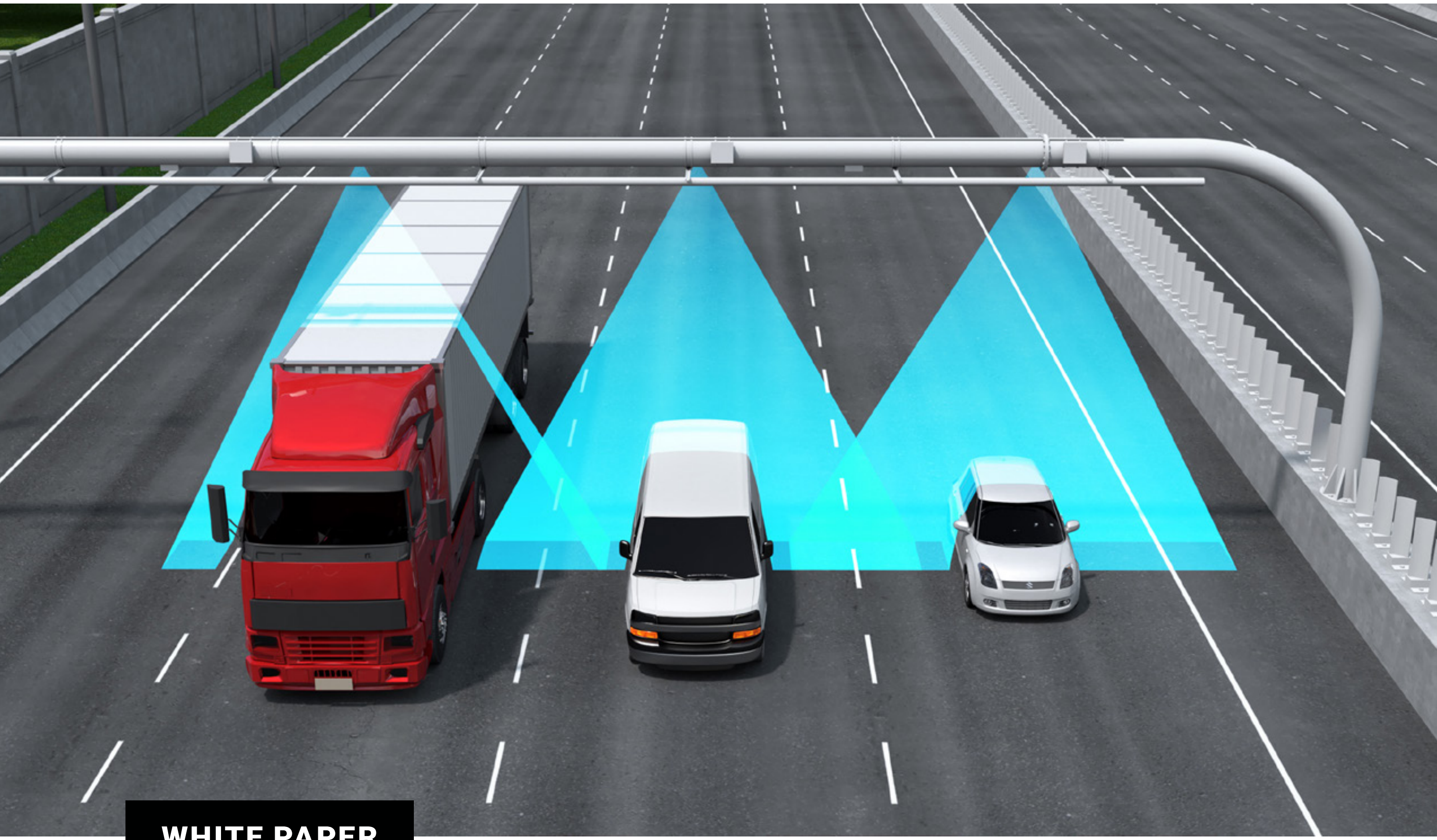

WHITE PAPER

USING FLASH SOLID-STATE LiDAR TO GENERATE BETTER PROFILING DATA IN E-TOLLING APPLICATIONS

ALEXANDRE DESJARDINS, SALES & APPLICATION ENGINEER
BENOIT-MAHEUX LACROIX, DIRECTOR, PRODUCT LINE MANAGEMENT
JOHN DINAN, SALES & APPLICATION ENGINEER

leddartech.com

WHITE PAPER

USING FLASH SOLID-STATE LiDAR TO GENERATE BETTER PROFILING DATA IN E-TOLLING APPLICATIONS

ABSTRACT

The fundamental challenge for providers of electronic toll collection (ETC) systems is to identify and deploy the most reliable, high-performance and cost-efficient sensing technology possible to ensure accurate vehicle detection, profiling, classification and revenue collection. In the highly competitive tolling industry, any technological enhancements that improves system reliability and performance as well as reduces capital and operating expenses will provide operators and integrators with advantages that will improve their chances of winning RFPs.

This White Paper describes the benefits of Flash Solid-state LiDAR (SSL) sensor technology for Intelligent Transport Systems (ITS), more specifically for vehicle detection, profiling and classification in Electronic Toll Collection (ETC) systems.

Challenges and limitations of current sensing technologies used in e-tolling will first be addressed. An overview of Flash SSL technology as well as a section on its advantages compared to current technologies and how it can be used to profile and classify vehicles will follow. The white paper aims to highlight the significant value that Flash LiDAR sensors can bring to existing or future e-tolling installations.

ABOUT LEDDARTECH

LeddarTech is the developer and owner of Leddar, a patented solid-state LiDAR sensing technology that constitutes a novel approach to light detection and ranging. Developed over 10+ years of R&D, Leddar is a unique combination of advanced light wave digital signal processing and software algorithms that enable the production of solid-state LiDARs delivering superior performance and reliability at a highly competitive price. LeddarTech sensors are used in multiple mobility-related markets including automotive, intelligent transport systems, drones, and industrial vehicles. Its technology contributes to improving safety and quality of life through applications minimizing the risks of accidents, reducing traffic congestion, and improving transport efficiency.

leddartech.com

©2018 LeddarTech inc. Any use of this white paper or portions thereof, including reproduction, modification, distribution or republication, without the prior written consent of LeddarTech, is strictly prohibited.

1. CHALLENGES AND LIMITATIONS OF CURRENT ETC TECHNOLOGIES FOR VEHICLE PROFILING

The fundamental challenge for providers of electronic toll collection (ETC) systems is to identify and deploy the most reliable, high-performance and cost-efficient sensing technology possible to ensure accurate vehicle detection, profiling, classification and revenue collection. In the highly competitive tolling industry, any technological enhancements that improves system reliability and performance as well as reduces capital and operating expenses will provide operators and integrators with advantages that will improve their chances of winning RFPs.

There are several challenges and limitations of current sensing technologies used in ETC for vehicle profiling:

High operational costs: Latent technologies for vehicle profiling, such as in-ground induction loop-based systems, are reaching a point of failure, making them expensive to replace and maintain. Also, their installation and maintenance require invasive road work, affecting road surfacing integrity and surrounding infrastructure. In addition, lane closures can cost thousands of dollars and might not be possible in some areas.

Tailgating vehicles: ETC systems based exclusively on axle-counting methods for vehicle profiling might not be able to distinguish between tailgating vehicles (two vehicles closely following each other), a single longer vehicle and/or a vehicle pulling a trailer. This limitation impacts the system's classification rate and directly translates to a revenue loss, and incorrect billing and customer service issues when users are overcharged.

Low detection rates: Some vehicle-profiling sensing technologies cannot detect and profile certain vehicle shapes or colors, such as very shiny or black vehicles and non- reflective objects, or have difficulty detecting vehicles at very high speeds. These reduced detection rates inevitably cause ETC operators to lose revenues.

Sensitivity to environmental and weather conditions: Environmental conditions, such as snow, rain, fog and even road accumulation can have a negative impact on some ETC technologies' ability to operate properly and maintain a high classification rate. Rain, splashes and snow in particular can even create false positives with respect to vehicle detection and profiling.

Vehicle classification limitations: Since they are installed at ground level, ETC systems based exclusively on axle-counting methods are limited regarding the acquisition of essential information about vehicles. Indeed, some vehicle classes can only be distinguished by their shapes, which sometimes cannot be differentiated from ground level with axel counting. For example, inductive-loop traffic detectors cannot properly distinguish flatbed semi-trailers from semi-trailer trucks since their axles are identical and the difference lies in the trailer body.

Long-term reliability issues: Any sensor failure in a tolling installation can impact its ability to properly operate. Over time, malfunctions can hurt the overall system performances and raise maintenance costs, negatively impacting operators' bottom lines.

2. LiDAR AS A VIABLE, HIGH-PERFORMANCE ETC DETECTION SOLUTION

Over the past few years, remote sensing companies have offered different alternative solutions to in-ground inductive loop for ETC systems to enable efficient vehicle classification. Among these solutions, LiDARs have emerged as a promising option to solve the many issues faced with in-ground system.

LiDAR is an active detection technology that functions similarly to a radar but uses the time of flight of light signals, instead of radio waves, to detect and profile objects. LiDARs mainly use two different types light emission: collimated beams and diffuse beams. A collimated beam is a light with rays that are parallel; it spreads minimally as it propagates. A perfectly collimated beam, with no divergence will not disperse over distance. On the other hand, a diffuse beam is a light that, as the name suggests, is diffused through emission options to spread the beam over the sensor's entire field of view (FoV).

For the purpose of this white paper, we will present two main categories of LiDARs. Mechanical scanning LiDARs, which use collimated beams, and Flash Solid-state LiDARs, which use diffuse beams. The pros and cons of each are illustrated below.

©2018 LeddarTech inc. Any use of this white paper or portions thereof, including reproduction, modification, distribution or republication, without the prior written consent of LeddarTech, is strictly prohibited.

2.1 MECHANICAL SCANNING LiDARS FOR ETC APPLICATIONS

Mechanical scanning LiDARs use powerful collimated laser beams to concentrate the return signal on the receiver units through highly focused optics.

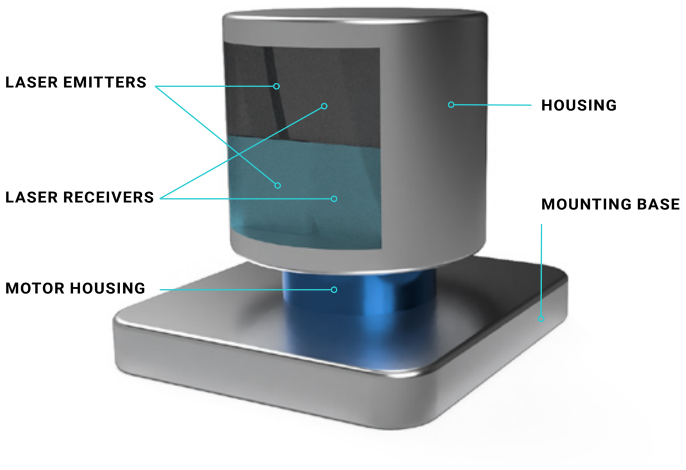

Figure 1. Representation of a conventional mechanical scanning LiDAR

Simpler mechanical LiDARs use a single laser source that rotates and/or oscillates (usually with a motor) to capture a single vertical line of data points at each cycle. More sophisticated mechanical LiDARs use an assembly of multiple emitter/receiver combinations (up to 128) that rotate mechanically to capture multiple vertical lines of data points data over up to 360 degrees. However, some limitations of mechanical scanning LiDARs make them a less than ideal alternative solution for vehicle detection and profiling in modern ETC systems. The speed of rotation of the optical assembly generally limits the measurement rates of such sensors to 100 Hz or less. This affects the system's ability to accurately detect tailgating vehicles, differentiate vehicle types at high speeds and reliably detect hitches.

Moreover, the reduced signal sensitivity, in addition to highly collimated beam of these sensors, impacts their ability to detect specular surfaces such as black and non-reflective objects.

Mechanical LiDARs are also prone to performance deterioration in poor environmental conditions and weather due to their use of highly collimated lasers. A single drop of rain or a snowflake can significantly impact a collimated laser beam and send back misleading information for vehicle detection and profiling.

Finally, mechanical LiDARs, by their very nature, are assembled with multiple moving mechanical components, which triggers increased maintenance costs and reduces the overall lifespan of the system.

2.2 FLASH SOLID-STATE LiDAR

Various technologies are currently under development to bring to market Solid-state LiDAR solutions (LiDARs which do not feature any moving parts). The most mature solid-state technology that is commercially available today is the Flash Solid-state LiDAR (Flash SSL).

Flash SSL is similar in principle to a photography flash on a standard camera that sends over 100,000 light pulses per second. Each of these light pulses illuminate the entire FoV, covering 100% of the scene without any blind spots. In comparison, mechanical scanning LiDARs use a collimated beam which is a light with rays that are parallel; it spreads minimally as it LiDARs use collimated laser beams and rotate to scan an area, leaving several undetected zones in between each line and each data point captured.

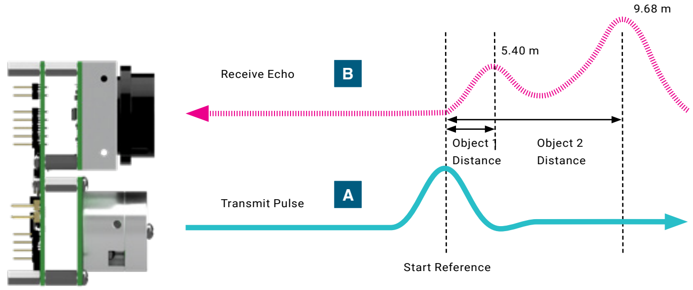

Figure 2. Leddar data acquisition process.

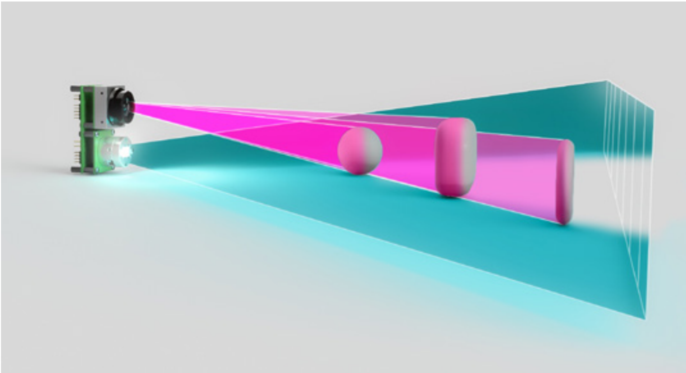

Figure 3. Object detection with a Leddar-based Flash SSL module.

©2018 LeddarTech inc. Any use of this white paper or portions thereof, including reproduction, modification, distribution or republication, without the prior written consent of LeddarTech, is strictly prohibited.

After the light is reflected off an object, time-of-flight calculations allow the flash-based sensor to accurately measure the distance and provide the angular resolution of the object using a solid-state photodiode array underneath the optical receptor. The result is a high object detection rate that is consistent and reliable at a high measurement rate, enabling important ETC applications, such as vehicle detection and profiling, which require sensing speed, accuracy and robustness at a reasonable price.

Flash LiDARs modules also have a large, diffuse light emission which improves detection rate over specular surfaces such as black cars due to the higher probability to collect back the light in a larger reception aperture.

Since Flash SSL solutions do not have the physical limitation of mechanical LiDARs, they are able to achieve higher measurement rates for better profiling and high-speed vehicle detection. In addition, Flash SSL systems also achieve better temperature range. For instance, Leddar-based LiDAR traffic sensors operate in a wider ambient operating temperature range: -40 °C to 60 °C for Leddar sensors compared to -30 °C to 50 °C for mechanical LiDARs[1].

2.3 IMPROVED FLASH SSL PERFORMANCE THROUGH DIGITAL SIGNAL PROCESSING

Flash SSLs have lower return light signal, due to its diffuse beam, which generates a weaker return signal than a collimated beam. A weak return signal will mean a low signal-to-noise ratio, which reduces the effective detection rate and range of the sensor. To address this limitation, significant work has been carried to develop methods of signal processing that significantly enhance Flash SSL's range and detection performance levels. While most LiDAR approaches rely predominantly on hardware-based methods and raw analog signal data, advanced signal processing algorithms used by some Flash SSL solutions, such as those based on Leddar technology, acquire, sequence and digitally process light signals, which significantly improves Flash SSL's sensitivity, immunity to noise.

This powerful digital signal processing effectively enables

- Higher range-to-power ratio and lower detection thresholds for significantly higher sensitivity and range
- Less signal degradation, thanks to multi-pulse methods and noise filtering that increase the likelihood and quality of measurement for improved performance in challenging weather conditions (rain, snow, fog)
- Strong immunity to interference from other light sources, thanks to a combination of multi-pulse processing and specific signal emission methods

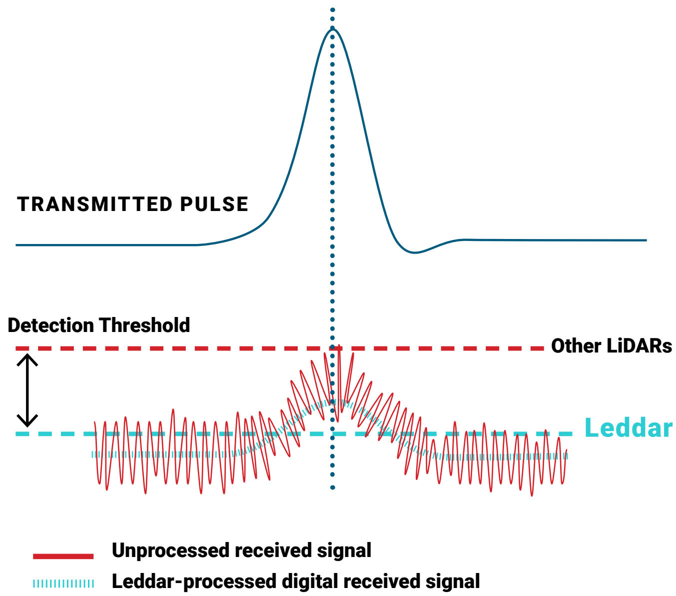

Figure 4. Leddar technology's advanced signal processing.

Leddar technology's signal acquisition and processing generate a cleaner signal that enables lower detection thresholds for significantly increased range and sensitivity over other SSL methods

- Rather than working directly on analog signal, Leddar samples the receive echo for complete detection range of sensor
- Through patented methods, Leddar iteratively increases the sampling rate and resolution of this sampled signal
- Analyzes resulting discrete-time signal and recovers distance for every object utilizing sophisticated software algorithms

Leddar technology generates up to 25x improvement in sensitivity over other LiDARs; it can therefore work with lower cost components (ex.: 905nm, silicon-based light sources) —all while meeting performance requirements.

[1] LeddarTech T16 compared to a SICK LMS511.

©2018 LeddarTech inc. Any use of this white paper or portions thereof, including reproduction, modification, distribution or republication, without the prior written consent of LeddarTech, is strictly prohibited.

This advanced signal-processing ability allows for rapid delivery of accurate measurements, extends range and measurement capabilities, and provides the critical capability to detect and track multiple objects simultaneously in the sensor's FoV. Leveraging Flash-LiDAR technologies with advanced signal processing allows manufacturers to develop solutions that are up to 10 times more robust[2] or have a form factor that is up to 17 times smaller[3] in volume than their mechanical scanning counterparts—without any moving parts.

2.4 BENEFITS OF FLASH SSL SOLUTIONS FOR ETC SYSTEM OPERATORS

Flash SSL offers a value-added solution to ETC systems operators and integrators that provides significant benefits that were previously unattainable with current sensing technologies.

Higher classification rates: Offering accurate detection of tailgating vehicles, providing reliable 3D vehicle profiles, and ensuring a high detection rate on low reflectivity objects and black cars, Flash SSLs offer a solution that significantly increases the classification rates of ETC systems.

No revenue loss: Flash SSLs' diffuse emission patterns offer better detection capabilities over historically hard to detect objects for LiDARs, such as black cars or low reflectivity objects. Moreover, they maintain a high detection rate in even the harshest weather conditions. This significantly reduces the error rate and maximizes revenue.

Limited lane closures: ETC installations that rely entirely on Flash SSLs are more reliable, thereby limiting lane closures, and maintenance is simplified. The equipment can often be accessed from overhead and even be troubleshooted and fixed remotely.

Higher potential revenues: Overhead profiling systems are necessary to properly identify vehicles classes, because some differences can only be seen from above. Increasing the number of identifiable classes provides a major opportunity for ETC operators and system providers to generate more revenues.

Reduced operational expenses: As Flash SSLs are more reliable than mechanical LiDAR solutions and can be installed overhead, they do not require in-ground maintenance work like inductive-loop technologies. As a result, maintenance, costly downtimes and lane closures are reduced to a minimum, improving operator's bottom line over time.

The chart below presents the six most restrictive problems typically met in the ETC industry, along with how Flash SSL can reduce or even eliminate them.

ETC CHALLENGES	FLASH SSL SOLUTIONS	FLASH SSL ROI
Tailgating vehicles	Precise 3D profiling capabilities and fast measurement rates improve vehicle separation and hitch detection	Higher classification rate No revenue loss
Lane closures for in-ground installation and maintenance	Overhead installation for simpler maintenance Remote maintenance	Limited lane closures
Errors in harsh weather conditions	Diffuse light emission and signal processing/noise filtering improve harsh weather performance	Higher classification rate No revenue loss
Limited number of classes possible based on axles counting	Precise 3D profiling capability and fast measurement rates improve vehicle profiling and classification capabilities	Higher potential revenue
Low detection rates on dark vehicles	Large, diffuse light signal emissions, signal accumulation and digital processing improves dark vehicle detection compared to other LiDARs	Higher classification rate No revenue loss
High operational costs due to long-term reliability issues	Solid-state design increases LiDAR robustness, MTBF, and maintenance requirements	Higher reliability Reduced operational costs

Table 1. The ETC industry's most frequent problems and how Flash SSLs solve them.

[2]Based on MTBFs: LeddarTech T16 compared to a SICK LMS211.
[3]LeddarTech M16-LSR compared to a SICK LMS511.

©2018 LeddarTech inc. Any use of this white paper or portions thereof, including reproduction, modification, distribution or republication, without the prior written consent of LeddarTech, is strictly prohibited.

3. VEHICLE PROFILING WITH FLASH SSL

Flash SSL profiling is very similar to profiling with other types of LiDAR scanning methods. Instead of generating a point cloud, it produces a 3D profile of the vehicles' surface. As the vehicle passes underneath the gantry and into the sensor's detection area segments— which can be referred as a row matrix —each segment acquires height measurement data at a rate of 5 ms to 10 ms. As the data generated by each scan is accumulated over time, the 3D rendering of the vehicle's surface and shape takes form in a very similar way 3D printing is achieved. This 3D row matrix representation constitutes the main advantage of Flash SSL profiling, enabling efficient vehicle classification based on multiple differentiators, such as vehicle height, width, length and design details. This also allows system integrators to develop specialized classification algorithms with significant value-added potential, as these algorithms can be subsequently used by ETC operators.

The example below shows a 3D profile of a pickup truck travelling at 100 km/h with a trailer attached. It should be noted that the hitch is clearly visible in this representation, making it possible to readily identify the trailer as opposed to it being mistaken for a tailgating vehicle.

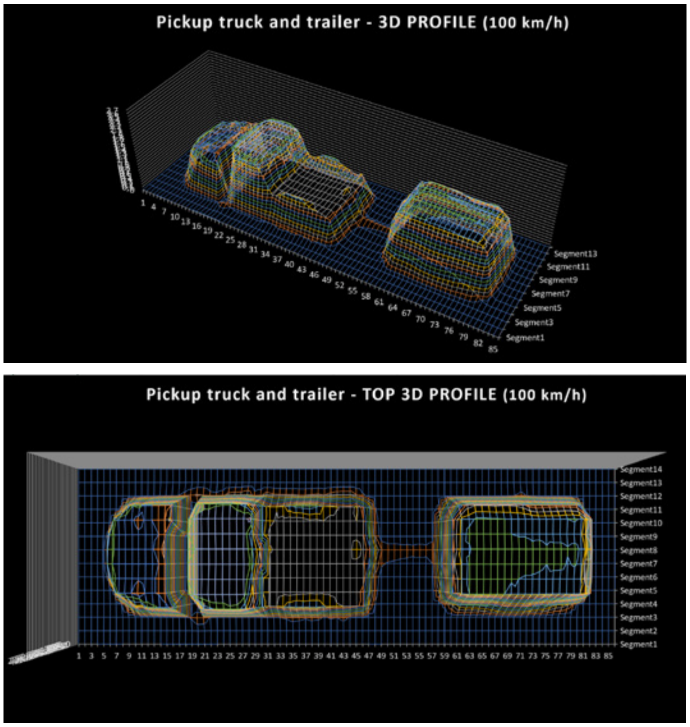

Figure 5. 3D rendering of a pickup truck with a trailer travelling at 100 km/h using Leddar Flash SSL technology.

3.1 RECOMMENDED SETUP

To get the most out of such Flash SSL sensors in ETC applications, experts recommend that they be mounted to overhead structures, such as down facing gantries perpendicular to the road, to allow the sensors to achieve optimal length and width resolution.

The following diagram shows a typical recommended installation with one or two sensors per lane mounted at a 90° angle, perpendicular to the ground. Using one Flash SSL sensor per lane with a 48° FOV in the gantry set-up will ensure coverage of the entire lane, and detection of any straddling vehicles.

For an even better detection rate and overall dimension precision, including for vehicles that straddle two lanes, a different setup could be used with two types of sensors with narrower FoV per lane: one sensor would be dedicated to each lane and a second laser would cover each straddling point.

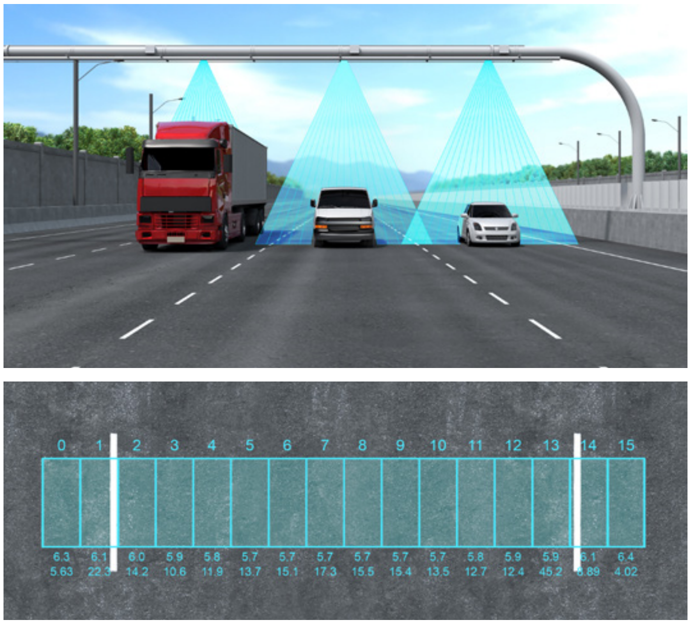

Figure 6. A recommended setup of Flash SSL sensors, with one sensor per lane.

©2018 LeddarTech inc. Any use of this white paper or portions thereof, including reproduction, modification, distribution or republication, without the prior written consent of LeddarTech, is strictly prohibited.

3.2. VEHICLE CLASSIFICATION BASED ON SSL DATA

The figure below shows an example of a simple classification algorithm based on a raw 3D vehicle profile generated by a Leddar T16 Traffic Sensor. This profile was used to calculate the dimensions of the vehicle.

Height calculation is based on the maximum height of the central part of the vehicle. In this example, the height of the top-central part of the vehicle is 1.56 m.

Width is determined according to the number of segments filled by a vehicle multiplied by each segment footprint at their respective height. In this example, there are 8 segments at a 1.4 m height that each cover 27.5 cm, meaning the vehicle's width is 2.2 m.

Length is determined by the number of frames filled by a vehicle multiplied by the time length of each frame (5 ms in this example) multiplied by the speed (in m/s). In this example, the car is detected in 51 consecutive frames of 5 ms each at a speed of 22.22 ms, meaning the vehicle's length is 5.67 m.

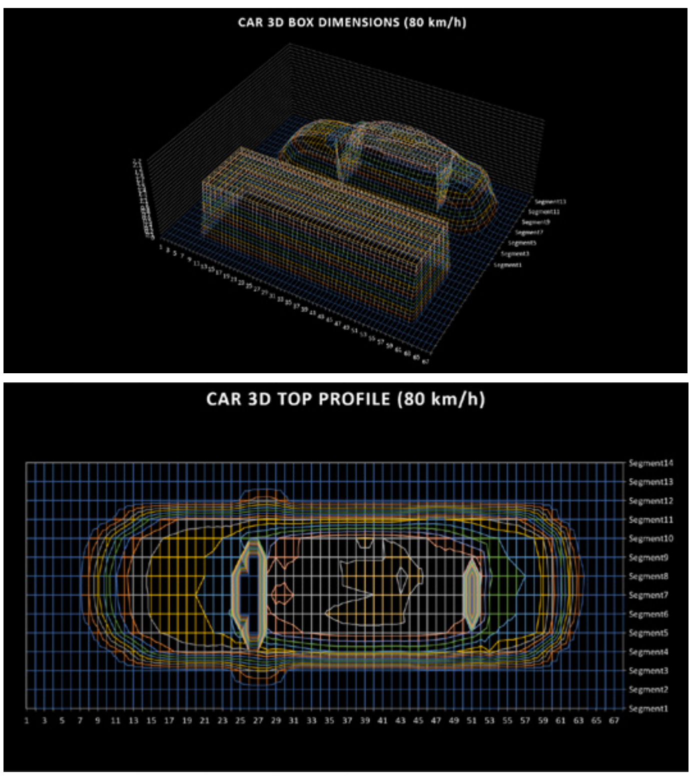

Figure 7. Vehicle size data acquisition using Leddar Flash SSL technology.

3.3 MODULE PERFORMANCE

The table below shows the resolution for specific dimensions (length, height and width) achieved at different speeds using a 16-segment Leddar T16 with a 48° x 7.5° FoV configuration at 200 Hz. Height and width parameters are independent of speed but the faster the vehicles are going, the more difficult they are to classify due to length resolution loss. Width resolution depends on the distance of the vehicle to the sensor and the latter's horizontal FoV; larger detection segments mean lower detection quality.

LENGTH RESOLUTION	
Vehicle speed	Resolution
At 100 km/h	14 cm
At 180 km/h	25 cm
At 250 km/h	35 cm
HEIGHT RESOLUTION	
Vehicle speed	Resolution
At any speed	5 cm
WIDTH RESOLUTION *(Detection segment width)*	
Measurement height	Resolution
At ground level	31 cm (5.3 m FOV, with 82 cm overlap)
At sedan height of 1.43 m	24 cm
At truck height of 4.1 m	10 cm

Table 2. Resolution for specific dimensions (length, height and width) achieved at different speeds using a 16-segment Leddar T16 with a 48° x 7.5° FoV configuration at 200 Hz.

3.4 HITCH DETECTION FEASIBILITY

Hitch detection is now possible from an overhead installation with Flash SSL solutions, thanks to their high measurement rate and the 100% light density of the detected area. The example below illustrates hitch detection using Leddar technology. In this specific use case, the hitch was detected primarily in Segment 9 (0.15 m to 0.2 m). A small part of the hitch was also captured in Segment 8 (0.04 m to 0.12 m), as shown by the slight increase in the height sensor measurement.

©2018 LeddarTech inc. Any use of this white paper or portions thereof, including reproduction, modification, distribution or republication, without the prior written consent of LeddarTech, is strictly prohibited.

At a speed of 100 km/h, 8 frames (or lines of data) cover the distance between the vehicle and trailer so that the hitch can be accurately profiled. The resulting 3D surface scan shows clear 15 x 8 cm frame length profile that can be used by algorithms to identify a hitch part connecting two distinct vehicle types and then create a specific classification profile for the combined vehicle type.

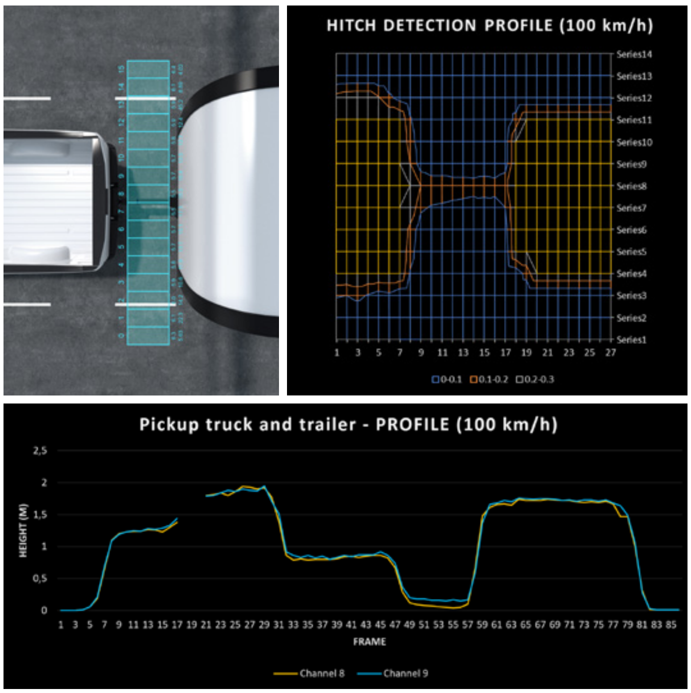

Figure 8. Hitch detection profile using Leddar technology.

Some limitations and considerations are important to understand in order to accurately and reliably detect hitches.

Hitch position in the segments: If a hitch is detected in between two segments, the resulting signal will be split in two and may be too weak to be adequately detected.

Reflectivity properties of the hitch material: The reflectivity properties of the hitch material are also an important factor, because the ability to reflect infrared light varies from one material to another. For instance, a black or other dark-coloured hitch, may not return enough signal to the sensor to offer a strong and reliable detection.

Hitch size: Since bigger surfaces reflect more light back to the sensor, some smaller hitches might not be big enough to trigger a detection. As the hitch's size becomes smaller in proportion to the segment, the space it occupies in a single segment will be reduced in scale. The ground detection in the same segment will merge with the hitch itself, falsely lowering the distance measurement to the ground. As a result, the distance measured might be too low to be flagged as a hitch.

When using Flash SSL technology for vehicle classification, two solutions exist to resolve the issues mentioned above. The first one is to select a sensor with more emission power (such as the Leddar T16) to compensate for limitations. The second one is to opt for a sensor with a reduced horizontal and vertical FoV size, which will increase the light density over the hitch, thereby facilitating its detection. Reducing the FoV decreases the size of segments, resulting in smaller hitches occupying more space in proportion, reducing ground merging possibilities. More information on these solutions and their respective benefits can be found in LeddarTech's ***PRODUCT SELECTION GUIDE: Selecting the Right Flash Solid-state LiDAR for E-toll Systems.***

CONCLUSION

As shown in this white paper, Flash SSL sensor technologies, with enhanced signal processing, are highly powerful, cost-efficient, robust and reliable. They also offer ETC suppliers and operators an opportunity to create value by working directly on raw vehicle profiling data. These advantages make Flash SSL sensor technologies ideal for ETC- related applications, such as vehicle detection, profiling, classification, and offer a long-awaited alternative to more expensive detection solutions, including inductive-loop systems and mechanical scanning LiDARs.

©2018 LeddarTech inc. Any use of this white paper or portions thereof, including reproduction, modification, distribution or republication, without the prior written consent of LeddarTech, is strictly prohibited.