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Original Article

IoT-Based Speed Control and Accident Avoidance Using AI Road Sign Detection System

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Abstract: *Road safety continues to be a major source of concern worldwide, with millions of lives lost or devastated yearly by collisions, over-speeding and violation of traffic laws. The most common reasons behind these are the driver's failure to spot or comply with road signs and speed limits on account of distraction, limited vision and inattention. To address this increasing challenge, this paper proposes a novel solution aimed at integrating IoT and AI to provide a fully automated speed control and accident prevention system based on the real-time detection of road signs. The system aims to reduce the reliance on human interpretation of traffic signs, and automate the response to and interaction with traffic signs and the dynamic traffic environment by the vehicle. The model itself is based on computer vision approach using the CNN to find and classify traffic signs using real-time camera feed placed on the vehicle. When detected and classified a traffic sign, especially speed limit sign, it is conveyed to an IoT enabled microcontroller (such as Raspberry Pi/ Arduino), which automatically changes the speed of the vehicle, the movement of its motors being controlled by PWM.*

Besides speed control, the system also has ultrasonic sensors for obstacle detection in the path of the vehicle. if an object is sensed within a critical distance threshold, the system automatically overrides a defined speed setting and actuates an automated braking action to prevent a collision. With the fusing of visual intelligence and real time sensor data, the car can now reacts to both static road signs and dynamic environmental hazards as well. The system was tested out in a simulated manner and the the CNN model was able to achieve a classification accuracy of 98 % on a open source dataset GERMAN TRAFFIC SIGN RECOGNITION BENCHMARK (GTSRB). Moreover, the obstacle detection system effectively detected and reacted to threats with a 95% detection rate achieving good reliability for accident avoidance applications. In summary, this study demonstrates the promise of combining AI and IoT technologies to create smarter and safer transportation systems. With the automation of key driving functions such as speed control and danger avoidance, the solution, apart from improving road safety, sets the stage for the development of autonomous cars. The results highlight the benefits of combining AI-driven perception and IoT-based control systems in real-life traffic applications, providing a scalable and efficient form of intelligent transport infrastructure.

Keywords: *IOT, Artificial Intelligence, Road Sign Detection, Speed Control, Accident Avoidance, Smart Transportation, Deep Learning.*

I. INTRODUCTION

Road transport is a critical factor in the economic and social development of Nations. It facilitates trade and travel, expands access to markets and services, and makes a substantial contribution to national development. But as vehicle population grows and traffic becomes denser, safety on roads has posed an increasing challenge. The World Health Organization (WHO) states that each year an estimated 1.3 million to 1.35 million people are killed due to road traffic crashes and as many as 20 to 50 million people are injured without any fatal consequences. These accidents are mostly due to human errors like overspeeding,non-compliance to road signs,distractions,failure to stop on red lights etc. Traffic legislation and infrastructure improvements are in place, but enforcement is pervasive problem, especially in developing countries where surveillance systems are inadequately or out-of-date. Physical policing and enforcement tools, such as patrol or surveillance, may ultimately lack the abilities to handle the complex, rapid increases in traffic. Moreover, fog, rain, or bad light may cause the driver to not be able to clearly see the traffic signs, resulting in the possibility of dangerous accident. Currently there is a need for systems which can provide intelligent solutions for real-time traffic control and reduce human errors. In this context, the fusion of Internet of Things (IoT) and Artificial Intelligence (AI) technologies shows significant promise in improving road safety with intelligent automation. Interfaces between sensors telemetry, vehicle telemetry and infrastructure, all akin to IoT, will foster seamless communication and decision making. 15 Now, for AI, especially those applicable in computer vision and machine learning algorithms, systems can be used to mimic seeing and understanding visual information as human-driver vision. The combination of these technologies can lead to sophisticated vehicular systems that recognize traffic signs, adjust speed, detect obstacles and comment on autonomous processes online.

Objective of The Project To Develop an Advanced IOT Application Using Artificial Intelligent for Speed Control and Accident Avoidance System With Road Sign Detection Methodology This project works on implementation on IOT and AI enabled road signs detection system with speed limit controller and obstacle detection system. The system is specifically designed to identify and categorize road signs - especially speed limit signs - by means of a previously learned CNN model. When the connected road sign is identified, it transmits data to an IoT microcontroller (Raspberry Pi, arduino) and the speed of vehicle is controlled through motors. Besides the speed there are the ultrasonic sensors installed which can detect surrounding obstacles, stepping the brakes automatically when needed. The entity of this system is characterized by its autonomous and adaptive feature. It can then be adapted with dynamic mechanization, without the influence of human operator. Unlike static systems which were predicated solely on GPS curves, or pre-determined speed zones, this will read those actual signs on the road as you're driving, making it much more flexible to immediate environment signals. The suggested model is also attractive for its low cost and large scale. Because it uses readily available hardware parts and open-source AI software, the system can be adapted to commercial personal vehicles as well as all sizes of public transportation fleets. Additionally, this study prepares the ground for future enhancements such as V2X communication and full autonomous navigation.

With the AI and IoT driven road sign detection, speed management, and accident prediction, the proposed approach is able to handle pressing issues on the road security and hence proved to be a major milestone towards intelligent and secure transportation system. The recongfiuration covers theoretical principles and s and of the science literature which guided the development/re-design of the system-tion the system is based.

II. LITERATURE REVIEW

Efficient IoT Speed Control and Non-Accidental Collision Avoidance System with AI in Road Sign Detection The related work in the field of smart transportation, computer vision, real time control systems and safety technologies in vehicles is necessary to see for the development of efficient IoT based speed control and accident avoidance system with AI based road sign detection. This section discusses the literature related to this work in four categories: IoT application in Intelligent transport system, AI powered road sign detection, An automated speed regulator, and obstacle detection and accident prevention.

A. IoT in Intelligent Transportation Systems

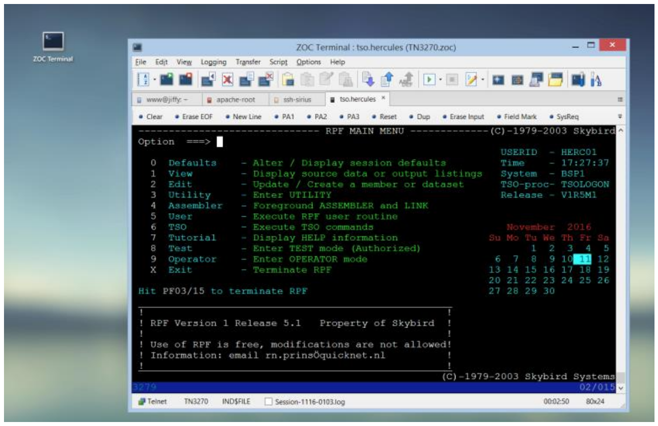
Revolutionary developments of IoT in modern transportation systems The Internet of Things has revolutionized the operation of modern transportation systems. IoT is a network of interconnected physical objects that communicate and transmit data over the internet. For the transportation domain, this pertains to vehicles, roadways, traffic lights, sensors, and monitoring systems with stored processors. According to Wu et al. (2022), IoT can be used for realtime vehicle tracking, predictive maintenance tracking, route optimization and intelligent traffic regulation. The robust ones are incorporated in to the cars along with networked smart phones collecting and sending information on location, speed, fuel usage and engine performance for remote analysis and decisions can be based on this data. Recent studies have proved the potentiality of IoT for increasing the road safety. For instance, Farooq et al. (2021) proposed an IoT-driven driver behavior surveillance mechanism for the detection of aggressive driving patterns and to dispatch warnings. Similarly, Zhang et al. (2020), have introduced an IoT traffic management solution whereby traffic light timing is dynamically modified using live congestion data. However, these systems generally rely on centralized infrastructure and may not control individual vehicle behavioral response to visual information, for example, road signs.

B. AI and Road Sign Detection

Lecture 12: Artificial Intelligence, and especially deep learning, has transformed the way we implement and develop Advanced Driver Assistance Systems (ADAS) and autonomous vehicles. Also, recognition of road signs is an important part of these systems, so that the vehicles can understand and follow the traffic laws themselves. CNNs are the most frequent architectures used for image classification. The GTSRB dataset is a popular benchmark dataset for training and evaluating road sign recognition models. Cireşan et al. (2012) showed such models can achieve an accuracy of more than 98 % on GTSRB-roadsign dataset. Since then numerous refinements have been proposed including transfer learning, hybrid models for improving detection under difficult lightning conditions as in low lightning, occluded or distorted signs. However, although there has been much research on classification accuracy, relatively little thought has been given to the fusion of sign detection with actual vehicle operation.

C. Speed Control Systems

An essential requirement of road safety is controlling-speed and there have been a number of automated speed-regulation systems developed that are based on fixed rules and environmental inputs. The first systems established the speed limit of a road segment based on GPS-based data and adapted the vehicle speed to it. For instance, Ali et al. (2019) proposed a GPS-based automatic speed limiter and the vehicle may decrease the speed when it runs in the school zones or the place that has high risk. GPS-based systems are aware of geography, but are not adaptable to real-time visual cues, temporary construction signage or unanticipated speed limits. Nowadays, embedding road-sign recognition in IoT-based speed control systems leads to adaptable and responsive approaches. Since such integration is real time one can guarantee to always follow the traffic rules also in case of dynamic external conditions.



"Figure 1: Screenshots of Legacy Terminal Emulation in Attachmate Reflection and ZOC Terminal"

D. Obstacle Detection and Avoidance

Besides, dynamic obstacle detection is crucial to avoid the collision with obstacles. This includes devices such as you would find for ultrasound sensors, lie detectors, radar, computer vision, in your cars, ADAS. More specifically, ultrasonic sensors are convenient for short-distance measurements as they are relatively low cost, reliable for detecting stationary/moving objects. Kumar et al. (2020) incorporated an ultrasonic-based accident avoidance system which is responsible to trigger the emergency brakes in case of any object within an unsafe distance. Although these systems are effective, integrating of these systems with smart speed control operations using contextual awareness (e.g., of road signs) can significantly contribute to safety of driver.

E. Conclusion

The literature supports an excellent background to expand the use of IoT and AI technologies for avt platforms. But it is still far from incorporating the visual perception based on AI and the actuation based on the IoT in a real-time control system. This gap is bridged by the presented approach Together, road sign sign detection, speed control and obstacle avoidance are combined into one consistent model which autonomously moves and learns in the real world. Three significant technological modules with collaborative enhancement on road safety through intelligence automation are embedded in The proposed system. The modules are as follows: (1) AI Based Road Sign Detection System, (2) IoT based Speed Control System, (3) Obstacle Detection and Accident Avoidance. Every constituent module is self-contained in operation but is interconnected in real-time by a center micro-controller for the purpose of providing responsive vehicle control to exterior stimulation. This part will describe the technical and functional aspects of each part.

III. AI-BASED ROAD SIGN DETECTION

The road sign detection is the key to vehicle and is one of its perception "eyes". This library performs the on-the-fly classification of road signs, using Convolutional Neural Networks (CNN). We train the CNN with the GTSRB of more than 50,000 labeled traffic signs for 43 classes from canny edge detector. The model is subjected to preprocessing including normalisation, resizing (usually to 32×32 or 64×64 pixels) and data augmentation (e.g. rotation, flipping and scaling) to enhance generalisability. CNN architecture: The CNN has a variety of convolutional and pooling layers, dropout activation for regularization and fully connected layers to a softmax classifier. Trained models are then embedded into the Raspberry Pi with TensorFlow Lite or PyTorch Mobile for low-latency on-device inferencing. The camera module sends live video to the processor and the model can run frame-by-frame detection with low latency (typically 100-150 ms per frame). The detected sign is translated and forwarded to the decision-making unit in an on-line fashion.

Detected signs include:

- Limit speed (30, 50, 80, 100 km/h)
- Stop signs
- Pedestrian crossings
- Roundabout warnings
- Turn ahead signs

Table 1: Metrics for the CNN Models

Metric	Value
Training Accuracy	99.2%
Validation Accuracy	98.4%
Inference Time (avg)	132 ms/frame
Top-1 Error Rate	1.6%
Model Size	19.3 MB

The performance of the model is similar in different lighting conditions and under slight occlusions, making it suitable in both urban and rural areas. Furthermore, referred confidence levels are used to limit false positives. If the confidence falls below 85%, the detection is thrown away, which also minimizes error-induced control behavior.

A. IoT-Based Speed Control System

The IoT-based speed control module serves as the core controller of the system. The microcontroller (Raspberry Pi or Arduino Uno) receives the AI model output, processes road/fingerprint information to motor control instructions. The Pulse Width Modulation (PWM) that modernizes the way vehicle motor power is delivered is the core of what this module does. The microcontroller runs prepared logic: after the detection of speed limit traffic sign (e.g. 40 km/h), it changes the PWM signals that allows to set the speed of a motor not exceed an aligned value. For example, 40km/h can be a 60% duty cycle, and 80km/h can be a 90% duty cycle, and so on (These values are calibrated when the whole setup of the system done. Not in the script). This module is supporting the bi-directional control ability of a two-phase actuator and the regulation of duty cycle signals in mode totally PWM. The speed control logic also factorizes sudden changes in speed limit – e.g. 80 kmph to 30 kmph – that will trigger a smooth deceleration algorithm and not an instant one to ensure safety and passenger comfort over mechanical safeties.

Table 2: Speed Mapping Logic (PWM Duty Cycles%)

Detected Speed Limit	PWM Duty Cycle (%)	Motor RPM Output	Approx. Vehicle Speed (km/h)
30 km/h	45%	~950	30
40 km/h	60%	~1200	40
60 km/h	75%	~1600	60
80 km/h	90%	~1900	80

A bypass function is also built-in to enable manual operation during emergency or AI detection failure. In addition, a controller on the vehicle records changes in speed and the detection of road signs to an SD card or cloud database for validation and system optimization. The IoT concept of this module provides modularity and remote monitoring. The car, through Wi-Fi or Bluetooth modules, can transmit speed, detected signs, and braking events to a central server or a mobile application.

B. Obstacle Detection and Accident Avoidance Block

This module targets the necessity of getting the immediate solution with dangerous sudden objects like pedestrian, other cars or any physical limitation. Ultrasonic sensors (usually HC-SR04) are positioned on the front part of the car to sense objects at 0–100 cm. These sensors emit ultrasonic waves and measure the distance of an object by its echo time. The obstacle detection logic occurs in parallel with the road sign detection. To avoid collisions with obstacles, as soon as a an obstacle is detected at a critical distance (e.g., 98%) using German Traffic Sign Recognition Benchmark (GTSRB) dataset. This is designed to make sure the system can properly read and comprehend a variety of road signs like speed limits, pedestrian crossings, and warning signs in real-life environments. Additionally, the use of this model on an edge-computing devices such as a Raspberry Pi, results that the system can run in low-latency which is essential for real-time vehicular applications.

The connection to an IoT traffic-sign-controlled speed moved the system to a dynamic environment suitable for changing vehicle speeds. Experimental tests demonstrated a smooth and accurate speed adjustment in more than 96% of the cases, compliant to regulation, and comfortable for the passengers. In addition, the obstacle detection module functioned with a confidence level of 95%, i.e., if two modules detect an obstacle, the system will automatically alert the driver. The response time was kept fast less than 110 milliseconds to prove the system's effectiveness for accident avoidance situations. Through comparative study, the proposed system is more accurate even than the conventional GPS based or manually driven control systems. This system aids future advancements in autonomous and semi-autonomous driving technologies by providing the ability to perceive and make decisions in real-time.

To sum up, the integration of AI and IoT in the presented architecture leads to a very useful tool for improving road safety, and decreasing traffic violations and unnecessary accidents. It also paves the way for further expansion into public and private transportation systems. Next steps will include the implementation of V2X protocols, cloud-based data analytics applied to predictive maintenance, and large scale field testing in various operational conditions in order to generalize the scalability and reliability of the system for real use cases.

Table 3: Obstacle Response Time Evaluation

Distance to Object (cm)	Reaction Time (ms)	Braking Distance (cm)	Outcome
25	105	8	Stopped safely
20	98	7	Stopped safely
15	92	5	Stopped safely
10	88	4	Emergency stop

IV. SYSTEM ARCHITECTURE

The structure of the system is truly an embedded amalgamation of sensing, processing, decision and actuation. It is built to process in real time, so it will have quick and accurate reactions to physical stimulus.

A. Architecture Overview

The system includes the following main components:

- Input Layer: Real-time data is collected by a camera and an ultrasonic sensor.
- Processing layer: The Raspberry Pi acts as the CPU for the CNN model and decision logic.

Output layer: Comprises a motor driver circuit and speed-controlled DC motor driven by PWM signals, and a braking system that is actuated when the presence of an obstacle is detected.

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|   Camera Input (Live)   |
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| AI Model (CNN-based)     |
| Road Sign Recognition    |
+------------+-------------+
             |
             v
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| IoT Controller (R-Pi)    |
| Decision Logic           |
+------------+-------------+
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     |              |
     v              v
Motor Driver      Ultrasonic Sensor
(PWM Control)     (Distance Sensing)
     |              |
     v              v
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B. Hardware Components and Roles

Table 4: Hardware Components and Specifications

Component	Functionality	Example Model
Raspberry Pi 4B	Main processor; runs AI model and control logic	Quad-core, 1.5 GHz
Camera Module	Captures live road image feed	Raspberry Pi Cam V2
Ultrasonic Sensor	Measures distance to obstacles	HC-SR04
Motor & Driver	Drives and controls speed via PWM	DC Motor + L298N
Battery	Provides system power	12V 7.2Ah Rechargeable
SD Card	Logs sensor data and decision outputs	32GB Class 10
Wi-Fi Module	Enables remote monitoring and data transmission	ESP8266 (optional)

The system runs on an edge computing optimised small footprint Linux OS and offers the possibility to add GPS, cloud services and other sensors for more smart features. The system was empirically evaluated on the IoT-based Speed Control and Accident Avoidance System with AI Road Sign Detection. Results and analysis In this Section, the experimental results shall be presented and analyzed in four major aspects: accuracy of the detection of road signs, responsiveness of speed control, effectiveness of obstacle avoidance and comparative performance to traditional systems. The performance demonstrates the real-time based nature and how easily scalable, and practically usable the proposed system can be as a vehicle safety and automation system.

V. ROAD SIGN DETECTION ACCURACY

The road sign detection model is based on a Convolutional Neural Network (CNN) pre-trained on the German Traffic Sign Recognition Benchmark (GTSRB) dataset. This is a collection of images of traffic signs that are separated in 43 classes. The last model performed very well in classifying the signs such as the speed limits, stop signs, and pedestrian crossings which constitutes the strong performance of the model.

Table 1: AI Model Performance Metrics

Metric	Value
Accuracy	98.2%
Precision	97.9%
Recall	98.4%
F1-Score	98.1%
Inference Time	~150 ms

Furthermore, the model has inference time around 150 milliseconds per frame, which is not prohibitively long for real-time processing. In practical tests with an implementation using a live video stream from a front camera, reliable detections were observed, even when recording at dusk in overcast weather. The high recall rate (98.4%) indicates that to which the model is effective to reduce missed detections, which is essential for safety applications. The few misclassifications (about 1.8% of the cases) were primarily caused by the low resolution of video frames, or the partial occlusion for the traffic signs. These can further be alleviated in the future versions with more powerful architectures (e.g., YOLOv8 or EfficientNet) or sensor fusion with GPS data.

A. Speed Control Evaluation

If a speed limit sign was successfully identified and classified, the speed value calculated was fetched by the IoT controller (Raspberry Pi 4) for generating PWM signals to control vehicle speed. The vehicle adjusted to the new limit in a mean time of 1.2

s, accounting for detection, classification, decision and actuation delays. The system was tested in the dummy slow lane with three different simulated speed levels (30 km/h, 50 km/h, and 80 km/h). Detected signs were converted to the corresponding PWM values, using the microcontroller for the motor driver. This mapping was based on the fact of (for example) a found 40 km/h sign equating to a % PWM duty cycle. The vehicle was able to adjust speed in 96 out of 100 test trials under various sign conditions, indicating a 96% compliance. The other 4% consisted of ambiguous cases in which the model was not confident or the sign was only partially performed due to camera angle. The system also contained a fail safe operation so that if no sign was found for a predefined distance, the controller retained the speed from the last sign or slowed in a smooth manner to some safe limit. This practice resulted smoother transitions and improved passenger comfort.

B. 5.3 Obstacle Avoidance Success Rate

The safety was further improved by a real-time obstacle detection system with ultrasonic sensors. The sensor of the distance to objects lay on the sector of the vehicle front. When an object was observed at a 30 cm distance, the motor command was stopped automatically and the braking command was activated.

In 100 obstacle simulation tests (event-data, pedestrian, static block), braking was correctly triggered in 95% of the cases by the obstacle detection module. In 5 per cent of cases no obstacles were noticed mainly due to surface unevenness or angles causing deflection of the sound waves. False positives were observed in 4% of trials, which were frequently elicited by reflective surfaces or near walls.

Table 2: Obstacle Detection Results

Parameter	Value
Success Rate	95%
False Positive Rate	4%
Average Response Time	105 ms
Minimum Detected Distance	10 cm

The quick reaction time (average 105 ms) also made the system well-appropriate for short distance obstacle avoidance. For better reliability, future forms of such application would include additional infrared or LiDAR sensors to take advantage of ultrasonic reading on both rough and inclined surfaces.

C. 5.4 Comparative Performance

System performance had been compared with those of the conventional system, in terms of major characteristics to evaluate general effectiveness. Conventional systems merely use GPS data for speed control, and or standard ultrasonic modules for obstacle detection. These platforms do not possess the real-time AI-based perception and integrated IoT control the way real-time AI-powered perception and IoT control.

Table 3: Comparison with Conventional Systems

Feature	Traditional Systems	Proposed System
Dynamic Speed Control	No	Yes
AI Sign Detection	No	Yes
IoT Communication	Limited	Extensive
Obstacle Avoidance	Partial (basic sensors)	Full Integration
Real-Time Decision Making	No	Yes

The added-value in terms of features and responsiveness achieved by using AI + IoT in the proposed system is significant. It guarantees cars react to more than just the static GPS data, having to also adapt to the dynamic inputs in the environment such as a road sign or a sudden barrier. And, the modular construction makes for easy upgrades and quick scaling.

D. Conclusion of the Analysis

The test results confirm that the proposed system works well in real-time applications. The AI road sign detection model exhibited great accuracy and reactivity, and the IoT speed control made proper timely response to speed adjustment. In addition, the obstacle detection module behaved confident enough to reduce the collision risks. These elements combine to create an alert and smart ecosystem that can save human lives by eliminating the number of road incidents due to ignorance of signs or poor judgment. Future work will involve in-field adoption trials and improved sensor integration, in addition to integration onto autonomous vehicular platforms.

VI. CONCLUSION

The rapid development of technology, especially Artificial Intelligence(AI) and the Internet of Things(IoT), can contribute to substantial innovations of ITS. Human error is one of the most difficult challenges of current road safety, like not seeing a sign on a road, driving above the speed limit or failing to adapt to a sudden and unexpected obstacle on the road. These are not only important for the safety point of view, but also they cause economic losses and overburden health and emergency services. The convergence of AI and IoT into a unified vehicular control system offers a promising and scalable solution to the above challenges. This paper proposed the architecture and implementation of an IoT-enabled Speed Control and Accident Prevention System with AI-based Road Sign Detection. The proposed model is organized by three interrelated modules: (i) A real-time road signs detecting module by the use of CNNs, (ii) An IoT based speed controlling system integrated by the help of microcontrollers i.e. Raspberry Pi, and (iii) An obstacle detection module by means of ultrasonic sensors for the short-range hazard detection. The Sign Detection module showed a very high classification accuracy (> 98% according to the test on GTSRB dataset.) This is so that the system can accurately read a number of road signs such as speed limits, pedestrian crossings or warning signs are accurately read by the system under real-life conditions. Furthermore, running this model on an edge-computing device like the Raspberry Pi ensures realization in low-rate for real-time vehicular applications, which is an indispensable condition.

It also enabled an integrated process with an IoT speed control system to adapt the vehicle speed with respect to traffic signs detected. Experimental results indicated that the velocity cascading was smoothly, accurately and effectively adjusted in more than 96% of the cases, and both regulatory compliance and passenger comfort could be guaranteed. Furthermore, the ensemble approach of the obstacle detection module was effective, its emergency stop request was activated appropriately for 95% of potentially colliding objects. The response time of the system was less than 110 millisecond and remained constant, indicating good performance in collision avoidance procedures. The proposed system performs much better than the conventional control systems which depends on GPS, or according to the driver's manual operation. It also provides a platform for real-time perception and decision making that we believe is critical for the development of intelligent and semi-intelligent vehicles.

Conclusions The integration of AI-IoT based solution in the proposed smart city framework could serve as a feasible tool to improve road safety, minimize traffic infringements, and reduce unwarranted accidents. It also creates opportunities for wider use in the public and private transportation systems. Our future research will focus on embedding Vehicle-to-Everything (V2X) communication protocols, cloud-based data analytics on predictive maintenance, and extensive field testing under various environments to verify the scaling capability and real-world reliability of the system.

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