A Laser Curtain for Detecting Heterogeneous Lane-less Traffic

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***Abstract*—Traffic management system plays a vital role in the present smart city applications. In developing countries, heterogeneous lane-less traffic management is a significant challenge. This paper proposes a dual-purpose laser-based sensor configuration for vehicle classification. It classifies heterogeneous and less-lane disciplined traffic based on vehicles width. This work also suggests a methodology for the vehicle to infrastructure (V2I) communication using visible light.**

***Index Terms*—Vehicle detector, Intelligent transportation, VLC, V2I Communication.**

I. Introduction

The majority of individuals in developing economies are preferred to travel with own mode of transportation due to the rise in quality of urban lifestyle [1], which leads to an increase in traffic congestion. To solve the traffic congestion and improve the capacity two methods are in use, one is to expand the road infrastructure and second is to use a traffic management system (TMS) [2]. The capacity of road infrastructure in developing countries have not increased as par with the traffic, so adopting a TMS provides a feasible solution. The traffic sensor is an essential component in TMS, which detects the number of vehicles, types of vehicles, speed, etc. At present, most of the available sensors are for disciplined and homogenous traffic. Only a few traffic counter/detectors are available for monitoring the heterogeneous and lane-less traffic. Each of them has its advantages and limitations.

Sheik Mohammed Ali et al. [3] [4] proposed an inductive loop structure which detects different classes of vehicles such as two-wheelers, cars, auto rickshaw, bus, etc. For single-lane traffic Aravind et al. [5] proposed a vehicle classifier system based on optical beam interruption, where laser light was projected across the road such that vehicles interrupt the light beam; with this, they estimated the vehicle tire size, speed, and distance between axles. This system works better for single-lane traffic and may not be suitable for multi-lane traffic. Mallikarjuna et al. [6] modeled a traffic classifier with video and image processing technique. In this system performance limited to weather and lighting conditions.

Samer Rajab et al. [7] designed a configuration for classifying the vehicles using the piezoelectric sensor. The sensor was mounted diagonally to the road surface, and it classifies disciplined mixed traffic. This configuration may not work for undisciplined traffic. Since, at an instant of time, two or more vehicles could occupy the sensor. Gabriela et al. [8] [9] designed a lidar-based sensing system which obtains 2D and 3D profiles of vehicles but this system additionally requires an induction loop. Also, the accuracy of Laser scanners or Lidars greatly depends on environmental conditions and surface of the objects.

Some other significant contributions on mixed and lane-less traffic are as follows; Sen et al. [10] proposed a traffic state classifier using RF-link. In this case, based on the RF-link strength, traffic was classified into three different states like the empty, free flow and congested. Sen et al. [11] classified traffic state based on the sound they produced. This method results entirely depends on the behavior of the driver. If traffic signal duration was very long, the driver might switch off the engine, so the accuracy of the system varies. Rajeshwari et al. [12] modeled a traffic control system with RFID tags equipped with the vehicles. In an emergency, the system clears the way for necessary vehicles like ambulance, police, etc., but RFID tags are not mandatory in many developing countries.

Based on the literature survey, it could be observed that undisciplined traffic poses more challenges than disciplined traffic. Therefore building a low-cost, easily deployable and multi-purpose traffic classifier is needed. This paper proposes a sensor configuration which classifies vehicles and simultaneously acts as a V2I communication facilitator. Following the introduction, Section II explains the sensor configuration and its working principle. Hardware implementation of the proposed system and methodology of V2I communication is in section III, and Section IV concludes the work.

II. Sensor Configuration With Laser Curtain

The proposed sensor configuration is in Fig. 1, Where a gantry consists of a series of laser diodes. They project laser beams on the road surface perpendicular to vehicle moment, which appears like a laser curtain. Photo-detectors are mounted on road surface in opposite to laser diodes in the line of sight. Customized road studs [13] could incorporate these photodetectors.

During the absence of a vehicle, there is no obstruction for laser beams; this corresponds to a logic '0' at the output of

This work is funded by Intelligent Surveillance Data Retriever (ISDR) for SmartCity Applications, IMPRINT by Make in India, Project. Grant No:-7794/2016.

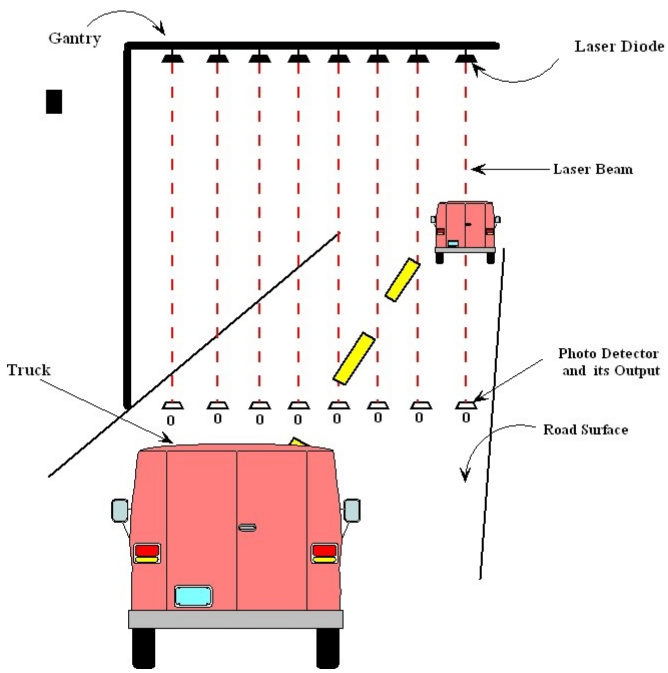

Fig. 1. Sensor configuration without a vehicle through laser curtain.

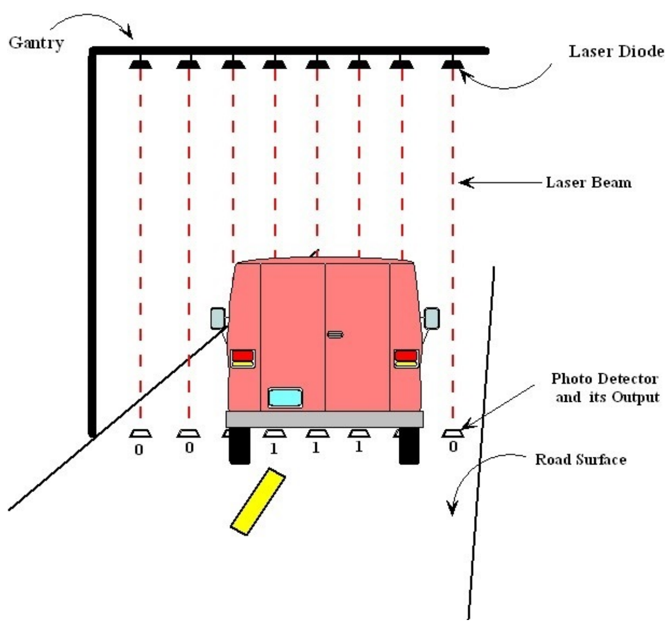

Fig. 2. Sensor configuration with a vehicle through laser curtain.

respective photodetector which is shown in Fig. 1. Whenever a vehicle moves through laser curtain some of the laser beams are obstructed; this produces a logic '1' at the output which is given in Fig. 2. The vehicle classification can be carried out based on the number of beams obstructed by it. The data obtained from the photodetectors can be stored on a computer with the help of a microcontroller unit (MCU). Here, laser light source gives better results during night-time and low light conditions. In addition, the proposed configuration is capable of communicating with visible light communication (VLC) [14] [15] [16]. Fig. 3 represents the block diagram of the proposed sensor configuration, where, D_1, D_2, $\ldots$,D_N are the photodetectors interfaced to a comparator circuit, which detects the presence of a vehicle. If the vehicle is present it transmits a logic '1' to the MCU; else it transmits logic '0'. The entire mechanism explained with a flowchart shown in Fig. 4.

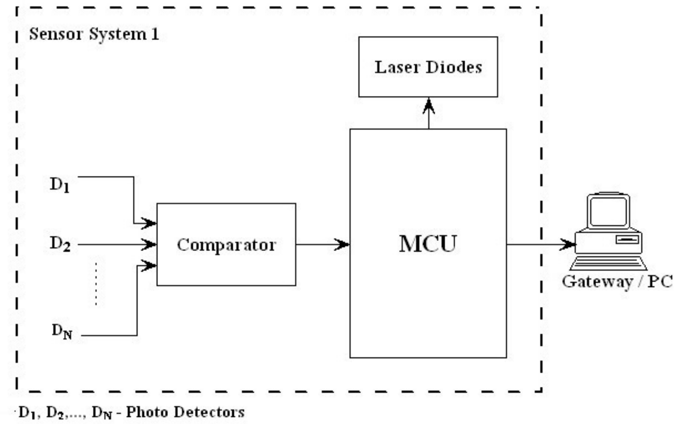

Fig. 3. Block diagram of the proposed sensor configuration.

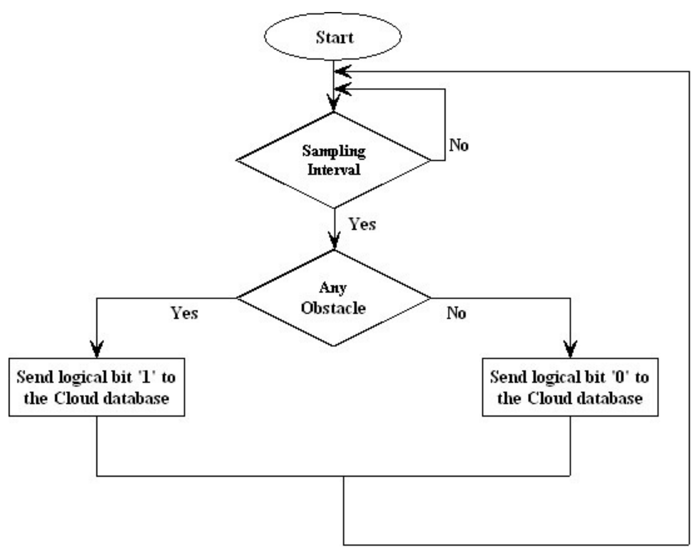

Fig. 4. Flowchart of vehicle detection.

Under different lighting conditions, an additional photodetector helps to control the laser power, which might be installed on the pavement. Even this system works fine with bright sunlight since the vehicle occupies the photodetector which reduces the amount of received light. For further processing, the logged information given to a gateway, and it uploads the data to a remote server or cloud database [17]. An additional ultrasonic sensor improves the classification accuracy, by obtaining the height profile of the vehicles.

The proposed sensor configuration enables Vehicle to infrastructure (V2I) communication as it consists of photodetectors, which are typically used to receive information with visible light communication (VLC) [14] [15] [16]. V2I communication allows mitigating motor vehicle accidents for safety and mobility benefits [18].

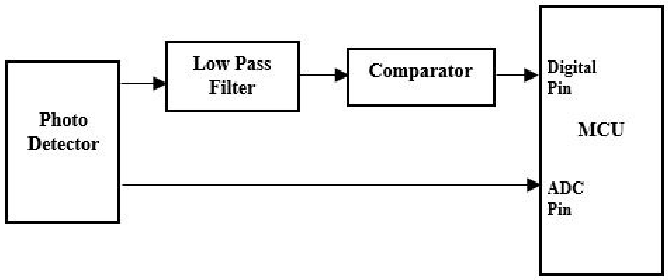

Fig. 5. Scheme for differentiating modulated and unmodulated light sources.

In the proposed configuration, a photodetector (photodiode or transistor) helps to determine the occupancy of the vehicle. Simultaneously, this detector can also be used for V2I communication. In this case, the challenging task for the receiver is to distinguish the laser light and modulated LED light. Where laser light is for vehicle classification and the modulated light is for V2I communication (assume underneath the vehicle this LED is mounted). The photodetector produces a voltage proportional to the intensity of the light source. For an unmodulated light, the rate of change from light to corresponding voltage is meager. But in the case of modulated light, this change is very high. To distinguish the different light sources a low pass filter could be interfaced in between the photodetector and comparator as shown in Fig. 5. The lowpass filter attenuates the modulated light of high frequency, then by setting the comparator at a particular threshold differentiates the source of light.

III. Experimental Set-Up and Results

The given experimental set-up was used for both vehicle classification and V2I communication.

A. *Vehicle Detection and Classification*

Table I consists of the standard vehicle dimensions. Successful identification of two-wheeler occurs when the spacing between the successive photodetectors is less than 0.6-meter. So a 0.5-meter spacing was considered. Table I also provides information regarding the number of beams obstructed by a vehicle when it passes through the laser curtain.

TABLE I
Vehicle dimensions and number of laser beams obstructed by them when detectors are placed at 0.5 meters apart [19]

Vehicle Class	Width (meter)	Length (meter)	Number of Laser beams obstructed
Two wheeler	0.6	1.8	1 or 2
Auto Rickshaw	1.5	2.6	3
Car	1.7	4.2	3 or 4
Bus	2.5	10.3	5 or 6
Truck	2.5	7.2	5 or 6

The Fig. 6 shows schematic of a detector module. Whenever the laser light falls on phototransistor, the corresponding detector voltage crosses the minimum threshold voltage which indicates the absence of the vehicle.

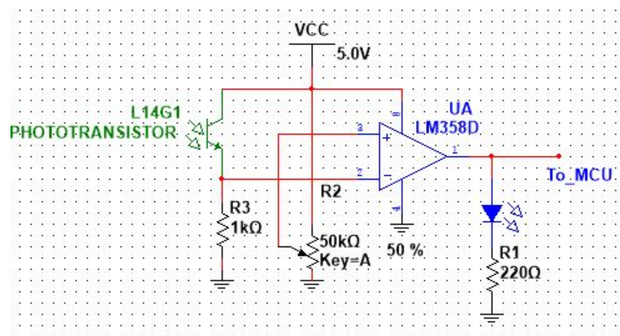

Fig. 6. Schematic of the detector module.

As given in Fig. 7 a lab-scale experimental setup has been prepared where the distance between photodetectors is 3.5 cm (scaled down by a factor of 14.28).

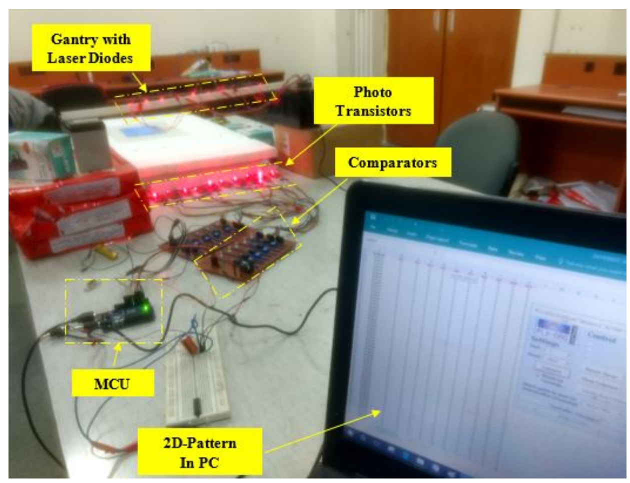

Fig. 7. Experimental setup.

As shown in Fig. 8 equivalent vehicle plates (scaled down by a factor of 14.28) were used for validation. Here the blue, green, black colored 2D shapes are scaled down equivalents of the car, auto rickshaw, and two-wheeler respectively. Manually these 2D plates were moved across the laser curtain, and they obstruct the laser beams in proportion to their widths. Finally, with the help of detector modules, a 2D width bit patterns of traffic was recorded.

The Fig. 9 represents acquired 2D bit patterns of different vehicles at different timestamps. The first column represents the time at which the samples recorded. The remaining columns contain data collected from each photodetector module, i.e., $D_1 - D_{10}$ respectively. The sampling rate in this experiment was approximately 30 samples/second (In the figure some of the data bits were removed deliberately to show the obtained pattern). As mentioned the vehicle classification

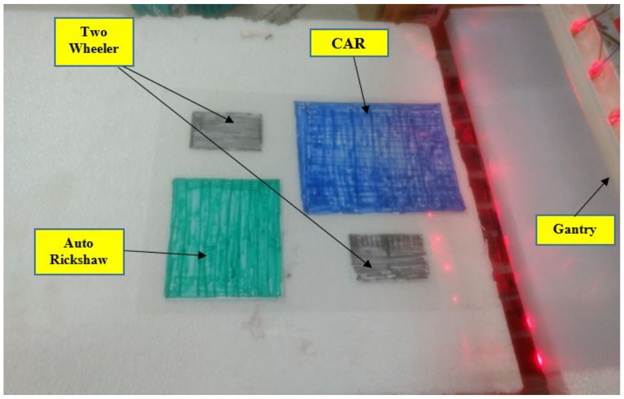

Fig. 8. A two-dimensional scaled-down version of vehicle equivalents passed through laser curtain.

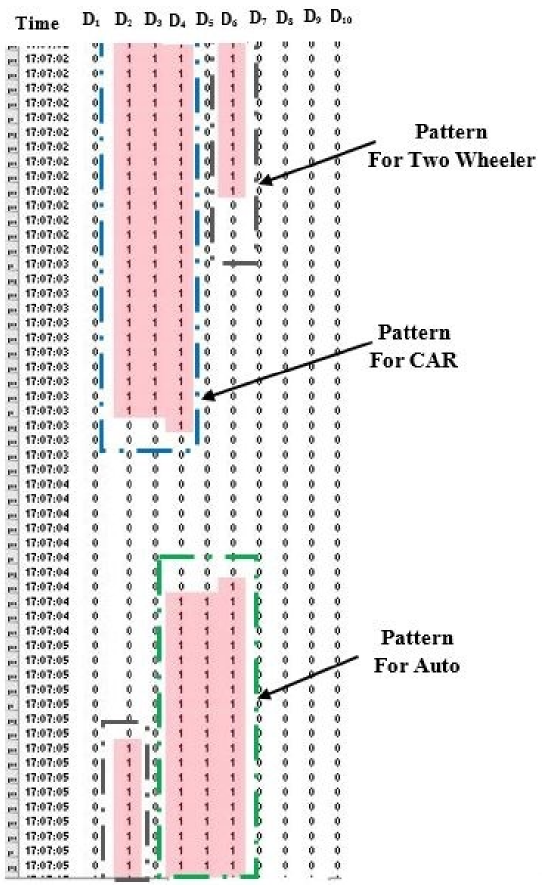

Fig. 9. 2D bit pattern captured in a spreadsheet.

can be carried out by observing the number of columns occupied by each vehicle, spacing between two successive photodetectors effects the accuracy. Usually, bicycles have the lowest length, when it travels at 100km/h, then the successful identification of it happens when the sampling frequency is 100 samples/sec (calculated based on the length and speed of the vehicle). If the user installs one more laser curtain at a certain distance, the length and speed of vehicles can be approximated, provided there was no lateral vehicle movement.

B. V2I Communication

This section explains the implementation of VLC based V2I communication with the proposed sensing system. In VLC transmitter, receiver consists of a LED and photodetector respectively. An LED was employed to demonstrate V2I, assume it was underneath the vehicle. With On-Off keying (OOK) modulation a dummy data was transmitted [20]. By using photodetectors and MCU, the receiver decoded the transmitted information. When modulated LED light falls on a phototransistor or photodiode, it instantaneously produces a voltage according to the intensity of received light which is given in Fig. 10. Deployed low pass filter differentiates modulated light from laser light. The Fig. 10 shows the sensor values before and after filtering, where the blue line indicates modulated light values before filtering, the green line shows the values after filtering, and the red line shows the sensor values with the laser light. From the Fig. 10, it can be observed that filtering operation attenuates the modulated light which means distinguishing the laser light and modulated LED light possible.

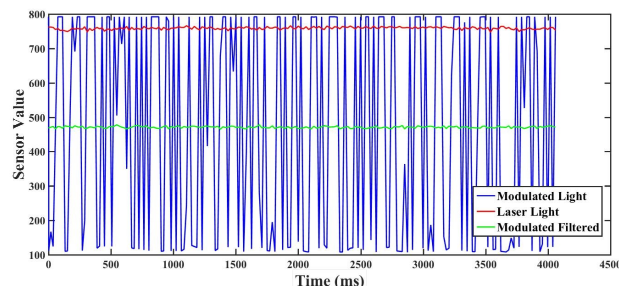

Fig. 10. Sensor values for different light sources.

IV. Conclusion

In this paper a dual-purpose sensor configuration has been presented, where it detects the vehicles in mixed and lane-less traffic conditions as well as it acts as a receiver for VLC communication. The proposed method works fine in real time; regular cleaning of road studs will be essential. To achieve the user safety class 1 lasers can be used. The given configuration may yield good results in VLC since vehicle covers the photodetector and there will be no direct sunlight on the receiver. The future work includes classifying the vehicles using different machine learning algorithms, improve the accuracy of vehicle detection with sensor fusion techniques, modeling a road stud to incorporate the photo-detector, and studying the VLC performance with different vehicle speeds and lighting conditions.

Acknowledgment

The author G. S. R. Satyanarayana would like to thank “Vignan’s Foundation for Science, Technology and Research” for their financial assistance to carry out research at National Institute of Technology, Rourkela.

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