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Approaches of Road Boundary and Obstacle Detection Using LIDAR

O.Yalcin* A.Sayar O.F.Arar*** S.Akpinar**** S.Kosunalp*****

* Information Technology Institute, TUBITAK BILGEM, Kocaeli, Turkey,
(Tel: +90-262-675-3302; e-mail: ozkan.yalcin@tubitak.gov.tr)

** Computer Engineering Department, Kocaeli University,
Kocaeli, Turkey, (e-mail: ahmet.sayar@kocaeli.edu.tr)

*** Information Technology Institute, TUBITAK BILGEM, Kocaeli, Turkey,
(Tel: +90-262-675-3023; e-mail: omer.arar@tubitak.gov.tr)

**** Information Technology Institute, TUBITAK BILGEM, Kocaeli, Turkey,
(Tel: +90-262-675-3168; e-mail: samet.akpinar@tubitak.gov.tr)

***** Electronics Department, York University, United Kingdom,
(Tel: +44-7411668128, (e-mail: sk772@york.ac.uk)

Abstract: This paper introduces an overview of the studies of two problems; (1) road boundary detection and (2) obstacle detection, in order to allow the movement of autonomous vehicles. Light Detection and Ranging (LIDAR) is the most used technology for solving these two problems. It is thoroughly described with its operating mechanism and its use in other areas. We explore comprehensively the methods used in the literature to solve the detection of road boundaries and the obstacles as well as the recent trends in the relevant area. Furthermore, the solutions based on the previous works and suggested future works will be described.

1. INTRODUCTION

Transportation has become increasingly fast and comfortable with the use of the vehicles since the beginning of the seventeenth century. During the twentieth century, there were many advances in vehicle comfort and technology with the result that human life has become vehicle-dependant. Therefore, the number of vehicles has significantly increased. However, widespread use of the vehicles has brought new problems. These problems are briefly: traffic jam, air pollution from exhaust emission, injuries and deaths from road accidents. The main reasons for these problems are the sheer vehicle density and the effect of people not complying with the rules. In the last decade, automotive companies added new functionalities which provide flexibility in the use of vehicles. Examples of these functionalities are self-parking, an alert when changing lane, and maintaining a constant distance from the vehicle in front. Some projects have been undertaken in both the academic arena and the automotive world to design vehicles which do not require a driver and these are still on-going. These vehicles can be named as 'autonomous' or 'driverless' vehicles. Prototypes have been designed in different countries. Some of the prototypes have participated in an Urban Challenge competition which was hosted by the Defense Advanced Research Projects Agency (DARPA) in 2003 in U.S.A. An example of autonomous vehicle, Boss, was the winner of the competition; it was designed by Carnegie Mellon University (Urmson *et al*., 2008). Considering that most accidents are human-induced, more intelligent vehicles can reduce the rate of accidents and improve energy efficiency by maintaining the optimum level of fuel consumption. There are a number of problems that need to be solved in autonomous vehicles. Some of these problems are: route planning, precise positioning, detection of traffic lights, sensing traffic signs, obstacle detection and identifying the boundaries of roads. The most important of the problems is the detection of obstacles and road boundaries as this plays a vital role in the safety of the drivers, animals and passengers in traffic. There are many methods and sensors in autonomous vehicles for the detection of the road boundaries and obstacles. Typical examples are cameras and image processing techniques, sensitive radars, ultrasonic sensors and LIDAR. Cameras and image processing techniques have long been used as a research topic because cameras are cheap devices and easy to supply compared with sensors (Choi *et al*., 2012). Cameras are a relatively old technology and carry high-resolution information which has resulted in a great deal of successful work (Wijesoma *et al.*, 2004).

Some examples of works are: likelihood of image shape (LOIS) (Kluge et al., 1995), generic obstacle and lane detection system (GOLD) (Bertozzi et al., 1998), autonomous land vehicle in a neural network (ALVINN) (Pomerleau et al., 1992), automated road curvature and direction estimation (ARCADE) (Kluge et al., 1994), rapidly adapting lateral position handler (RALPH) (Pomerlau et al., 1996). Image processing techniques are negatively affected by basic

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weather conditions such as rain, fog, cloud and poor light. Therefore, the design of road boundary and obstacle detection with image processing techniques could be quite difficult but some of the methods have achieved a good agreement (Wijesoma et al., 2004). Cameras are lightweight and low-cost devices, running at low energy level but because they are vulnerable to changing weather conditions they usually are used as an assistive system for obstacle detection in autonomous vehicles which require high reliability (Han et al., 2012).

Using sound-based ultrasonic sensors are another method of obstacle detection. Ultrasonic sensors send out high frequency sound signal and evaluate the echo which is received back by the sensor. The time interval between sending the signal and receiving it back is calculated to determine the distance to an object. In this method, the sound signal expands like a funnel and shrinks back. Hence, any changes that are smaller than the track of the signal propagation cannot be detected. It may not be possible to know and predict much about the shape of the obstacle detected. On the other hand, some of the obstacles do not reflect back the sound signal but absorb it instead. Because of that, detecting such obstacles might not be feasible with ultrasonic sensors because it renders them inadequate and unsafe in this circumstance. Currently, they are mostly used as a warning system for parking.

Another technology used in detecting obstacles is radar systems. Radars can detect distant objects and are not affected by the weather conditions and the amount of light (Wenger et al., 2005). The principle of the radars is similar to that of ultrasonic sensors. Unlike ultrasonic sensors, however, they send out radio signals. As in ultrasonic sensors, based on time difference between the radio signal transmission and reception, the distance from radar to an obstacle is estimated. There are two type of radar in land vehicles: short-range radars which operate at 24-Ghz wavelength and long-range radars which operate at 77-Ghz wavelength (Wenger et al., 2007) (Freundt et al., 2008). Radars are used in modern vehicles to sort out many problems such as blind-spot control, maintaining the distance between vehicles and parking. There are a number of studies reported in the literature which take advantage of radars (Lakshmanan et al., 1996). However, due to their mechanisms, their scanning speeds are low and they may be inefficient for real-time obstacle and road boundary detection (Wijesoma et al., 2004).

Recently, LIDAR sensors have been used as one of the main technologies in detecting objects. The principle of LIDAR sensors is similar to that of radars and ultrasonic sensors but they use laser to measure the distance. After a laser beam sent from a LIDAR hits an object, it reflects back to LIDAR. The distance between the LIDAR and the object is calculated as follows: the round-trip duration of the beam is multiplied by the speed of the light, then the result is divided by 2, the final result represents the distance. Resolution of the LIDAR sensors is high as they use laser technology. They would have high accuracy when image processing techniques are insufficient due to the weather conditions. However, they seem to be more expensive when compared with the other types of sensor.

2. PROBLEM DEFINITION

Autonomous vehicles are expected to stop instantly or find an alternative way in order not to damage when they detect an obstacle. Examples of the obstacles are vehicles, pedestrians and potholes on the road, speed bumps, sidewalks and barriers at the edge of the road. Fig. 1 shows an example road environment in which the road is bordered by shrubs and open ground. Also, there is a barge in the middle of the road. The problem in this situation is to detect the boundary lines of the road and find an appropriate route for the vehicle. Let us call the area on the right-hand side of the barge A and the area on the left-hand side of the barge B. An autonomous vehicle is expected to choose either A or B in order to avoid crashing into the barge. This study focuses on the finding a route for vehicle to detect the obstacles on the road and pass through safely.



Fig. 1. An example road: with a barge in the middle of the carriageway, shrubs and lighting.

3. ROAD BOUNDARY AND OBSTACLE DETECTION APPROACHES

3.1 Lidar Sensors

LIDAR sensors are used for many purposes in industry. Some typical areas of use are: measuring the density of particles in the air (rain, fog, nitrogen-oxygen ratio and wind speed), making three-dimensional topographic maps and picture of works of art, obtaining seismic data, obtaining information about the surface of Mars, analysis of the ocean floor and detecting obstacles for autonomous vehicles. This paper studies the published research on the use of LIDAR sensors for autonomous vehicles.

LIDARs are used for detecting obstacles and producing detailed information about the obstacles in very high-resolution. For example, the resolution of the SICK LMS-511 LIDAR is around 0.167 degrees and the fault tolerance in 80 meters is around 30-40 mm. They provide high resolution even in the case of bad weather conditions.

A common problem for lasers is that black-colored obstacles absorb the light and only weakly reflect the signal. Some of the LIDAR sensors can tolerate this problem. For instance, the LMS-511 sensor produced by SICK; its range for black-colored obstacles is 26 meters while its 80 meters in others. The range of a LIDAR sensor with a 190 degree scan angle is shown in Fig. 2.

There are three types of LIDAR sensor: one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D). One-dimensional (1D) lasers work like laser meter which provides distance from a point to the meter. 2D LIDAR sensors, according to their scanning angles, make a land scan and try to work out x and y coordinates of a point. 3D LIDAR sensors comprise a set of 2D sensors. They analyze the x and y coordinates of 2D sensors on the z axis.

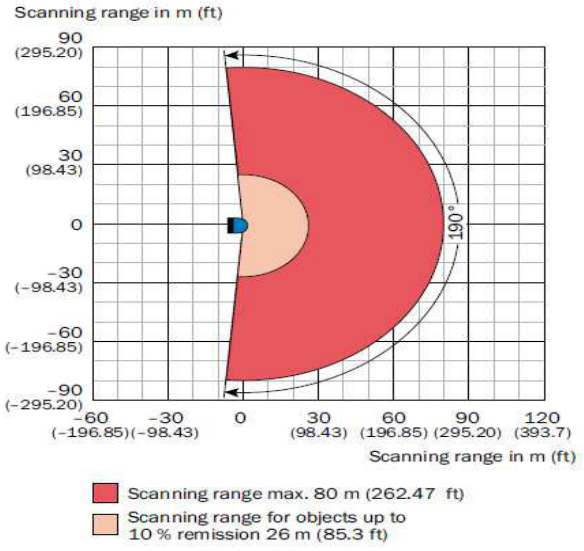

Fig. 2. An example of 2D LIDAR sensor.

LIDAR sensors are high-speed devices and generate information at 100Hz. The amount of information generated in an autonomous vehicle using three or four LIDAR sensors can reach to millions point levels. This high load of information needs to be processed in real-time by vehicle decision support system. Delays and faults in processing the information can cause critical problems for the movement of the vehicle.

3.2 Positioning the LIDAR sensor on the Vehicle

The position of the LIDAR sensor on a vehicle is an important issue for the detection of the obstacles and road boundaries. Fig. 3 shows a vehicle which has a 2D LIDAR sensor positioned on the top of the vehicle and aligned parallel to the ground. Let us assume an inclination angle of 0 degrees and a ground height of h cm in this position. In this case, only obstacles which have a height of h cm or more can be detected. Two obstacles are shown in Fig. 3, a yellow cylinder higher than h cm and a green cylinder lower than h cm are given as an example. The position of the green cylinder cannot be detected while the yellow cylinder is detected. If the LIDAR sensor is placed in a lower position, the green cylinder can be detected. However, speed bumps and potholes on the low level of the ground cannot be detected. For these reasons, LIDAR sensors must be aligned at an angle, sloping downwards. Fig. 4 shows an example of a LIDAR sensor positioned with an angle.

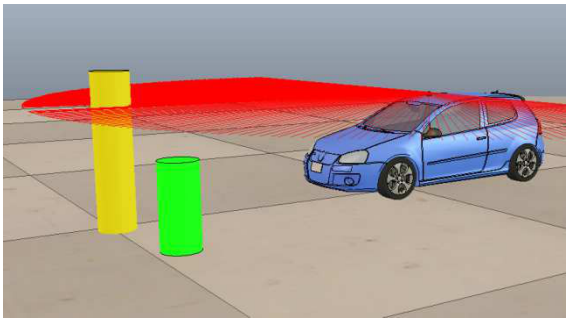

Fig. 3. 2D LIDAR sensor with scan angle of 180 degrees.

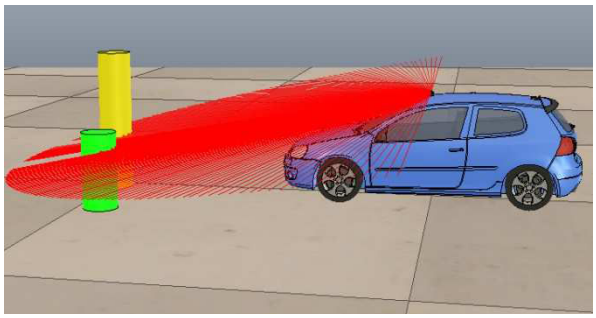

Fig. 4. 2D LIDAR sensor with an inclined degree of an angle.

Han *et al.* designed a vehicle using LIDAR sensor with a downwards-sloping angle (Han *et al.*, 2012). Their vehicle won first place in the 2010 Autonomous Vehicle Competition (AVC). Similarly, Wijesoma and his colleagues designed a vehicle which can reach known targets. (Wijesoma et al., 2004).

There are number of disadvantages of positioning LIDAR with a downwards-sloping angle. When the first scan of LIDAR sensor starts an area under the scan, in front of the vehicle, is not covered. There might be an obstacle in this area which may cause problems even though it is not very likely. To alleviate this probability, Han *et al.* used two LIDAR sensors, one with a sloping angle and one parallel to the ground.

3.3 Approaches of the Detection of Road Boundaries

In this study we introduce two new terms: physical road boundaries and logical road boundaries. Edge points of the road on which traffic flows and includes crosswalk, traffic lights is defined as physical road boundary. On the other hand logical road boundaries are calculated by taking obstacles into account. It is the points on a road where vehicle can pass through. E and F points represent the physical road boundaries and C and D points represent logical road boundaries in Fig. 6. E and A points are not assumed to be logical road boundaries because the width of the vehicle is larger than the length of from E to A so that the vehicle cannot pass through.

The main principle of detection of logical road boundaries using a LIDAR sensor is to find more regular and larger planes to allow vehicles to go through. The term of 'more regular' refers to the linear changes of height, distance and inclination of the points that continuous laser beams reflect back. The main feature of algorithm of the Han *et al.*'s vehicle is that if the continuous laser beams from the LIDAR sensor continue to stay on the same object then a smooth change on the measured distances is expected. If the measured distance difference is beyond a given threshold then two consecutive laser beams are reflected by different obstacles. These two points are used as a breaking point in the algorithm (Han *et al.*, 2012). Fig. 6 presents an environment with obstacles and physical and logical road lines. The black points show the breaking points. According to the LIDAR beams shown in Fig. 5, if the distance between the consecutive points (P1, P2) is beyond a threshold value and the tangent of the line through the two points is beyond a threshold value, P1 and P2 are breaking points. To decide whether or not P1 and P2 are breaking points, formulas 1 and 2 can be used (Kang *et al.*, 2012). Formulas 3 and 4 have been used to decide breaking points in Wijesoma *et al.*'s work. The value of $\boldsymbol{d_{i+2}}$ is the measured distance between P3 and the LIDAR. If the consecutive LIDAR sensor beams reflect back smoothly, with the distance information of the two points previously known and LIDAR's resolution degree, the position of a third point can be estimated using formula 3 as $\boldsymbol{d_p}$.

Also, if the difference in the value of $\boldsymbol{d_p}$ in formula 4 and measured $\boldsymbol{d_{i+2}}$ is beyond a pre-determined threshold value, this is a breaking point (Wijesoma *et al.*, 2004).

$$\sqrt{(x_i - x_{i+1})^2 + (y_i - y_{i+1})^2} \leq p_{th} \quad (1)$$

$$\left| tan^{-1}\left(\frac{x_i - x_{i+1}}{y_i - y_{i+1}}\right) \right| \leq t_{th} \quad (2)$$

$$d_p = \frac{d_i d_{i+1}}{2 d_i cos\gamma - d_{i+1}} \quad (3)$$

$$\left| d_{i+2} - d_p \right| \leq d_{th} \quad (4)$$

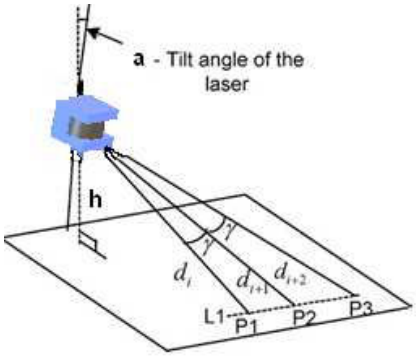

Fig. 5. LIDAR sensor aligned with a downwards-sloping angle and notations used in formulas.

The ground height of the LIDAR sensor is $\boldsymbol{h}$, the sensor slope with the ground is $\boldsymbol{a}$ and the resolution is $\boldsymbol{\gamma}$. The reflection points of beams are ***P1***, ***P2*** and ***P3***. The coordinates of the reflection points are $(\boldsymbol{x_i, y_i})$, $(\boldsymbol{x_{i+1}, y_{i+1}})$ and $(\boldsymbol{x_{i+2}, y_{i+2}})$ respectively. The distances from the reflection points to the sensor are $\boldsymbol{d_i}$, $\boldsymbol{d_{i+1}}$ *and* $\boldsymbol{d_{i+2}}$.

We call the set of points between the two breaking points a 'segment'. From A to B, B to C and C to D are segments in Fig. 6. Han, Wijesoma, Kang, Qin and Kim have divided the breaking points into segments. Later, the angle of gradient of the segments and the ground height of the segments based on LIDAR sensor's position are considered in deciding whether there is a segment or not.

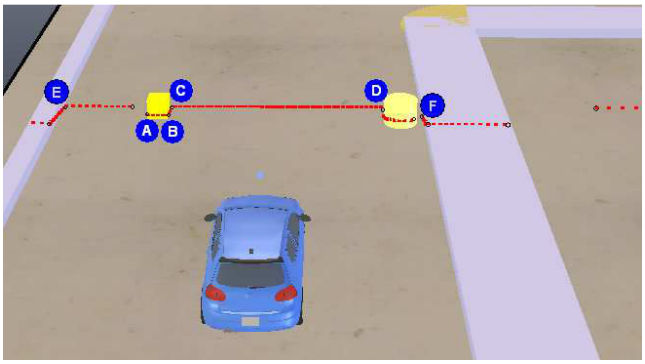

Fig. 6. Road pavements and laser beams propagation with some obstacles

3.4 Approaches of detection of obstacles

One of the main problems to be solved in autonomous vehicles for safe driving is to map obstacles around the vehicle. If GPS with high accuracy performs positioning, the obstacles in the map can be shown in their real locations (latitude/longitude). If there is no accurate GPS, the obstacles' position can be shown relative to position of LIDAR. Another property that should be in the map is to show the type of the obstacles and the level of the danger which they present. The type of an obstacle refers to a mobile or a static state. The level of danger is determined by obstacle type. These levels can be classified as dangerous, low dangerous, safe and blind spot (Peterson *et al.*, 2011). A blind spot is a place that cannot be scanned by the LIDAR sensor.

To map obstacles, there are six steps to be done:

I. Breaking points are found.
II. Segments are obtained from the breaking points found.
III. Logical road segments are produced from the segments.
IV. After subtraction of the logical road segments, the rest of the segments are obstacles segments. They are compared with the obstacles found in the previous map. If the location of the obstacle has changed, the obstacle is mobile, if not the obstacle is static.

V. The obstacle segments identified are placed into the obstacle map. The obstacles passed by the vehicle are removed from the map.

VI. From the properties of the obstacle such as length and type, the level of danger is determined.

The final map is used in vehicle decision support.

4. CONCLUSION

In this study, the approaches in detecting road boundaries and obstacles using LIDAR sensors and the advantages of the approaches have been evaluated. Some of the approaches were implemented in a VREP simulation environment and the performances of the algorithms have been successful. There are still lots of problems that need to be solved in autonomous vehicles. The current performances and reliabilities of the algorithms need to be further improved.

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