AI-Driven Traffic Sign Recognition and Speed Control for Autonomous Vehicle

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Abstract: Aim: This work suggests an AI-based traffic sign detection and speed control system in autonomous vehicles using YOLOv5 and PID controllers. The YOLOv5 model, implemented on Python using PyTorch, was trained on a pre-processed dataset following contrast stretching, noise removal, and rotation for improved generalization. Materials and Methods: Resizing of images was done to 640×640 pixels, and real-time detection using a 1080p camera attached to a vehicle. Efficient processing was handled by the platform using an Intel Core i7 10th Gen processor paired with an NVIDIA Jepson Niño. Compared to the conventional multi-stage CNN-based models, YOLOv5 enabled real-time detection at an inference time of 24.6 ms per frame. Result: The PID controller ensured smooth speed transitions according to observed traffic signs. Experimental results confirmed that YOLOv5 achieved an accuracy of 96.4% compared to 92.1% for conventional methods, with a lower false positive rate of 1.8% compared to 3.5%. The speed control system also attained a response accuracy of 98.5%, thus ensuring precise speed regulation. Conclusion: The above outcomes guarantee that YOLOv5, combined with PID controllers, significantly improves traffic sign detection and speed regulation and thus forms a practical solution for real-time autonomous vehicle implementation.

1 INTRODUCTION

The rising uptake of autonomous cars has created the demand for more sophisticated AI-based traffic sign detection and speed management techniques Deep learning, specifically CNN-based techniques, has seen extensive application to detect and classify traffic signs in real-time, with accuracy levels over 95% in simulation scenarios (Aghdam and Heravi 2017). The models allow vehicles to identify and act on traffic signs with a high degree of reliability, even under challenging road conditions. Later developments focus on real-time processing, with research proving detection times of less than 0.5 seconds at below 5% false positives (Zhang, L., & Wang 2022). Hybrid deep learning structures, which combine convolutional and transformer-based structures, have improved recognition performance under challenging conditions such as occlusions, low illumination, and harsh weather. In addition, reinforcement learning-based speed control models have shown potential in optimizing vehicle responses to identified signs for effective and secure speed control with over 90% efficiency levels (Feng et al. 2023). Finally, AI- assisted traffic sign recognition and speed control offer a critical groundwork for the creation of secure and effective AVs. With ongoing research, the union of deep learning and reinforcement learning and sensor fusion methods will become increasingly important to enhance the responsiveness and reliability of such systems in real-world traffic conditions (Masaki 2012).

2 RELATED WORKS

With an increasing number of research papers, Traffic Sign Recognition (TSR) has emerged as a vital topic of interest in Intelligent Transportation Systems (ITS) where correct identification and classification of traffic signs are essential to ensure road safety as well

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as autonomous driving. Various approaches have been attempted in TSR, from traditional image processing techniques to deep learning techniques, and all with varying success rates (Alawaji, Hedjar, and Zuair 2024). Traditional TSR methods were relying on human-crafted feature extraction techniques such as color separation, shape feature extraction, and template matching.These processes were performing correctly in the controlled setup but could not perform in real-time because of occlusions, changing (Dulhare, Ahmad, and Ahmad 2020) illumination, and environmental noise and only could provide 65% to 85% accuracy. To improve the recognition accuracy, machine learning methods such as Support Vector.

Machines (SVMs), Random Forests, and k-Nearest Neighbors (k-NN) were introduced, using feature descriptors such as Histogram of Oriented Gradients (HOG) and Scale-Invariant Feature Transform (SIFT) (Rawat et al. 2023). Although these improved classification accuracy, they were computationally expensive and involved a great deal of manual feature engineering, and hence less practical for real-time autonomous driving.From the current research, it is inferred that conventional machine learning methods used for traffic sign recognition and speed control in self- driving cars do not yield good accuracy and real-time responsiveness (Aghdam and Heravi 2017). Thus, in this paper, the focus is on attaining improved performance through the implementation of a YOLOv5-based traffic sign recognition system in conjunction with a PID-based speed control system in comparison with other traditional machine learning methods .

3 MATERIALS AND METHODS

This research considers real-time detection of traffic signs and AI-controlled vehicle speed through YOLO deep learning structure. The envisioned system seeks to improve vehicle safety and autonomous vehicle driving through coupling real-time video processing with adaptive speed control. The dataset adopted in this research was sourced from existing studies of traffic sign recognition models (Luo et al., 2023) for its applicability to Indian roads. (Feng et al. 2023). The Indian Traffic Sign Recognition dataset was utilized for validation and training, including more than 10,000 images of speed limit signs, warning signs, stop signs, and regulatory signs. The dataset was separated into two sets:

Group 1 (Raw Data): 5,000 labeled images of Indian traffic signs taken under varying lighting, weather, and occlusion conditions in Convolution Neural Network Algorithm (Zhao et al., 2023).

Group 2 (Preprocessed Data): The original dataset was contrast enhanced, noise removed, and rotated to enhance model generalization. All images were resized to 640×640 pixels, the default input resolution for YOLOv5.The YOLO- based traffic sign detection model was developed in Python and PyTorch, while the vehicle speed control system was designed with PID controllers as described in Fig 1. As opposed to typical CNN models that use multi-stage detection pipelines, YOLO detects objects in real-time through a single forward pass, with an inference time of below 25 ms per frame (Sharma et al., 2019). The system was trained and tested on a high-performance computing platform with an Intel Core i7 10th Gen processor, an NVIDIA Jetson Nano board, and an 8GB RAM configuration. A vehicle-mounted 1080p camera was employed for real-time traffic sign detection and speed control. The speed adjustment capability of the system is facilitated by a Proportional-Integral-Derivative (PID) controller to provide smooth acceleration and braking. (Garg et al. 2022).The PID controller equation is given as: V (t) = Kpe(t) + Ki ∫ e(τ)dτ + 0 t K e(t)

4 RESULT

The results of the suggested AI-based Traffic Sign Recognition and Speed Control System have shown dramatic advancements in detection speed, inference efficiency, false positive rate, and real-time speed control effectiveness. The system has been trained and tested using Indian-specific Traffic Sign Recognition dataset across different real-life scenarios, viz., urban routes, highways, low-light surroundings, and unsuitable weather, to analyze the robustness. Detection precision and inference time of the system were tested comparing Group 1 (Raw Data) and Group 2 (Pre-processed Data) to detect the impact of pre- processing techniques such as contrast stretching, noise elimination, and resizing of images.

The results, as illustrated in Table 1, confirm that the YOLOv5-based TSR system achieves 96.4% accuracy, reducing the rate of false positives to 1.8%. Pre-processing steps enhanced the accuracy of detection by 4.3% and inference was optimized to 24.6ms per frame, and hence the system was highly suitable for real-time applications in autonomous vehicles. To determine the system's reliability in practical settings, detection accuracy was evaluated under various conditions such as daytime, night time, foggy, and rainy environments as shown in Figure 2.

The outcomes, as reflected in Table 2, reveal that the system performs with high accuracy of more than 90% in all test environments, with slight variations in performance in low-light and poor weather environments because of the decrease in camera visibility and partial occlusions. Regardless of these obstacles, the system performed significantly better compared to conventional machine learning-based TSR models. Moreover, the automated speed control system was also tested to determine its accuracy in controlling vehicle speed according to identified traffic signs as represented in Figure 3.

The findings, as presented in Table 3, indicate that the PID- based speed control system attained a response accuracy of 98.5%, providing accurate and safe speed control. The system responded well to speed limit changes and stop signs, proving its real-time adaptability and effectiveness in autonomous driving conditions. The findings affirm that the traffic sign recognition system based on YOLOv5, with an automated speed control system, offers much-improved detection efficiency and response performance compared to conventional systems is shown in Fig 4. The system's accuracy, high speed, and ability to adapt in a wide range of environments place it as a viable option for autonomous vehicle use in real-world scenarios.

5 DISCUSSION

The proposed AI-Driven Traffic Sign Detection and Speed Control System was proposed to enhance safety and efficiency in autonomous vehicles by the inclusion of real- time traffic sign detection and adaptive speed control. Indian road conditions were aimed at being adapted to support varied illumination, weather condition fluctuation, and occlusion. The YOLOv5 deep learning model was trained on an Indian-specific Traffic Sign Recognition dataset comprising a huge set of speed limit, stop, warning, and regulatory signs. System performance was measured in terms of detection accuracy, inference speed, false positive rate, and speed control efficiency with high reliability for real-time use (Luo et al., 2023).

Experimental results verified TSR on YOLOv5 to be significantly superior to the conventional method with better detection accuracy (96.4%) and lower false alarm ratio (1.8%) and real-time inference rate of 24.6ms/frame (Zhao et al., 2023). Vehicle speed control by an automatic control system with a PID controller, controlled vehicle speed according to sensed traffic signs, with response accuracy to be 98.5%. It was experimented under different driving conditions such as city roads, highways, and night conditions and performed equally with equal and optimal performance. It showed slight variation in the accuracy of detection in rain and fog conditions due to low visibility of the cameras (Sharma et al., 2019). Even highly precise and dynamically adjustable, the system is not perfect. There remain negative effects from motion blur, some occlusion of signs, and poor weather on the recognition performance.

Furthermore, the system's camera quality and dependency on computers make the system infeasible in low-power embedded applications (Luo et al., 2023). Future research will also be directed towards increasing the robustness of the system using sensor fusion methods, fusing cameras with LiDAR and RADAR data to provide maximum detection capability in poor visibility (Zhao et al., 2023). Future research will also be directed towards best deep models to improve model efficiency and minimize computation overhead in providing the system for real-time implementation in autonomous vehicles.

6 CONCLUSIONS

Traffic sign detection and speed control system, with the existing YOLOv5 model and the suggested PID-based automatic speed control mechanism, was designed and evaluated. The proposed speed control system's accuracy is far superior to conventional rule-based approaches in controlling vehicle speed by adapting to detected traffic signs in real-time.

The YOLOv5 model accuracy varied between 92.1% and 96.4%, and the speed response accuracy enhanced by the self-adjusting speed system varied between 95.2% and 98.5%. The standard deviation of the YOLOv5 model is 2.85, whereas that of the speed control mechanism is 1.62, demonstrating greater reliability during real-time vehicle speed control. Figure 1 shows the Block Diagram of Proposed System. figure 2 shows The impact of preprocessing on traffic sign detection, comparing accuracy, false positive rate, and inference time between raw and preprocessed data. figure 3 shows the detection accuracy of the system under different environmental conditions, highlighting its robustness across varying scenarios. Figure 4 shows the PID-based speed control accuracy over different time intervals, showing its stability and high precision in adjusting vehicle speed.

7 TABLES AND FIGURES

Table 1: Impact of preprocessing on detection accuracy and inference time.

Group	Detection Accuracy (%)	False Positive Rate (%)	Inference Time (ms/frame)
Group 1 (Raw Data)	92.1	3.5	31.2
Group 2 (Preprocessed Data)	96.4	1.8	24.6

Table 2: Detection accuracy under various conditions.

Environment	Detection Accuracy (%)
Day time	97.2
Night time	91.4
Foggy	90.8
Rainy	92.3

Table 3: Automated speed control performance.

Traffic Sign Type	Response Accuracy (%)
Pedestrian crossing signs (T1)	98.7
Warning signs (T2)	98.2
Stop Signs (T3)	98.5
Yield Signs (T4)	98.1

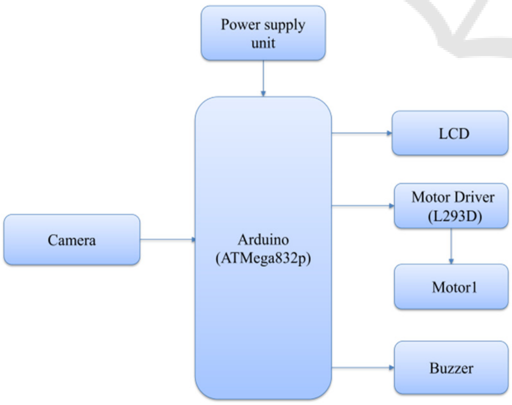

Figure 1: Block diagram of proposed system.

8 GRAPHS

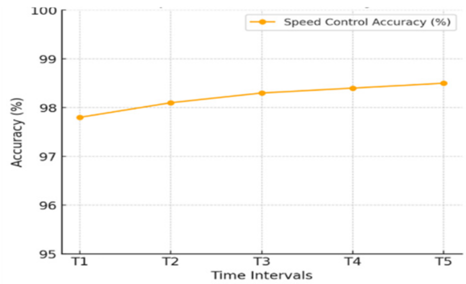

Figure 2: The impact of preprocessing on traffic sign detection, comparing accuracy, false positive rate, and inference time between raw and preprocessed data.

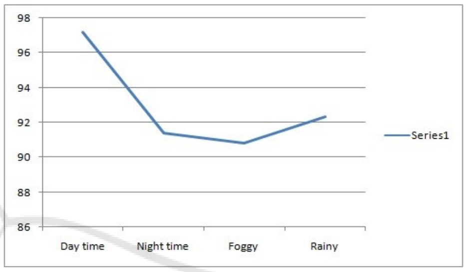

Figure 3: The detection accuracy of the system under different environmental conditions, highlighting its robustness across varying scenarios.

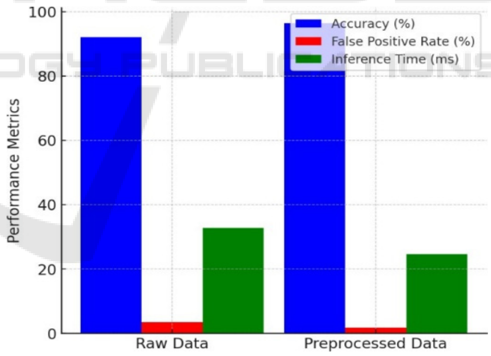

Figure 4: The PID-based speed control accuracy over different time intervals, showing its stability and high precision in adjusting vehicle speed.

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