Road Safety Application Using LIDAR Sensor

Farjana Ahmed
Automotive Software Engineering (MSc.)
Technische Universität Chemnitz
Chemnitz, Germany
farjana.ahmed@s2019.tu-chemnitz.de

***Abstract*—In the automotive industry to reduce road fatalities,Active safety features are one of the vital concerns. With the help of sensing technologies, to avoid collisions and accidents various safety applications have been integrated into today's autonomous vehicle. Light detection and ranging (LIDAR) sensor is prominent in this area as in recent years it is emerging as a powerful asset for security system integrators and solutions providers. This passage mainly focuses on the working principle of LIDAR sensors, components, and applications on safety system development. Additionally, the performance of the LIDAR over different active road safety applications and the algorithm outline and recognition resultin the real world has been denoted.**

***Index Terms*—Road safety, LIDAR, Automobile, Time of flight, WHO, ADAS, FOV, Ego-vehicle,**

I. Introduction

We must consider driving safety,when we think of driving a machine on the road. A recent statistical definition of WHO (World Health Organization) shows that every year almost 1.4 million fatalities caused by road accidents [1]. In recent years, it is an important social needs to reduce the traffic accidents and the various improvement of the vehicle safety capability has some effects on the reduction of the traffic accident. There are several safety approaches such as pedestrian detection, lane recognition, emergency braking system, and collision avoidance system integrated into vehicle to reduce road fatalities. Although various sensing technologies such as RADAR and Vision sensors used in improvement, LIDAR plays an increasingly vital role as vehicle safeguards. In the context of in-vehicle active safety system development, the state of the art of using LIDAR sensors is much more reliable than any other sensor technologies having the excellent advantage of high spatial resolution and high range accuracy.

LIDAR is an effective remote sensing method. In distinction to other sensors, it has distinguished features in fulfilling the demands of adequate safety functions. All standard feature constraints, for instance, extensive range coverage, and accurate distance measurement of objects required for the advancement of on-road security enhancement can be achieved by using the LIDAR sensor module.

In the subsequent sections, LIDAR technology and its performance contribution in active safety application development defined. In segment 2, the LIDAR sensor working principle and component outlined inclusive prerequisites of sensor usages in motor vehicles. In section 3, active safety functionality, and different algorithms such as pedestrian detection, lane recognition stated. Segment 4 continues to explain the experimental setup and assessment effects in several application developments.

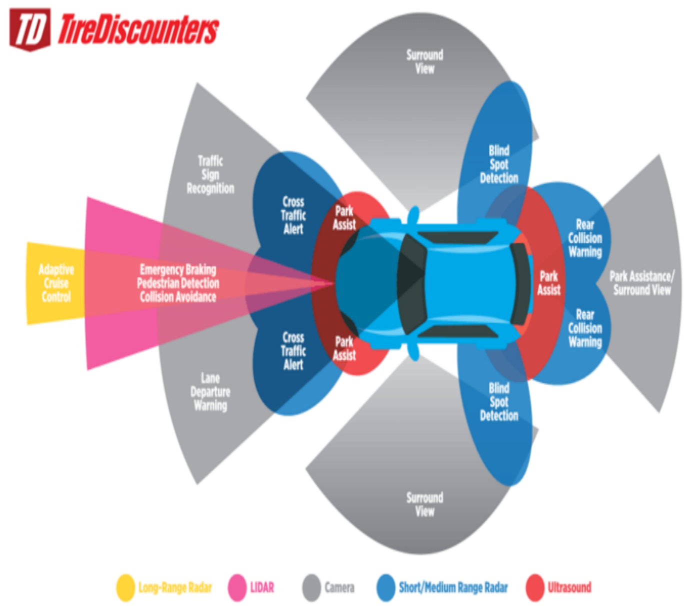

Fig. 1. Functionalities of road safety [5]

In this paper, a quantitative evaluation using the range data collected from a moving vehicle is carried out in a real road environment. The final result demonstrates the effectiveness of the proposed method.

II. LIDAR Sensor

A. Working principle

LIDAR is an active remote sensory method, which extracts the feature of objects by scanning surroundings at high resolution by emitting laser beam of high directivity, which allows highly precise measure of the road side environment. LIDAR obtains a very straightforward working mechanism. According to the description of Yuung(1996), using a photodiode a highly optical emitter emits a laser beam, and pulse reflects from objects is detected. By analysing the shape and size of the modulated laser light from photodetector anticipate the characteristics of a visual object.

To sense, the object presence LIDAR applies the time of flight (TOF) concept [2]. The time of flight method calculates the travel time of the emitted laser pulse among the transmitter and receiver. There are two types of time of flight concept used in time series measurement, one is direct (DTOF) and the other is indirect (ITOF) [3]. The indirect time of flight implies in LIDAR for continuous and long-range pulse modulation and On the other hand, a more widespread beam emits from DTOF is very short, which takes a few seconds to reflect and mostly used in Vision sensors. In Figure 2 , the basic architecture of the TOF circuit has shown. The circuitry consists of a transmitter, receiver, and timer module. The main moto of the transmitter is to continuously fires up the infrared laser beam towards the object and it collects the reflected pulse by the receiver. The integration between receiver and transmitter has done by the timer module which estimates the run time accurately, along with the speed of the light. According to WHO, the standard mathematical formula for timer circuit has shown below [2]:

$$D = V * \frac{T}{2} \tag{1}$$

Where D, V, and T represent the distance, constant speed, and variable time, respectively. The equation works for calculating the time of flight to translate into the distance measurement continuously. Then the 3D representation of object data has maps to application development.

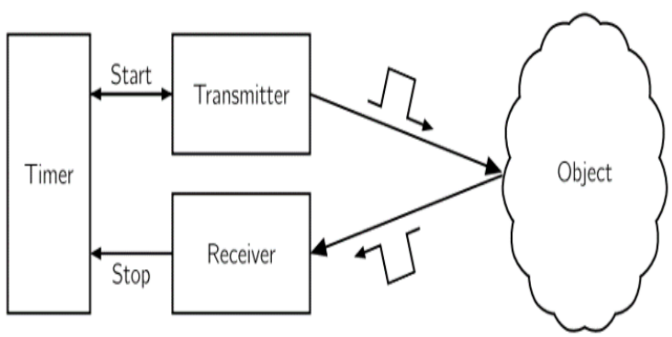

Fig. 2. Basic architecture of TOF [9]

B. LIDAR Components

The main architecture of LIDAR consists of four fundamental components but there can be some variations in design approaches, stil the working process is similar. Figure 3 illustrates the onboard component diagram.

1) ***Laser*** : The source of the light sensor is a modulated laser beam which is emitted to an object or surface. There are many different types of laser available according to their wavelength and usage, in LIDAR based safety application development use the wavelength of 600-1000nm ranged lasers. Object distance characteristics can be measured accurately using this maximum powered laser beam, short-range(up to 200m),.

2) ***Telescope*** : Feature extraction of various objects with various resolutions is the principal purpose of the scanning module or optic. From the reflected laser light, the surroundings of the object scanned in the system . The result of the optical scanner then represents by a 3D coordinator, which factors object parameters, for instance, point, density, and field of view (FOV). The FOV of the sensor determines the angle of the transmitted and received signal.For the performance optimization of the LIDAR sensor custom optical electronics are responsible

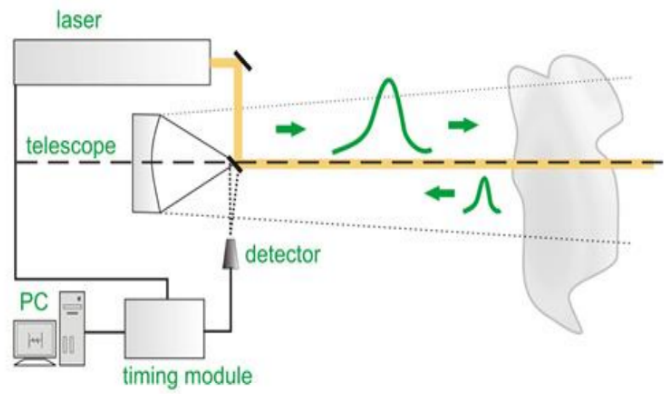

Fig. 3. Basic components of LIDAR [10]

3) ***Detector*** : By photodiode device, extracted features of the scanning unit stores and read. The detector works as the receiver unit and to sequentially process the digitized data an onboard timing circuit integrated to store into a storage system. There are two types of photodetectors are available in the market as per sensitivity requirement. Avalanche photodiode (APD), which is introduced as a highly sensitive receiver and another one known as a solid-state photomultiplier.

4) ***Computer or storage unit*** : For further processing,the LIDAR collects the filtered data and stores. It mainly focuses on information retrieving from the surrounding objects. Then the development level classifies the data applying algorithms based on which application decision is processed.

III. LIDAR IN ROAD SAFETY APPLICATION

Active road safety is the practice of design and construction regulation to limit the number of traffic collisions and accidents related to on-road vehicles. Road site visitor protection more broadly consists of traffic safety design now-a-days.In the sector of auto-car active road safety is frequently uses to describe systems that use a knowledge of the state of the vehicle assisting in the prevention of a crash and minimize the outcomes of damages and accidents. That includes lane recognition, pedestrian detection in the street. Functions can reduce prevalence as well as the severity of accidents by monitoring pre-notifications of this safety.

An efficient data record is needed on vehicle safety which provides the overall performance of autonomous car safety. Within the development of vehicle protection, various sensor systems have been equipped, such as RADAR, Ultrasonic, Vision sensors [4]. In compare to the other sensors, LIDAR represents highly logical information required for developing safeguard functions.

TABLE I
COMPARISON OF SENSOR TECHNOLOGIES [4, 7]

Features	LIDAR	VISION	RADAR
Range Coverage	$\sim 120m$	$\sim 100m$	$\sim 250m$
Target Resolution	High (0.5° to ∼5°)	Average	Low (∼0.1°)
Performance in Bad Weather	Average	Not applicable	Very good
Measurement Accuracy	High	Low	Medium
Performance in Dark	High	Not applicable	Medium
Ability	Object detection, distance estimation	Object detection, classification	Object detection, distance estimation

In recent automakers, LIDAR sensor gain popularity for having the following performance specification in the system [12]. Medium range coverage of surrounding objects Accurate measurement of data in a different environment, for instance, harsh environment Most importantly it is reliable and provides real-time data requirements

The following part of this section discusses pedestrian detection and lane recognition as an active road safety functional application using in-vehicle LIDAR.

A. pedestrian detection

For automakers, pedestrian detection is one of the principal safety concerns. In urban areas,the significance of accidents associated with pedestrians is very high. It implies to lessen the accident between pedestrians and vehicle on the intersection and the public transport by way of giving a driver the facts in which there are pedestrians.To activate the pedestrian protection system it is important to recognized pedestrians. The concrete pedestrian detection makes the motorvehicle informed of a potential uncertainty of several accidents.

To overcome pedestrian-related security issues, several innovative approaches have been developed in today's vehicle. One of the major innovations is in the Advanced Driver Assistance System (ADAS), to aware the driver about the different hazardous situations is the main moto. There are two types of the pedestrian detection method in ADAS are involved. One is passive pedestrian detection where Measurement of passive pedestrian protection often involves automobile safety and occurs during a collision to decrease the effect of the pedestrian leg or head hit. Although it reduces the impact of injury level, the system cannot avoid the occurrence of an accident. Another is active pedestrian where most of the safety features converge, particularly on active pedestrian detection, and notifies the dangerous situation beforehand of time.This preciously determines all the pedestrian-related constraints. The system will not only recognize the object moves or motionless but also distinguish whatever is the nature of the object. Moreover, driver can decide to avoid situation and act according to the pedestrian protection system based on localization and tracking of pedestrian information such as speed, movement direction, size of the pedestrian analyses. For these safeguard systems, a low rate of false pedestrian detection is a vital concern.

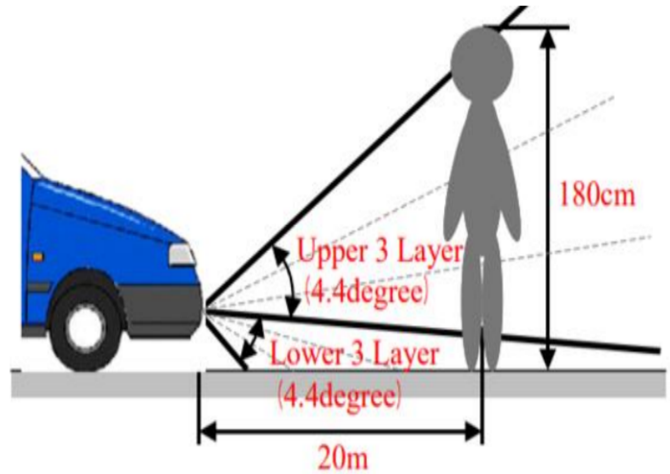

Fig. 4. Active pedestrian detection [6]

B. Lane recognition

Lane recognition is another crucial traffic safety requirement. To avoid road fatalities, many safety integration are reliable based on (e.g. ADAS) the recognition of the road boundary and the relative position of the vehicle. A lane recognition system can detect lane boundaries in different road environments, including marked and unmarked pathways. The maximum prominent capabilities that assist the estimation of the street course are intensity, colour, texture, area strength, aspect route, and height-over-ground [11]. Providing accurate measurement of the street track is the aim of the sensor system involved with the development lane recognition. Here Figure 5 illustrates an example of a lane tracking scenario.

IV. EXPERIMENTAL SETUP

Both pedestrian detection and lane recognition estimations have been carried out, in a distinctive experiential setting to develop efficient active-safety systems. Using the generated prototype, data is collected from different real-world traffic environments. A combination of various hardware and algorithms are used to conduct the experiment, which listed in table II

A. Hardware configuration

DENSO has been contributing its on-vehicle measuring device since 1997 and providing a compact circuit to car makers in pedestrian security development [11]. The DENSO LIDAR sensor recognizes the pedestrian position and its dimension precisely by using 2-dimensional scanning capability. By pivoting hexagonal mirror to identify pedestrian, this LIDAR emits laser pulse to the surroundings. The sensor

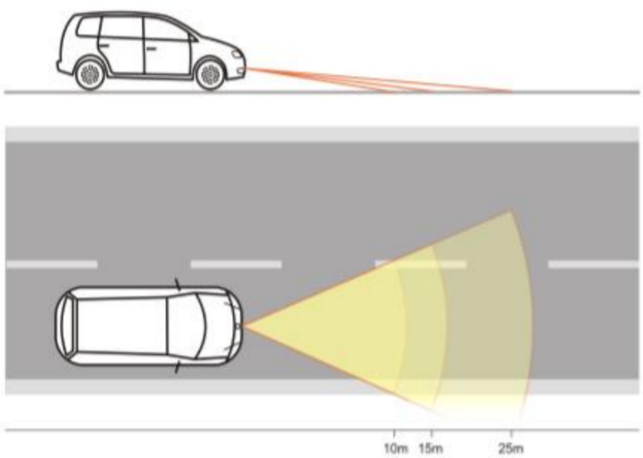

Fig. 5. Scanning process of road lane detection [14]

TABLE II
CONFIGURATION OF TESTING ENVIRONMENT [11]

Safety Feature	Hardware	Algorithm
Pedestrian Detection	DENSO LIDAR, Ego-vehicle	Object detection and classification
Lane Recognition	Velodyen LIDAR, Ego-vehicle	Line segment recognition and pattern matching

contains six rotating reflectors to concurrence pedestrian in front of an ego-vehicle. The synchronous scanning capability between transmitter and receiver of this LIDAR provides high resolution with high detection sensitivity.

TABLE III
SPECIFICATION OF DENSO LIDAR [11]

Feature	Specification
Detection range of pedestrian	80 m
Horizontal Field-of-View (FoV)	40°
Vertical Field-of-View (FoV)	4°
Horizontal resolution	0.1°
Vertical resolution	1°
Measurement frequency	10 Hz

In the long-range, the sensor-technology efficiently performs to identify appropriate targets similar to the car and pedestrian. Moreover, the mirror set on the rare forestall of the motorcar could be detected over 80 m far away, therefore, on a bright day the pedestrian in black boarders with the reflectivity approx. 10% is detectable, which is a considerably rare state of purposes for the measuring devices. The FoV is $40°$ in horizontal and vertical routes, $4°$ respectively adequate to suppress the dangerous pedestrian-involved accidents, for instance, pedestrian is running to cross over the street. Moreover, the horizontal and vertical angular resolution plays a vital role in the detection of the pedestrian and easily find out from a similar type of non-cubic substances just like the street surface. A multi-beam Velodyne VLP-16 measuring device is configured in ego-vehicle in the development of a lane recognition safety feature. The high speed and high-density point cloud characteristics of the sensor performs for efficient lane mark identification. The chain of TOF hits created by the 16 laser emitter/detector of the sensor detects the current position of a vehicle on road and apart from the medium-range distance measurement, the VLP-16 LIDAR provides an azimuth angle, rising angle, high resolution of 256-bit, moreover time-base pulse modulation. The distinctive aspects of the Velodyne VLP-16 in lane recognition safety system listed below [13]:

Laser emitter/detector: 16
Horizontal Field of View: 360°
Vertical Field of View FOV: 30°
Cycle rates: 5 Hz to 20 Hz
Maximum range coverage: 100 meters

B. Algorithm description

This sub-section mainly focuses on algorithm definition for road safety application. The algorithm approximately consists of two basic parts of working mechanism where the first one introduce object detection inclusive motion tracking and classification. Another one introduces lane tracking which involves identifying whether the vehicle is on the correct lane or in near future it is running out of the lane mark.

The pedestrian detection algorithm is having a pair of steps. Firstly, the object detection step, which identifies the moving object forward to the ego-vehicle in the road. By the residence grid mapping method, the static objects gets removed.Directly mapping to the 3D coordinate system is the true value of this step. By using Kalman-filter, the coordinated data are filtered and clustered under the supervision of the detection model.

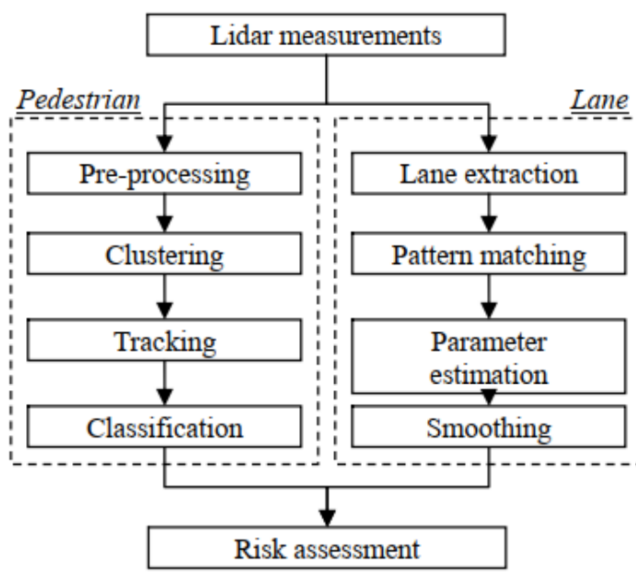

Fig. 6. Workflow of road safety algorithm [12]

Using the kinetic bicycle model, the motion of the ego-vehicle and pedestrian are calculated and to get an accurate measurement the result passes through a Kalman filter.

$$Y_1 = C_1(\delta - \beta - \frac{\Psi * l_v}{v}) \tag{2a}$$

$$Y_2 = C_2(-\beta - \frac{\Psi * l_h}{v}) \tag{2b}$$

$$s = (\Psi + \beta) \tag{2c}$$

$$m * v * s = Y_1 + Y_2 \tag{2d}$$

Here in equation 2, C_1 and C_2 are cornering power, m vehicle mass, β floating angle, δ angle of steering, v velocity, Ψ way. By the LIDAR sensor, detection data then translated into grid representation and rejected the non-pedestrian data.

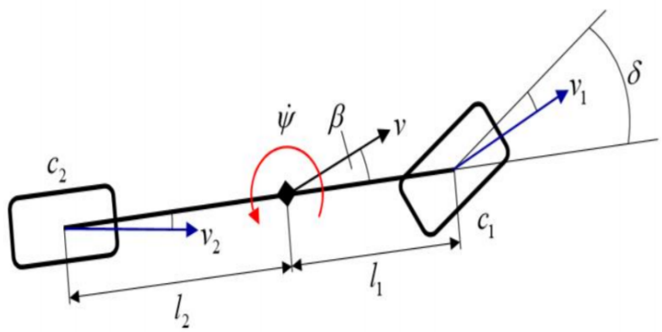

Fig. 7. Motion detection model [6]

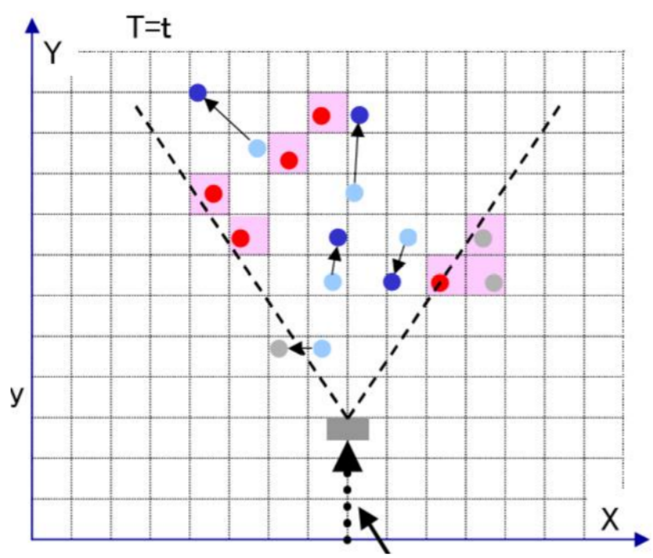

Fig. 8. Pedestrian data by mapping of grid [6]

The algorithm consists of several steps. Mainly the recognition of a road border depends on the description of roadside reflectors. Objects beside the road indicates the highway lane border in the real-world. Using the least-square method, safety application has been developed by taking into consideration these reflector object data and measuring the distances from the road. The static objects are separated from the pedestrian using the combined result of the bicycle model and grid map. Both sides of the road lane calculates by a least-square mathematical equation. According to the position of the egovehicle, the measurement is adjusted including change of lane. The lane width can be measured by the lane number and the changing of lane detection.

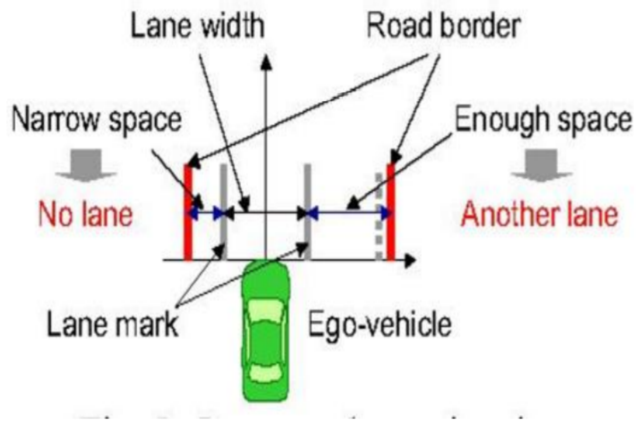

Fig. 9. Lane number estimation of road lane recognition [11]

Taking into consideration the position of the ego-vehicle and white central line, lane change decision is performed. The lane change decision made when the vehicle moves right or left from the central line up to a threshold value. The following equation demonstrates the lane centre measurement.

$$x = a_0 + a_1 + a_2y^2 \tag{3}$$

Where, a_0, a_1, a_2 represents horizontal centre lane, angle way, and curvature consecutively. The progression of lane change is shown in figure 9 (a, b, c, d, e shows the sequence). The road edge safety software creates a notification through lane number and lane change assessments, as sound or display meaning full indicator.

V. Result

The performance of LIDAR based pedestrian detection and road lane detection tested on real-world traffic, including the highway to reduce road fatalities. In different real-world conditions, dataset of 1000 pedestrian observed and detection rate was almost human level (97%). The maximum error rate of detection was in highly density pedestrians moving on the road.

To reduce the error rate and improve the performance, algorithmic improvement is necessary, also the hardware configuration is required. Additionally, detection accuracy is involved , compared with the pre-existence vision-based pedestrian

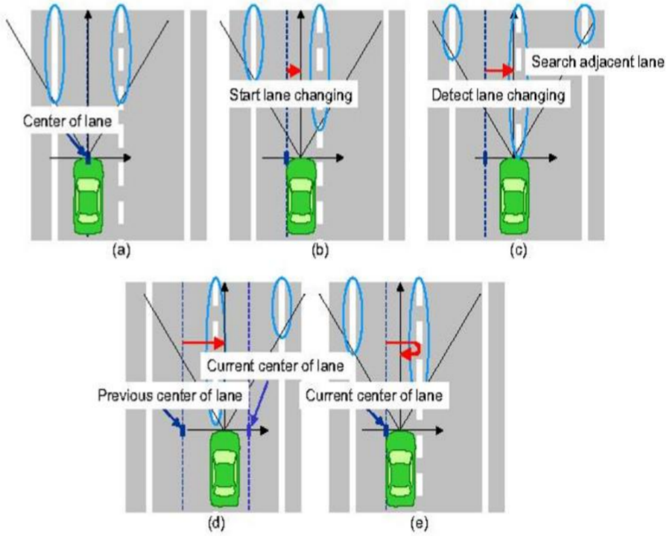

Fig. 10. Sequences of Lane switching [11]

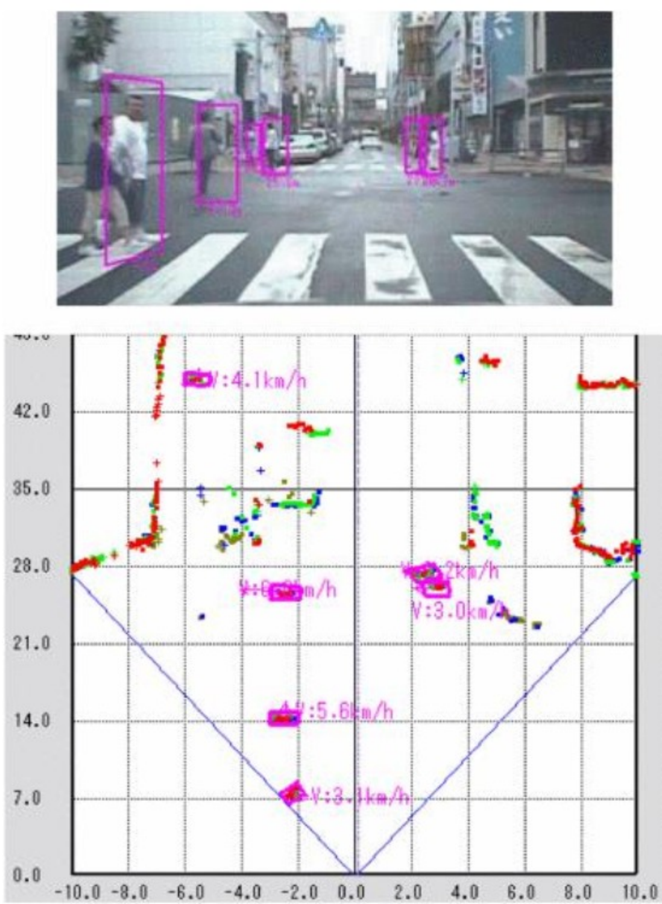

Fig. 11. Pedestrian detection and movement analysis [12]

detection safety system. Up to 50 m LIDAR performance is error-free while faulting rate increases from 30m in a vision-based pedestrian detection system has shown in figure 9. It indicates that in terms of long-distance, the LIDAR based detection system is more efficient and accurate.

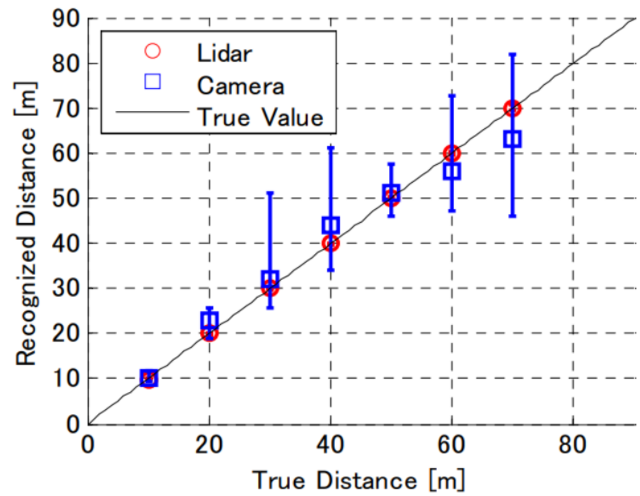

Fig. 12. Distance detection between Recognized and True distances [12]

The final estimation result of roadside reflec'tors and road boundaries detection also simulated. The performance is much more better in LIDAR based lane detection. Fig. 11 represents the simulation result of lane recognition. The safety application can detect the road boundaries and pedestrians up to 100 m recognition with less error rate in this application.

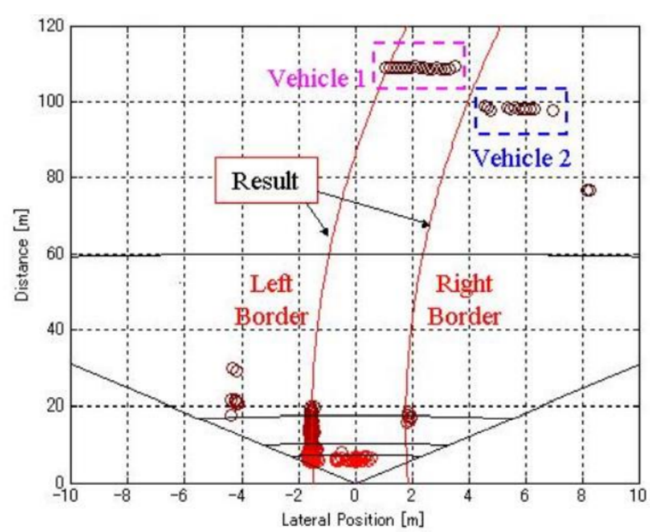

Fig. 13. Estimated result for lane recognition [11]

VI. Conclusion

This report reviews the working principle and specification of the LIDAR sensor system.Discussing the feature of the LIDAR sensor, referring several experiments, has showed the improvement of environmental robustness and the advantage of pedestrian detection and lane recognition to the application for road fatalities. The estimated performance is high in pedestrian detection and lane mark recognition. The Pedestrian detection rate is 97%, which might improve by sing highly efficient algorithms and hardware configuration. Lane mark recognition is also comparatively better than other sensory safety systems. It has shown that the error rate of recognition is less up to 100 m distance. Still, the improvement required in the architectural level for more reliable and efficient safety application development.

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