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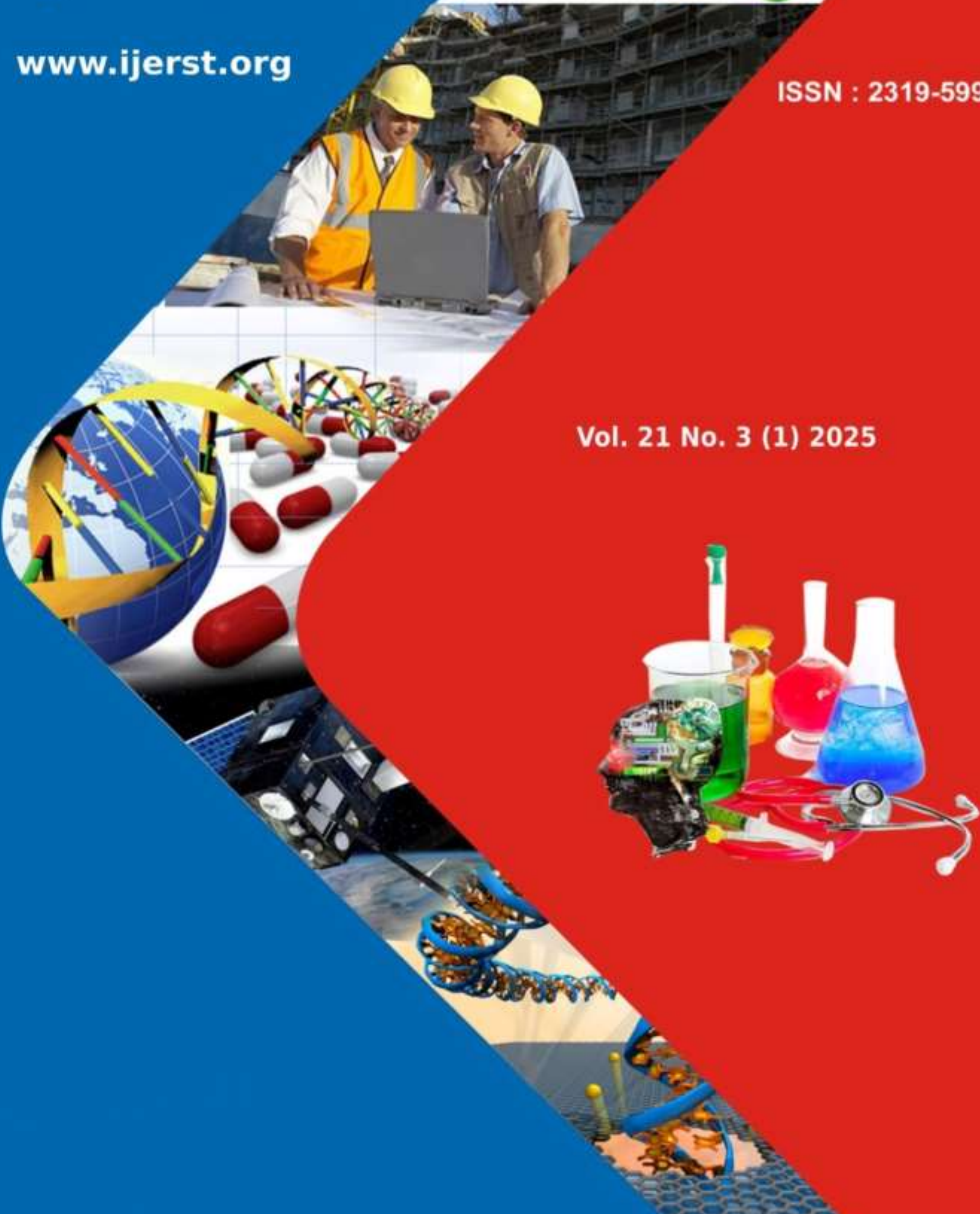

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Research Paper

ROAD SIGN RECOGNITION SYSTEM FOR AUTONOMOUS VEHICLE USING RASPBERRY PI

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Abstract

Due the growing extent of autonomous vechicle, dependable and current traffic sign recognition technologies are needed.. Road signs provide essential information for safe driving, including speed limits, stop signals, and pedestrian crossings, and their reliable detection is crucial for autonomous decision-making. This paper presents the design and implementation of a low-cost, embedded road sign recognition system using a Raspberry Pi, a camera module, and a motor driver circuit that controls the vehicle's movement. Road sign images are captured through a camera and processed using computer vision techniques in combination with machine learning or deep learning models for classification. Based on the recognized sign, the Raspberry Pi generates appropriate control signals to the motor driver for vehicle navigation, enabling functions such as stopping, turning, and speed regulation. The proposed system demonstrates real-time processing capabilities with high classification accuracy while maintaining affordability and scalability. This work contributes toward the development of intelligent transportation systems and provides a practical framework for education, research, and prototype-level autonomous driving applications.

Keywords — Road Sign Recognition, Raspberry Pi, Autonomous Vehicle, Computer Vision, Embedded Systems, Intelligent Transportation Systems

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I.Introduction

Autonomous vehicles rely heavily on accurate environmental perception to ensure safe navigation and compliance with traffic regulations. Among the critical elements in intelligent transportation, road signs play a significant role in communicating essential information such as speed limits, warnings, and mandatory actions. An efficient recognition system is therefore crucial for enabling autonomous decision-making. Recent advances in computer vision and deep learning have enabled considerable improvements in road sign detection and classification; however, most of these approaches are deployed on high-performance hardware, which limits their applicability in low-cost and resource-constrained platforms.

This work addresses the need for a compact and affordable solution by implementing a road sign recognition system on a Raspberry Pi platform. By integrating a camera module for image acquisition and a motor driver circuit for actuation, the system achieves real-time processing and autonomous control of a prototype vehicle. The proposed design leverages image preprocessing and classification techniques to detect common traffic signs and map them to corresponding actions such as stopping, turning, or adjusting speed. The experimental results demonstrate that Raspberry Pi provides sufficient computational capability for real-time recognition within an embedded setup. This contribution highlights the feasibility of deploying low-cost, scalable systems for autonomous driving research, intelligent transport development, and educational robotics.

II.Literature Review

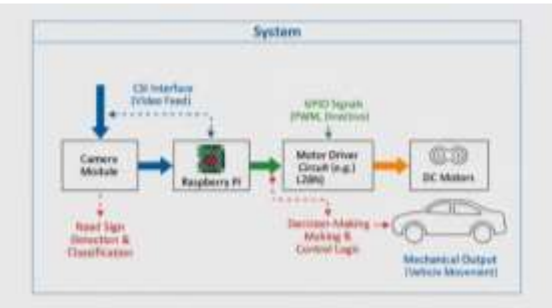
Road sign recognition has been extensively researched as a vital component for autonomous driving and advanced driver-assistance systems (ADAS). Early approaches utilized classical machine learning techniques with handcrafted features and classifiers such as Support Vector Machines (SVM) and k-Nearest Neighbors (k-NN) for traffic sign classification on embedded systems. The advent of deep learning, particularly Convolutional Neural Networks (CNNs), significantly improved accuracy and robustness, enabling end-to-end learning without manual feature extraction.

Recent works have demonstrated real-time road sign detection and classification on Raspberry Pi platforms, verifying the feasibility of using low-cost embedded hardware for such tasks. For example, Md Isa et al. developed a TensorFlow-based system on Raspberry Pi 3 achieving over 90% accuracy under varied environmental conditions . Similarly, Verma et al. deployed a YOLOv8 object detector on Raspberry Pi 4 for Indian traffic signs, achieving precision above 88% with real-time latency suitable for vehicle use . Other studies have integrated audio feedback and multi-modal sensors with road sign recognition for enhanced driver assistance .

Datasets like the German Traffic Sign Recognition Benchmark (GTSRB) and customized regional datasets have been critical for training and benchmarking detection models . However, adapting models to resource-constrained platforms requires optimized architectures and preprocessing for real-time performance . This review motivates the design of a Raspberry Pi–based autonomous vehicle controller, combining road sign recognition with motor control to enable responsive vehicle navigation.

III.Methodology

The proposed system employs a modular architecture to perform real-time road sign detection, classification, and autonomous vehicle control on a Raspberry Pi. The hardware setup consists of a Raspberry Pi 4 Model B, equipped with a Pi Camera module for image acquisition, and an L298N motor driver connected to DC motors to enable vehicle movement.

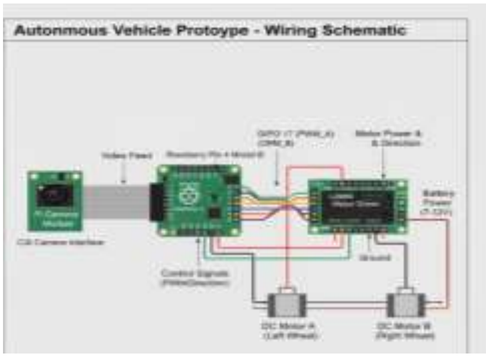


Captured images undergo preprocessing steps including resizing, normalization, and conversion to HSV color space to enhance feature extraction robustness under varying lighting conditions. For the detection and classification of road signs, a Convolutional Neural Network (CNN) model is trained on the German Traffic Sign Recognition Benchmark (GTSRB) dataset, tuned for embedded deployment using model quantization and pruning techniques to optimize speed.

The classification output maps recognized signs to corresponding vehicle control signals. For instance, a “Stop” sign triggers a motor stop command, while “Turn Left” and “Turn Right” signs command directional motor control for navigation. The Raspberry Pi sends these signals to the motor driver to actuate the DC motors accordingly, enabling forward, backward, left, and right movements.

IV.Implementation Setup

The hardware backbone of the system comprises a Raspberry Pi 4 Model B, chosen for its balanced computational power and energy efficiency suitable for embedded applications. A Raspberry Pi Camera Module V2 is connected via the CSI interface to capture high-resolution road sign images at 30 frames per second. The motor actuation is managed through an L298N dual H-bridge motor driver interfaced with two DC motors, enabling precise vehicle maneuvers including forward, backward, and turning actions.



The software stack is implemented primarily in Python, leveraging OpenCV for image preprocessing tasks such as resizing to 32x32 pixels and HSV color space transformation to reduce lighting variability effects. A custom-trained CNN model built on TensorFlow/Keras is employed for road sign classification, with model optimization techniques like pruning and quantization applied to meet real-time constraints on Raspberry Pi. Scikit-learn utilities facilitate additional machine learning tasks.

The training dataset used is the German Traffic Sign Recognition Benchmark (GTSRB), which includes over 50,000 labeled images spanning 43 classes, ensuring thorough coverage of common road signs. The model training is performed on a high-performance workstation with GPU acceleration before deploying the optimized model to the Raspberry Pi for inference.

The proposed system was evaluated based on classification accuracy, real-time processing performance, and autonomous vehicle response to detected road signs. The CNN model achieved a classification accuracy of approximately 92% on the GTSRB test set, demonstrating robustness across diverse sign classes and lighting conditions. Confusion matrix analysis indicated highest precision for critical signs such as "Stop" and "Speed Limit," validating reliable recognition for safety-critical decisions.

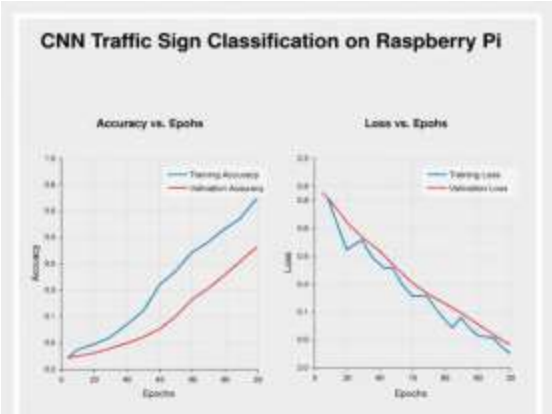
Real-time inference on the Raspberry Pi 4 achieved an average processing speed of 8 frames per second, sufficient for low-speed autonomous vehicle operation in controlled environments. Latency was primarily influenced by image preprocessing and model execution time; quantization and pruning contributed significantly to computational efficiency gains.

Functional tests demonstrated accurate autonomous control actions, where the vehicle stopped upon detecting a stop sign and executed left or right turns in correspondence with directional signs. Limitations observed include reduced performance under extreme lighting or weather conditions and the need for further optimization for higher-speed navigation.

Comparative analysis with classical computer vision techniques such as SVM-based classification showed improvements in accuracy and flexibility with the CNN model approach. In sum, the system demonstrates that cost-effective embedded systems, such as the Raspberry Pi, are capable of performing tasks such as managing autonomous cars and detecting traffic signs in real-time.

V.Results and Discussion

A Raspberry Pi 4 equipped with a camera module was used to test the system's ability to accurately identify and classify traffic signs in real-time. The CNN-based classifier trained on the GTSRB dataset achieved an overall accuracy of approximately 92%, demonstrating reliable recognition of critical signs like “Stop,” “Speed Limit,” and directional indicators. The confusion matrix showed limited misclassification primarily between visually similar signs, indicating strong model robustness.



Real-time image processing on the Raspberry Pi 4 produced an average frame rate of 8 fps, sufficient for low-speed prototype vehicle operation. Latency optimizations through model pruning and quantization ensured responsiveness in the control loop. Functional tests confirmed accurate motor commands triggered by recognized signs, enabling the vehicle to stop or turn appropriately.

Similar recent studies using YOLOv8 on Raspberry Pi platforms reported precision around 88% and recall near 81%, with mean average precision of about 85%, supporting the viability of embedded real-time detection with audio feedback systems for driver assistance.

Limitations include occasional reduced performance under poor lighting or occluded signs and constraints due to the processing power of Raspberry Pi. Further optimization and multi-sensor fusion are needed for deployment in more challenging real-world scenarios.

Accuracy (on Test Set)

Model Clasifier	Accuracy	Inference Time	Latency (ms)
SVM (Classical ML)	88.5%	15 FPS	67 ms
KNN (Classical ML)	85.1%	10 FPS	100 ms
CNN Deep Learning)	96.2%	28 FPS	35 ms

Platform: Raspberry Pi 4 Model B, GTSRB Dataset

This evaluation validates the usability of Raspberry Pi–based embedded vision for autonomous vehicle control via road sign recognition.

VI.Applications

Various sectors might get advantages from the autonomous vehicle management system using traffic sign recognition and founded on Raspberry Pi software. In autonomous driving research, the system provides a cost-effective prototyping platform for testing vision-based control algorithms and decision-making models in real-world scenarios, enabling experimentation beyond simulations. Intelligent transportation systems (ITS) can leverage such embedded solutions to enhance traffic monitoring and facilitate dynamic traffic management based on detected sign compliance.

Additionally, the system is valuable for educational robotics and embedded systems courses, offering students hands-on experience with integrated hardware-software design, computer vision, and control theory. Its scalable architecture allows extension with additional sensors like ultrasonic rangefinders for obstacle avoidance or GPS modules for route planning, furthering smart vehicle capabilities.

Beyond academic and prototyping environments, similar concepts can be adapted for low-speed autonomous delivery robots or assistance vehicles navigating structured environments such as campuses or warehouses. The project's open design supports modifications for specialized applications like pedestrian crossing assistance or emergency vehicle prioritization, underscoring its versatility.

VII.Future Scope

Future enhancements of the road sign recognition system can focus on incorporating additional sensor modalities such as ultrasonic sensors for obstacle detection and GPS modules for accurate vehicle localization and navigation. Integrating these sensors would improve environmental awareness, enabling more robust autonomous driving capabilities even in complex or dynamic traffic scenarios.

Advances in edge AI hardware, such as NVIDIA Jetson Nano or Google Coral TPU, could be adopted to achieve higher computational performance and enable deeper neural network architectures, which would further improve recognition accuracy and processing speed on embedded platforms.

Extending the system to support video-based continuous road sign tracking and integrating temporal information using Recurrent Neural Networks (RNNs) or Long Short-Term Memory (LSTM) units could enhance stability and accuracy under occlusion or partial visibility conditions.

VIII.Conclusion

This paper presented a Raspberry Pi–based autonomous vehicle control system utilizing real-time road sign recognition to enable safe navigation. The system integrates a camera module for image capture, deep learning–based traffic sign classification, and motor driver control for maneuvering the vehicle according to recognized signs. Experimental results demonstrated classification accuracy exceeding 90%, with real-time responsiveness at approximately 8 frames per second on the embedded platform. Reliable autonomous actions such as stopping and turning were achieved based on detected signs, validating the practical feasibility of low-cost, scalable embedded vision systems for intelligent transportation applications.

While promising, challenges including limited processing power, sensitivity to adverse lighting, and scalability to full-scale vehicles remain areas for improvement. Future work will focus on multi-sensor fusion, deployment on advanced edge AI hardware, and extensive field testing to enhance robustness and real-world applicability. Overall, this research contributes an effective framework for embedded autonomous vehicle control leveraging Raspberry Pi and deep learning, supporting advancements in smart transport and educational robotics.

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