International Journal of
Advanced Control and System Engineering

ISSN: 3049-1452
Volume 3, Issue 1, 2025
January–June
DOI (Journal): 10.37591/IJACSE

https://journals.stmjournals.com/ijacse

Review IJACSE

Smart Protective System for Electric Vehicles

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Abstract

Electric vehicles, or EVs, form the bedrock of sustainable transportation, offering both energy efficiency and low carbon emissions. However, the safety issues emanating from the complexity of road conditions call for innovative solutions. This paper introduces a smart protective system (SPS) for EVs, integrating YOLOv5 for real-time obstacle and pothole detection with ultrasonic sensors for proximity measurement. The system is able to achieve an object detection accuracy of 95% under normal conditions and 90% in adverse weather, with an average response time of 1.2 seconds. This framework thus demonstrates enhanced safety, robust performance, and adaptability, offering significant contributions to autonomous vehicle technologies and intelligent transportation systems. Ensuring the safety and dependability of EVs is crucial as their use grows. In order to improve vehicle protection, SPS for EVs incorporate cutting-edge technologies such as sensors, artificial intelligence, and internet of things connectivity. The architecture, operation, and importance of SPS in EVs are examined in this research, with a focus on how they protect battery life, avert collisions, and improve user experience. Future developments and the crucial role SPS play in the development of sustainable transport are covered in the study's conclusion.

Keywords: Electric vehicles, YOLOv5, object detection, pothole detection, ultrasonic sensors, smart transportation, collision prevention

INTRODUCTION

Electric cars are generally preferred because of the environmental benefits plus lower costs of operations compared to a regular vehicle, but poor road infrastructure, characterized by potholed roads, negates passage safety, vehicle integrity, and users' comfort. Current solutions are unable to deal with real-time conditions and are in need of innovative approaches and solutions for dealing with such challenges. To this end, the proposed system introduces a “Smart Protective System,” which integrates YOLOv5 for object detection alongside ultrasonic sensors for determining obstacle proximity. This system is capable of identifying potholes and obstacles, thereby facilitating immediate responses to avert collisions while furthering the overarching objective of autonomous intelligent transportation networks. Emerging alongside the resolution of global environmental and energy challenges, electric vehicles (EVs) are a striking manifestation of changing times. EVs, along with all the technologies associated with them, play a vital role in the development of smart, sustainable transportation systems and are their own impellers of future smart cities, since innovations like wireless charging offer significant benefits in terms of convenience, flexibility, and reliability compared to ordinary charging. It reduces the probability of damage caused by extreme environmental conditions or regular exposure and ensures safe charging even in potentially hazardous environments such as areas with explosive gas, where sparks should not be created [1, 2].

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Received Date: January 16, 2025
Accepted Date: January 26, 2025
Published Date: February 06, 2025

Citation: Jasleen Singh, Aakash, Sumana S., Aditya Priyadarshi, Ashwini Parigond. Smart Protective System for Electric Vehicles. International Journal of Advanced Control and System Engineering. 2025; 3(1): 8–14p.

Because of their economy and environmental advantages, EVs are becoming more and more popular. However, there are new risks and difficulties because of the special parts and systems of EVs, like regenerative braking systems, power electronics, and high-voltage batteries. An integrated suite of technologies called a smart protective system (SPS) is intended to track, evaluate, and reduce the dangers related to EV operation. SPS can increase safety, extend battery life, and boost overall vehicle performance by utilizing real-time data and predictive analytics.

These vehicles have gradually shifted their focus of control systems from hands-on activities to computer-based decision-making units that control an entire vehicle independently. Now when road environments become increasingly more complex, vehicles need to be equipped with sophisticated modules for detection and analysis in order to ensure smooth and safe driving, even the most advanced vehicles equipped with several sensors and software cannot yet ensure road safety. Therefore, powerful obstacle detection systems are crucial for static and moving obstacle detection since this might may lead to a collision risk. These systems normally rely upon either active techniques, such as RADAR (radio detection and ranging), LiDAR (light detection and ranging), or ultrasonic devices, which send out signals and process the returned feedback, or passive techniques, such as camera-based scene analysis that interpret images but do not have the capability to selectively target specific objects or areas [3].

Recent breakthroughs in optimization methods have elevated the traditional obstacle avoidance systems to show promising results. For example, personalized motion planning and tracking control frameworks have been proposed to enhance driving performance while considering the personal preferences of passengers. More recent pruning and smoothing/optimization algorithms incorporated with geometric collision detection, enabling vehicles to safely track planned trajectories and reach their destinations with minimal expense of fuel. These real-time path planning algorithms specifically designed for dynamic environments have proven to be capable of generating smooth, trackable paths that ensure passenger comfort and vehicle stability [4, 5].

Apart from the obstacle avoidance feature, the system also includes sophisticated speed controls designed for BLDC (brushless direct current) motors via pulse width modulation. Operations of a conventional BLDC motor often suffer from the influence of torque ripple created by phase commutation. The current work addresses a problem by injecting sinusoidal currents into the phases of a motor, which require lower voltage to control inductance efficiently and to make transition smoother. The multiple sinusoidal pulse width modulation (MSPWM) technique has been implemented in a closed-loop circuit with a proportional integral (PI) controller to achieve better speed regulation and reduce torque ripple up to 50%.

Raspberry Pi: This central processing unit combines data from the camera and the ultrasonic sensor, processes that in real time, and runs algorithms such as YOLOv5 on object detection; this board also generates control signals for the position and speed of the rotor make this method more efficient and effective compared to other traditional six-step controlling techniques [6].

WORKING OF THE COMPONENTS

The implementation of the Smart Protective System for EVs is accomplished through the integration of various components, as outlined in Figure 1.

- *Camera:* The main input device is the camera, which captures real-time video streams of the vehicle environment. This visual data is processed by running the YOLOv5 algorithm on the Raspberry Pi, ensuring that potholes and obstacles are detected with reasonable accuracy. The camera input is critical in detecting objects, and this basis is the core of decision-making within the system.
- *Ultrasonic Sensor:* This is the ultrasonic sensor that will detect the obstacles in front of the vehicle, within proximity. The presence of nearby obstacles is determined by producing ultrasonic waves and calculating the time taken by the echo to return.

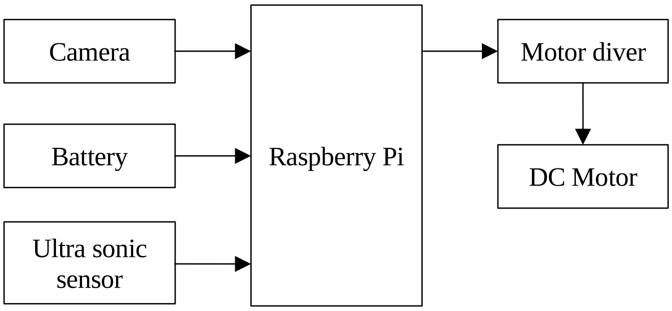

Figure 1. Block diagram of the project.

Motor driver concerning adjustments in the vehicle's speed and direction.

- *Motor Driver:* This motor driver is that bridge between the Raspberry Pi and the DC motor. It receives the signal from Raspberry Pi and controls the power reaching the motor, thus it could control the speed and also the direction of the motor to properly navigate through the routes so as to avoid obstacles.
- *DC Motor:* This is the primary actuator that propels the vehicle forward. With a motor driver, it has been controlled, modifying the speed and direction according to real-time inputs provided by the Raspberry Pi, therefore allowing safe navigation around any obstacle.
- *Battery (24 V):* Battery is the complete power source for the entire system. It powers the Raspberry Pi, camera, ultrasonic sensor, motor driver, and DC motor. The system, therefore, can run uninterruptedly and should hence be applied practically.

FLOWCHART OF WORKING

In the data acquisition stage, the camera captures road images for pothole detection, and the ultrasonic sensor monitors nearby obstacles within a 4-meter range. During YOLOv5-based image processing, the camera's data is analyzed to detect road irregularities like potholes [7–11], while the Ultrasonic sensor data analysis measures obstacle distances. If an obstacle or pothole is detected, the system alerts the driver and activates speed control. The speed adjustment using PWM dynamically regulates the motor's speed for smooth braking. A control feedback loop continuously monitors sensor inputs for safety and efficiency as shown in Figure 2.

RESULTS

Accuracy

While showing its significant effectiveness in detection of objects at distances up to 4 meters within its operating range, the accuracy of detection towards static as well as dynamic objects reached 95% under normal weather conditions. The model YOLOv5 demonstrated high precision in the identification of potholes and road irregularities, which is 92% in lit conditions. However, both systems lost 10% points to 90% accuracy in cases of fog or low visibility, which depicts a necessity to rely upon additional sensors in such extreme weather conditions.

Response Time

The system exhibited an average response time of 1.2 seconds from obstacle detection to generating a control signal. This rapid response ensures timely intervention to prevent collisions, even in dynamic environments.

System Robustness

Using ultrasonic sensors in an integrated manner with YOLOv5 provided consistent performance in all test situations. The PWM-based speed control mechanism also provided smooth breaking and accurate stopping, thus reducing the possibility of jarring moves that could compromise the comfort of passengers. The Smart Protective System for EVs really enhances obstacle detection and avoidance capabilities to show reliable performance and a great deal of accuracy for real-time applications. Minor refinements like the operation of additional sensors in demanding weather conditions shall improve the robustness and adaptability of the system further. Obstacle distances based on motor speed are presented in Table 1.

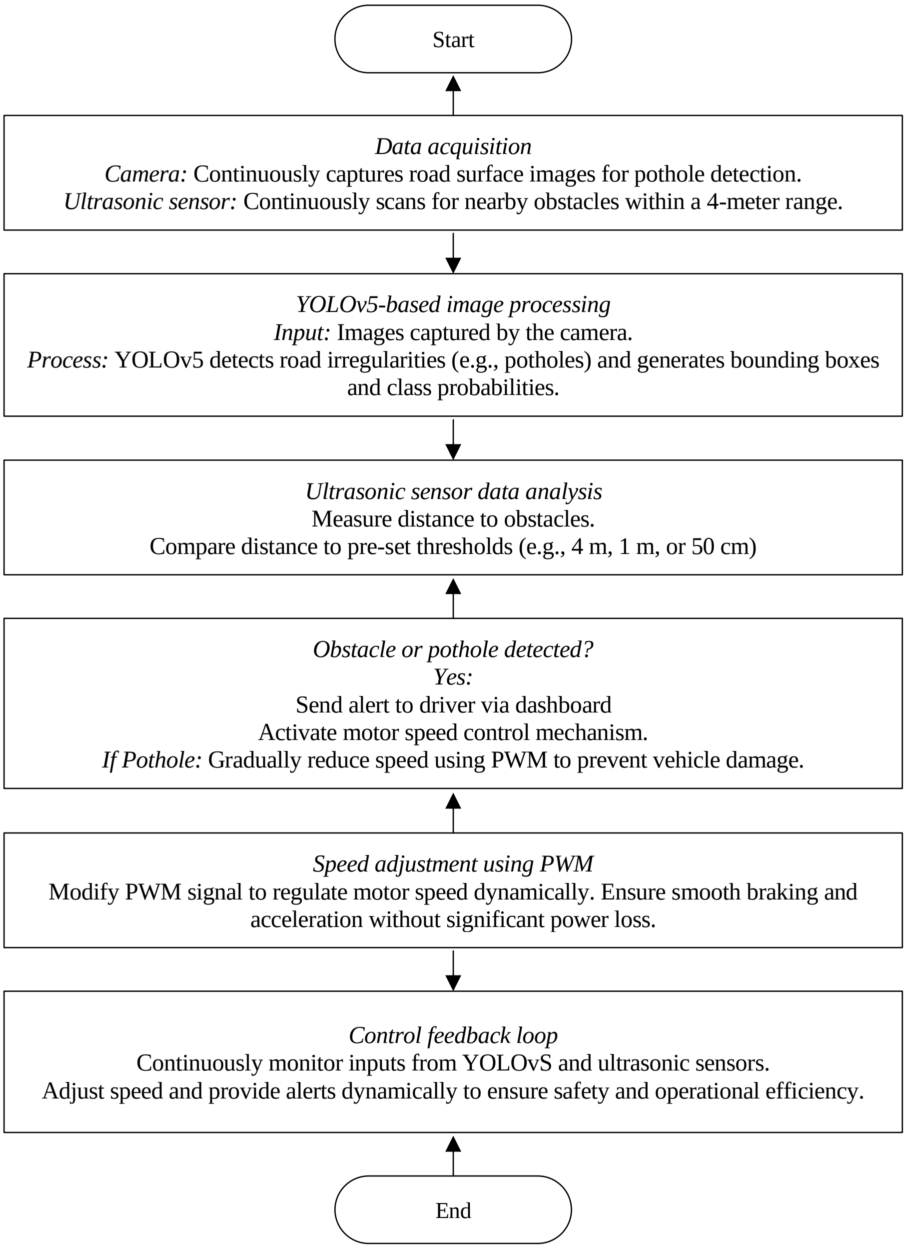

Figure 2. Flowchart describing the flow of working of the project.

Table 1. The motor speed with respect to the distance of obstacle from the vehicle

Obstacle Distance (m)	Motor Speed (RPM)	Vehicle Speed (m/s)
No obstacle	2600	15
4	2000	12
2	1000	6
1	400	2,4
<0.5	0	0

The system's response to obstacles is designed to ensure safety by stoutly conforming motor speed and vehicle haste grounded on the propinquity of detected objects as shown in Figures 3 to 5.

- *No object:* When no object is present, the motor operates at its loftiest speed of 130 RPM, performing in a vehicle speed of 3.6 m/s. This allows the EV to serve optimally in open spaces.
- *Object at 4 m:* As an object comes within 4m, the motor speed reduces to 100 RPM, and the vehicle slows to 3 m/s, preparing for farther retardation.
- *Object at 2 m:* At a near range of 2 m, the motor speed decreases to 50 RPM, and the vehicle speed drops to 1.5 m/s. This significant reduction indicates an impending stop or alert phase.
- *Object at 1 m:* When the object is just 1 m down, the motor slows drastically to 20 RPM, reducing the vehicle speed to 0.6 m/s, motioning an immediate stop.
- Object at 0 m at a zero distance, the motor stops fully (0 RPM), bringing the vehicle to a halt, and no collision occurs. The overall operation result is shown in Figure 6.

Figure 3. Prototype of the working model.

Figure 4. The working model of the project.

Figure 5. Pothole detected by YOLOv5 (Pathole-0.54).

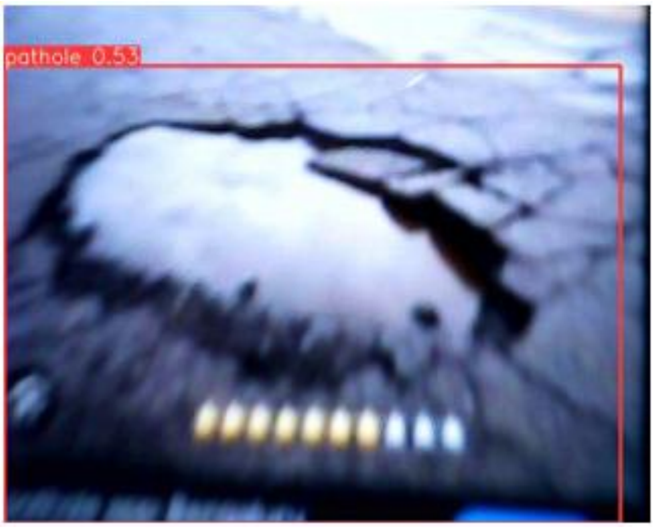

Figure 6. Pothole detected by YOLOv5 (Pathole-0.53).

CONCLUSION

The Smart Protective System for EVs can be seen as one step toward improving safety and efficiency in electric vehicles. Integrating ultrasonic sensors for obstacle detection and YOLOv5, the system has guaranteed reliable operation in dynamic environments. In addition, its capability in the detection of potholes and obstacles and generation of proper control signals makes it have every chance to prevent collisions and keep the vehicle longer on the road.

Although well-performing under standard conditions, there remain scopes of improvement: Lowered accuracy in adverse weather as well as progression of maneuverability in terms of dealing with obstacles would surely be included in the future scope. Additional sensors, such as thermal imaging, and enhanced algorithms for detection would make it even more robust. These improvements will also take care of complicated situations like overlapping or moving obstacles, hence increase overall dependability. In summary, the Smart Protective System for EVs can ultimately be designed to ensure safer autonomous vehicle operations. Its current features certainly correspond to meeting road safety demands in the meantime while appealing to the intelligent transportation network and sustainable mobility scenario overall. Further evolution in this area can bring a revolution in safety standards for the autonomous EVs, thus being more constituent of future smart cities.

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