problem:**
- **At highway speeds of 65 mph (100 km/h), nodding frequency would be much too slow to fully detect an object at 100 meters and still react in time to avoid a collision.**

Single-Laser

- **IBE0 markets a four-line Lux sensor for simple ADAS features that do not require 360°**
- **Offers one or two lines on target, with a restricted horizontal field of view (145°).**
- **IBE0’s approach of using 4x laser lines, spaced over a few degrees though significant solution but has limitations for higher-level autonomous features**
- **In this configuration, typically just one or two laser beams hit an object, making classification of that object difficult.**
- **Radar system detects but it unable to analyze it physical form.**
- **A narrow vertical field of view (3.2°). Any deviation results in object not being detected but can detect road instead.**
Camera and Radar

“Unlike camera imagery, which has an abundance of information, but requires pattern-recognizing software to bring meaning to all those pixels, LiDAR systems deliver a potent stream of point-clouds that is easily digestible by a car’s computer network. These rapid-fire accurate 3D snapshots of every object surrounding the vehicle can occur day or night, rain or shine. Lidar would turn cars into machines keenly aware of their surroundings—with the ability to discern details to the centimeter from 100 meters away.”

- 11-Feb-2015 Automotive Engineering magazine

LiDAR is a direct measurement of distance and reflectivity. LiDAR is not like stereovision; distances are measured by determining the time it takes for a pulse of light to travel from the sensor to an object and back again based on time of flight principle. The return signal level is used to determine reflectivity after normalizing for distance and laser power.

Cameras are high-res only in 2D, but are quite poor in the third dimension, and traditional radar has a very limited spatial resolution. LiDAR, by contrast, can not only be used to identify objects around the car but also classify them, distinguishing pedestrians, bicycles, other vehicles, etc. High resolution LiDAR creates pictures, versus the abstract spots radar produces. Based on the classification, prediction models of path interference can help to control the vehicle in a manner that avoids collisions (Autonomous Intelligence).

Cameras have problems at both extremes; blinding sunlight over saturates the data with false positives and it has trouble “seeing” at night. Because SH LiDAR uses its own light source (e.g., lasers), it works equally well in bright sunlight as well as in the darkness of night.

LiDAR data is especially computer-friendly, providing full 5D information (X,Y,Z, Reflectivity and time), which is easy for ADAS software to process. While camera data might provide higher pixel density, the information in those pixels is much more limited, since the third dimension is missing. In order for camera data to be interpreted correctly, higher computing power -- by orders of magnitude -- is necessary; native LiDAR data is much more content-rich, which makes for better, more reliable Autonomous Intelligent decisions.

Photographic solutions, like Mobileye use a method called “structure from motion,” to analyze the 2D image and gain some 3D information. However, if a vehicle comes to a stop at a stoplight and is not moving, the information can’t be computed. Mobileye method’s method has limitations in bright sunlight and in darkness due to the 2D camera technology. It has software with an extensive dictionary of roadway symbols, car descriptions, and road signs, so that the Mobileye makes the most of photographic 2D data for level 1 and 2 safety. The camera system works well for low level safety, but not it is not suited to autonomy or advanced safety.
Comparative Analysis of Camera and LiDAR

Exhibit 06. LiDAR Systems in Comparison to Camera and Radar

3D LiDAR has the highest spatial resolution in the X, Y, and Z coordinates. Can not only be used to identify objects around the car but also classify distinguishing them as pedestrians, bicycles, other vehicles, etc. Avoid collisions.

LiDAR uses its own light source (e.g., lasers), it doesn’t depend on environmental lighting. LiDAR works equally well during the day and at night, and unlike a camera, is not blinded when pointed in the direction of the sun.

Computer-friendly, providing full 5D information (X,Y,Z, Reflectivity and time), which is easy for ADAS software to process. Necessary. LiDAR data is much more content-rich, which makes for better, more reliable Autonomous Intelligent decisions.

Cameras

Quite poor in the third dimension, and very limited spatial resolution.

Depend on environmental lighting

While camera data might provide higher pixel density, the information in those pixels is much more limited, since the third dimension is missing. In order for camera data to be interpreted correctly, higher computing power – by orders of magnitude -- is necessary.

Radar has the historical advantage of measuring speeds of objects over relatively large distances (300 meters), and Radar sensors can be hidden behind the bumper, since radar is not a line-of-sight measurement, as LiDAR is. On the other hand, Velodyne Lidar has already increased its detection range to 200 meters with a range of 300-400 meters to be attained at the latest by 2017.
LiDAR has no problem calculating the speed of an oncoming car and now the technology is replacing radar as the first choice for determining car speed by police. Radar doesn’t come close to approximating LiDAR’s spatial high resolution and object detection. Radar has problems with false positives that need to be filtered out by advanced software.

**MEMS, Flash Lidar, and Phased Array (OPA) Technology for 3D Visualization**

Companies developing MEMs (micro-electrical-mechanical systems) and Phased Array LiDAR technology have proposed as methods to challenge SH LiDAR. The technologies face serious obstacles:

1) Small beams fundamentally lead to more divergence which leads to less range. The three LiDAR technologies of Flash LiDAR, MEMS based LiDAR and OPA LiDAR currently operate in limited range and limited FOV. They also face increases in laser power which would need to be made in order to scale for usefulness.

2) Limited actuation means limited horizontal and vertical range. Yes, limited horizontal range could conceptually be covered through multiple sensors around the vehicle, but these would also need to be stacked several times vertically to achieve the vertical range, which is not practical. Finally, the software effort to stick such sensor together is both highly impractical and costly.
3) Continuous detection of the LiDARS field of view will jeopardizes safety, reliability and performance as the sensor is greatly susceptible to sun noise, other sensors and foul-play. A false positive from one of these factories could lead to continuous vehicle stoppage (or worse).

4) Thermal and manufacturing issues with both laser actuation and detection have not been solved for a practical working system.

MEMS, OPA, and Flash Lidar system solutions address one part of the whole working Lidar system, without addressing the detector system solution and power source. Storage of the power supply, the powerful laser, and a detector system are not solved for its form factor at this time. The detector system is the most expensive and complex part of the sensor system. It is not clear if the MEMS or Phased Array systems will require a larger, more powerful laser which will run up the power requirement for the system and run hot. The powerful laser may need to be stored in the car trunk because it is so large.

Until the detector is developed and its solution solved for MEMS and Phased Array systems, it is premature and a leap of imagination to assume either technology will work as a full system. There is reason to assume it will be effective at data collection, compact in a small ID, or prove to be an inexpensive alternative for autonomy.

MEMS and Phased Array technology have limited FOV (field of view.) which need to be stitched together with the computational complexity to do this. The limited field of view in mirror solutions causes highly degraded and less abundant data. The range for Mems has been tested at best currently to 50M.

Current MEMS and Phased Array systems produce less data and degraded data in comparison to multi-Laser LiDAR systems. This is due to trouble functioning in bright sunlight, darkness, and the limited FOV. The systems are limited in range, resolution, object detection, object identification, and data reliability. There is speculation by LiDAR developers asserting software can enhance the degraded data, but so it is unproven. Both systems have trouble working in bright sunlight from over-saturation with unreliable data.

There isn’t evidence showing a well-developed progression of the technology toward autonomy that would ultimately replace the multi-laser Lidar system in the next ten years. The experimental alternatives so far tested may be applied to ADAS applications that address level 1 and 2. Prototypes of the experimental technology described above have yet to cross multiple road blocks and become viable alternatives for autonomous driving or autonomous intelligence that address levels 3 and 4. The rotational Lidar is patented and currently only used by Google and sold by Velodyne. Thus, the developers have been scrambling to find other methods for a robust and affordable solution to 3D visualization. Developers have philosophical ideas for approaching the difficulty of autonomy but they face serious roadblocks.

Driverless cars and those with autonomous intelligence systems depend on abundant, accurate data. Algorithms must be sophisticated to understand the driving environment’s direct and indirect messages in terms of traffic and maneuvering.
5. TESTING DURABILITY AND RELIABILITY OF SH LIDAR

Sensors used in safety systems demand hours testing including actual road testing before use on public roadways. Current LiDAR selling on the market passes all safety tests currently imposed on LiDAR manufacturing including eye safety. Velodyne Lidar stands out as a system road-tested over a period of seven years. Starting in 2009, Velodyne’s LiDAR technology has been tested on the Google fleet of “driverless cars,” well publicized as it drove on more than a million miles of road.

In the Google Self-Driving Car Project “In 2009, Google started the self-driving car project, since then…Google cars have self-driven over 1 million miles and are currently out on the streets of Mountain View, California and Austin, Texas…we tested with the Toyota Prius, each designed from the ground up to be fully self-driving. There are safety drivers aboard all vehicles…”

- Google 2015 website
Source: bhttps://www.google.com/selfdrivingcar/

In June, 2015 Google published the safety results of the tests and no errors were attributed to the technology of the autonomous cars. Seven small incidents were caused by human error of other cars on the roadway.

Caterpillar purchased hundreds of Lidar units from 2009 to the present, mounting them on large mining trucks and other construction vehicles for 3D real-time visibility. Caterpillar was satisfied with the SH Lidar performance and safety record and entered into a multi-million dollar deal exclusivity contract with Velodyne to supply LiDAR for mining and construction vehicles. However, before signing Caterpillar demanded stringent tests and “hardening” of the LiDAR. Caterpillar vehicles often work in extreme weather conditions, including the freezing cold and hot desert.

The Lidar was hardened and manufactured to pass tests for extreme heat, extreme cold, visibility and functionality in rain, snow, and sleet, waterproofing, intense vibration, humidity tolerance, sensor cross-talk, multi-echo capability (necessary for functioning well in snow, sleet, rain, dust, and fog.) The sensor had to test negative on “blinding,” caused by light sources such as the sun, headlights, light towers or highly reflective targets. The Lidar was tested for accuracy of intensity, scan rate, beam divergence, range accuracy, field of horizontal view and field of vertical view. It was drop tested and shock tested, tested with chemical spray and salt water spray. The Lidar passed all of the environmental and mechanical tests and the agreement was signed in 2012.
6. LIDAR FORM FACTOR AND PLACEMENT ON VEHICLES

There is concern by car makers that the form factor of LiDAR system integrates seamlessly into car design. Fortunately, the developers and manufacturers have addressed the concern with new designs in 2015 and even more in 2016.

The SH LiDAR is no longer bulky, but has been reduced in size to the size of a hockey puck. SH LiDAR developers have multiple design concepts which will be introduced at 2016 CES.

Current design concepts for Lidar integrated with automotive designs are modern and streamlined. Designs include puck shapes that integrate with the two side mirrors or on the two front “A” frames of a vehicle. The puck-sized Lidar can also be mounted inside the car, integrated and close to the position of the driver’s rear view mirror.

Exhibit 08. Latest Innovative Approach to Automotive Safety by Velodyne

Velodyne Lidar mounted on two front, side mirrors

Source: Velodyne Inc.

7. ROADMAP TO AUTONOMY

Velodyne Roadmap: In 2016, the following products will be released, but their feature set, specifications, technology details, and release dates are top secret.

- New design HD Lidar concepts for vehicle integration, January 2016
- VLP-Auto specific with enhanced resolution
- VLP-Drone will be a light weight Lidar developed for drones
- VLP-Robot will be for robotic industrial use
Quanergy Roadmap: Quanergy announced recently: “Quanergy Systems, Inc. will introduce in 2016 the first solid-state LiDAR sensor for advanced driver assistance systems (ADAS)” The sensor will likely address safety level 1 and 2.

Mobileye Roadmap: Mobileye plays in the level 1 and 2 safety level. On their website, November 2015, Mobileye states, “Mobileye is already working on the next evolution - autonomous driving – and is planning to launch, in the 2016 timeframe…The technology is enabled by a number of forward-facing cameras and low-cost radars for redundancy…”

**Exhibit 09. LiDAR in Automotive - Key Developers and Manufacturers**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Number of Channels in LiDAR</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Velodyne</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Valeo</td>
<td>X</td>
<td>Yes</td>
</tr>
<tr>
<td>Quanergy</td>
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<tr>
<td>IBEO</td>
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<td>Yes</td>
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<tr>
<td>Denso</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Continental</td>
<td>Yes</td>
<td>X</td>
</tr>
</tbody>
</table>

Source: Frost & Sullivan

Google Roadmap for Autonomy: Google announced on their 2015 website their short range plan, including launching a large fleet of limited-speed fully autonomous vehicles tested as robotic service vehicles.

**8. MASS PRODUCTION OF LIDAR AND COST REDUCTION**

The cost of SH Lidar units is impacted by the cost of materials, components, and several more factors. The cost will dramatically drop as they are manufactured in large volumes. Velodyne SH Lidar has been selling on the commercial market for several years and the cost is estimated to be reduced by 90% from 2007 to 2017/2020.
Cost reduction is accelerating as more LiDAR is selling in larger quantities and is in the process of being designed mass production. The cost to be reduced to $500 at an annual production volume of 1M units that is likely happen after year 2018.

**Current SH Lidar Production**

Velodyne LiDAR is currently used by most autonomous car research teams which the company manufactures in Morgan Hill, California, in a 60,000 sq. ft. facility. Here they have been engineered, tested, and for five years and also sold in moderate industrial quantities. With recent growth in demand for the Lidar products, plans are underway for facility expansion and additional hiring to accommodate larger production.

In 2015, the Velodyne has expanded its team by adding to its engineering talent, program managers, a new VP of Operations, VP of Engineering, CFO, 30 new engineers, President and acting COO. Staff has been added with skills to specifically engineer cost reduction while maintaining the high quality of the LiDAR. Also in 2015, the Velodyne Puck (VLP-16) was introduced; the smallest, newest, and most advanced product of the Velodyne LiDAR series, it sells at 90% of the cost of the original Lidar 64. Significantly more cost-effective than similarly priced sensors and developed with mass production in mind, it retains the key features of Velodyne’s breakthrouts in LiDAR: Real-time, 360°, 3D distance, calibrated reflectivity measurements and unmatched accuracy.
To this last point, it is the LiDAR industry’s responsibility to educate automakers on the potential of autonomous intelligence for ADAS and vehicle safety. This can be accomplished through seminars, editorials, press activity, website activity, social media, TV, and presentations at major trade shows. The goal of Lidar industry should be to educate the public and decision makers about the technology and its benefits. With education, the conversation will be more about how the technology will provide radically enhanced safety for vehicle travel.

9. CONCLUSION

There is an important role for Solid-State Hybrid LiDAR in the near future for automotive safety and autonomous driving. LiDAR technology provides a reliable perception method of 3D data collection, acting as the eyes and ears of a navigation system in real-time. The invention of the Solid-State Hybrid LiDAR technology was a result of the Darpa Grand Challenge Robotic Car Races, making it possible to robotically navigate across desert terrain in real-time.

LiDAR technology has been road tested over a million miles of road in ten years by Universities, Google, Caterpillar, and others, so today the technology is ready to be applied more widely and sold in the market for autonomous driving and safety.

Less robust and smaller sensors are in use today, providing passive safety for vehicles, covering levels 1 and 2, but safety levels 3, 4, and 5 will require the robustness and accuracy of Lidar technology.
The Solid State Hybrid Lidar technology is leading the way toward advanced automotive safety and the convenience of vehicle autonomy. When combined with advanced software and computer technology, LiDAR equipped safety systems can provide features and meet the requirements of SAE Safety Levels 1 to 5. Other 3D viewing sensor technologies on the horizon have been compared to LiDAR, yet none are promising for the enormous task of autonomous navigation or autonomous intelligence for advanced safety.

Semiconductor hybrid LiDAR is now miniaturized to the size of a hockey puck and its price has dropped by substantially (approximately by 90 percent) since first on the market. The technology has evolved to be small in form factor and affordable, providing key safety for vehicle travel. As the trend goes the cost of LiDAR is estimated to drop substantially again in 2016, becoming more affordable for car makers who will eventually provide impactful safety features and autonomy the massive automotive world market. Due to recent innovations of LiDAR, automotive users will experience safer, robotic, and futuristic methods of travel, sooner than ever imagined.

Safety systems with advanced back-up features can become the norm in our lifetime, preventing the alcoholic from killing himself along with others, allowing seniors to be independent by driving longer, and helping the disabled drive. It can be a back-up for young teen drivers who are documented to take more chances, speed, and text more often while driving. The future will also see driverless service vehicles in the cities for the general public. Navya is partnering with Postbus, a public bus company in Switzerland to provide the first bus service for the public, open on a limited route in March, 2016. It has been tested for more than a year with an SH LiDAR for navigation.

Source: http://chb44.com/2015/10/navya-arma-french-autonomous-vehicle-that-wants-to-compete-with-google-car/
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