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Traffic Sign Recognition to Automatic Speed Control in IoT-Enabled Electric Vehicles

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Abstract – *Electric vehicles are increasingly being integrated with intelligent control technologies to improve automation and road safety. Traffic signs provide important information to road users, and a vehicle capable of recognizing these signs can automatically adjust its operating behavior. This paper presents a low-cost prototype for controlling the speed of an electric vehicle according to predefined traffic signs using an ESP32-CAM. The proposed system combines an ESP32-CAM for image capture and traffic-sign recognition, a NodeMCU for control or communication functionality, an L293D motor driver for motor interfacing, and a BO DC motor representing the vehicle drive motor. Four traffic-sign classes are considered: START, STOP, SPEED LIMIT 20, and SPEED LIMIT 60. Based on the detected sign, the controller generates a corresponding motor command. The START sign initiates motor operation, the STOP sign stops the motor, while the two speed-limit signs select lower and higher PWM control levels, respectively. PWM is used to regulate the motor through the L293D driver. The proposed prototype demonstrates the integration of camera-based traffic-sign recognition with embedded motor control using economical and easily available components. The system is intended primarily as an educational and research prototype and provides a foundation for future development involving additional traffic signs, speed feedback, obstacle detection, GPS-based speed zones, and fail-safe vehicle control.*

Keywords- *Electric vehicle, ESP32-CAM, traffic sign recognition, NodeMCU, L293D, PWM, DC motor, intelligent transportation system.*

INTRODUCTION

Road safety is an important concern in modern transportation, particularly as vehicles are becoming increasingly automated and connected. Traffic signs provide essential information such as speed restrictions, stopping instructions, and other road-related guidance. Traditionally, the driver is responsible for observing these signs and manually adjusting the vehicle speed. Integrating traffic-sign recognition with vehicle control can reduce dependence on manual speed selection and provide an important foundation for intelligent transportation systems.

Electric vehicles offer a suitable platform for demonstrating such intelligent control concepts because their drive motors can be controlled electronically. A camera-based system can be used to capture traffic signs, recognize the sign type, and generate an appropriate command for the vehicle motor.

The proposed project develops a prototype electric vehicle in which an ESP32-CAM is used to capture traffic-sign images and recognize predefined traffic signs. The recognized sign is converted into a motor-control command. A NodeMCU can provide additional control or communication functionality, while an L293D motor driver interfaces the controller with the BO DC motor. The basic operating sequence is:

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Traffic Sign → ESP32-CAM → Sign Recognition → Speed Command → Motor Driver → EV Motor

The prototype focuses on four predefined traffic signs: START, STOP, SPEED LIMIT 20, and SPEED LIMIT 60. Their corresponding commands demonstrate automatic starting, stopping, and selection between different motor-speed levels.

The primary purpose of the work is not to develop a road-certified autonomous vehicle but to demonstrate how computer vision and embedded motor control can be combined using low-cost hardware.

LITERATURE REVIEW

Traffic-sign recognition has become an important research area within intelligent transportation systems. Camera-based recognition provides a practical method for obtaining visual information from the vehicle's surroundings. Compared with systems that require multiple dedicated sensors, a camera can provide information about the appearance, shape, and visual characteristics of a traffic sign.

Embedded controllers such as ESP32 and NodeMCU are increasingly used in IoT, automation, and embedded-control applications because of their compact size and relatively low hardware cost. These platforms can be integrated with sensors, communication modules, and control systems to develop small-scale intelligent prototypes.

PWM is a commonly used technique for controlling the speed of DC motors. By changing the PWM duty cycle, the effective power delivered to the motor can be varied. However, a motor generally cannot be connected directly to a microcontroller GPIO because the GPIO cannot provide the required motor current. A motor-driver circuit such as the L293D can therefore be used as an interface between the controller and the DC motor.

Many advanced traffic-sign recognition systems use high-performance processors and sophisticated computer-vision or machine-learning algorithms. Such systems can provide higher recognition capability but generally involve greater computational and hardware requirements. The present project explores a simpler and economical embedded approach for demonstrating the relationship between traffic-sign recognition and automatic vehicle speed control. The project document identifies this low-cost embedded implementation as the main research gap being explored.

METHODOLOGY

The methodology follows a sequential embedded-system workflow in which traffic-sign images are captured, recognized, converted into control commands, and applied to the BO DC motor through the L293D driver. The implementation uses the hardware, software, recognition logic, PWM control, and operating sequence described in the project documentation.

In a conventional small-scale electric-vehicle prototype, the operator or controller must manually select the motor speed according to the surrounding road conditions. This approach does not demonstrate automatic response to traffic signs.

Therefore, the problem addressed in this project is to develop a low-cost embedded system capable of:

1. Capturing traffic-sign images using a camera.
2. Identifying predefined traffic signs.
3. Generating an appropriate motor-control command.
4. Starting the motor when a START sign is detected.
5. Stopping the motor when a STOP sign is detected.
6. Reducing the motor-control level when SPEED LIMIT 20 is detected.
7. Allowing a higher motor-control level when SPEED LIMIT 60 is detected.

The proposed system provides a compact prototype for studying camera-based intelligent vehicle control.

Proposed System

The proposed system consists of four major sections: the traffic-sign recognition section, controller section, motor-driver section, and power-supply section.

The ESP32-CAM acts as the vision unit. It captures images of the traffic signs and performs or initiates the recognition process. Once the sign is identified, a corresponding control command is generated.

The NodeMCU can be used as an additional control or communication interface between the vision and motor-control sections. It provides flexibility for implementing the control logic and communication required by the prototype.

The L293D motor driver acts as the interface between the microcontroller and the BO DC motor. It receives control signals from the controller and supplies the required drive interface for the motor.

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The BO DC motor represents the drive motor of the prototype electric vehicle. Its speed is controlled by PWM according to the detected traffic sign.

The overall operation can be represented as:

Traffic Sign
↓
ESP32-CAM
↓
Traffic Sign Recognition
↓
Speed/Control Command
↓
NodeMCU / Control Section
↓
L293D Motor Driver
↓
BO DC Motor
↓
Vehicle Motion

Fig. 1- Proposed system architecture.

The power supply provides appropriate power to the controller and motor sections. The project specifically requires the motor to be connected through the L293D rather than directly to an ESP32 GPIO. The controller and motor-driver grounds should be connected appropriately.

Hardware Requirements

ESP32-CAM. The ESP32-CAM is the primary camera-based sensing unit of the proposed system. It captures images of the traffic signs and provides the visual information required for recognition.

NodeMCU. NodeMCU can be used as an additional control and communication unit. It can assist in transferring or processing control information between the recognition and motor-control sections.

L293D Motor Driver. The L293D provides the electrical interface between the microcontroller and BO DC motor. It allows the controller to control the motor without directly supplying motor current through a GPIO pin.

BO DC Motor. The BO DC motor represents the drive motor of the prototype electric vehicle. Its operating level is controlled through PWM signals provided through the motor driver.

Power Supply. The power supply provides suitable voltage and current for the controller and motor sections. The motor supply must be selected according to the motor requirements.

Chassis and Wheels. An EV or robotic chassis with wheels provides the mechanical platform on which the motor, controller, driver, and other components are mounted.

Traffic Sign Images. Four predefined traffic-sign classes are used during prototype testing:

- START
- STOP
- SPEED LIMIT 20
- SPEED LIMIT 60

The hardware requirements are based on the components specified in the project documentation.

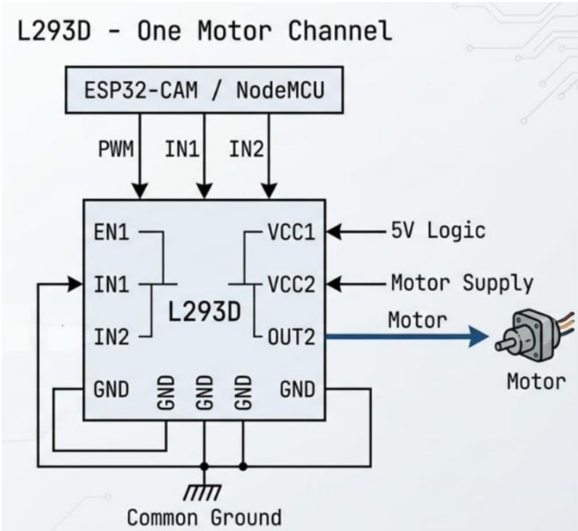

Fig. 2- Circuit diagram of the proposed traffic-sign-based motor-control system.

Software Requirements

The proposed system can be developed using the following software tools:

- Arduino IDE
- ESP32 board support package
- ESP32-CAM libraries
- NodeMCU/ESP8266 board support
- Embedded C/C++ programming
- Image-processing or image-classification software/model

The major software functions include:

1. Camera initialization
2. Image capture
3. Traffic-sign recognition
4. Sign classification

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5. Speed-command generation
6. PWM generation
7. Motor control

These functions provide the software connection between the captured traffic-sign image and the physical response of the vehicle motor.

Traffic Sign Recognition

The proposed prototype recognizes four predefined traffic-sign classes. Each class is associated with a specific vehicle response.

START Sign. When the START sign is recognized, the controller generates the predefined starting PWM command. The motor begins operation and the prototype vehicle starts moving.

STOP Sign. The STOP sign has the highest priority among the demonstrated control commands. When it is recognized, the motor PWM is set to zero, causing the motor to stop.

SPEED LIMIT 20. When the SPEED LIMIT 20 sign is detected, the controller selects a lower PWM level. This represents a low-speed operating zone in the prototype.

SPEED LIMIT 60. When the SPEED LIMIT 60 sign is detected, the controller selects a higher PWM level, representing a higher-speed operating condition.

The project document identifies image matching/classification, color and shape-based detection, and lightweight trained image-classification models as possible recognition approaches for the prototype.

Table 1- Traffic-sign classes and vehicle response

Detected Sign	Vehicle Action	Prototype Response
START	Start motor	Starting PWM
STOP	Stop motor	PWM = 0
SPEED LIMIT 20	Low-speed operation	Lower PWM
SPEED LIMIT 60	Higher-speed operation	Higher PWM

PWM-Based Motor Speed Control

PWM is used to control the speed of the BO DC motor. Instead of supplying a continuously variable analog voltage, the controller rapidly switches the motor-control signal between ON and OFF states. The ratio of ON time to the total PWM period determines the duty cycle.

The L293D Enable input can be used for PWM-based speed control. A higher duty cycle generally results in a higher motor operating level, although the actual mechanical speed depends on the motor, supply voltage, load, wheel size, and other physical factors.

For prototype demonstration, the following PWM levels can be considered:

Table 2- PWM levels for prototype demonstration

PWM Duty Cycle	Prototype Action
0%	Stop
30%	Low speed
60%	Medium speed
90%	High speed

These values are examples for prototype control and should be experimentally calibrated. A PWM value of 60%, for example, should not be reported as 60 km/h. The project documentation explicitly notes that PWM percentage is not necessarily equal to vehicle speed in km/h.

Motor Direction Control. The L293D input configuration can be used for motor direction control:

- IN1 = HIGH, IN2 = LOW → Forward
- IN1 = LOW, IN2 = HIGH → Reverse
- IN1 = LOW, IN2 = LOW → Stop/Coast

The main focus of this project is automatic selection of the motor-control level based on the recognized traffic sign.

System Working

The complete operation of the proposed system takes place through the following sequence:

Step 1: The ESP32-CAM initializes the camera.

Step 2: The camera captures an image containing the traffic sign.

Step 3: The captured image is processed by the selected recognition method.

Step 4: The system identifies the sign as one of the predefined classes.

Step 5: The recognized sign is converted into a control command.

Step 6: The command is transferred to the motor-control section.

Step 7: The L293D receives the appropriate control signal and drives the BO DC motor.

Step 8: The vehicle responds according to the detected sign.

The operating sequence can be represented as:

START
↓
Initialize ESP32-CAM
↓
Capture Traffic Sign Image
↓
Process Image
↓
Recognize Sign
↓
Is START? → Yes → Start Motor
↓ No
Is STOP? → Yes → PWM = 0 / Stop Motor
↓ No
Is SPEED 20? → Yes → Low PWM
↓ No
Is SPEED 60? → Yes → Higher PWM
↓
Continue Monitoring

Fig. 3- Flowchart of the traffic-sign recognition and speed-control process.

RESULTS

The prototype results are evaluated from the expected response of the four predefined traffic-sign classes and the corresponding motor-control commands.

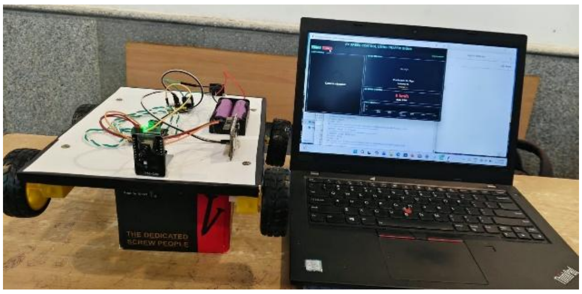

Fig. 4- Fabricated prototype of the proposed electric vehicle.

The proposed prototype demonstrates the relationship between traffic-sign recognition and automatic motor control. The expected response for each predefined sign is summarized in Table 3.

Table 3- Expected system response

Input Traffic Sign	Expected Motor Response
START	Motor starts
STOP	Motor stops
SPEED LIMIT 20	Motor operates at lower PWM
SPEED LIMIT 60	Motor operates at higher PWM

When the START sign is detected, the motor receives the predefined starting PWM and the vehicle begins movement. When the STOP sign is detected, the motor command is reduced to zero. The SPEED LIMIT 20 and SPEED LIMIT 60 signs select different PWM levels to demonstrate automatic speed-level selection.

The performance of the recognition system can be influenced by several environmental factors. Lighting conditions can change the appearance of a sign, while camera position and sign size affect the captured image. Image quality also affects the reliability of recognition.

The physical speed of the prototype is influenced by factors including battery voltage, motor characteristics, vehicle load, and wheel size. Therefore, PWM values should be experimentally calibrated rather than directly converted into road speed.

The prototype should be considered a demonstration of automatic speed control rather than a certified road-going EV safety system.

Advantages

The major advantages of the proposed system are:

1. Low-cost implementation: The system uses commonly available embedded components.
2. Compact hardware: The complete control system can be implemented on a small prototype vehicle.
3. Camera-based operation: Traffic-sign information is obtained visually.
4. Automatic speed control: Motor control is generated according to the recognized sign.
5. Automatic START/STOP: The system can start or stop the motor without manual speed selection.
6. Simple motor interface: The L293D provides a straightforward interface between the controller and DC motor.
7. Easy modification: Additional traffic-sign classes can be incorporated.
8. Educational value: The prototype demonstrates the integration of computer vision and embedded control.

The project identifies these characteristics as key advantages of the proposed low-cost platform.

Applications

The proposed system can be used for:

- Educational electric-vehicle prototypes

- Smart robotic vehicles
- Autonomous mobile-robot demonstrations
- Intelligent transportation system demonstrations
- Traffic-sign recognition research
- Campus or shuttle vehicle prototypes
- IoT-based vehicle-control projects
- Embedded computer-vision projects

The system provides a practical platform for demonstrating how visual information can be converted into vehicle-control commands.

Limitations

Although the prototype demonstrates the basic concept successfully, several limitations remain.

First, the current system is designed around four predefined traffic-sign classes. It therefore does not represent the complete range of signs encountered in real road environments.

Second, recognition performance depends on image quality, lighting conditions, camera orientation, and the size and appearance of the traffic sign.

Third, the current prototype uses predefined PWM levels rather than closed-loop vehicle-speed feedback. Consequently, the selected PWM level does not represent an exact vehicle speed.

Finally, the system does not currently include obstacle detection, automatic braking, advanced sensor fusion, or fail-safe mechanisms. These functions would be necessary before attempting any real-world road-vehicle implementation.

Future Scope

The proposed system can be improved in several directions.

Additional Traffic Signs. More traffic signs such as NO ENTRY, TURN, SCHOOL ZONE, and ROAD WORK can be added to increase the range of vehicle responses.

Improved Recognition. A more robust machine-learning model and improved image preprocessing can be implemented to improve recognition under different lighting and viewing conditions.

Speed Feedback. An encoder can be added to measure the actual wheel or motor speed. This would allow closed-loop speed control rather than relying only on predefined PWM levels.

Obstacle Detection. Ultrasonic or radar sensors can be integrated to detect obstacles in front of the vehicle.

Automatic Braking. An automatic braking mechanism can be incorporated for emergency situations or when an obstacle is detected.

GPS-Based Speed Zones. GPS can be used to identify location-based speed restrictions and generate additional speed commands.

IoT Monitoring. Cloud-based monitoring can be added to transmit vehicle status, detected signs, and operating information to a remote dashboard.

Sensor Fusion and Fail-Safe Control. Combining camera data with other sensors can improve reliability. Fail-safe mechanisms would also be essential for any future real-world vehicle application.

These future improvements are consistent with the proposed extensions listed in the project documentation.

CONCLUSION

This paper presented a low-cost prototype for traffic-sign-based speed control of an electric vehicle using an ESP32-CAM. The proposed system connects camera-based traffic-sign recognition with embedded motor control through a NodeMCU control section and an L293D motor driver.

Four predefined traffic signs—START, STOP, SPEED LIMIT 20, and SPEED LIMIT 60—are used to demonstrate different vehicle responses. The START sign initiates motor operation, the STOP sign stops the motor, and the two speed-limit signs select lower and higher PWM control levels.

The project demonstrates that a relatively simple embedded platform can be used to connect visual traffic information with automatic vehicle-control decisions. It provides a useful foundation for students and researchers working in electric vehicles, embedded systems, computer vision, and intelligent transportation.

However, the prototype is intended for demonstration and research purposes rather than direct road deployment. Future improvements such as encoder-based speed feedback, improved machine-learning recognition, obstacle detection, automatic braking, GPS-based speed control, IoT monitoring, sensor fusion, and fail-safe mechanisms can significantly increase the capability and reliability of the system.

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