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ORIGINAL ARTICLE

# Python Inspired Smart Braking System to Improve Active Safety for Electric Vehicles

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**ABSTRACT** – In today's world, electric cars are gaining popularity as a mode of transportation due to their smooth and comfortable rides. Since electric cars/bikes do not emit exhaust emissions, environmental standards will improve; however, an unintended upcoming risk of accidents has been identified due to the quiet nature of electric vehicles. The increasing trend of road accidents is resulting in serious injuries or even severe disability. In view of this, it was intended to develop the smart control system by using neural network techniques to enhance safety, especially for electric vehicles. The obstacle detection and smart control strategy were achieved by employing a state flow network. Furthermore, The driver's behavior was monitored with the aid of a web camera. If the drowsiness/fatigue state of the driver is being detected by the system, then immediate precautionary steps would be carried out such as warning indicators, emergency braking, and stop. To execute this method, the number of input processing hardware devices and software algorithms were used collaboratively. The prototype has been developed to conduct the necessary trials for vindication. The findings show that the control strategy of the proposed model was successfully incorporated on the test bed with consistent results concerning control in numerous situations. The proposed smart braking system would be beneficial to both road users and passengers for improving safety.

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## INTRODUCTION

The automotive vehicle braking systems have always been given great importance for safety concerns and particularly active safety. Stopping safely at the will of the driver is the prerequisite for any automotive braking system. Although a disc braking device would aid in-vehicle control in a shorter time, the driver's attention is also regarded as a significant consideration for a safe drive [1]. Many causes have contributed to driver disruptions, including roadside advertising, passenger conversation, cell phone use, in-vehicle infotainment (IVI), or in-car entertainment (ICE), among many others [1]–[3]. To accelerate vehicle safety, the prominent factors associated with fatal/incidence need to be assessed thoroughly.

Mortality and injury caused by road accidents are critical and increasing issues of public health in India. Road traffic accident fatalities have risen to 1.35 million a year. That's about 3,700 people die every day on the highways of the planet [4]. There are several contributors to this trend: rapid urbanization, ignorance of safety standards, lack of compliance, intoxicated or sleepy drivers, drug or alcohol-influenced drivers, speeding, and refusal to wear seat belts or helmets [3], [5]–[7]. As a result, some researchers argued that there is an immediate need to recognize the deterioration of the situation in terms of road accidents and injuries and to take necessary measures [8], [9]. Keeping this in mind, it is required to add key strategies to augment the overall safety of vehicles by incorporating either driver's behavior monitor system, or driver's assistive systems for crash prevention. Considering the safety of drivers on which all passenger safety relies, the primary priority of research related to driver conduct has been well thought out. Since then, to great extent research has been focused on improving the safety of drivers considering numerous parameters like eye movement detection, drunken state detection, driver's distractions, and many more. Therefore, it was planned to review the past available literature relating to driver safety to examine the extension of the existing study related to the enhancement of safety.

At the same time, electric vehicles are emerging on the road with great popularity [10]. Although electric vehicles have a variety of advantages, the new upcoming unintentional risk has been identified due to quiet running operations. The presence of electric vehicles is tricky to hear for road users [11]. Although the variety of safety features like Tyre Pressure Monitoring System (TPMS), Head-up Display (HUD), Driver Monitoring System (DMS), Anti-Lock Braking System (ABS), Night Vision System (NVS) are available in electric cars, the travel with safety is still being a great challenge, especially for electric vehicles [12], [13]. Further, It has been discussed that the anonymous auxiliary sound would not be the possible feasible solution for indicating the presence of electric vehicles [14]. The rising trend of road accidents is a major concern in today's fast-moving world, as shown in Figure 1. The number of suffered people is increasing following the linear trend and therefore, it seems crucial conditions that lead to high-risk forms of road crashes are to be carefully considered and recognized. Among which, accidents due to low noise characteristics of electric vehicle could be considered as one of the upcoming situations. As a result, it was intended to develop the new kind of advanced intelligent braking system especially for electric vehicles.

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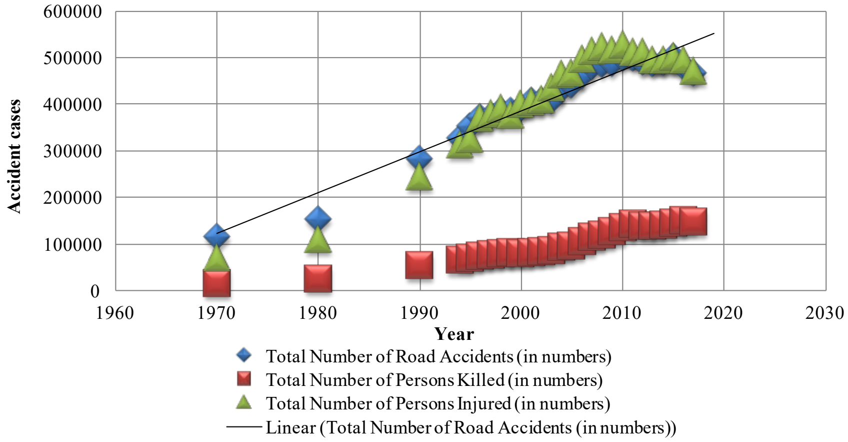



**Figure 1.** The scenario of road accidents in India from Open Government Data (OGD) platform India.

To control road accidents, the factors need to be assessed and demonstrated with extreme care. With the assistance of advanced technological inventions, it is now possible to monitor and control human emotions with pinpoint accuracy. Numerous modern approaches, such as fuzzy logic and artificial neural networks, have shown their ability to track driver behavior, car crash control, and many other things. Vehicle crashes may be classified as single-vehicle crashes (SVCs) and multiple-vehicle crashes (MVCs). Single-vehicle crash takes place due to driver's fault, vehicle brake failure, or overspeeding of vehicle. On the other hand, multiple vehicle crashes take place with or without the driver's fault. For example, when the oncoming vehicle would be faster and unable to control by the driver, vehicles coming from the opposite sides may be subjected to risk. However, pedestrians may suffer in both cases of crashes. Consequently, safety for road users needs to be enhanced.

As discussed above, electric vehicles are coming on the road with great popularity. At the same time, pedestrians are in trouble due to the low noise characteristics of electric vehicles. The rising trend of accidents needs to be controlled with some advanced control strategy. Many times driver's fatigue causes accidents whereas many accidents were reported due to driver's mistake. In quest of this, the main objective of this study was to design and develop a novel smart braking system for continuous monitoring driver's drowsiness and obstacle detections with emergency braking control of vehicles. The real-time data was captured with sensors and hardware with Raspberry Pi. The research was carried out in three main steps. Firstly, the driver's drowsiness model was developed in python with advanced artificial neural network techniques. The correctness of the model was evaluated by conducting numerous trials with different person face for drowsiness detection. Secondly, the obstacle detection algorithm and control model was developed in Matlab by following a Fuzzy neural network. Finally, the interfacing of these control modules with the previously designed test bed was ensured to evaluate the feasibility of the systems.

## RELATED WORK

In automotive vehicles, brakes are among the most essential safety and performance elements. However, safety relies on diverse factors such as driver's behavior, the health state of drivers, road situations in addition to a good braking system. Both fundamental and applied research has been focused on detecting drowsiness as a means to enhance crash avoidance. In quest of this, it was meticulously analyzed the past available literature to get acquainted with numerous available methods and their applications.

Several accidental cases were found more particularly in the traffic region, to control this, IoT based smart monitoring system was designed and developed to monitor traffic violations. A traffic violation may include rash driving, over the speed of vehicles, drunken driving, and not following traffic light rules [15]. Samczynski et al. proposed a GSM-based traffic monitoring system [16]. The over-speed of vehicles may cause serious accidents; in quest of this, RFID based speed monitoring system was introduced with some new features for regulating the speed of road vehicles [17]. Alcohol detection mechanism and auto-lock system was designed by few researchers to enhance road safety [18]. An intelligent vehicle control system was suggested particularly for school zone/hospital regions for the betterment of safety. RF transmitters are well suited for such signal processing applications, thus they can be utilized in the region where precaution should be taken by vehicle drivers [19]. Further, several researchers reported that engine braking difference exists between conventional vehicles and electric vehicles which need to be assessed and sort out for immense safety [20].

The growing popularity of e-bikes has prompted research regarding the health and environmental impacts [21], as well as abnormal riding behavior [7]. A comprehensive study was conducted by Guo et al. at Ningbo, a city of China to assess factors influencing e-bike crashes and license plate use in China [22], who found that type of e-bike, riding experience, usage of e-bike are the significant contributors in e-bike crash. Also, it was found that the noiseless nature of EVs is linked to a moderate risk [11]. Previous risk studies suggest that pedestrians are having more trouble, especially when electric vehicles pass nearby [23]. Further, it was also commented that EVs are intrinsically unsafe [24]. The crashworthiness of electric vehicles was studied to identify the most significant factors and it was noted that the centre of gravity and length of the frame are the prominent factors for the crashworthiness of electric vehicles [25]. Human error, climate change such as bad weather, poor road maintenance, or technical issues with the car may all contribute to road crashes.

With the aim to improve safety on the road, many scientific studies have been conducted on driver behavior [26]–[28]. Driver exhaustion and sleepiness can be the cause of up to one-fifth (20%) of crashes on highways and other monotonous forms of roads [6]. There is a clear connection between obstructive sleep apnea syndrome and traffic crashes, with drowsiness being a major factor in raising the likelihood of a crash [6]. Some researchers developed the model to detect the drowsiness of drivers [27], [29], [30]. Accordingly, a new method was suggested for yawn detection based on thermal image processing [31].

IoT has great applications in the field of vehicle safety. Detection of accidents and immediate medical attention was proposed by some researchers [32] using IoT. Fuzzy logic, artificial neural networks, and decision-based control design were identified as some of the several strategies that could be used to apply the necessary control strategy for enhancing the safety of vehicles [33]–[35]. Mamdani fuzzy logic control-based smart braking model was proposed with braking force as an output followed by two different inputs adopted from the velocity of vehicle and obstacle distance [36]. What's more, some researchers propose a multi-input, single-output fuzzy logic controller for anti-lock braking systems, in which both slip and vehicle velocity are regarded inputs and are controlled equally, impacting the controller decision [37, p. 1]. Now a day, Interval type 2 fuzzy logic controllers were widely used because it has lower computational complexity than general T2FS [38]. Further, the TSK algorithm was proposed for the development of a fuzzy-based automated brake controller [39].

An additional stream of literature attempts to focus on some advanced neural network techniques for vehicle safety. Xiong et al. developed a strategy for avoiding forward collisions depending on driver braking behavior [40]. The systematic review on driver's behavior monitoring techniques using various machine learning techniques was proposed by Elassad et al., recently [34]. Some model for the prediction and detection of driver's drowsiness was presented by Nauroisa et al., considering two models; firstly, the degree of drowsiness was detected in every minute and further time required to reach the drowsiness level.

Since previous studies have been restricted in their ability to explore safety factors related to the safety enhancement of electric vehicles, it is essential to undertake research in this area to create a combination of modules for the betterment of road safety. In quest of this, it was proposed to develop the novel driver's behavior monitor system by using an artificial neural network. Further, the separate car crash prevention module was developed using a machine learning approach. Finally, the modules were put together and their consistency was assessed on a test bed. The details of components used in the test bed, as well as the proposed intelligent braking modules, are given in subsequent section.

## EXPERIMENTAL INVESTIGATION

### Test Setup

The trials were performed on the newly developed smart braking prototype. It consists of a motor, contactors, sensors, flywheel, disc brake, controller, and hydraulic actuators as shown in Figure 2.

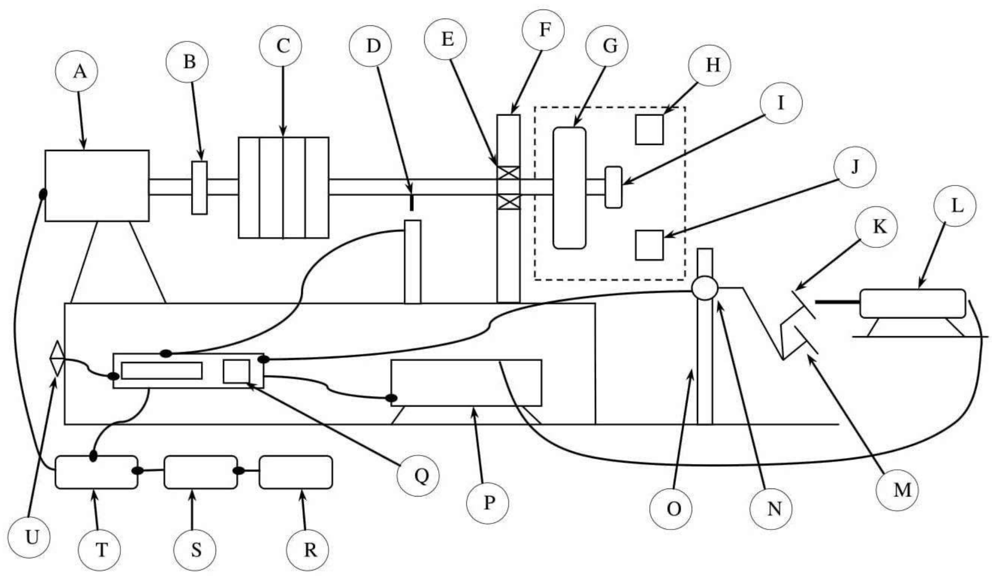



**Figure 2.** The layout of smart braking system.

(A-3 Phase Ac Induction Motor, B-Coupling, C-Flywheels, D-Bolt to detect motion for proximity senor, E-Bearing, F-Support plate, G-Disc Brake, H-Noise measuring device, I-Provision for attachment of wheel, J-Wear particle measuring device, K-pedal extension for automatic braking application, L-Hydraulic plunger, M-Manual brake pedal, N-pressure sensor, O-stand for support to brake pedal assembly, P-Hydraulic actuator, Q-Relays, R-Starter, and Miniature Circuit Breaker, S-Variable Frequency Drive, T-Contactors, U-Web Camera)

In this smart braking model, the 3phase - 5HP electric motor was used to gain the initial running environment of the vehicle. The variable frequency drive regulates the vehicle's speed based on the value defined by the driver or user. Particularly, flywheels were employed to add the required load of the vehicle to attain the vehicle's momentum. What's more, the brake pedal assembly along with a pressure sensor was introduced to control the motion of the vehicle. The brake blending was achieved through the correct controlling of torque as per the requirement as shown in Figure 2. While disc brakes are used in the smart braking system, they are only used in certain situations.

The three-phase induction motor with 1440 rpm was used to gain the rotational energy to the wheel. The purpose of the variable frequency drive was to adjust the speed of the vehicle as per test conditions. Hence, it was possible to achieve the speed of the shaft for a proposed model with numerous speed situations which may occur in real-time vehicle activities. To meet the vehicle's momentum, the flywheels were added. What's more, we used the proximity sensor to monitor the speed of the shaft as per our test conditions. Another explanation for this kind of sensor was settling on the decision-based signal sent to the microcontroller. The embedded systems have demonstrated their ability to accurately monitor the real-time environment. As a result, it was intended to use an embedded system to regulate the smart braking system. The flow chart for the smart braking system is shown in Figure 3.

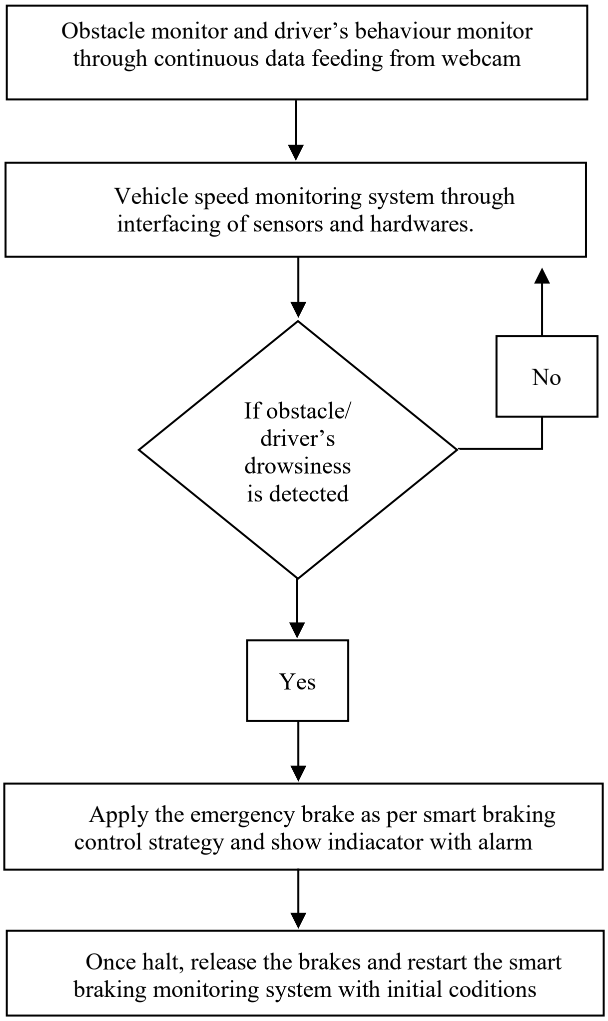



**Figure 3.** The flow chart of the smart braking system.

## Neural Network Modelling

The advanced features like face detection with deep learning available in python could be integrated with numerous applications for betterment in safety. Haar Cascade is a machine learning-based method for training a classifier that uses a large number of positive and negative images [41]. Because of its comprehensive coverage of computer vision activities, the OpenCV4 library is widely used. Also, the interfacing with raspberry–pi and ease in programming had increased the popularity of such advanced libraries available for python modules. Therefore, it was planned to employ raspberry pi and the neural network technique by using python. The trained model was stored in Raspberry Pi. Further, with the aid of relays, the control strategy was implemented on a test bed with real-time data monitoring system. The neural network modelling consists of the input layer, hidden layer, and output layer as shown in Figure 4.

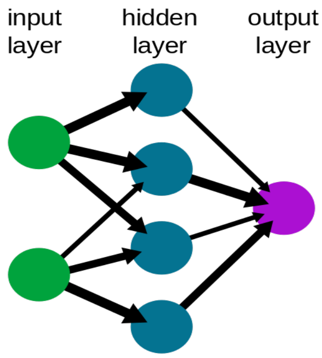



**Figure 4.** Artificial neural network architecture.

### Architecture of Drowsiness Detection

Initially, the haar cascade classifiers, as well as OpenCV, were trained on a dataset of human faces, and classes were generated based on facial and eye characteristics [42]. The second step consists of identification. It is mainly concerned with tracking and recognizing target items, the face, and the eyes in the exhaustion framework. The detailed flow diagram for the driver's drowsiness monitoring system is shown in Figure 5.

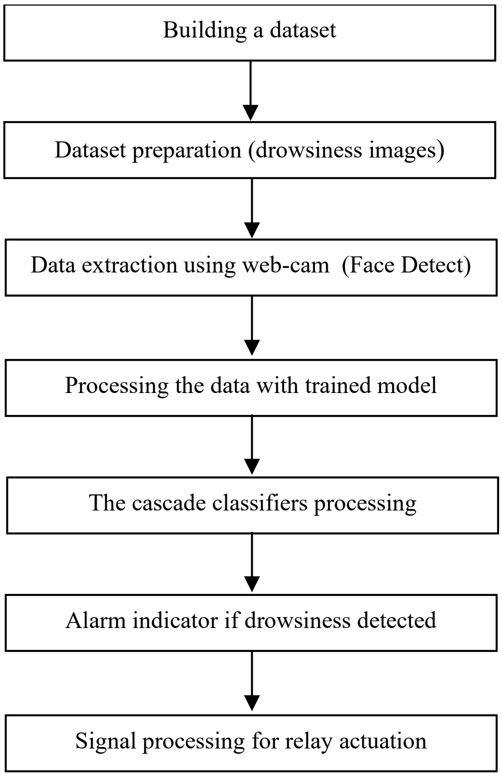



**Figure 5.** The flow diagram for smart braking with drowsiness detection module.

Some open access necessary packages were considered in python to build the program as per our requirements, such as scipy, numpy, argparse, playsound and many more [42]. The eye aspect ratio can be considered as one of the important factors for drowsiness detections as shown in Figure 6. The webcam stream was captured at 40 frames per second then encoded into discrete images before being robustly processed by the haar cascade algorithm. An algorithm for detecting eye blinks in real-time was introduced [43]. The outer frame around the driver's face with a red colour indicator is proposed for quick recognition of drowsiness state with alarm sound. Numerous trials were carried out with the same, and the details of the findings are presented in section 4.

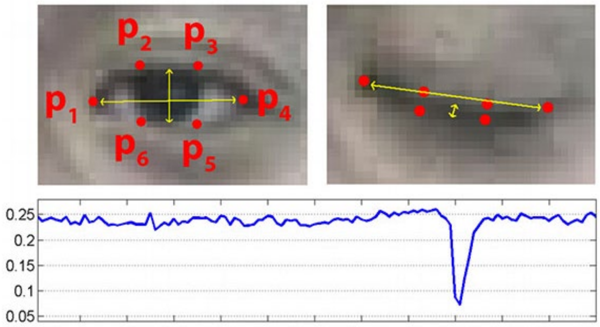



**Figure 6.** Open and closed eye monitoring scheme [43].

### Architecture of Crash Detection

Rising car accident cases are recorded as a result of over-speeding, rule violations, failure to follow signs, rash driving, fatigue, and alcohol in driver's conduct; while pedestrians are often responsible for accidents as a result of their carelessness while walking on the road or crossing at unsafe places [5], [9], [44]–[46]. In pursuit of this, it is contemplated to create a smart crash warning system and combine it with a test bed for testing the system's correctness in terms of vehicle control.

The first task considered when creating a dataset was assembling input parameters like the distance between vehicle and obstacle for various conditions. The training process entails preparing a trained model with provided datasets. The systematic flow of the crash detection monitoring system is presented in Figure 7.

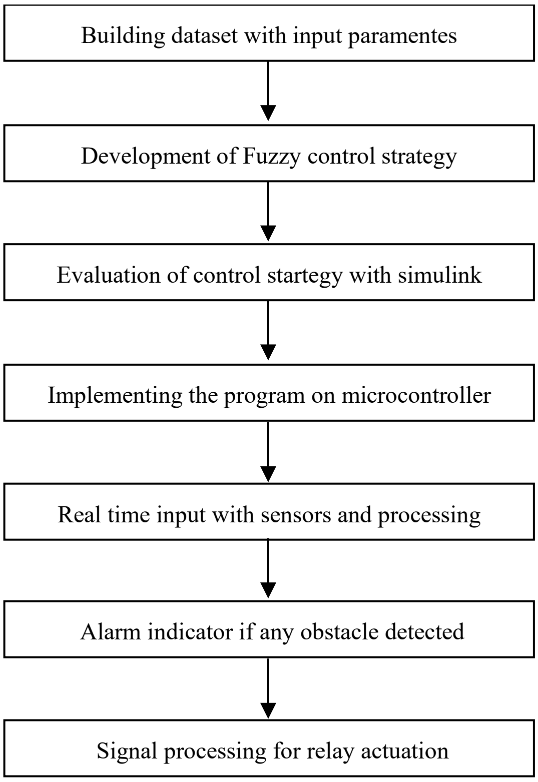



**Figure 7.** The flow diagram for smart braking with vehicle crash control module.

The Matlab-based program has been assessed by using Simulink for smart braking control. The relays are the well-proven electromechanical components to convert electrical signals into larger currents. Therefore, it was proposed to carry out necessary control actions by using a relay in the smart braking system. The control strategy used for smart braking control is shown in Figure 8.

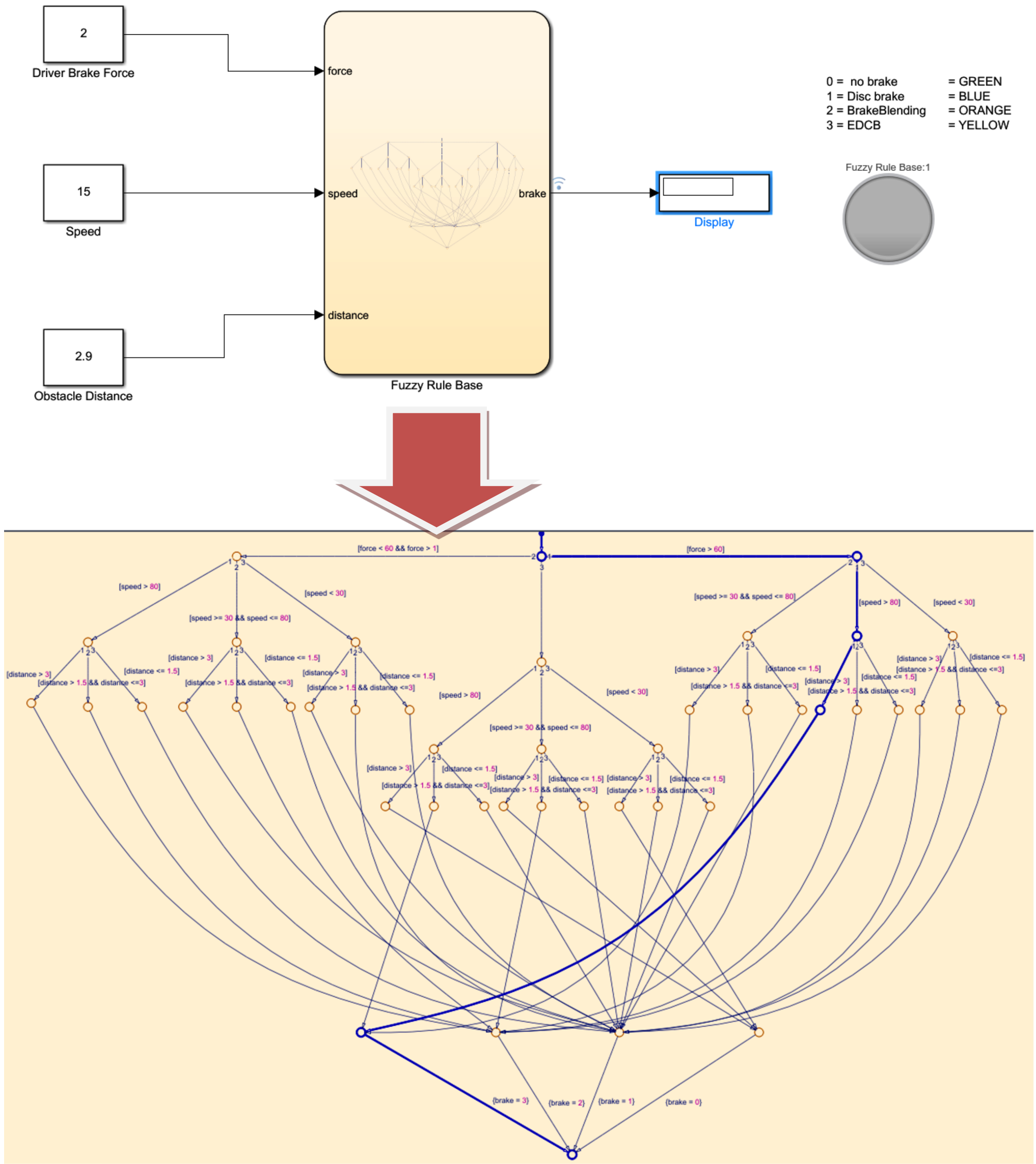



**Figure 8.** Proposed fuzzy control strategy and path flow.

## VERIFICATION OF MODEL

A test bed is a framework for systematic, open, and replicable testing of emerging technology, experimental concepts, and computational tools [47]. For validation of the proposed control system, the present conditions have been experimented through numerous trials on the test bed. To go into details, verification is the process of determining whether a product, service, or device meets a rule, necessity, specification, or implemented condition. Therefore, it was planned to check every possible situation on the test bed. The components and test set are shown in Figure 9. For emergency braking situations, the hydraulic plunger has been incorporated in the test bed following the signals achieved from the hydraulic actuator. The intention behind such an arrangement was to facilitate the control strategy in automatic braking contexts. The relays are employed to monitor the appropriate actions as and when required by the Raspberry Pi.

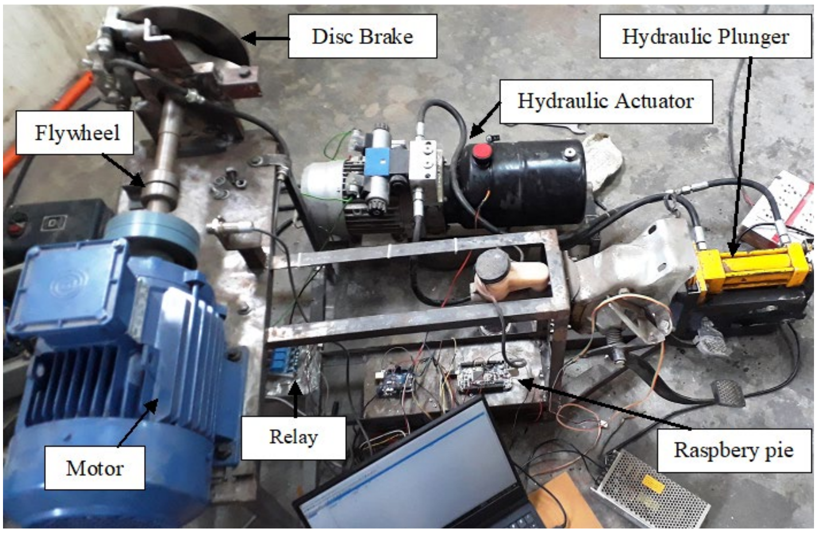



**Figure 9.** Proposed setup for testing of smart braking system.

Numerous trials were successfully conducted on the smart braking system setup for evaluation of emergency braking environments considering either drowsiness of drivers or on-road obstacle detections. Initially, the motor is allowed to run at desired rotations to gain the required speed of the vehicle. The wheel tyre rim diameter is assumed as 381 mm (15inch). The speed of the vehicle is calculated by using the following formula

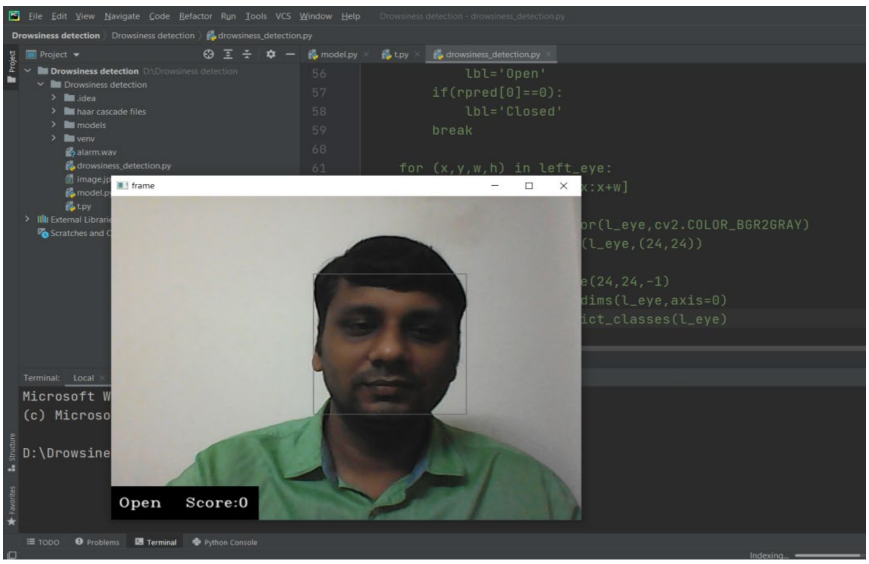
$$S = \text{Wheels RPM} * \text{Tyre dia} * \pi * 60 / 63360 \quad (1)$$

where π represents the ratio between the tyre's perimeter and its diameter, Wheel rpm represents motor speed, Tyre dia. represents the diameter of the tyre.

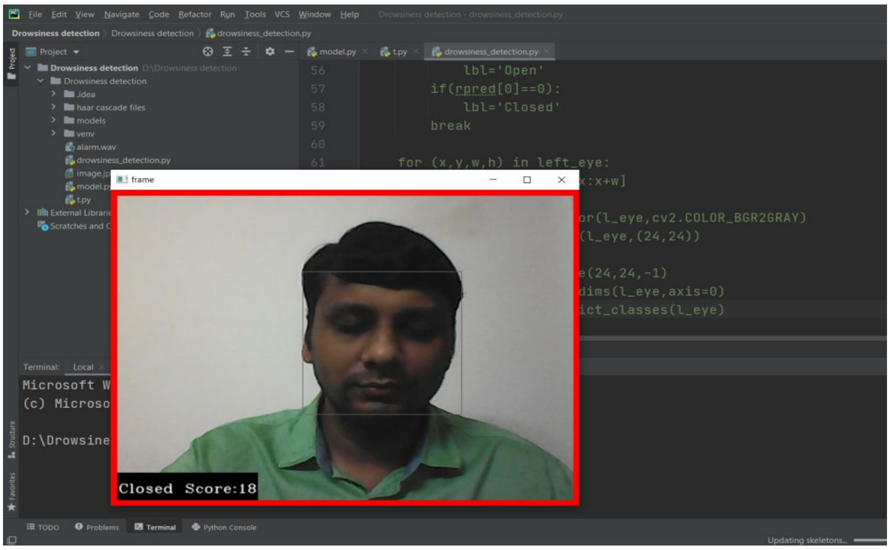
The feasibility of the proposed model was assessed at three different speeds of vehicles: medium, average, and high. The random obstacles were introduced in front of the test bed at different locations. The emergency brake was actuated if the obstacle appears in the given range. At the same time, the driver's behaviour was monitored through a Raspberry Pi web camera. The emergency brake gets automatically applied if the driver's drowsiness is detected. Drivers of different ages and gender are considered for trials to analyze the consistency of outcomes. The findings reveal that the proposed smart braking system performs well and consistently regardless of the driver's age or gender.

## Drowsiness Detection

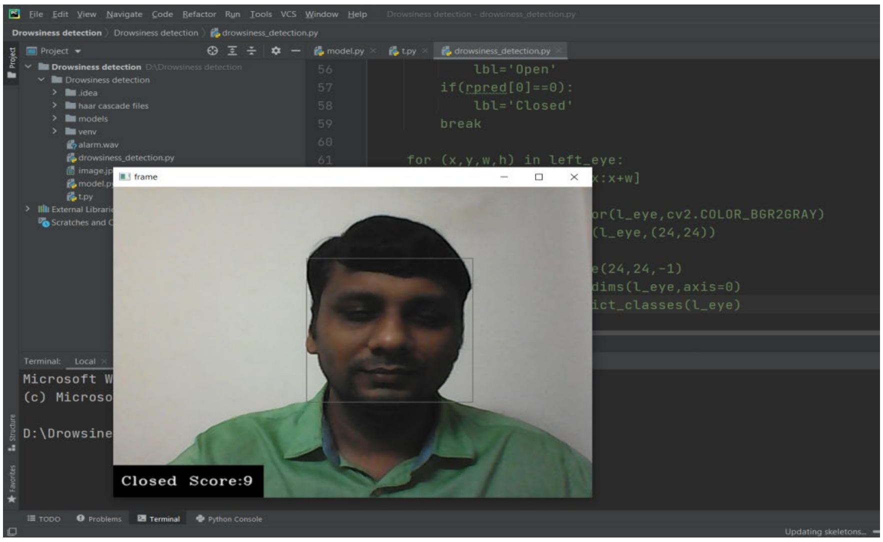
The primary objective of the drowsiness identification process/the monitoring phase was to alert assigned users and apply emergency brakes if the drivers lose control of the vehicle's steering. The program was built by using neural network modules in python. The Python programming language was chosen because it is open source and simple to learn. The normal driver's state, as well as drowsiness detected state, is shown in Figure 10(a) and 10(b) respectively. If the driver is exhausted and some nominal tiredness is identified then such situations are also considered with a closed score of 9 as shown in Figure 10(c). The identified drowsiness state of drivers with the highest closed score is shown in Figure 10(d).



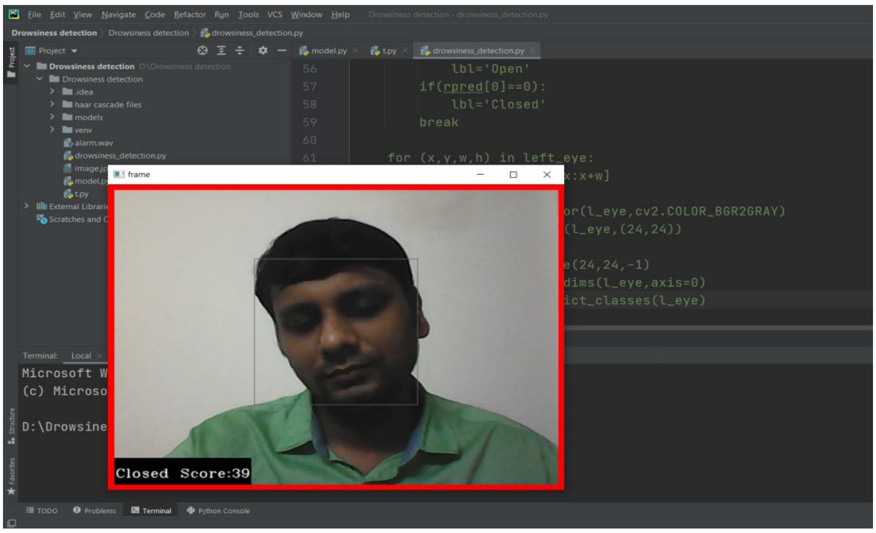

(a) drowsiness not detected




(b) drowsiness detected




(c) partial drowsiness detected with closed score 9




(d) drowsiness detected

**Figure 10.** Driver's behavior state.

### Crash Detection

The secondary goal of our research was to monitor and control the electric vehicle if an obstruction, such as a vehicle or a pedestrian, was observed on the lane. It was successfully achieved with the proposed smart braking control strategy. The control over electric vehicles by running several trials demonstrates the strategy's correctness.

The vindication of the proposed system was achieved through experimental trials conducted on a test bed with different conditions. The signals received from the ultrasonic sensor were provided to the smart braking model. The rest of the work was left on a microcontroller and relays to control the vehicle if any unwanted obstacle was detected. As the emergency braking of the vehicle is planned with pedal extension for automatic braking application, the signals gained from the hydraulic actuator followed by the plunger operates the brake lever to the desired extent. The fuzzy neural network was used to develop the crash control model. The identification phase for obstacle detection on-road as well as necessary braking action is shown in Figure 14. The blue line indicates the selection of brake and the orange line shows the distance of the obstacle.

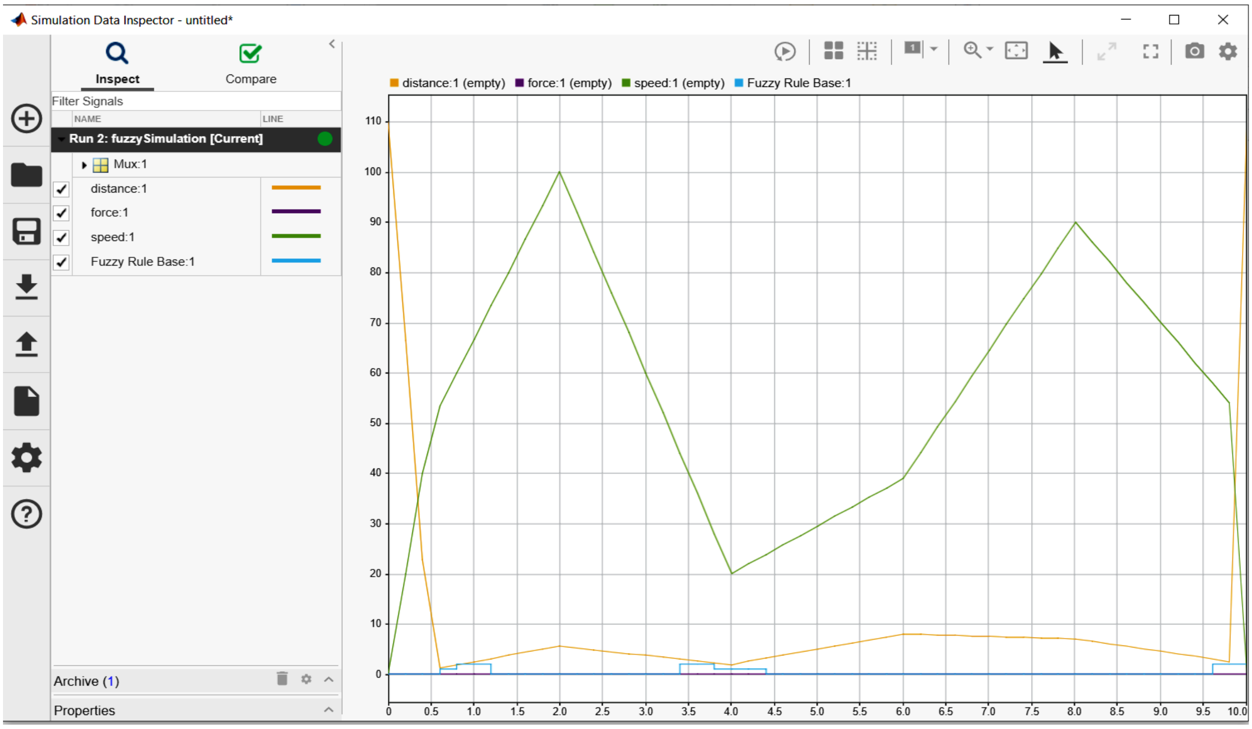



**Figure 14.** Proposed braking control strategy for crash detection.

## DISCUSSION

The smart braking system is intended to avoid a large number of collisions. The system follows the recommendations suggested by previous researchers in regards to the development of necessary control strategies to enhance safety for human beings [9], [48]. It performs automatically rather than manually, reducing the risk of driver's mistakes and, as a result, the risk of injuries. Electronics and mechanical components are combined in this task. To better understand the consequences of a driver's behavior at various stages, a real-time monitor system plays a significant role in identifying the fatigue/exhaustive nature of the rider [27]. Many previous studies have attempted to recognize the behavior of drivers; however, real-time implemented studies were found less [49]. To examine the real-time controlling consequences, the trials were conducted successfully using a test bed. Embedded system architecture was used to construct a brake system that could be mounted on a vehicle to make driving safer. The developed smart braking model was found to be reliable and effective in its responses.

While electric vehicles are becoming increasingly common on the road, the unintended risk for pedestrians due to noiseless operations when driving cannot be neglected [11], [23]. In pursuit of this, several solutions were proposed, such as introducing anonymous noise to electric cars; However, this will not be the appropriate solution to enhance safety for pedestrians [14]. Accidents are becoming more common, and it is a significant source of concern for global human health [4]. The proposed smart braking system would be the best suitable solution to tackle such kind of safety issues related to electric vehicles. The continuous vehicle obstacle monitor system with a smart braking module will enhance the safety of pedestrians as well as drivers.

Furthermore, several studies revealed that driver drowsiness is the leading cause of accidents, especially in the afternoon or late at night [50], [51]. Although many studies are devoted to safety enhancements, research related to electric vehicles found was very limited. Hence, it was intended to develop and assess the smart braking system for electric vehicles. Now, to go into details, the components adopted in the smart braking systems were similar to previous studies [29], [35], [49]. Raspberry Pi, webcam, relays, hydraulic systems were the components used in the system. The control strategy adopted in the system was evaluated in our previous research by using the simulation technique [35]. In addition, it was effectively applied with the help of hardware and sensors; moreover, it functions well. It has been discovered in previous studies that the Arduino Uno can also be used in driver assistance techniques[49].

The limitation of this study is that car obstacle detection tests had only been performed by just introducing the obstacle in front of the test bed as it cannot be moved on the road. However, the position of the ultrasonic sensor can be mounted on EVs to implement the same on any electric vehicle. The second limitation was noticed that the proposed system can detect the obstacles on the road; however, real-time pedestrians and vehicles can be detected using sensors. Hence more research is required to build stabilize model for the obstacle detection module. Although the present research has certain limitations, still it can be served as a base model for future studies related to safety.

The consistency of the driver's drowsiness model was vindicated by conducting numerous trials with different drivers. Almost every time, the system enables detection of the drowsiness state of the driver and acts accordingly to control the vehicle.

## CONCLUSION

In this study, the smart control system was developed and its feasibility was tested to enhance safety, especially for electric vehicles. The findings obtained from comprehensive experimental studies have been appended as follows:

i. The electric vehicle speed can be controlled with an emergency brake if any obstacle is detected and the driver failed to apply the brakes by using a fuzzy-based control strategy.
ii. The present smart braking system improves vehicle safety through the continuous monitoring of driver's drowsiness behavior with application of emergency brake if required.
iii. The perceived risk associated with the noiseless operations of electric vehicles can be addressed by incorporating the proposed smart braking system in electric vehicles.
iv. The suggested neural network model developed for accident avoidance has responded effectively to the innovative smart brake arrangement developed.

The proposed smart braking system will prevent crashes and save precious lives and society if implemented.

## ACKNOWLEDGEMENT

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