Vehicle Clearance

Literature Review

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13. ABSTRACT (Maximum 200 words)
This project will investigate and test truck-mounted LIDAR and optical sensors to determine their feasibility for detecting hazardous bridge/tunnel heights for warning the driver of an overheight truck. This document, which describes the problem and reviews potential solutions, is the first deliverable of the project.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	g
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
mL	milliliters	0.034	fluid ounces	fl oz
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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List of Abbreviations

Abbreviation	Term
LIDAR	Light Detection And Ranging

1. Literature Review

1.1 Purpose

The purpose of this project is to identify and demonstrate a vehicle-based technology for (i) detecting a low-clearance overpass in the path of a commercial vehicle (heavy-duty truck or heavy-duty bus) and (ii) demonstrating the feasibility of warning the commercial driver about the low clearance in time to avoid striking the low-clearance overpass.

1.2 Requirements

We conducted a literature review to identify potential vehicle-based technologies that can be used to detect low-clearance overpasses and warn commercial drivers of the impending low-clearance danger in time to avoid impact. A suitable technology will need to detect a bridge or tunnel ceiling at sufficient range to provide enough warning for the driver to stop the truck in time to avoid a collision. It needs to be sufficiently accurate and repeatable to minimize false alerts without missing a real detection. It needs to have good enough resolution to measure height well enough to determine if the obstruction is too low without generating many false alerts. It needs to be truck mountable and environmentally robust.

1.3 Findings

Most solutions to date have been associated with the overpass rather than with the vehicle. They have relied on fixed Infrared (IR) beams like Trigg Industries detectors[1],[2] that go back to the 1960s or mechanical devices like hanging bars[3],[4],[5] and spring loaded arms[6] for mounting by the road side or at portals. A more modern approach to infrastructure-based overheight vehicle detection uses digital video[7] to provide a lower cost alternative to physical and IR beam detectors. Unfortunately, it is still expensive to put a detector in front of every bridge.

Patents for mechanical devices mounted on trucks go back many years[8] but are not suitable for vehicles

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[1] http://www.triggindustries.com/ (accessed 9/16/2015)
[2] http://www.irdinc.com/pages/its-solutions/overheight-vehicle-detection-system.html (accessed 9/16/2015)
[3] http://www.cisco-eagle.com/catalog/c-7835-low-clearance-alarm-bars.aspx (accessed 9/16/2015)
[4] http://www.alvaradomfg.com/low-clearance-alarm-bar-watchman/ (accessed 9/16/2015)
[5] http://futurenetsecurity.com/products/access-control/overheight-detection/ (accessed 9/16/2015)
[6] http://heightdetector.com/products.html (accessed 9/16/2015)
[7] https://smartech.gatech.edu/bitstream/handle/1853/44893/Sandidge_Matthew_J_201208_mast.pdf (accessed 9/16/2015)
[8] http://www.freepatentsonline.com/5424713.html (accessed 9/16/2015)

traveling at normal traffic speeds.

Passive systems (which only receive energy already in the environment) appear not to have sufficient range and resolution. Active sensors (which transmit a beam of energy) have the potential to meet range and resolution requirements. The three most common types of noncontact distance sensors use ultrasonic, microwave, and laser beams. There are sensors in all three categories that are used for fixed station measurements of the kind described above to measure overheight vehicles or detect vehicles for traffic flow.

There are industrial systems designed to prevent robots and forklifts from having collisions in industrial settings. An example would be a laser-based device like the CATTRON LCAS.[9] It appears that it can be used in fixed or mobile applications.

The same for the Laser Technology Inc, (LTI) detector which is typical in industrial settings but lists bridge height clearance detection as an application.[10] In fact, this particular LTI detector[11] was suggested as a solution to bridge strikes like this one.[12] This OSI Laser Scan device is used to scan for vehicle heights[13] but could be turned around and mounted on the truck to scan for bridge and tunnel heights. That would require developing the control and data acquisition software to make a working system.

Ultrasonic systems have also been proposed[14] or are on the market.[15]

The development of autonomous vehicles in response to the DARPA challenge and the Google Car in the last few years has resulted in active distance measuring sensors designed specifically for mounting on vehicles. Therefore we were able to focus our search on devices already developed for mobile use without looking at fixed station devices that might be adapted to the application.

Autonomous vehicles use a combination of radar and LIDAR (sometimes with video) to sense their surroundings. Radar, which uses microwaves, provides a longer range, lower resolution sensor that is not sensitive to weather or illumination. LIDAR uses laser beams the same way pulsed radar uses microwaves. It bounces pulses of light off of objects in range to form a picture of the environment. The time it takes a pulse to return measures the distance of an object. Because of the much shorter wavelengths and much narrower beams Lidar provides more accuracy and resolution within its range than the radar. Due to its proven real-time capabilities in autonomous vehicles LIDAR technology is a feasible solution to detecting low clearance obstacles.

Microwave ranging systems are not affected by weather as much as other sensor technologies and can

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[9] http://www.lairdtech.com/products/collision-avoidance-system-0 (accessed 9/16/2015)
[10] http://www.lasertech.com/Industrial-Laser-Sensors.aspx (accessed 9/16/2015)
[11] http://www.lasertech.com/trupulse-200X-laser-rangefinder.aspx (accessed 9/16/2015)
[12] http://www.lasertech.com/blogs/Professional-Measurement/post/2014/02/05/Lesson-Learned-Confirm-Bridge-Height-Before-Going-Under.aspx (accessed 9/16/2015)
[13] http://www.roadtraffic-technology.com/contractors/detection/osi/ (accessed 9/16/2015)
[14] http://www.freepatentsonline.com/5389912.html (accessed 9/16/2015)
[15] http://giraffeg4.com/technology/ (accessed 9/16/2015)

have longer range but generally have less range and angle resolution than other technologies. We typically found it used in conjunction with another sensor with complimentary capabilities like vision or LIDAR. We did not find microwave devices that could satisfy this application alone so we will not discuss them further.

1.4 LIDAR Devices

The LIDAR scanner is the technology used to scan the environment in front of the truck in real-time, collecting distance and time measurements in relation to the corresponding angle at which the laser is projected. Software must process the information to identify objects, particularly bridges and overpasses, calculate the height of those bridges and overpasses in relation to the vehicle, and provide warning to the driver.

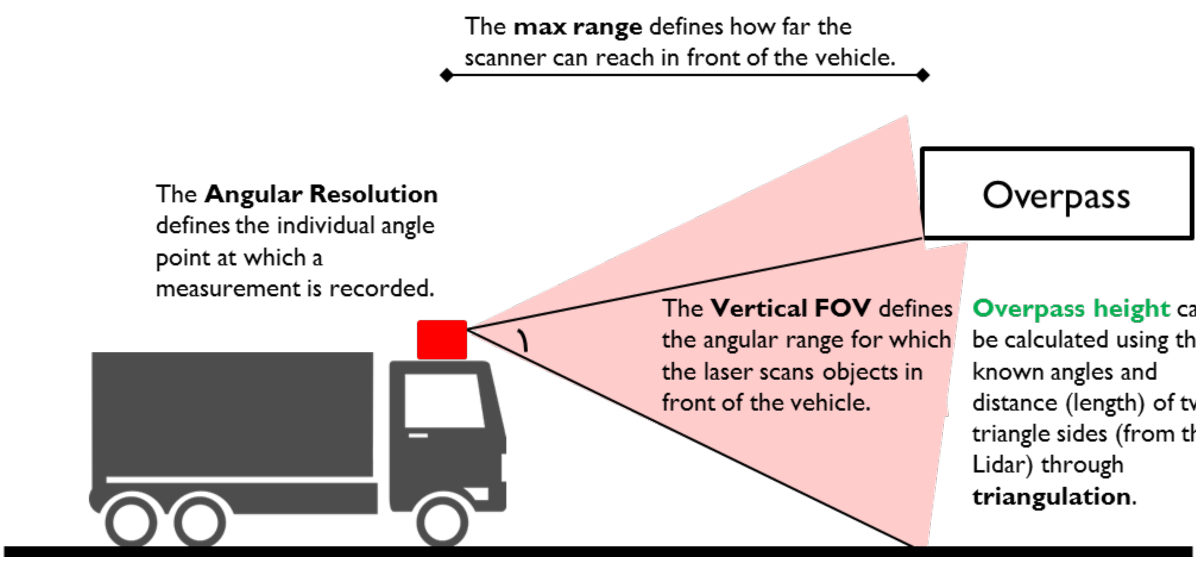

Figure 1. Operation of a Beam Sensor

Overpass objects are identified along a plane in front of the truck by LIDAR sensor measurements. Each reflection received by the LIDAR detector is defined by 4 variables: the time it took the pulse to travel to the target and back, the horizontal angle of the beam, the vertical angle of the beam and the strength of the reflected signal. The last variable is useful to detect material and “color” to some extent, like to discriminate between pedestrians and cars but may not be a factor for detecting bridges and tunnels which are all hard materials.

The distance given by half the travel time is the hypotenuse of a triangle and the vertical angle one of the angles of that triangle. One calculates the legs of the triangle with simple trigonometry which provides horizontal range and height of the target. See Figure 2.

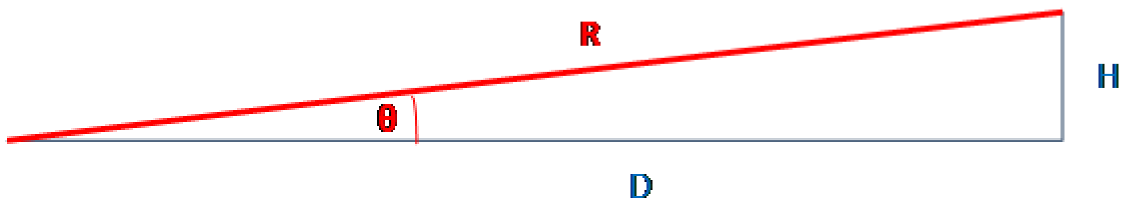

Figure 2. Calculation of Height and Distance

Measured		Calculated	
Range[16]	R	Height	H = R Sin(θ)
Vertical Angle	θ	Travel Distance	D = R Cos(θ)

Once the lowest point of the overpass structure is found the calculations shown in Figure 2 provide the height of the overpass and driving distance to it.

1.5 Evaluation criteria

The key performance variables to judge a sensor for this application are:

- Maximum range
- Vertical Field of View (FOV)
- Horizontal FOV
- Range resolution
- Vertical angular resolution
- Horizontal angular resolution

The maximum range of the sensor is a critical parameter since it must detect and warn a driver in time to stop. Figure 3 shows typical stopping distances as calculated by the Utah Department of Transportation.[17] The sensor must have a range at least as great as the stopping distance for the speed to be protected. Since most non-standard bridges are not on interstate highways but on lower speed roads, the range of the sensor may not need to accommodate the higher speeds shown in this chart. We will determine the actual speed and range requirements for this application in the next phase of this work.

[16] Round trip time t is actually measured. R = t *c, c = speed of light
[17] http://udot.utah.gov/trucksmart/stopping-distances.php (accessed 9/17/2015)

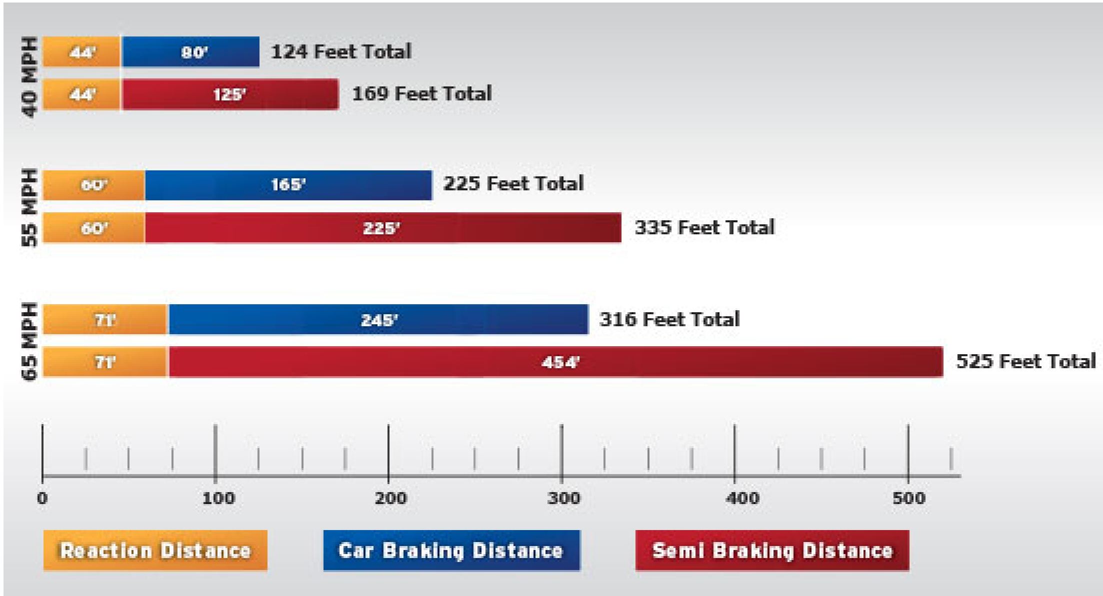

Figure 3. Total Stopping Distances at Various Speeds

The <u>vertical FOV</u> as shown in Figure 1 must be great enough to measure heights at the warning threshold (height that may be too low) from maximum range down to at least the range by which a decision must be made in order to stop the vehicle in time. That would be the Total Braking Distance minus the Reaction Distance shown in Figure 3.

The <u>horizontal FOV</u>, which is essentially the angle looking right and left of the vehicle, needs to be wide enough to measure across the lane the truck is traveling, or perhaps the entire road, from maximum range down to at least the range by which a decision must be made in order to stop the vehicle in time. That would be the Total Braking Distance minus the Reaction Distance shown in Figure 3. It may be preferable to limit this FOV to just the road to avoid processing and falsely alerting on objects that may be too low but not over the road so pose no threat. Narrowing the horizontal FOV to a lane width might be too strict for curving road so the optimum value of this parameter is still too be determined and may be determined experimentally.

<u>Range resolution</u> has to be good enough to meet the resolution requirements of the height calculation.

<u>Vertical angular resolution</u> also has to be good enough to meet the resolution requirements of the height calculation. The smaller the uncertainty in the height calculation the fewer false alerts that will be made while maintaining a safe margin for legitimate low clearance detections.

<u>Horizontal angular resolution</u> has to be good enough to be certain the sensor is looking at targets in the path of the vehicle.

Table 1 summarizes these criteria.

Table 1. Criteria for Choosing a Lidar Technology

<table>
<tr><th>Metric</th><th>Description</th></tr>
<tr><td>Maximum Range</td><td>Maximum distance the sensor can accurately and reliably measure distance.</td></tr>
<tr><td colspan="2">The range needs to be enough that the driver has enough time to stop the vehicle before collision.</td></tr>
<tr><td>Horizontal FOV</td><td>The horizontal range looking right and left of the vehicle facing forward.</td></tr>
<tr><td colspan="2">Need to detect targets in the vehicle’s path but not false alarm on targets off the road.</td></tr>
<tr><td>Vertical FOV</td><td>The vertical range in front of the vehicle that will be determined by how far the laser scans up and down.</td></tr>
<tr><td colspan="2">Has to be sufficient to see the low clearance obstacle until the vehicle is too close to the obstacle to avoid a collision</td></tr>
<tr><td>Range Resolution</td><td>The smallest increment of changing distance that can be measured.</td></tr>
<tr><td colspan="2">This resolution of the range measurement determines the resolution of the height measurement (Figure 2) so indirectly false alarm rate.</td></tr>
<tr><td>Vertical Angular Resolution</td><td>The smallest increment of changing angle that can be measured.</td></tr>
<tr><td colspan="2">This determines the resolution of the height measurement so indirectly, the false alarm rate.</td></tr>
<tr><td>Horizontal Angular Resolution</td><td>The smallest increment of changing angle that can be measured.</td></tr>
<tr><td colspan="2">Determines how well the sensor can discriminate low targets close enough to the vehicle’s path to be a threat from those that are off the road and no threat.</td></tr>
</table>

2. Candidate Solutions

2.1 Ultrasonic/Acoustic

2.1.1 Giraffe G4

Website: http://giraffeg4.com/technology/

Figure 4. Operation of Giraffe 4 Sonic Bridge Height Measurement

The Giraffe G4 technology is a device currently on the market for truckers and RV owners to measure bridge or tunnel height. The unit is a piezoelectric sensor that transmits sound waves at 4 Hz. The driver measures the height of his or her vehicle and manually programs this into the in-cab unit. They mount the sensor somewhere on the cab, say with a magnetic mount on the roof or clamped to an external mirror and program that height into the unit as well. Upon reaching a bridge, the driver must slowly easy the cab underneath and the in-cab unit displays the measure height and buzzes if that height is too low. The truck can then back out to avoid a collision.

The sensor has a range from 20 inches to 12 feet, so if mounted on a mirror at a height of 6 feet for example, the unit will make measurements up to 20 feet.

It can be used for pilot cars up to 30 mph at which point wind shear affects the pulses enough to disrupt the measurement. Note that at 30 mph (44 ft/sec) the vehicle will move 11 feet between pulses. Given human and brake system reaction time of say 1.5 seconds the car would stop roughly 80 feet after a detection. This is longer than a truck length.

Under ideal conditions and reaction times it takes 32 feet to stop a fully loaded tractor-trailer at 10 mph and that is longer than the tractor. So operational speed is limited to perhaps 5 mph and requires the driver already be concerned about the bridge height.

Advantages:

Low cost (list price $300 but available online for $200)

The user can power it from cigarette lighter or any 12v connection in the vehicle.

Disadvantages:

It cannot be used at normal driving speeds. In fact, the truck must essentially stop. That may disrupt traffic, but not as much as a bridge strike.

It requires the driver already be alert and concerned about the bridge height.

It requires the driver to manually measure and program vehicle height and mounting height.

2.2 LIDAR

Table 2 on the following page summarizes potential products found in the literature review that may meet the criteria described in Table 1. Of all the devices examined these may meet both range and FOV requirements. In most cases, that would mean rotating the sensor 90 degrees to get high angular resolution for the vertical FOV which is needed for the low clearance detection application. Autonomous vehicles would need the widest range and resolution in the horizontal plan to scan around the vehicle. Hence, the column in Table 2 for Horizontal FOV would be the Vertical FOV for our application.

Table 2. LIDAR Specification Comparison Chart

Manufacturer	LIDAR	Pricing[18]	Software	Horizontal FOV	Min Range	Max Range	Distance Resolution	Scan Rate	Interface	Angular Resolution	Vertical FOV	Power	Voltage	Mass	Size	Tracking Targets	Sensor / Fusion Options
IBEO Automotive	LUX 2010 Standard 4 Layer	14500	ILV visualization software	110° (50°-60°)	<0.3 m	200m (90%)	4cm	12.5HZ 25HZ 50HZ	Ethernet, CAN, RS232	Up to .125°	3.2"	SW (avg) <10W (Max)	9V-27V	Approx 1 kg	W164.5mm D93.2mm H88mm	Up to 64 objects	Yes, up to 6 sensor fusion system
IBEO Automotive	Scala[19]	16100		145	0.3	250m	10 cm	25Hz	Ethernet, CAN	Up to .125°	3.2	SW (avg) <10W (Max)	9V-27V	0.5 kg	W105mm D100mm H60mm	Up to 64 objects	
SICK	LMS151	6000	SOPAS ET	270°	0.02 m	50m >75% 18m (10%)	+/- 12mm +/- 30mm	50HZ 25HZ	Ethernet, RS232	0.25"-0.50"	N/A	60W	10.8V-30V	1.1kg	105mm 102mm 162mm	N/A	No
LeddarTech	IS16[20]	1900	IS16 software			50m	10mm	Up to 50HZ	USB, RS-485		45°	5.6W	12-30 VDC	430g	136mm 86mm 70mm		
LeddarTech	M16	300[21]	Software Development Kit			100m	10mm	Up to 50HZ	USB, RS-485, CAN, UART		9-95°	4W	12 or 24 VDC	180g	104mm 66mm 48mm		
Velodyne	HDL-64E	75000	VeloView	360°	0.9m	50m (10%) 120m (80%)	+/-2 cm	5HZ 10HZ 20HZ	Ethernet	0.08° 0.17° 0.35°	26.8°	60W	10V-32V	15kg	H284mm D203mm		
Velodyne	HDL-32E	29900	VeloView	360°	1 m	100m	+/-2 cm	5HZ 10HZ 20HZ	Ethernet	0.08° 0.17° 0.35°	30°	12W	9V-32V	1kg	H145mm D86mm		
Velodyne	VLP-16	8000	VeloView	360°	1 m	100m	+/-3 cm	5HZ 10HZ 20HZ	Ethernet	0.1° 0.2° 0.4°	40°	8W	9V-32V	0.83kg	H72mm D104mm		
Optech	Lynx SG1 Mobile Mapper	630,000-780,000	Lynx Survey Optech LMS	360°	1 m	250m (10%)	5mm	Up to 250HZ	proprietary		360°	480W max[22]	12 VDC	200 lbs	W~ft' L3ft H~3.5ft	N/A	No
Optech	Lynx MG1 Mobile Mapper	550,000	Lynx Survey Optech LMS	360°	1 m	250m (10%)	5mm	Up to 200HZ	proprietary			360W max	12 VDC	60 lbs	W~2ft L~2ft H~3.5	N/A	No

[18] Single unit pricing. Many of these devices have lower volume prices.

[19] The Scala is scheduled to be the first LIDAR manufactured for mass production lowering price to a few hundred dollars. Availability estimated December 2016.

[20] Industrial version, enclosure meets harsh environmental standards.

[21] Evaluation kit including sensor $300, standalone sensors after that $1000 each.

[22] Maximum power used at initialization.

Optech	**ILRIS-HD**	**>90,000**		**40°**	**3 m**	**400m (10%)** **1250m (80%)**	**7 mm**	**0.001 to 20°/sec**	**Ethernet or WiFi**	**0.001146° (20 µrad)**	**40°**		**24-28 VDC**	**14 kg**	**W320mm L320mm H240mm**	**N/A**	
Optech	**ILRIS-HD-ER**	**>100,005**		**40°**	**3 m**	**650m (10%)** **1800m (80%)**	**7 mm**	**0.001 to 20°/sec**	**Ethernet or WiFi**	**0.001146° (20 µrad)**	**40°**		**24-28 VDC**	**14 kg**	**W320mm L320mm H240mm**	**N/A**	
Optech	**ILRIS-LR**	**>120,000**		**40°**	**3 m**	**1330m (10%)** **3000 m (80%)**	**7 mm**	**0.001 to 20°/sec**	**Ethernet or WiFi**	**0.001146° (20 µrad)**	**40°**		**24-28 VDC**	**14 kg**	**W320mm L320mm H240mm**	**N/A**	

2.2.1 IBEO Automotive LUX 4 Layer LIDAR

Website: http://www.autonomoustuff.com/ibeo-lux-standard.html

The software architecture that processes the sensor data is the biggest difference between the IBEO LIDAR and other LIDAR sensors. The IBEO LIDAR uses four layers to the signal processing. The first layer, the "Point Cloud" layer, turns the received raw returns into a 3-D collection of points to represent the environment around the sensor. The second or "Object Recognition" layer clusters these points to identify objects like pedestrians and vehicles. The third or "Object Tracking" layer determines the location, direction and speed of up to 65 objects. The last or "Application" layer leverages the processing of the 3 preceding layers to support the actual application. Processing for stationary low clearance obstacles should be simpler than what is done for autonomous vehicles to track moving objects; therefore the software should be easy to implement.

IDEO employs multiple echo detection to improve performance in bad weather. The multiple layers also help reduce sensitivity to pitching as the vehicle moves.

Advantages:

Range of 200m should be sufficient for stopping trucks at any realistic speed.

Disadvantages:

Cost

Figure 5. IBEO LUX LIDAR

2.2.2 IBEO Scala LIDAR

Website: http://www.autonomoustuff.com/ibeo-scala.html

The Scala has wider angle and longer range than the LUX but less range accuracy. What is most significant is that the Scala is scheduled to be the first LIDAR manufactured for mass production lowering price from ~$16,000 to a few hundred dollars. Target release date for the mass produced version is December 2016.

Advantages:

Range of 250m should be sufficient for stopping trucks at any realistic speed.

Production version will have the lowest cost of LIDAR alternative.

Disadvantages:

Lower range accuracy.

Figure 6. IBEO Scala LIDAR

2.2.3 SICK LMS151

Website: https://www.mysick.com/PARTNERPORTAL/TopFrameset.aspx?AutoSelect=SK_Products

Sick makes a number of LIDAR sensors. The LMS151 is a small, lightweight economical sensor used in some automated vehicles. It uses 2 pulses per data point. The LD- MRS sensors have much longer range and could be better suited for the vehicle clearance application. They use 3 pulses per data point for more weather robustness. One measures in 4 planes simultaneously and the other in 8 planes and has a longer range. Listed applications include road cleaning and agricultural vehicles. It turns out that one of the LD-MRS sensors is essentially the IBEO sensor. IBEO is a spinoff of Sick with the complete rights to sell LIDARS for automotive. (The sensor would be purchased from IBEO as the LUX and not as the Sick LD-MRS. The other sensors in the LD-MRS family would not be easily available for our application.) The LMS151 is pictured to the right below. The square sensor to the left is an LD-MRS series device which should be the same as an IBEO device (other than color note the similarity).

The LMS151 does not have long range but has greater range accuracy than the other sensors. So though it may not be best suited for the full range of truck stopping scenarios it could be a better developmental device just to demonstrate the concept at short range (i.e., low speed) scenarios.

Figure 7. SICK LIDARS, LD-MRS

Figure 8. SICK LIDARS, LMS151

2.2.4 LeddarTech M16 and IS16

Website(M16): http://leddartech.com/en/leddar-sensor-products/leddar-m16
Website(IS16): http://leddartech.com/en/leddar-sensor-products/leddar-is16

Unlike the other LIDARs which have mechanically scanned laser beams, the LeddarTech sensor is a 2-D array without moving parts. The receive array breaks the FOV into 16 segments. That defines the maximum angular, hence height resolution possible. The M16 device has twice the range but the IS16 is built for harsh industrial environments. The IS16 is already used as a collision avoidance sensor for heavy vehicles (mining trucks).

Both of these are much cheaper than the scanning LIDARs which justifies investigating whether they can sufficiently meet the requirements. They also come with analysis software and should be easily programmable. The M16 development kit which comes with one sensor is $300. Additional sensors are $1000 and the IS16 is $1900.

Advantages:

- Low cost
- No moving parts so high reliability
- Simultaneous measurement across FOV

Disadvantages:

- 2-D rather than 3-D representation of targets
- Less angular resolution

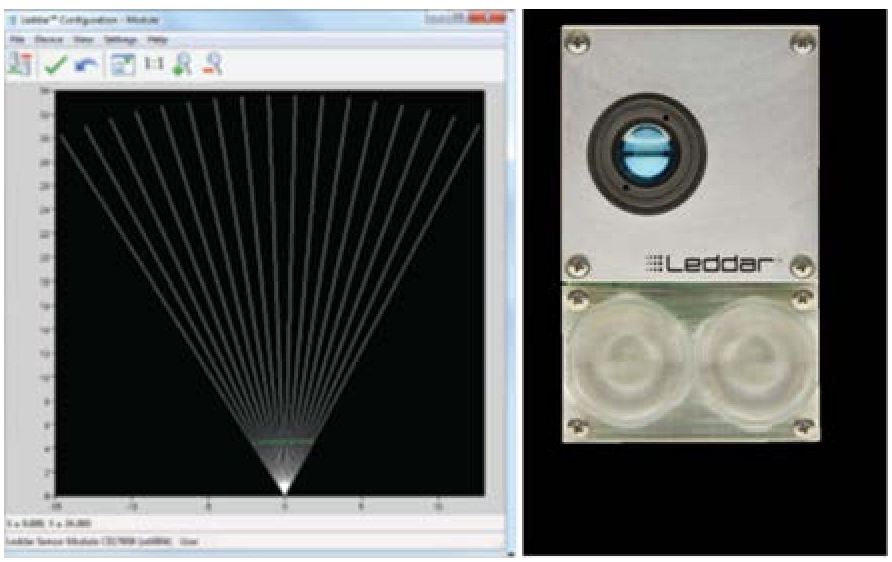

Figure 9. Leddartech Non-Scanning Array LIDAR

2.2.5 Velodyne Lidar

Website: http://velodynelidar.com/index.html

Originally developed for use in the DARPA (Defense Advanced Research Projects Agency) autonomous vehicle competitions, Velodyne LIDARS offer 3 technical solutions suitable for overpass clearance detection. The primary difference is in price and the number of points per second they make to define the surrounding environment.

The high-end Velodyne HDL-64E is large, consumes a lot of power but measures 1.3 million points per second and defines the environment in 64 slices at a price of $80,000. At the other end the VLP-16 is small, compact, consumes little power, has somewhat less range and angular resolution measuring only 300,000 points per second to define the environment with 16 slices but costs only $8,000. The HDL-32E fits in between providing 32 slices with performance similar to the HDL-64E but sized much more like the VLP-16. Our application may be best served by rotating the sensor 90 degrees to use the fine horizontal angular resolution in the vertical plane. Velodyne LIDARS using this mounting scheme have been successful in surveying and mapping type applications.[23]

Advantages:

A range of options from high to low end.

Disadvantages:

Some options may be too costly while the suitability of the lower end performance still needs to be determined.

Figure 10. Velodyne LIDARS - HDL-64E (left), HDL-32E (center), VLP-16 (right)

2.2.6 Teledyne Optech

Website (Lynx): http://www.teledyneoptech.com/index.php/product/lynx-sg1/

Website (ILRIS): http://www.teledyneoptech.com/index.php/product/optech-ilris/

Optech provides two mobile mapping solutions, Lynx SG1 and Lynx MG1. The SG1 comes with two LIDAR sensors that provide 360 degree field of view at a 250HZ scanner speed and 5mm precision. The MG1 is a smaller scale version of the SG1, providing 360 degree field of view but at 200 Hz speed using only one lidar sensor. The SG1 uses a more precise Inertial Measurement Unit which gives if better than 2 cm positional accuracy compared to 9cm for the MG1. The MG1 is used in mapping applications and

[23] http://velodynelidar.com/docs/papers/HDL%20white%20paper_OCT2007_web.pdf

the SG1 is used for surveying applications which need greater precision. They are long range devices that are candidates for our application but consume the most power. Both products utilize a complete software solution that includes LIDAR post-processing and information extraction.

One of Optech's original LIDAR products might be more appropriate for the overheight clearance application. Those are the ILRIS product line of long range survey LIDARS. The ILRIS-LR is the long range unit. Its range of up to 3000m is by far the longest range of any device we found. Even with a 10% reflective target it has a range of 1330m. The ILRIS-HD offers the highest angular resolution but still has a longer range than LIDARS from other vendors. The HD has a higher angular resolution because it uses a different laser that has a narrower beam. The ILRIS-HD-ER is the HD with a range extending module.

Advantages:

A range of options from high to low end.

Very long range.

High angular resolution.

Disadvantages:

Cost

Size

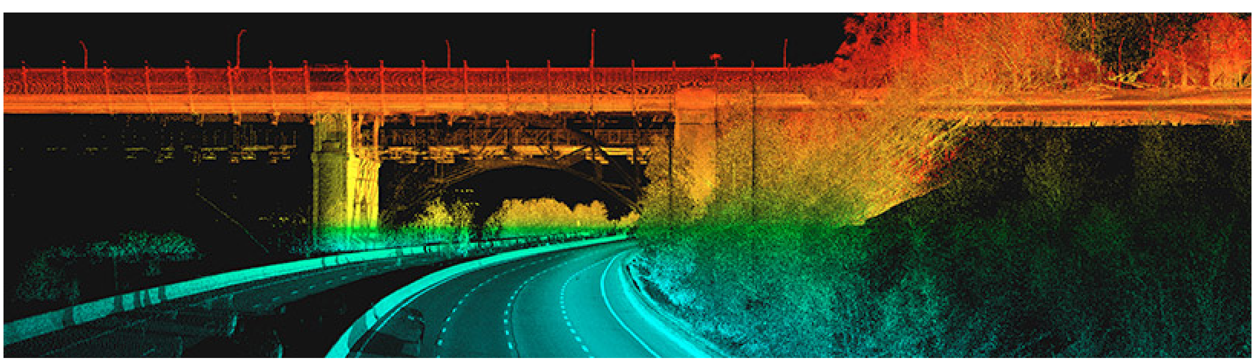

Figure 11. 3D Point Cloud Collected at Highway Speeds with Optech LIDAR

Figure 12. ILRIS-HD (high angular resolution)