Autonomous Driving Vehicle System Using LiDAR Sensor

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8 authors, including:

Saiful Islam
Technische Universität Chemnitz

Md Shahnewaz Tanvir
North Carolina Agricultural and Technical State University

Md. Rawshan Habib
Murdoch University

Tahsina Tashrif
Ahsanullah University of Science & Technology, Bangladesh, Dhaka

Autonomous Driving Vehicle System Using LiDAR Sensor

Saiful Islam, Md Shahnewaz Tanvir, Md. Rawshan Habib, Tahsina Tashrif Shawmee, Md Apu Ahmed, Tafannum Ferdous, Md. Rashedul Arefin, and Sanim Alam

Abstract An overview of light detection and ranging (LiDAR) sensor technology for autonomous vehicles is presented in this paper. The sensor called LiDAR sensors is a key component of autonomous driving's for the upcoming generation as an assistance function. LiDAR technology is discussed, including its characteristics, a technical overview, prospects as well as limitations in relation to other sensors available in the industry. Comparison and comment on sensor quality are based on factory parameters. The basic components of a LiDAR system from the laser transmitter to the beam scanning mechanism are explained.

Keywords LiDAR sensor · Velodyne HDL-64E · Laser · Pulse · Sensor

1 Introduction

Every year, around 1.35 million people died because of vehicle crashes throughout in the world. Among those people, over half are pedestrians, cyclists, and motorcyclists and the number goes beyond fatalities. Consistently, each year nearly 50 million peoples are injured vehicle crashes in the worldwide [1]. The great majority of these accidents have a common thread which is human error and inattention. Additionally, there are several factors including speeding, distraction, drowsiness, and alcohol consumption. The autonomous vehicle can assist in reducing risky behaviors and accidents. Autonomous driving vehicles are known as driverless vehicles that combined sensors and the software for control to navigate self-driving. It depends on their perception systems and ability to gain information from the nearby environment. For proper self-driving, it is important to identify the presence of different

S. Islam (✉) · Md S. Tanvir · Md A. Ahmed
Technische Universität Chemnitz, Chemnitz, Germany

Md. R. Habib
Murdoch University, Murdoch, Australia

Md S. Tanvir · T. T. Shawmee · T. Ferdous · Md. R. Arefin · S. Alam
Ahsanullah University of Science & Technology, Dhaka, Bangladesh

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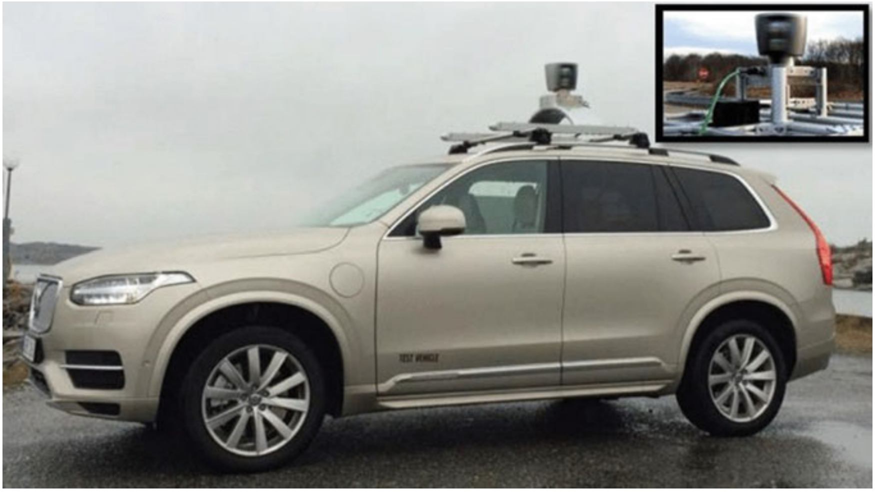

Fig. 1 Autonomous vehicles Volvo CX-90 used HDL-64E LiDAR [3]

vehicles, pedestrians, and other significant substances. LiDAR abbreviation is light detection and ranging. LiDAR was discovered in the early 1960s after invention of the lasers. The wavelengths of these laser waves usually range between 600 and 1000 nm [2]. LiDAR sensors work by sending a focused light beam to a distant object and then receiving it back with the reflected light. The distance that a remote light reflectivity of the object is determined by the beam's intensity. To handle obstacle situation smoothly on the road and identify roadblocks, we might have installed rotating device on the top of the autonomous vehicles. Sometimes these devices are ascended above the bonnet which is called as LiDAR shown in Fig. 1.

LiDAR serves as the self-driving vehicle's eye and giving a 360° view of its surroundings to ensure safe driving. In every second, thousands of laser pulses are sent out by a continuous rotating system which collides with different objects on surrounding vehicles and reflect the signals. These reflections of light make 3D point cloud and the computer records every laser reflection point for converting into animated in 3D representation. The 3D position helps to monitor distance between the vehicles that cross by other vehicles. It helps to control the brakes in order to slow down or stop. When the road is clear in ahead it also can allow to rise the speed. The LiDAR also incorporates by pre-scan technology that helps to achieve collision-free riding. Not only does LiDAR provide more comfortable driving, but it also enhances safety. Data is captured by sensors and processed by algorithms perception based on information represented in the environment. In self-driving vehicles, perception systems are comprised of active and passive sensors, such as cameras, radars, and LiDARs. LiDAR is the active sensor that provides emitting laser to the surrounding. Laser reflection returns are processed by processing the reflected beams.

Compared with other technologies, LiDAR has a significantly higher resolution, making it very sensitive to objects that might disrupt its path. Distances between the vehicle and nearby objects can be accurately calculated with LiDAR sensor. For interpreting the environment, LiDAR data can easily be transformed into 3D maps. In low light conditions, LiDAR performs well, regardless of ambient light variations. Direct measurement of distance is enabled by LiDAR data which does not require decoding or interpretation, therefore enabling faster processing. In LiDAR, a large amount of measurements can be made instantaneously and can be precise to a centimeter.

2 Working Principle

Electronic distance measuring instruments (EDMIs) and LiDARs work based on the similar principles. It consists of a transmitter, receiver, and reflector (object) as shown in Fig. 2. The distance among transmitter and the reflector measured by the travel of the time. Reflectors can be made from either physical objects or artificial devices, such as prisms. The distance between the LiDAR sensor and object can be calculated as follows:

$$S = c * \frac{t}{2} \tag{1}$$

where s is covered distance, c is the speed of light (3×10^8 m/s), and t is time taken by laser beam between emission and reception. Various factors contribute to find the range for pulse-based laser system whose equation is as follows:

$$\text{Range} = \sqrt{(P * A * T_a * T_o)/(D_s * \pi * B)} \tag{2}$$

where P is the power of laser, A is Rx optics area, T_a is the atmosphere's transmission, T_o is transmittance of optics, D_s is detector of sensitivity, and B is the radians with diverging beams.

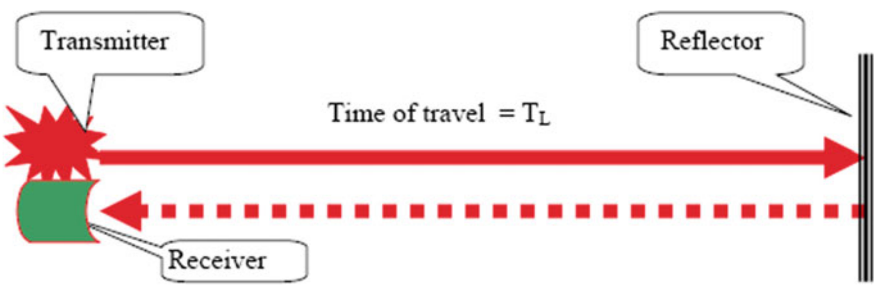

Fig. 2 Laser range measurement [4]

LiDAR consists of three components which are embedded in its package [3]. The first one is a transmitter which is usually a laser that stands for light amplification through stimulated emission of the radiations. The laser is characterized by rapid sending of laser light pulses that emit normally 150,000 pulses/sec. It is classified according to its wavelength between 600 and 1000 nm toward the shorter wavelength range. It is not visible in human eye as can be seen in electromagnetic spectrum in Fig. 3. The majority of methods are based on continuous lasers, and pulsed is used.

Another component is the receiver which is shown in Fig. 4, and travel time is determined by measuring the incoming light beam. The object's reflected light scans the surroundings and generates the 3D coordinates. Low-intensity light demands a highly sensitive receiver. The following apparatus is used for low light detection:

- Silicon PIN detector
- Silicon avalanche photodiode (APD)
- Photomultiplier tube (PMT).

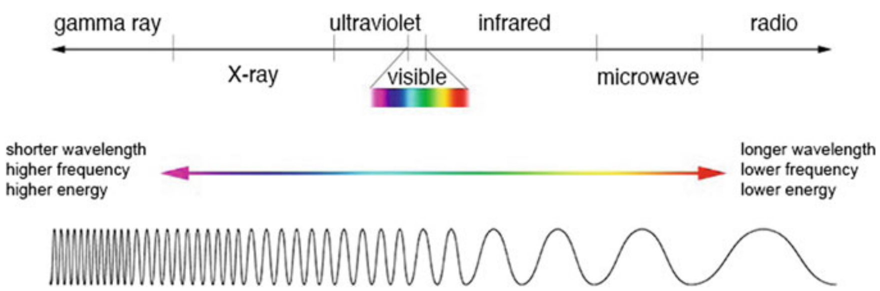

Fig. 3 Electromagnetic spectrum [5]

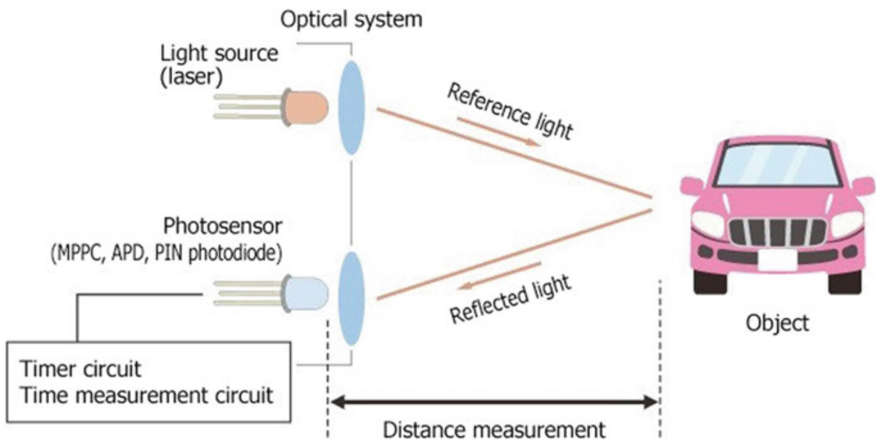

Fig. 4 Travel time measurement [6]

The last component is position and navigation system. This navigation system is used for determining the position and angle with the respect to the current position. The object's position is determined using the global positioning system (GPS), which measures an object's longitude, latitude, and altitude. In contrast, the inertial measurement unit (IMU) allows us to precisely measure an object's angle [7]. It is especially used in airborne sensors.

3 Setup and Construction

An active LiDAR sensor always can be divided into two sections. Figure 5 shows the basic configuration of LiDAR system. One transmitter sends the signal in the form of a laser beam while a receiver reflected radiation by an optical detector in the form of a photodiode that electric signal analyzes in computer. The beam expander is able to include in the system within the sender unit to decrease the branching of light beam prior it emits into atmosphere. The reflected photons are captured by geometrical optical structure throughout the atmosphere at receiving end. It is followed by optical analyzing method that depends on specific application and selects wavelength which states out accumulated light. The detector receives the specified optical wavelength and converts it into the electrical signal. The signal performance is defined by number of time that elapses since the laser pulse is emitted. The object's distance is determined by using electronic time measurements and stored data in computer. Figure 6 depicts the three-dimensional configuration of LiDAR sensor. For perform scanning over at minimum one layer of these systems focuses on single pair emitter that combined some moving mirror effect. This mirror reflects the emitting light from diode and also reflects return light to detector. This device can swiftly measure the surface area, and

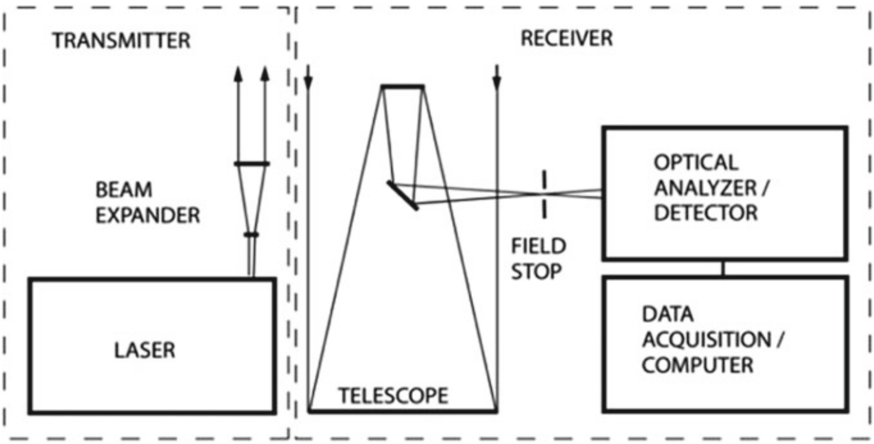

Fig. 5 Structure of LiDAR sensor [7]

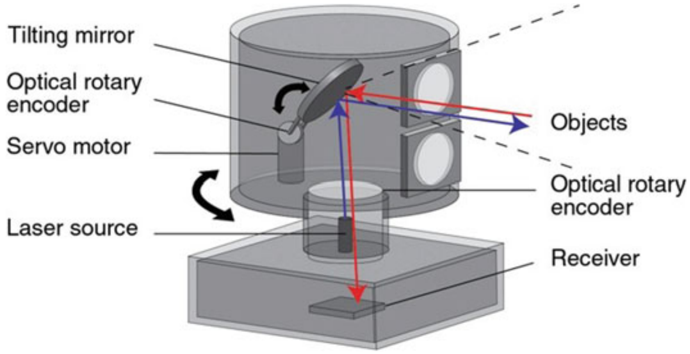

Fig. 6 Principle of mechanical spinning LiDAR [6]

the rate is more than 150 kHz. Wavelengths of LiDAR depend on application, and it extends the range between 250 and 11 μm. LiDAR uses several beams to minimize the movement mechanism. For example, Velodyne series uses array laser diode to enhance point of cloud density.

In automotive LiDAR scanning system, the most popular solution is spinning mechanism [5]. In general, two types of systems are used: polygonal mirror system and nodding mirror system, for instance, as shown in Fig. 6, a mechanical spinning mechanism. The lasers are tilted by an integrated nodding mirror system to create a vertical field of view. LiDAR base is rotated to achieve 360° horizontal field of view (FOV). The state of the art for multiple beams is used in LiDAR to decrease the moving mechanism. Mechanical spinning offers a number of advantages over large FOV. The Velodyne VLP series, for example, increases point cloud density with arrays of laser and photodiodes. A rotating mechanism is enormous for implementation inside the vehicle and is vulnerable to extreme circumstances like vibration, which is ubiquitous for automotive applications. FOV is the angle that is captured by a sensor. When using a camera with a LiDAR sensor, it is better to select the FOV carefully so that the LiDAR outputs match the region covered by aerial photographs.

4 LiDAR Technologies

LiDAR operates with many laser beams by scanning field of view. This is accomplished of a delicately constructed beam controlling system. This amplitude pulsed laser diode emitting at infrared frequency generates with laser beam. The surroundings reflect to the laser beam which returns to scanner. Photodetector receives the returning signal. The signal is filtered by fast electronics, which measures the difference between transmitter and receiver signals that are proportional to distance. This difference is used to calculate the range from sensor model. Almost all 3D points and

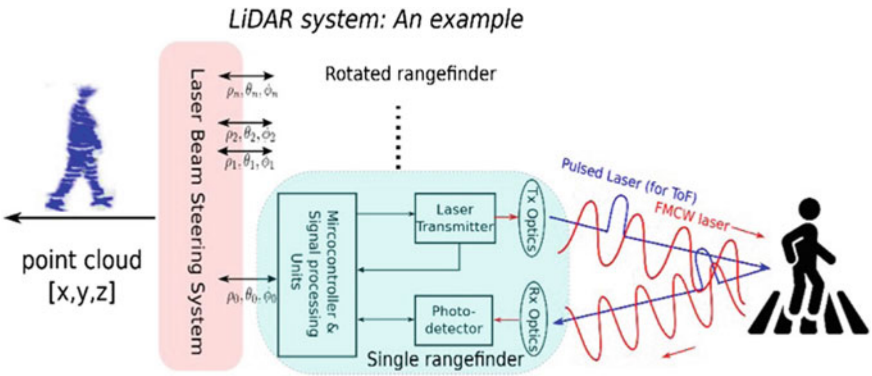

Fig. 7 Time of flight (ToF) lager rangefinder [8]

intensities corresponding to reflected laser energy are included in LiDAR outputs. Figure 7 shows conceptual presentation of operating principle.

LiDAR system is divided into two parts: laser rangefinder and scanning system. Laser rangefinder uses the modulated rays of a laser transmitter to illuminate target. After optical analysis and photoelectric transformation, the photodiode creates an electrical signal from scattered photons. Laser beams are usually steered by scanning systems. Different horizontal and vertical angels are shown by $\emptyset_i$, θ_i, where i indicates an index which specifies in direction that is pointed in the beam. This portion discusses basic principles of the rangefinder to understand the assessment process and constraints. In the following, it explains how scanning systems determine the sensor field of view.

4.1 Principle of Laser Rangefinder

An object-ranging device that measures distance with a laser beam is called a laser rangefinder. The operation depends on the shape of modulation that is used on the laser beam. Direct detection rangefinder uses pulsed lasers so that their time of flight (ToF) can be determined. A frequency-modulated continuous wave (FMCV) works indirectly for velocity and distance measured using Doppler effect [9]. The term coherent refers to these types of structures.

4.2 Laser Reception and Transmission

In order to receive the reflected signals, the laser signals must be generated, emitted, and received by the receiver electronics. Additionally, the rangefinders performance and cost are determined by reflected signals. The ToF LiDAR sensor requires the pulsed (amplitude modulated) laser signal. A fiber laser diode or pulsed laser is used for generating this type of signal. The laser diode oscillates as an electric current flowing through diode junction. There are two types of diode lasers: surface-emitting semiconductor laser (VCSEL) and edge-emitting lasers (EELs). In the telecommunications industry, EEL has been used for a long-term period. The output of VCSEL beam is circular, and contrarily EEL sends elliptical laser beam and needs extra optics. In the automotive applications, pulsed laser diodes are hybrid devices. A capacitor is mounted on laser chip, and it is activated by a MOSFET transistor [10]. C. Photodetector: The photoelectric effect transforms light energy into electrical energy in a photodetector. One of the most important features is photosensitivity, which specifies how a photodetector reacts when it receives photons. The photosensitivity of a laser beam depends on its wavelength. As a result, it is very important to consider the selection of laser wavelength when choosing a LiDAR system's photodetector.

4.3 APD and SPAD

APD stands for avalanche photodiode, whereas SPAD means single-photon avalanche diode. It multiplies by applying reverse voltage at the photocurrent using the avalanche effect. Signals are multiplied by the APD, reducing the effect of noise. PIN photodiode has a greater internal input power (around 100) with SNR. As a result, APDs are broadly used in modern LiDAR systems. On the other hand, the performance of SPAD is much higher than that of APD, with the gain is 10^6. This feature allows SPAD to detect very weak light from a large distance. Additionally, the technology used to produce CMOS technology can be integrated into photodiodes in SPAD fabrication using single chip. This is required in order to enhance LiDAR accuracy while reducing costs and power usage.

4.4 Scanning System

A scanning system permits the lasers to transmit rapidly in a vast area. Mechanical spinning or solid-state scanning are the two most common scanning technologies. A rotating mirror system, such as the HDL64 from Velodyne, is typically included in the former autonomous driving history in its early stages. Automotive industry preferred moving parts where solid state refers only scanning system.

Figure 8 shows an example of a common product: Velodyne's HDL64. Although the Velodyne HDL-64E is a relatively expensive sensor, it is often used in the automobile sector. It offers a high-resolution picture and 3D information about the environment. This sensor has 64 lasers in a group of four, each with 16 laser emitters, and detectors in a group of two, each with 32 detectors. It is mounted on the car's roof and spins constantly at speed is 5–20 Hz. It possesses 360° horizontal and 26.8° vertical field of view. An angular resolution of very fine angular precision allows

Fig. 8 Velodyne's HDL64 [3]

for a very clear and detailed view. A distinction of 0.08° can be made between very small objects. A range of sampling points is also available up to 2.2 Mpoints/s [11].

5 LiDAR Perception System

A vehicle's perception system translates the perceived surroundings in hierarchical terms by analyzing the perception sensor outputs, and we can obtain object descriptions (physical, semantic, intention awareness) from map data and localization. Object detection, tracking, motion prediction, and identification are the four processes in the typical LiDAR data processing pipeline, as shown in Fig. 9. The emergence of deep learning technologies has modified this classic flow, which we will describe following classic approaches. As Velodyne LiDARs are popular in the research community, the existing data processing methods are applicable on primarily mechanical spinning LiDAR.

5.1 Object Detection and Recognition

An object detection algorithm extracts and estimates the physical characteristics of object candidates: the detecting objects' positions and shapes. This algorithm also included clustering and ground filtering methods. The ground filtering labels a point cloud as either ground or not. After that, clustering processes are used to group non-ground points into various objects. The spherical processing of LiDAR signals (r,

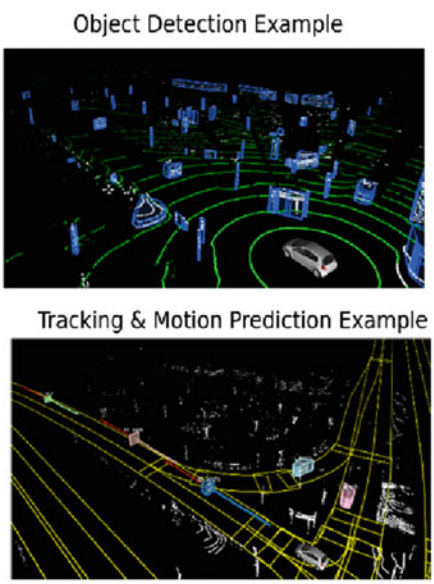

Fig. 9 LiDAR perception system [8]

φ, θ) provides a better method. Through distance and other criteria, the rest of the non-ground objects can be grouped easily [8]. On the other hand, the object recognition method based on machine learning approach provides semantic information (e.g., types of pedestrians, vehicle, truck, plant, building, etc.). The procedure of recognition feature extraction is employed to calculate compact object descriptors, and a step of modeling arises from pre-trained classification objects. Another way to acquire generic shape features is through principal component analysis (PCA) in 3D objects. By evaluating the eigenvalues generated by PCA, three salient characteristics (surfaceness, linearness, and scatterness) can be acquired [12]. An example of supervised machine learning is the classification method that provided by following feature extraction: The class of an input is predicted by a statistical model trained on the ground truth dataset. The number of well-known datasets is available, and KITTI provides an abundance of resources. There are plenty of machine learning (ML) tools available in the arsenal of ML, some algorithms, such as naive Bayes, support vector machine (SVM), KNN, and so on, maybe applied [13]. The SVM involving radial basis functions (RBF) is the most popular method due to efficiency and speed. Figure 6 illustrates the results of our implementations (SVM with RBF kernel) on the identified on-road items. The neural network is used to classify LiDAR objects. Often in practice, classes are unknown, so a classification method can well handle this situation.

5.2 *Object Tracking*

Objects are tracked using multiple algorithms which associate and locate the objects through information received from spatial–temporal consistency. As a model of movement in state space, a single object tracker evaluations the movement based on Bayesian filters. By extending the single dynamic model to several operation models, the interacting numerous model filter can pact with complicated cases. Particle filter (PF) is another frequent technique that is meant for more broad scenarios that do not fulfill the Gaussian linear assumption. Radar-based multiple object tracking (MOT) typically model all detectable objects as points, while LiDAR-based MOT model their detections as points is distinguished for tracking both the shape and the number of detected targets. A sophisticated method that uses multiple shapes models: polygons, lines, L-shapes, and points. The form of a moving item changes with variations in posture and sensor perspective when tracking it. A tracking method has been developed that estimates the states of both poses and movement simultaneously 2D polylines representing shapes. LiDAR detects objects as points as opposed to radar, which represents detections as points [14]. The distinctive feature of MOTs based on shapes is that the detections can be tracked along with their shapes.

5.3 *Deep Learning Methods Emerging*

Waves of deep learning (DL) follow the enormous success in computer vision and speech recognition, and the same applies to LiDAR data processing. An algorithm for deep learning is part of the machine learning field that works for multilayer neural network. The traditional methods of machine learning, such as in the same way that SVM efficiently extracts features from a raw input, DL systems are able to do the same. DL has also implemented object tracking. A deep structure model under tracking has been proposed by the traditional tracking algorithm [15].

6 LiDAR and Similar Technologies

RADAR and SONAR are two associated technologies that exploit the same phenomenon of generating pulses and receiving signals back as LiDAR. Radio detection and ranging is an acronym for RADAR. It employs longer-wavelength radio waves. The range of frequency used for detecting an object in front of it is 3 Hz–3000 GHz. In comparison with RADAR, LiDAR provides more accurate results. The differences between LiDAR and RADAR are shown in Table 1. Sound navigation and ranging is an acronym for SONAR. It detects objects using sound waves. The frequency range is extended from 10 kHz to 1 GHz. The differences between LiDAR and SONAR are shown in Table 2.

Table 1 Difference between LiDAR and RADAR

Properties	LiDAR	RADAR
Beam type	Laser waves	Radio waves
Accuracy	Possible and high	Not possible
Image surface	Provides 3D image	Unable exact 3D image
Transmission and reception	CCD optics uses	Uses antennae
Performance	Degraded in poor weather conditions	Operates in all weather conditions

Table 2 Difference between LiDAR and SONAR

Properties	LiDAR	SONAR
Beam type	Laser waves	Sound waves
Accuracy	High	Better than RADAR
Cost	High	Cheap
Sensor range	<=120 m	<=4
Working environment	Optimistic atmosphere	Not required clear weather

In comparison with RADAR and SONAR, LiDAR is a relatively new technology. At present, various challenges are being faced by LiDAR such as the following:

- *High cost*: The cost of LiDAR is high because it can provide three-dimensional types data. Therefore, it is relatively expensive to deal with multidimensional data as compared to other technologies.
- *False returns*: In different atmospheric circumstances such as heavy rainy weather, fog and clouds LiDAR cannot be utilized properly. Due to raindrops, it diffuses and refracts light, leading to give sometimes false information.
- *Complex Data*: In most cases, sensors deliver data point clouds containing x-, y-, and z-coordinates and aerial photographs do not have the same visual impact. As aerial photographs satellite imaging may also be used [16].
- *Unsafe*: There are some risks associated with using LiDAR. There can be a difficulty deciding who is responsible if an accident occurs whether it is the car manufacturer, the programmer, or the sensor firm.
- *Total reflection*: An object can be illuminated by focusing a light beam surfaces, such as flat, reflective ones, which are affected.

A comparison with LiDAR sensor has been included to show the benefits and drawbacks of sensors with similar purpose. The next generation of autonomous systems will be appeared secure due to technological advancement. The automotive industry is increasing their budget for autonomous driving.

- *Airborne LiDAR*: Airborne LiDAR has made the most progress in recent years by processing and delivering 3D point clouds. The drone industry is also developing lightweight sensors and autonomous drones.
- *Agriculture*: Farming technologies (AgTech) can use LiDAR to identify areas that get the best exposure to sunshine. A machine learning system can also use the data to identify crops that need water and fertilizer.
- *Robotics*: LiDAR technology is utilized to provide mapping and navigation capabilities to robots. This technology is used for self-driving cars, that the vehicle can detect the distance between itself and other objects in its surrounding [17].
- *Exploration for Oil and Gas*: LiDAR can detect tiny molecules in the atmosphere since it has a smaller wavelength than other technologies. Gas and oil deposits can be traced using differentiable absorption LiDAR (DIAL).
- *Land Management*: Organizations that manage land resources can monitor them in real time, which allows for an increased level of efficiency in mapping and less time spent conducting aerial surveys.
- *Renewable Energy*: In order to harness solar energy properly, LiDAR can be adapted to determine optimal panel positions. In addition to calculating wind direction and speed, it can also be used to place wind turbines at wind farms [18].
- *Military and Law enforcement*: In military, LiDAR technology is used to identify the targets such as image processing is used for tanks and missiles making digital maps of the terrain and different objects in their path. The same principles have been applied to law enforcement speed limits within cities. A laser speed gun is used to accomplish this, and a camera is used to capture the images based on the time of flight for calculating the speed.

7 Conclusion

In this paper, we have provided a review of LiDAR sensor technology and future safety roads may use it as a companion. LiDAR is generally more precise than camera or radar in terms of measuring distance. As a result, LiDAR-based algorithms are highly reliable in evaluating physical information (object positions, headings, shapes, etc.). We demonstrate that LiDAR-based detection systems for autonomous vehicles can be compromised by adversaries. Developing deep learning for 3D data from LiDAR's will be one of the most important future directions.

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