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Road Density Calculations with Unidimensional LiDAR Sensor for Dynamic Intersection Management

Dinamik Kavşak Yönetimi İçin Tek-Yönlü LiDAR Sensör ile Yol Yoğunluk Hesabı

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Abstract

The main aim of dynamic intersection management is to make instant detection of vehicles both at the intersection and approaching it. In this sense, vehicle detection sensors have been preferred for dynamic intersection management. Among these sensors, LiDAR (light detection and ranging) sensors are used in many different areas, but also focus on vehicle density detection at intersections. In this article, a unidimensional LiDAR sensor system that can detect the number, velocity, and class of vehicles at intersections with different densities and also the length of vehicle queues that may occur at this intersection has been studied. In this study, 96.36 % success has obtained in the detection of the velocity, and 96.35 % success has also obtained in the queue detection. This study stands out in terms of price and performance with its unidimensional LiDAR system, which has the features of a 3D LiDAR sensor.

Keywords: Dynamic intersection management, Unidimensional LiDAR sensor, Queue length detection

Öz

Dinamik kavşak yönetimi, kavşaktaki ve kavşağa yaklaşmakta olan araçların anlık tespit edilmesinden geçmektedir. Bu anlamda dinamik kavşak yönetimi için araç tespit sensörleri tercih sebebi olmuştur. Bu sensörlerden LiDAR (ışık tespiti ve menzil tayini) sensörler birçok farklı alanda kullanılmakla birlikte kavşaklardaki araç yoğunluk tespiti üzerinde de durmaktadır. Bu makalede farklı yoğunluklara sahip kavşaklardaki araçların sayısını, hızını, sınıfını ve yine bu kavşakta oluşabilecek olan araç kuyruklarının uzunluğunu tespit edebilen tek boyutlu LiDAR sensörlü bir sistem üzerinde çalışılmıştır. Bu çalışmada hız doğruluk tespitinde % 96.36, kuyruk uzunluğu tespitinde ise % 96.35 başarı elde edilmiştir. Bu çalışma 3D LiDAR sensörün özelliklerine sahip tek boyutlu LiDAR sistemi ile fiyat ve performans açısından öne çıkmaktadır.

Anahtar Kelimeler: Dinamik kavşak yönetimi, Tek boyutlu LiDAR sensör, Kuyruk boyu tespiti

1. Introduction

Today, with the crowded cities and the continuous increase in the number of cars, it has become a necessity to increase the number of existing roads or to use the existing road capacity in the best way. In addition, many factors such as the increase in the number of accidents, high fuel costs, travel stress, and environmental problems accelerate this process (Akanbi and Olajubu 2012).

The best way to use road capacity is through the management of intersections. Intersections are one of the most basic elements that connect the city and determine the traffic flow rate in the city. For intersection management, it is extremely important to determine the traffic signal times by detecting the vehicle density at the intersection. Determination of traffic signal times is carried out by two different methods. In the first type of system, fixed traffic light cycle times operate independently of the environment. In the second type of signal systems, light and cycle times are changed depending on the environment. Vehicle densities on the intersection and the roads connected to the intersection are

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detected by sensors in signal times depending on the environment. Green light durations are increased on roads with high vehicle density, and solutions are offered by increasing red light durations on roads with low vehicle density (Chiu and Chand 1993).

Said sensors can be divided into two sensors that are destructive to the road and those that are non-destructive to the road. Sensors such as magnetic detectors, pneumatic road tubes, piezoelectric and inductive loop (IDL) are destructive ones. These sensors, as the name suggests, are placed under the highway by stopping the traffic. They take up a lot of space, consume power, and the road must be closed to traffic for their installation and maintenance. It also has systems based on highway geometry. The highway disruptions caused by this system can make the data unreliable (Cheung and Varaiya 2006).

Due to such disadvantages, these types of sensors are viewed with prejudice. Non-destructive sensors, as the name suggests, include sensors that can be placed on the roadsides or on the top of the roads without intervening on the highway. These: Magnetic sensors, Wi-Fi sensors (Goodall 2017), Bluetooth sensors (Margreiter 2016), VIP (video image processing), radar (Zhao and Su 2017), LiDAR and ultrasonic detectors, etc., are sensors.

Among non-destructive sensors, LiDAR sensors are used for detection and ranging with light. These sensors are frequently used in autonomous vehicles in transportation planning (Ibisch et al. 2013, Yue et al. 2018) as well as in the detection of vehicles and pedestrians at intersections. Different solution algorithms are presented to observe and follow the situations of vehicles and pedestrians at the intersection with the LiDAR sensor. Background filtering, object clustering, object tracking, passenger and vehicle classification were performed with the 3D LiDAR sensor. As a result, the speed, position, presence, direction of pedestrians and vehicles could be determined.

In the 3D LiDAR study carried out to detect deer that can prevent vehicle passages on the highways and suddenly leave, the point cluster of the target object was created, the background filter and classification were made (Chen et al. 2019). Vehicle detection with sensors becomes difficult in rainy, windy and snowy weather conditions. Background filtering and point clustering operations were carried out in a presented algorithm for clearer and clearer detection of vehicles in these harsh weather conditions. Vehicle detections can be detected up to 22 m range and detection becomes more difficult at longer ranges.

LiDAR sensors are also used for vehicle queue detection at intersections. There have been applications trying to determine the ideal traffic signal time that requires queue length detection (Ban et al. 2011, Çıldır et al. 2022). A study used the shockwave theory to estimate the queue length with high resolution traffic signal data (Liu et al. 2009). In another study carried out with a 3D LiDAR sensor, vehicles at the intersection could be followed by performing background filtering, point clustering, object classification, and lane detection. In the algorithm of determining the vehicle queue length forming at the intersection, the vehicles approaching the intersection are considered to have stopped after a certain deceleration and the length of the vehicles at the intersection can be calculated (Wu et al. 2020) .

Non-destructive sensors are preferred because of their advantages such as being able to be installed without interfering with the flowing traffic and without destroying the road. In this study, a non-destructive LiDAR sensor has been preferred due to its unidimensionality and direct distance output. With the algorithm created for the unidimensional LiDAR sensor, the speeds and classes of the passing vehicles have been tried to be determined. At the same time, with this algorithm, the scenario of vehicle queues that may occur at the intersection has been created and the number of parked vehicles and the queue length they formed have been determined. The LiDAR sensor system created, respectively, in the presented algorithm, the materials used in this system, the measurements performed, the measurement evaluations and the results will be mentioned.

2. Materials and Methods

The materials used in the designed LiDAR system and the algorithm created are examined in two sub-titles.

2.1. The Design LiDAR System

In this study, unidimensional a LiDAR sensor system is shown in Figure 1. In this system, there is a 2-axis pan tilt kit, set on wood, with two servo motors and a unidimensional LiDAR distance sensor set on it as well. Servo motors are supplied from mains voltage with a 6V DC adaptor. There is also an Arduino Mega hardware board both managing servo motors, LiDAR sensor and performing calculation operations. The connection of the pan tilt of the Arduino and LiDAR sensor has been implemented with the connections on the board in Figure 1 below.

Benewake TF03 is a unidimensional long-distance sensor that is being mostly used in smart transportation systems,

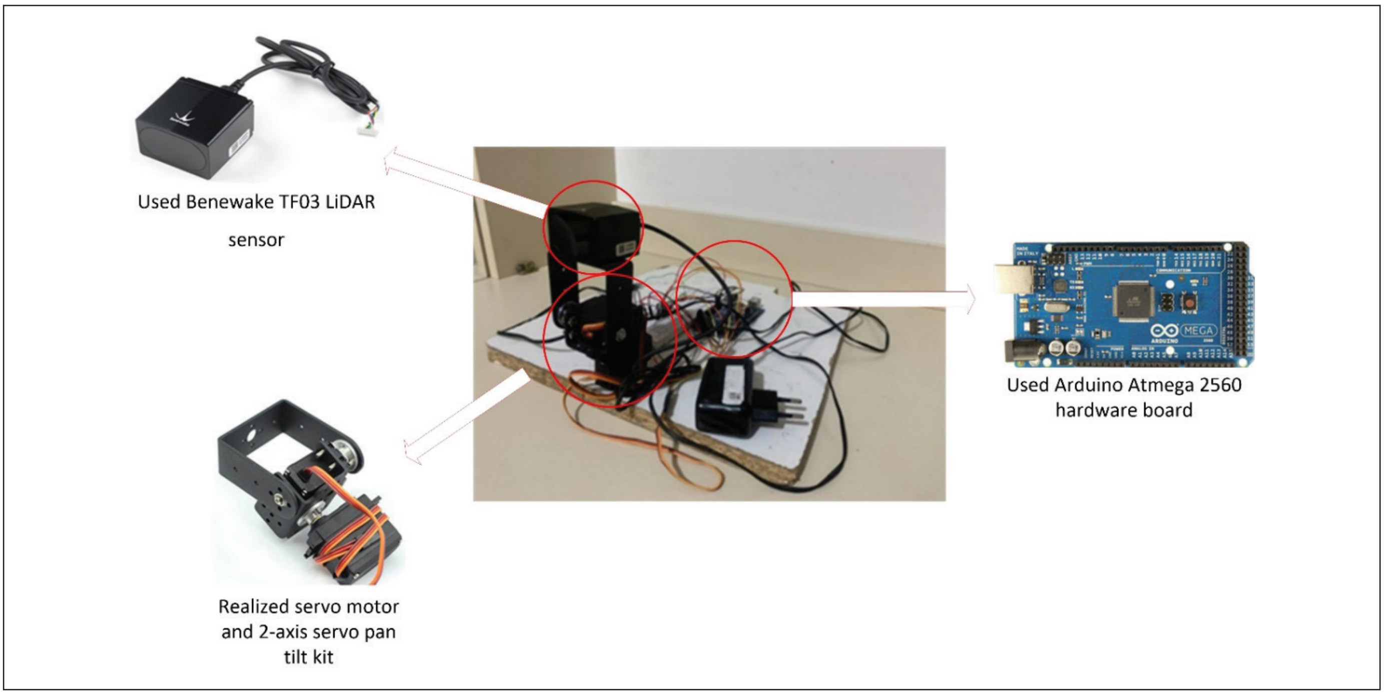

Figure 1. The setup LiDAR sensor system.

automotive sectors, and UAVs (unmanned aerial vehicles). And, also, it is a distance sensor that enables high frequency measurement up to 10 kHz, IP67 high enduring case, and some different communication interfaces in order to be used in different sections. The one with a 180 m distance range of this sensor has been preferred in this study. Even though it has a different structure from other 2D and 3D lasers due to its way of working, it is taken into account in LiDAR category as its laser light, 905 nm wavelength, falls under the category of laser light spectrum (Skoog 1981). Light Emitted Diode (LED) is used as a source of laser light (Sparkfun 2005).

16-input Arduino Atmega 2660 hardware board has been preferred as a programmer and controller in LiDAR sensor system. Arduino is a board that can be programmed with sub-software of C language. Its use is widespread as having a lot of libraries of sensors in it. This board has been used in this study as it has already-prepared libraries. The hardware board has been also used because it has much more out-port than any other Arduino group. Instead of Arduino hardware board used in this study, some different hardware boards may be used whenever is needed.

MG-996R is a servo motor that can reach up to 13 kg torque at 6V and has a capacity of 120 degree-rotation has been used in this LiDAR system. This motor can rotate by the command that is given and can take 60 degrees in 0.15 seconds. It basically consists of a gear mechanism with a DC engine, engine drive card, and potentiometer. The motor drive card has been checked by Arduino. Feeding of these motors has been brought about with a 6V-adapter from mains voltage.

One 2-axis pan tilt kit has been used to obtain the 3D LiDAR sensor. This LiDAR sensor which is called unidimensional has been aimed to be gained two more dimensions with this pan tilt kit and so a sensor has been obtained like a three-dimensional one used in sectors. At the same time, with this pan tilt can be detected the angle of the target object.

2.2. The formed Finite-State Machine Algorithm

The system algorithm has been made up in the form of a finite state machine, which is a behavior model that is frequently used in embedded systems and shows machine states. It is frequently preferred in numerical systems because it is easier to make changes to it and to improve the algorithm (Choudhary 2018). A finite state machine contains five (tuples) A= (Q, Σ, δ, q0, F). 'Q' refers to finite states (Festag et al. 2008). 'Σ' can be defined as the set of input symbols. 'δ' is the finite transition function. 'q0' represents the starting state. 'F' represents the finished state set (Xu et al. 2009). The finite states of 'Q' will be focused on in this study. The implemented finite state machine consists of four states. Respectively, there is no vehicle, the vehicle entered,

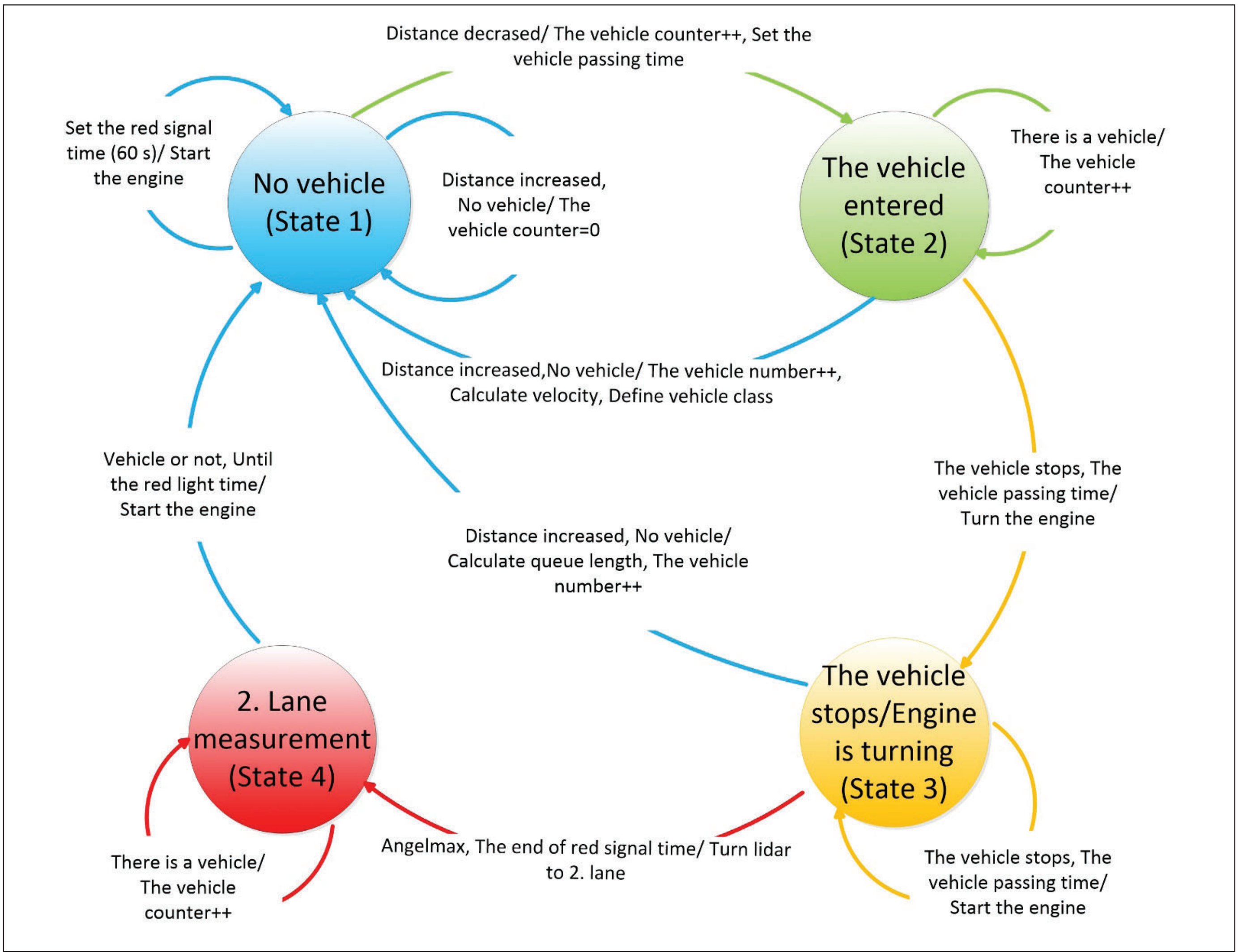

Figure 2. The formed finite-state machine diagram.

the vehicle stops/the motor rotates, and the 2nd lane measurement states. The state diagram created for the algorithm in this study is shown in Figure 2.

State 1 is no vehicle state. Considering the situation that this study will be carried out in real-time, a red light time of 60s has been established in this state. The algorithm completes four steps in 60 seconds. In state 1, when the vehicle enters in front of LiDAR sensor, the reference distance decreases, and the 2nd state is entered.

With the number of data obtained while the vehicle passes in front of the sensor, it is calculated how many seconds the vehicle passes in front of the sensor. Here, the pulse frequency of LiDAR sensor is 100 Hz, and the vehicle distance data obtained is calculated according to this frequency. This calculation formula is given in 1. Other formulas used in velocity calculation are given in 2 and 3, respectively.

$$t = \frac{nod}{f} \tag{1}$$

't' is second, a nod is the number of data obtained when the vehicle passes in front of LiDAR sensor and f is the frequency of LiDAR sensor.

The passing time of the vehicle in front of LiDAR sensor has been calculated with the formula 1.

$$X = V \times t \tag{2}$$

In calculating the speed of the vehicles, the average vehicle length (X) has been accepted as 3m. V is velocity.

In formula 2, the general road velocity formula is given. Based on formulas 1 and 2, the third formula has been formed and the vehicle speed has been calculated with this formula.

$$V = \frac{X \times f}{veri} \tag{3}$$

If the reference distance increases again after decreasing, it is understood that the vehicle has completely passed in front of the sensor and it returns to the 1st state. This situation is repeated every time a vehicle enters in front of the sensor for 60 seconds.

The situation in which the vehicle entering in front of LiDAR sensor is detected is the 2nd Situation. If the vehicle passes in front of the sensor without waiting, the number of passing vehicles increases by one and returns to the 1st state.

In this working algorithm, which is similar to the studies (Cai et al. 2010, Wu et al. 2013) that vehicles under a certain speed start to form a queue, it is passed to the 3rd State in the state machine when the vehicle waits for 5 seconds or more in front of the sensor.

State 3 indicates that queue formation has started. In this state, using the engine, the sensor scans from the beginning to the end of the vehicle waiting in the queue and calculates the queue distance. The same process is repeated for each queued vehicle and thus the total queue length is found. It takes 45 seconds from the start of the algorithm to the end of this state. At the end of 45 seconds, the 4th state is entered.

In the first three situations, the measurements of the vehicles in the 1st lane have been carried out. In Situation 4, it is determined whether there is a vehicle queue in the 2nd lane. In this situation, LiDAR sensor moves to the line of the 2nd lane from the point where the 1st lane finishes the tail measurement. LiDAR sensor looks at the tail end of the 2nd lane for 15 seconds and at the end of 15 seconds, it decides whether the queue length of the 2nd lane and 1st lane is equal. In this decision phase, as in lane 1, the empty ground is taken as a reference.

After the 2nd lane control for 15 seconds, the first cycle of the algorithm is completed and it is started again. Thus, it is possible to calculate how many cars queue at the red light and the resulting queue length during the red light. A unidimensional LiDAR sensor with a 2-axis pan tilt can observe horizontally and vertically like a 3D LiDAR sensor by controlling both the 1st and 2nd lane.

3. Measurements and Evaluations

LiDAR sensor measurement spot positioning and working format considered for a leg of a four-leg intersection are shown in Figure 3. This LiDAR system has been thought to place in the line of the estimated queue that may occur during the red light on one leg. Firstly, LiDAR sensor, which looks at 90 degrees angle perpendicularly to the road, will start to move with the queue formation in this leg and follow the queue to be formed. Roadside placement (Zhao et al. 2019, Wu et al. 2020) and lest there is human interference in the system, It has been thought to place 5 meters above the ground, which is similar to the suggestion of setting over 2 or 3 meters above the ground and set over the road being capable of overlooking the middle of the 1st line. The distance of LiDAR sensor to the intersection can be changed according to the density of the road. Since the distance detection of LiDAR sensor is 180 m, the angle made

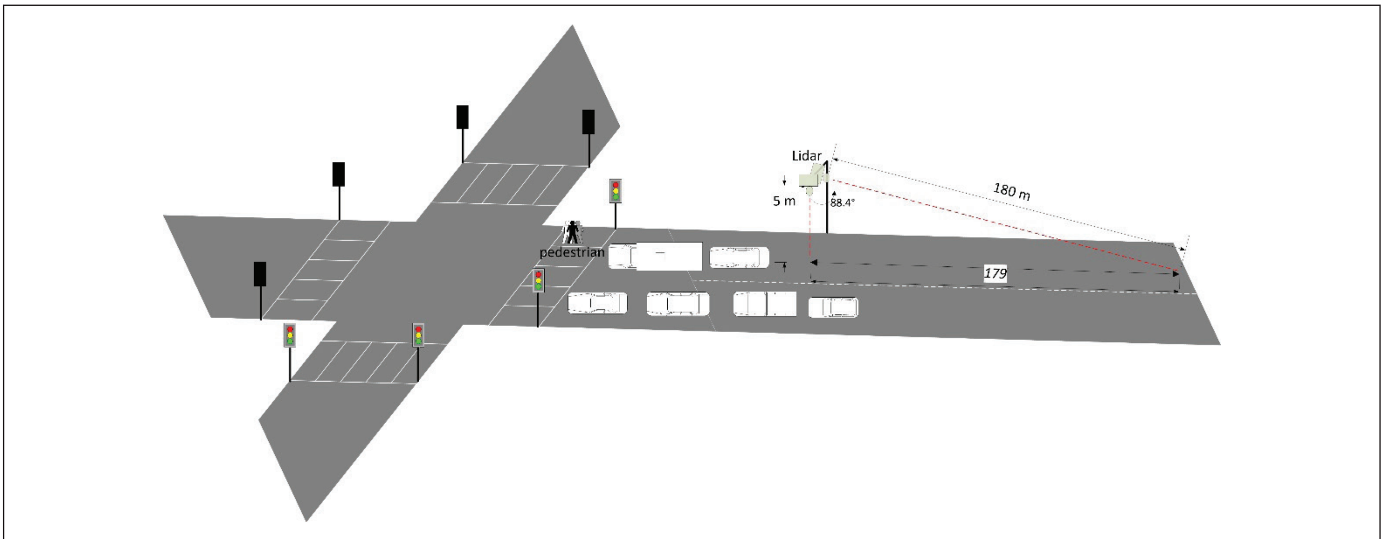

Figure 3. The suggested LiDAR system location and its working order.

with the servo motors will be approximately 89 degrees, and this will be able to detect the queue formation at a horizontal distance of 179 m from LiDAR sensor. Depending on the height of the place where the sensor is located, the queue length detection distance will also change.

Although the place considered for LiDAR sensor measurement is as in Figure 3, different methods have been applied because it is not possible to place the system in such a location. To provide the intersection environment in Figure 3, the measurements have been carried out in three different regions under two headings. In the first of the dynamic traffic measurements, the system has been placed over a pedestrian overpass, as in Figure 3, and real-time measurements have been taken for vehicle counting, speed measurement, and vehicle type detection. Due to the distance of the pedestrian overpass to the intersection, the queue has not been here and the queue length determination has not been performed in this environment. In the second dynamic measurement environment, although the speed of the vehicles over the pedestrian overpass has been detected in real-time, another controlled environment has been created to ensure that the vehicle speed detection of LiDAR system gave accurate results, where speed detection and vehicle count measurements have been repeated. The measurements and the places where the measurements have been taken will be given respectively.

The third measurement site has been performed by creating a controlled environment for the queue length determination under the static traffic sub-title. Thus, all the possibilities expected from the dynamic and static intersection have been realized. These measurements and their evaluations will be given respectively.

3.1. Dynamic Traffic Measurements and Evaluations

Dynamic traffic measurements have been carried out in two different environments. In the first measurement area: The number, velocity, and classification of vehicles have been determined in real-time dynamic traffic. In these environments, vehicles are examined in terms of their number, speed, and classification in real-time dynamic traffic. While determining the vehicle class, vehicles are divided into two classes. Large vehicles are classified as heavy ones and automobiles as light ones. All types of automobiles are considered light vehicles and some of these vehicles are shown in

Large vehicles such as trucks, semi-trailer trucks, and buses are included in the heavy vehicle class. These vehicle models are shown in Figure 4b.

The ground clearance of the vehicles has been used to categorize the vehicles as light and heavy. For this reason, most vehicles with height roofs taller than automobiles can be included in the heavy one class.

In the second environment, a more controlled dynamic environment is preferred for vehicle counting and speed detection. Thus, the speed and number of vehicles with known speeds and numbers have been tried to be determined.

3.1.1. Real-time dynamic traffic measurements

In Figure 5, the first of these regions, the image of the pe-

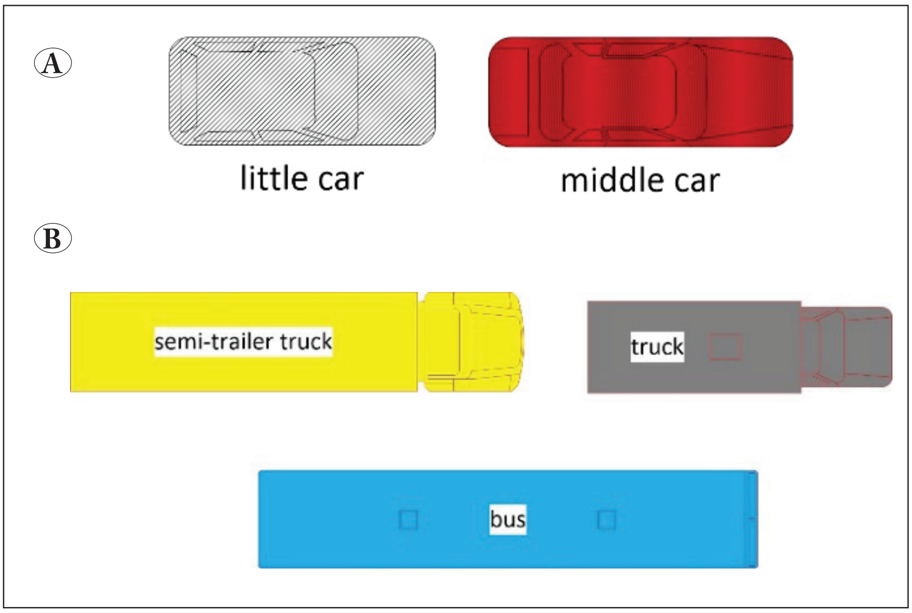

Figure 4. A) Light vehicle class images. **B)** Heavy vehicle class images

destrian overpass and LiDAR system, which is measured for vehicle counting, vehicle class, and vehicle speed determinations, is given together. Measurements have been taken at the pedestrian overpass, which is approximately 8 m high from the ground. As seen in the picture, the road consists of two vehicle lanes and an emergency vehicle passing lane. Vehicles have not used the emergency lane at the time of measurement.

The images, given in Figure 5, obtained from the system placed in real-time are shown instantaneously with the computer screen image in Figure 6. In this way, there are respectively 4 different images taken with the camera. So, the results can be instantly followed through the computer screen. The values of these measurements are summarized in Table 1.

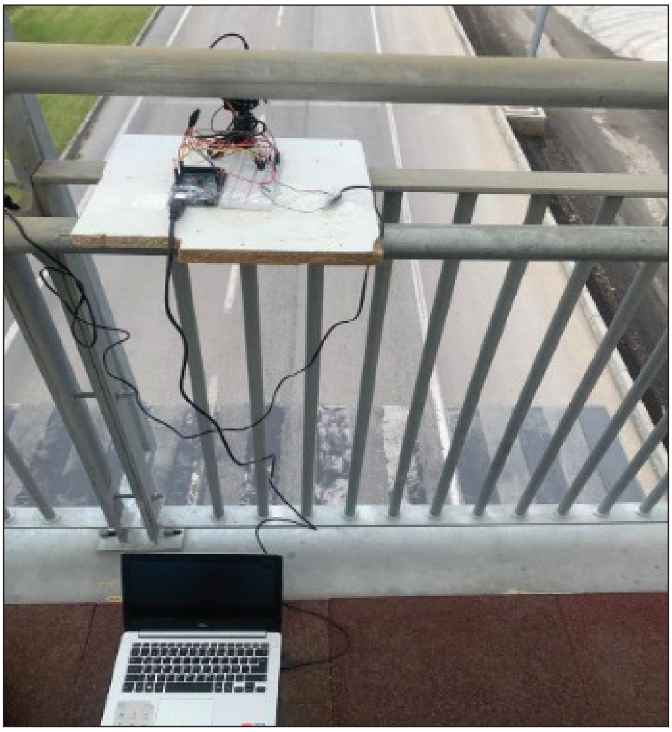

Figure 5. LiDAR system placed on pedestrian overpass and measurement site.

In Table 1, the number, velocity, and class of the detected vehicles are given together. As seen in Figure 6, a heavy vehicle passes in front of the sensor in the first situation, and a light vehicle in other situations, and as can be seen in Table 1, these have been detected correctly. Each vehicle has been counted one by one with a LiDAR sensor, and the number of vehicles reached four after a total of four vehicles passed. At the same time, the speeds determined for each vehicle are transferred to Table 1 from the computer screen.

Table 1. Real-time dynamic traffic measurement results.

Situation/ Image	The counted total vehicles	Velocity (km/h)	Vehicle class
1	1	25.71	Heavy vehicle
2	2	45.50	Light vehicle
3	3	51.43	Light vehicle
4	4	42.20	Light vehicle

3.1.2. The controlled region dynamic traffic measurements

Controlled second region measurement moment images are given in Figure 4. Although vehicle speed detection and vehicle counting have been performed in the previous study, it has been repeated in this region because the vehicle speed has more controlled and measurable. At the same time, unlike the previous working environment, LiDAR sensor is placed in such a way that it can see the vehicles from the

Figure 6. Real-Time dynamic traffic measurements.

side. In this study, which has been carried out with a single vehicle, the vehicles have been counted by LiDAR sensor and their speeds have been determined by moving the vehicle forward and backward.

The measurement location and vehicle are shown in Figure 7. As it can be understood from Figure 7, this vehicle will not be able to speed more than 10 km/h due to the small movement area of the vehicle.

Figure 7. Measurement region.

Vehicle counting, speed detection, and computer output screens have been instantaneously recorded in the measurement area with a camera. Measurement images are given in Figure 8. In this way, the results have been followed in real-time on the computer screen. Four different images are given together in Figure 8. Since the measurements were performed after it rained, the puddle seen in the pictures because of rain and has not affected the measurement conditions. In the first of these images, the vehicle is seen in a small way. In the other three pictures, the vehicles are not fully visible due to the desire to take the entire measuring setup with the camera. But in each picture, there is a vehicle and it is moving in the specified direction.

Since it is difficult to observe the results of these measurements on the computer screen in Figure 8, the values are summarized in Table 2. In each image/situation, the vehicle passed in front of the sensor once in the showed direction and its speed has been transferred to Table 2. The actual speed of the vehicle has been also included in Table 2 so that it can be compared with the measured vehicle speed. In each situation, vehicles have been counted with the detection of vehicle speeds together. The number of vehicles after each vehicle pass has been given in Table 2.

Table 2. The results of the controlled region dynamic traffic measurements

Situation/ image	The counted total vehicles	Velocity (km/h)	The real velocity (km/h)
1	1	10.09	10
2	2	8.57	9
3	3	9.64	9.5
4	4	7.46	8

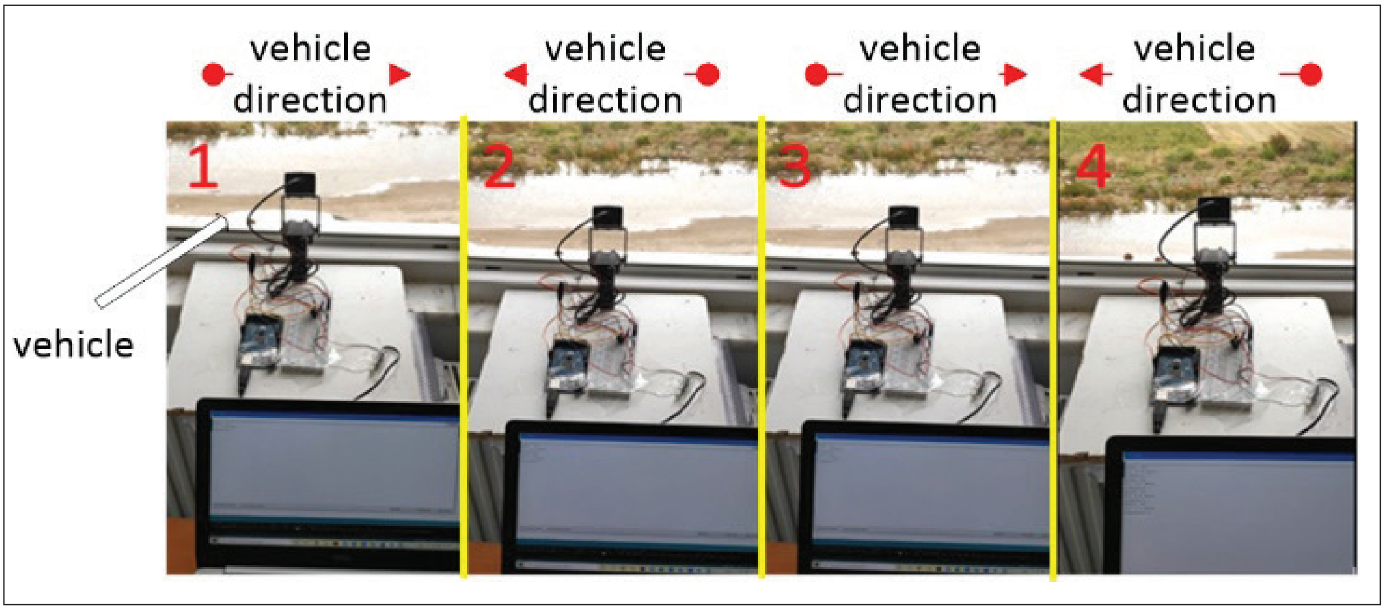

Figure 8. The controlled region dynamic traffic measurements.

3.2. Static Traffic Measurements and Evaluations

Figure 9 contains a virtual demonstration of how the queue length measurement is made. Since the queue length detection cannot be tested in a controlled manner at a real intersection, this part has been performed in a controlled parking lot. LiDAR sensor placed in the window on the 2nd floor of the building, being almost as highly equal as to the traffic light looks at directly the controlled parking lot and measurements have been conducted there. Upon seeing in the figure the height of the vehicle is considered fixed 3 meters). As tried to be shown in the figure, if the vehicle waits more than 5 seconds while passing in front of the sensor (it is considered stopped in the queue), the servo motor moves until it can see the empty road and stop when it sees the empty road. If two vehicles approach the sensor with an interval of more than one second, the sensor sees both vehicles separately and can detect the total queue length. The servo motor has an algorithm for angle calculation. By making use of this angle and the distance detection of LiDAR sensor, the horizontal tail length calculations of the vehicles standing throughout the road are shown in the figure. 'd' is the distance measured by LiDAR and 'l' is the tail length determined using the distance and tangent angle formula. LiDAR sensor system, which had to be positioned slightly different from the actual thought of set to the intersection tried to detect the vehicles from a certain distance. For this reason, calculations have been made by including the gap before every vehicle in the queue length.

As can be seen in Figure 10, four different pictures are given together. The first image is of the non-vehicle reference environment. The other environments are one vehicle queue, two vehicle queue, and two vehicle side by side, respectively. While performing the measurements in the 2nd, 3rd and 4th images of this Figure 10, the reference environment in the 1st image has been taken as a basis. In the 2nd and 3rd pictures, it has been desired to determine how much of a queue the vehicles formed. In the 4th picture, an environment has been created for the two vehicles to be in two different lanes. The measurements have been performed by considering that the vehicles in these two different lanes are the vehicles at the end of the queue.

Table 2 below represents the images/situations in Figure 10. If this table is examined, firstly the sensor measures the reference region at a distance of 9 m in the 1st image. Then, approximately 13 m queue length has been determined with one vehicle queue respectively in state 2. Approximately 15.5 m queue length has been detected in the 3rd situation with dual vehicles. At the same time, the actual queue lengths for each situation are given in this table. With the acceptance of the length of the vehicles, which had been accepted 3 m, it is seen that accurate results are obtained with small differences in the incorporated measurement.

In the 2nd and 3rd situations, when there is no vehicle in the 2nd lane, the queue length of the 2nd lane is not equal to the 1st lane info is received. In situation 4, it has been only tried to detect whether the 2nd lane control would take

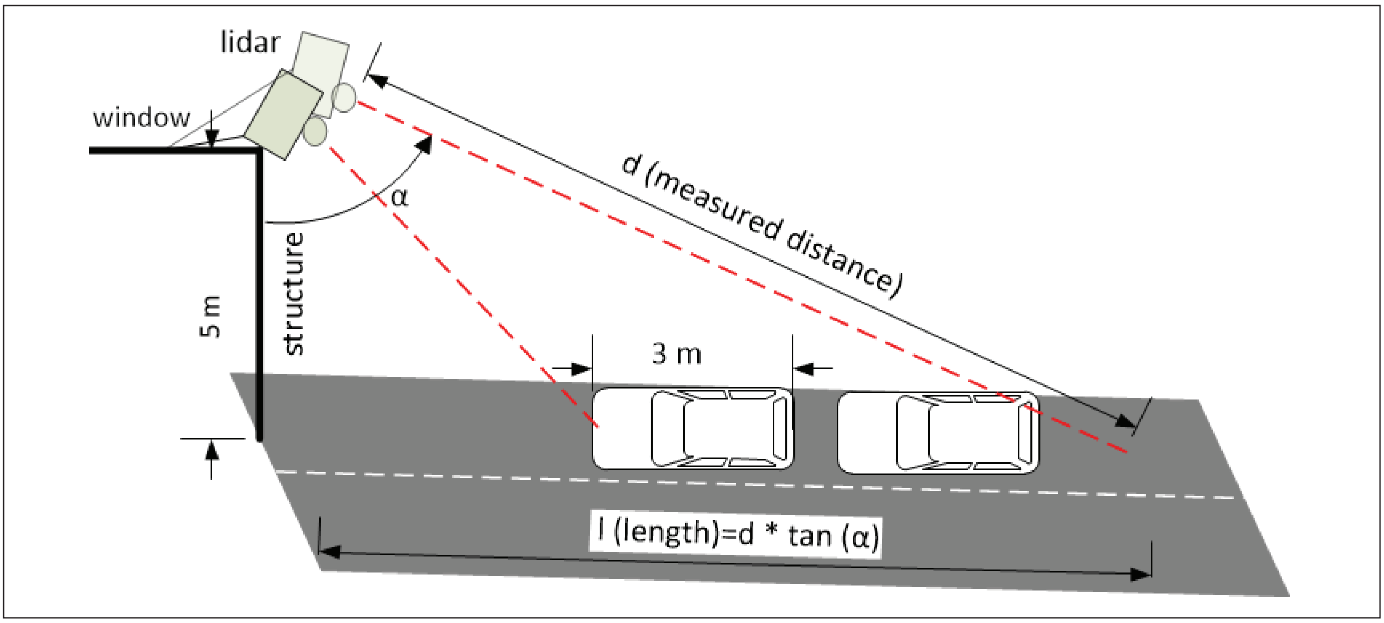

Figure 9. Queue length detection measurement working order.

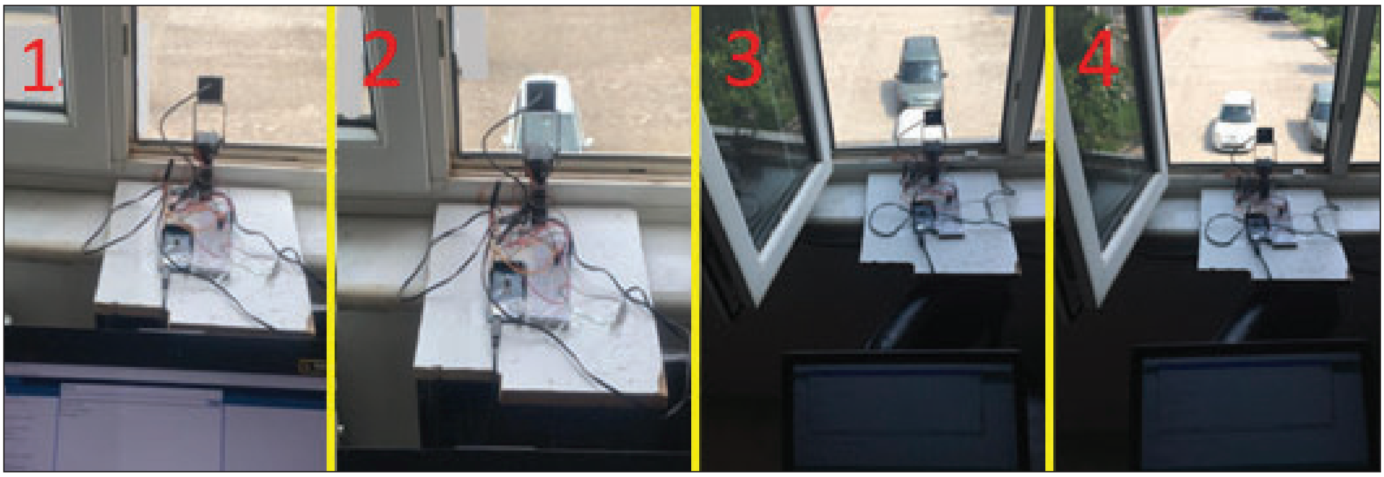

Figure 10. Static traffic queue length measurements.

Table 3. Static traffic queue length measurement results.

Situation/Image	Real Queue Length (m)	Measured Queue Length (m)	2. Lane Measurement
1 (no vehicle)	9	9	-
2	12	13	Not equal to 1. lane
3	15	15.5	Not equal to 1. lane
4	-	-	Equal to 1. lane

place. In this situation, as it should be, the output of the equability of the 2nd lane queue length to the 1st lane has been obtained and transferred to Table 3.

4. Discussions

In Table 4, comparisons of this study and some literature studies are given. As seen in this table, vehicle, speed, vehicle classification, queue length detections and distance and price comparisons are given together.

In this table, it has been paid attention to choose studies with LiDAR sensors from the methods used for vehicle detection. The study has been also placed in this table and compared with other similar studies.

When the study performed is compared with the other studies in Table 4, it appears to be similar to the study of the 6th article in terms of vehicle classification, queue length detection, velocity detection, and vehicle counting. Along with different methods carried out by this article in the study, it is also much superior in terms of cost. In article 6th, a 3D LiDAR sensor was used for queue length detection. While this 3D LiDAR sensor detects the queue, it accepts the vehicles under a certain velocity as stopped and as the queue end, and with this sensor clear queue length detections will not be possible with this sensor in long queues that may occur due to vehicles approaching behind the stationary ones. The implemented system, on the other hand, works fluently not only in moving traffic, but also in stationary traffic with servo motors, it can follow the stationary vehicle queue and gives clearer results in terms of queue length and distance instead of estimated values.

If it is paid attention to the study in article 9th, infrared sensor and camera were used together to detect the queue length. Vehicle number, classification, velocity detection, queue tracking, and queue length detection could not be made with a single point sensor.

Although there is only one unidimensional LiDAR sensor, it makes up for the lack of literature in that it can detect the number, speed, and type of vehicles in a single lane and the length of the queues of vehicles in two lanes. Since this sensor system contains a point sensor, it also precedes the systems with 2D and 3D LiDAR sensors in terms of cost. With this simple structured system, a different and new contribution has been made to the literature in terms of algorithm and performance. In the performed measurement environments, the success rates for dynamic intersection are 96.36%; for stopping traffic queue length determination, it is 96.35%.

Table 4. Literature comparisons.

Study	Detector	Method	Classification	Distance (m)	Queue Detection	Velocity	Vehicle Counting	Cost
1. Current Study	LiDAR	Unidimensional laser	+	180	+	+	+	lowest
2. (Zhao et al. 2019)	LiDAR	3D laser	+	80	-	+	-	high
3. (Emami et al. 2019)	-	Algorithm	-	-	+	-	-	~
4. (Lee and Coifman 2015)	2× LiDAR+ Camera	2D laser	+	80	-	+	+	highest
5. (Cai et al. 2010)	Camera	Image processing	-	~	+	-	-	~
6. (Wu et al. 2020)	LiDAR	3D Laser	+	80	+	+	+	highest
7. (Cheung et al. 2005)	Magnetic	Electromagnetic	+	10	-	+	+	low
8. (Tiaprasert et al. 2015)	-	Mathematics	-	-	-	-	-	-
9. (Rani et al. 2017)	LiDAR+ Camera	Infrared+ Image Processing	+	_	+	-	-	low
10. (Managuli et al. 2017)	LiDAR	Infrared	+	-	-	-	-	~
11. (Sen et al. 2012)	Camera	Image Processing	-	100	+	+	+	low

In the studies performed in controlled environments, it has not had possible to measure with more vehicles, since we only have had two vehicles. Although there are a small number of vehicles, measurements have been made considering all conditions. This system has been designed in conditions that can measure different vehicle numbers with LiDAR sensor range. Since the presented study includes all the conditions of a real-time intersection, it will be able to work at an intersection easily.

In future studies, queue length measurements can be taken for distances longer than 20 m by placing LiDAR sensor system at higher places and with more vehicles. Although LiDAR sensor used has 180 m distance measurement capability, it should be taken into account that the longer the measured distance increases, the quality of its resolution decreases, and losses due to reflection increase. In addition, On condition that there is an area to be placed above the road in the next studies, the queue length can be determined without creating a controlled environment. The study performed can be supported by a second LiDAR system for roads with more than two lanes or for determining the number, velocity, types of vehicles on each lane, and also different studies can be carried out. While LiDAR sensor system used is not affected by darkness due to the characteristics of LiDAR distance sensor, it can be affected by excessive sunlight, heavy rain, and reflection from the snow. Even if the study was carried out in some adverse weather conditions, it will be a new study to test its performance in harsh weather conditions (heavy rain, snow, hail) and to measure its performance under these circumstances. At the same time, this algorithm and the established system are open to new study subjects with different LiDAR sensors.

5. Conclusion

This article presents a new algorithm for intersection density detection with a unidimensional LiDAR sensor that can be placed above the road. In contrast to the 2D or 3D LiDAR sensors used in studies in the literature, a point-angle, and unidimensional LiDAR sensor has been used in this study. In this study, a single angle LiDAR sensor with 2 servo motors and a 2-axis pan tilt kit has been turned into a 3D dimensional one. Real-time measurements have been taken from LiDAR sensor mounted on a pan tilt that can be moved with two servo motors.

This study has been performed in three different measurement environments. These measurement environments contain all the possibilities expected from an intersection. With LiDAR sensor system placed over the pedestrian overpass in the 1st environment, the speeds, numbers, and classes of vehicles randomly passing in front of the sensor in dynamic traffic have been determined. For these measurements performed in a dynamic environment to be more comparable, a different environment has been needed. Therefore, in the second measurement, speed and number determinations have been made with a single vehicle in a controlled environment. In the third measurement, the environment of the vehicles approaching the intersection and forming a queue at the red light has been prepared in a controlled environment. In this measurement environment, which has been performed with two vehicles, the lengths of two vehicles in the queue have been detected for two lanes separately.

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