Intelligent Speed Bump Identification and Speed Control System for Autonomous Vehicles: A Conceptual Design

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***Abstract*— Road accidents have become one of the major problems for the health sector around the world, and are of the main causes of death particularly in Nigeria. There are several causes that can be associated with road crashes, ranging from poor road conditions, altitude, bad weather, to lack of driver attention. Reckless drivers are the main cause of road traffic accident worldwide. The late identification of bumps and the inability of drivers to slow down while hitting a bump has also been a big challenge faced by many nations. Therefore, an automatic and intelligent device is required to be built into vehicles to mitigate the number of road accidents through appropriate velocity control at speedbump locations. This study reviews existing speed bump identification techniques and proposes the development of an intelligent speed bump detection and speed control system.**

Keywords- autonomous Vehicle, fuzzy logic, image processing, identification, speedbump.

I. Introduction

Road travel has facilitated the flow of goods and services in both developed and emerging countries, increased the quality of living and has also led to global economic development. This distribution medium has now become the most important element of human society and may be one of the most dangerous elements for the human race if adequate steps are not enforced [1]. Accidents caused by road crashes are growing increasingly and tend to be the leading causes of morbidity and mortality in the 15 to 34-year-old age group [2]. Road injuries have been one of the big issues facing the health system around the world, and the need arises for a prevention plan that would be crucially successful. [3] stated that an additional 1.2 million people are killed as a result of traffic collisions and 50 million people are injured as a result of these injuries. The World Health Organization (WHO) predicts an escalation of more than half of this number in the next 20 years, if prevention steps are not enforced with a strong commitment [3]. A study between the years 2000 and 2004 shows that about 36,000 Nigerians died and 125,000 were injured as a result of road crashes, taking the death rate from traffic injuries in Nigeria to a high as compared to countries worldwide [3]. These accidents are usually caused by several factors such as inexperience, congestion, intoxication, intersection bottlenecks, distraction, drowsiness, and over speeding [4] [5]. In order to minimize the risk of road injuries, ensure life protection and prevent the occurrence of traffic accidents due to over speeding, a speed bump is installed on the road [6].

Speed bumps are structures that are built on the highways to limit traffic travel speeds in sensitive road areas, such as hospitals and schools [7]. Speed bump decreases driving speed by slowing down cars to control traffic and it can also create discomfort when driven over at high speed. In the development of speed bumps, there are no specific design considerations and this allows them come in various heights, distances, widths, and scales [8]. Such conditions can prompt driver warning by last minute, result in vehicle wear and tear, and are detrimental to patients in transit [9]. Therefore, the use of advance driver assistance (which is a function of autonomous vehicles) is required for precise and timely identification of speed bumps to help the driver regulate the vehicle speed [10].

An Autonomous Vehicle, also known as a driverless or self-diving vehicle, is a vehicle that is capable of operating with little or no input from the driver [11]. Autonomous vehicles can be defined as vehicles that, when exposed to various terrains, can sense their surroundings and maneuver around without the assistance of an external factor [12]. The implementation of computer vision and image recognition is very critical in facilitating proper object detection and self-navigation.

Application of computer vision are significant in the production of autonomous vehicles, as they are one of the sub-sets of electronics technologies related to automation, protection and safety. Mostly the technique involves viewing images as a two-dimensional signal, and then applying

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traditional technique of image processing. When combined with an embedded device, highly efficient, low memory and robust solutions can be obtained [13].

Detection of speed bumps can also be accomplished via a camera and microcontroller [14]. The identification of defects on the surface of the ground is a job of significant complexities. It is very common in just developed countries to have unmarked speed bumps on road surfaces, which reduce self-driving car protection and stability [15]. Detecting bumps late and drivers refusing to slow down while hitting a bump has been a big obstacle faced in Nigeria and other nations. This condition and habit leads to unnecessary road crashes, injury, and vehicle damage. As a result of these issues, the need arises for an integrated and intelligent system to reduce the number of road accidents.

Several works exist in literature in the area of speed bump detection. For instance, in [16], an abnormal road surface recognition technique was developed using smartphone acceleration sensor with the adoption of Gaussian background model and was optimized by a fuzzy logic inference machine. This made the methodology versatile and compatible to different types of vehicles.

Similarly, [17] developed a machine learning approach in identifying speed breakers for autonomous driving. The technique uses different and effective approaches and algorithms in the detection of speed bumps. The scheme employs machine learning techniques to detect speed breakers for different road conditions. A major limitation of this technique is the reliance of datasets and network training, which can be both memory and time consuming, thereby making it not cost effective.

In [18], an anomaly detection system was developed for traffic scenes which uses spatial aware motion reconstruction. The technique employed was robust, effective and efficient in analysis of motion orientation and detecting the magnitude of moving objects found in abnormal events. The system employs the use of Bayesian model to achieve significant results. However, the technique focuses on speed and object detection, not the road condition.

In addition, [19] designed a speed-bump based localization enhancement technique. This approach was used in detecting speed bumps and used a map information algorithm to determine the location and position of the vehicles and bumps. The method was also independent of the availability of network coverage. A major limitation of this technique was its inability to interact with the vehicle control system.

Also, [8] developed a speed breaker and road marker recognition system using image processing techniques. The method used optical character recognition and Hough transforms to identify speed bumps and road markers. The technique yielded positive and effective results when implemented. However, the system had an inability to function under varying conditions such as night hours and this limited the functionality of the system.

Furthermore, [12] developed a road surface condition monitoring and database system. The method implemented was effective in sensing road conditions and logging the information into the designed database. The information saved was also vital in road maintenance. However, the technique focuses on road monitoring and provides no countermeasures to be taken when anomalies are detected.

The review works show that image processing and computer vision have been applied in many area of image recognition and also object identification in the autonomous field. These approaches had some limitations in their area of application when implemented. Some of these limitations are: Ineffectiveness in detection of edges with a low accuracy rate of 75%, inability to differentiate between speed bump and cross work among others. In order to tackle the limitations observed in the works outlined, this study proposes the development of an intelligent speedbump detection and speed control system. The system will employ the use of Histogram of Oriented Gradients (HOG) to detect speed bumps on the road and evaluate the distance of the vehicle to the speedbump. Furthermore, this system will use a Fuzzy Logic Controller to regulate the speed of the vehicle when approaching a speedbump and return the vehicle to its original speed after passing over the speedbump.

The remainder of this paper is organized into four sections. An overview of HOG is provided in Section II. Section III presents the Fuzzy Logic Controller Design while Section IV gives an overview of the proposed methodology. Section V concludes and provides directions for future works.

II. Histogram of Oriented Gradients

Histogram of Oriented Gradient is one of the techniques used for features extraction on images. The features extraction is a vital process when carrying out image processing on any given image. HOG provides the basic functional structure of an image which corresponds to a feature on that image, this feature may vary from a single pixel to edges with contours, and can be as wide in the image as an object [21]. Feature recognition can be accomplished by the use of a feature descriptor strategy, which represents a subset of the total pixels in the observed feature points neighbourhood [20]. Histogram of oriented gradient feature descriptor is one of the well-known feature descriptors suggested by N. Dala and B. Triggs for robust visual object recognition [21].

The process involves dividing the image into small spatial regions called cells, after which each cell's orientation binning is performed which calculates the sum of the gradient magnitudes within each histogram orientation bin. Following the previous steps, the last step is to normalize the concatenated histogram result of the whole cell within a wide spatial area (i.e. the block) in order to obtain improved results against changes in the illumination. HOG feature can use the following functions to represent its cells and orientation; $F(i, \theta)$ (where i and θ are the *i-th* HOG cell and θ-*th*) orientation bin of the histogram respectively.

The HOG algorithm is presented as follows:

- Divide the image into small connected regions and compute a histogram of gradient direction for each cell or edge orientation for the pixels within the cell.
- Discretize each cell into angular bin according to the gradient orientation.
- Each cell's pixels contribute weighted gradient to its corresponding angular bin.
- Groups of adjacent cells are considered as spatial region called blocks. The grouping of cell into a block is the basis for grouping and normalization of histogram.

- Normalized group of histogram represent the block histogram. The set of these block histogram represents the descriptor.

The equations and techniques showed in [22] will be used for achieving histogram of oriented gradient.

Using the 1st order differential coefficient, $f_x(x, y)$ and $f_y(x, y)$,

$$f_x(x, y) = f(x + 1, y) - f(x - 1, y) \quad (1)$$

$$f_y(x, y) = f(x, y + 1) - f(x, y - 1) \quad (2)$$

where $f(x, y)$ in (1) and (2) is luminance at (x, y)

The magnitude and direction of the gradient (m & θ) can be calculated using (3) and (4)

$$m(x, y) = \sqrt{fx(x, y)^2 + fy(x, y)^2} \text{ (Magnitude)} \quad (3)$$

and

$$\theta(x, y) = arctan\frac{fx(x,y)}{fy(x,y)} \quad \text{(Direction)} \quad (4)$$

After computation of (3) and (4), the HOG is generated by the following steps;

- determining the class which $\theta(x, y)$ belongs to
- increasing the value of the class using the first step.
- repeating the above operation for all the gradient belonging to the cell. [22]

The formula $\boldsymbol{v} = \frac{\boldsymbol{Vk}}{\sqrt{||\boldsymbol{Vk}||2+1}}$, (5)

Equation (5) can be used in finding the final HOG feature.

Where V_k = vector corresponding to a combined histogram for a block and

V = normalize Vector [22].

III. Fuzzy Logic Controller

In 1965, Dr. Lofti Zadeh published Fuzzy Logic as a methodology for modelling ambiguity and vagueness in the natural language [23]. This is a strategy that imitates the human reasoning process and tries to decide in imprecise circumstances [24]. For linear and nonlinear control implementations, pattern analysis and also financial systems, Fuzzy Logic has become an effective methodology [23]. A fuzzy logic system consists of four key components that are the fuzzifier, the rules, the inference engine and the defuzzifier. A Fuzzy Logic System is shown in Figure 1.

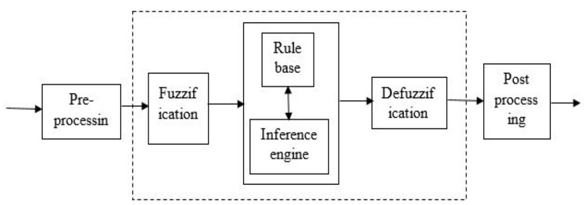

Fig 1: Fuzzy Logic System [25]

Fuzzification is the method of transforming a crisp input into a fuzzy input [24]. Typically, this is done by the use of membership functions. A membership function is a graphical description of how to map a crisp input to a degree of membership between 0 and 1 [26]. In fuzzy logic there are various types of membership functions that include triangular, trapezoidal, Gaussian and singleton membership functions [27].

Following Fuzzification, the fuzzy inference algorithm tests the output based on a set of predefined fuzzy rules. Fuzzy rules are usually of the form:

If x is A, then y is B

A and B are linguistic values defined by fuzzy sets. A linguistic value is an input or output value that is a natural language word, rather than a quantitative one [27]. The first part of the law is considered the antecedent, and the second section is considered the consequent section [26].

After the inference engine tests the rules based on the inputs it is important to make a control decision. This process is called defuzzification and involves finding a crisp output which sums up the fuzzy outputs. Several defuzzification approaches include centroid, bisection, weight average and largest of maximum [24].

In this study, the Fuzzy Inference System (FIS) will be designed using the Fuzzy Logic Toolbox in MATLAB (version R2019a). The Mamdani FIS will be used due to its intuitiveness, widespread acceptance and suitability for human inputs [27]. The FIS will comprise of two (2) inputs variable which represent the distance of the speedbump and the distance of the speedbump from the vehicle. The outputs of the FIS will be the velocity of the vehicle with respect to the distance of the detected bump. The centroid technique which evaluates the area under a curve, will be used for defuzzification.

In this project, the inputs and output parameters using a selected range will be used in generating the membership functions in the fuzzy logic controller designer. Figure 2 shows the membership functions of the input which detects the presence and absence of the speedbump. A range from 0cm to 100cm was used in indicting the presence or absence of speed bumps on the road surface. For the system detect the presence of the abnormally, the distance of the speedbump will be at a distance between 0 to 50cm from the vehicle and at a distance is above 50cm, the system will process it as the absence of speedbump.

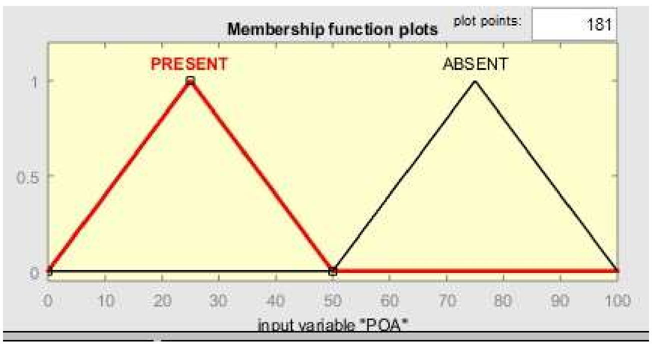

Fig 2: Membership function plot for the presence and absence of speedbump.

In order for the system to determine the required speed for the vehicle, the distance of the speedbump from the vehicle will be determined. This is done with the use of the image pixel gotten from the camera. The use of the image pixel is employed in determination of the membership functions used in determining the distance of the speedbump to the vehicle.

For the distance to be read as closed, the image of the speedbump falls in a pixel range of 0 to 256 while if the image pixel is above 256, the distance is read as far. The Figure 3 show the membership function the relate the distance of the speedbump.

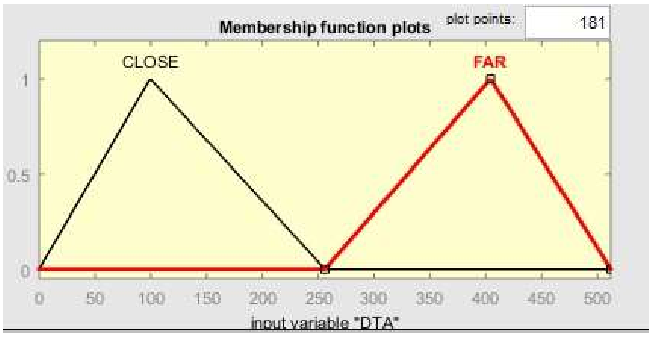

Fig 3: Membership function plot of the distance of the speed bump.

The output of the system is represented by the velocity of the vehicle is obtain, the velocity is determined based on the rules developed in the system while using a velocity range of 10m/s to 80m/s. These rules enable the system in making the right decision to either slow down the speed or maintain/increase the speed of the vehicle. Figure 4 and Figure 5 show the output membership function and the rules of the system respectively.

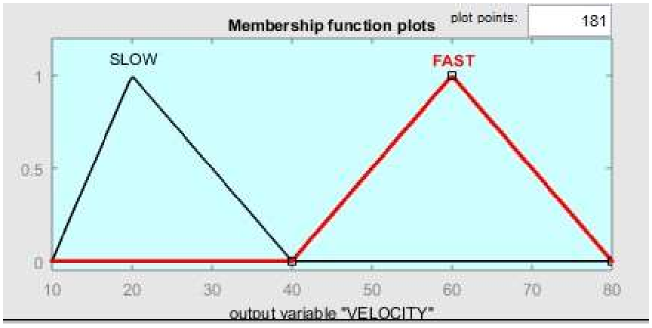

Fig 4: output membership function

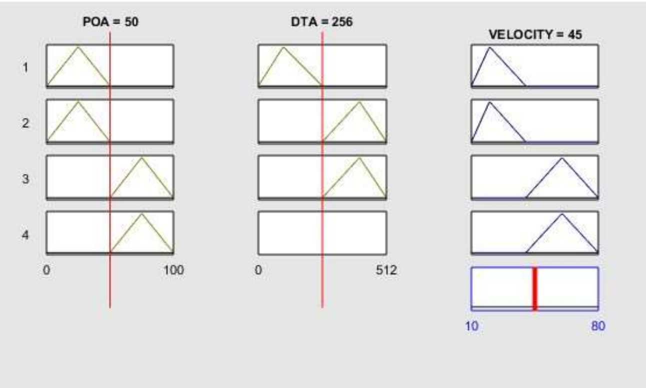

Fig 5: Representation of Rules governing membership function

From the fuzzy controller the rules generate are presented below:

Rule 1: If (POA is present) and (DTA is close) then (Velocity is slow) (1).

Rule 2: If (POA is present) and (DTA is far) then (Velocity is slow) (1).

Rule 3: If (POA is absent) and (DTA is far) then (Velocity is fast) (1).

Rule 4: If (POA is absent) and (DTA is far) then (Velocity is fast) (1).

Where:

POA (Presence of Abnormally (Speedbump)).

DTA (Distance to Abnormally (speedbump)).

The surface diagram of the system is represented in Figure 6. It presents the relationship between the input membership parameter to the output membership parameters.

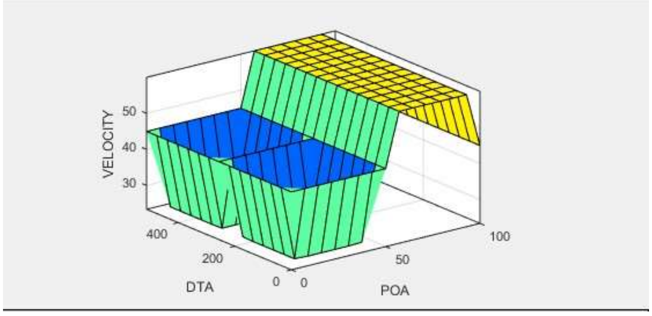

Fig 6: Surface diagram of the system.

The rationale for using Fuzzy Logic as the proposed control technique lies in its intuitiveness and its ability to model uncertainty and human reasoning. In addition, the application Fuzzy Logic Control has yielded significant results in the aspect of nonlinear control which makes it suitable for the dynamic environment of an autonomous vehicle.

IV. Proposed System Design

A. System Description

The proposed system block diagram is presented in Figure 7. The Raspberry pi microcontroller is the brain of the system. The inputs to the microcontroller are the images acquired from the camera as well as the speed of the vehicle at that instant. The outputs of the system are the speed of the DC motor and the LCD display which will indicate the status of the vehicle in terms of speed and bump detection. The microcontroller will run the image processing algorithm on the images gotten by the camera using HOG technique. When a bump is detected, the system will evaluate the distance of the vehicle from the bump and based on the data obtained, the fuzzy logic controller will determine the appropriate speed to use when approaching a speed bump. When the vehicle is close to a bump, the speed will be reduced by the controller and the vehicle will revert to its original speed after it has successfully passed over the bump.

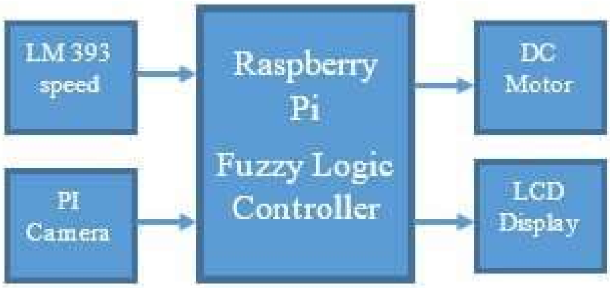

Fig 7: Block Diagram of System

The microcontroller will be programmed using the Raspberry pi Integrated Development Environment (IDE). The image processing algorithm as well as the fuzzy logic control algorithm will be implemented on the microcontroller. Figure 8 shows the flowchart representing the system operation.

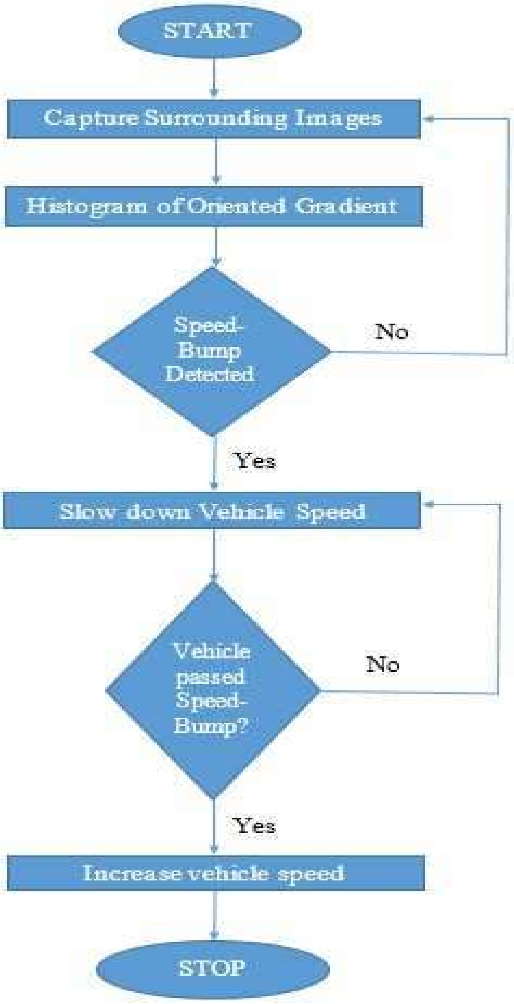

Fig 8: Flowchart Representing System Operation

B. *Vehicle Modelling*

The vehicle will be modelled in Simulink (r2019a version) based on the longitudinal and lateral dynamics of the vehicle. The Simulink vehicle model presented in [28] will be adopted for this study and is presented in Figure 9. This vehicle model is designed to exhibit a constant velocity for the vehicle, and due to this, the speed of vehicle will be regulated with respect to the detected speed bump and the distance of the vehicle from the speed bump.

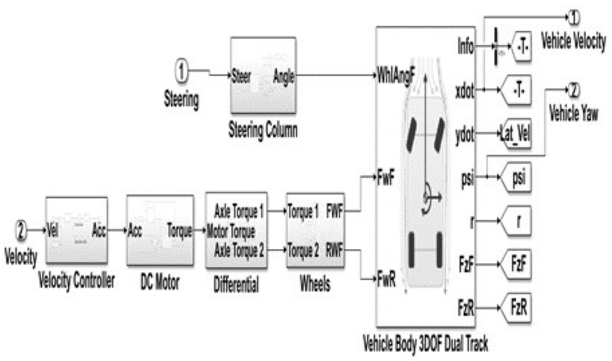

Fig 9: Simulink Model of Autonomous Vehicle [28]

C. *Hardware and Software Design Considerations*

The entire system will be programmed using the MATLAB software tools and also Raspberry pi Integrated Development Environment (IDE). The system will be powered by a 12 V DC battery. This will be stepped down to 9V for the Rasberry pi Microcontroller. The camera and the LM 390 speed sensor will serve as inputs to the microcontroller while the outputs will be a DC motor and an LCD display. The speed of the DC motor will be controlled by the fuzzy logic controller. These devices will be integrated on a model car and tested on a road for performance evaluation. The circuit diagram of the proposed system is presented in Figure 10.

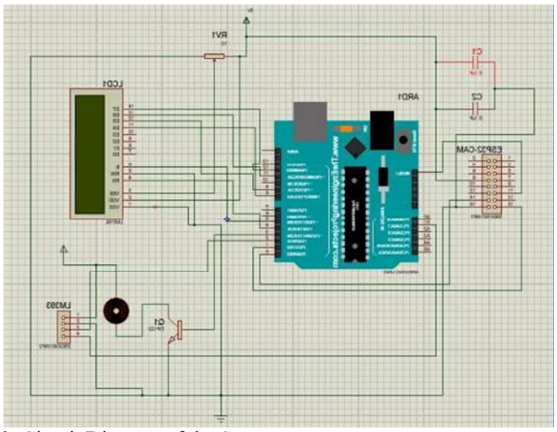

Fig 10: Circuit Diagram of the System

TABLE I.

S/N	Table of component and ratings	
	Components	***Ratings***
1.	Raspberry Camera	
2.	Raspberry pi 3b+	
3.	DC Motor	5volt
4.	LM 390 (Speed sensor)	
5.	Servo Motor	MG 996R
6.	Relay	5volt
7.	RC Chassis	
8.	Lipo Battery	2000 Mah

Fig. 11. Table of Componenets

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an

V. Conclusion

This paper reviewed existing works in the aspect of speed bump identification and vehicle control. It also presents a proposed methodology for the implementation of an intelligent speed bump detection and speed control system for autonomous vehicles. The proposed technique employs the use of HOG to identify speed bumps and the implementation of a Fuzzy Logic Controller to regulate the speed of the vehicle when approaching a bump.

This system when implemented is expected to autonomously drive a vehicle and regulate its speed in the presence of speed bumps with the use of the implemented control and computer vision techniques. This development is expected to help reduce the rate of road traffic accidents and improve road safety on highways. Future works will be focused on the implementation of the proposed designs and development of a system prototype.

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