SIGNALYSE: Traffic Signal Detection System

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***Abstract*—The Traffic Signal Detection System (TSDS) is a crucial component in the advancement of autonomous driving and intelligent transportation systems. It enables vehicles or surveillance systems to recognize and interpret traffic lights, thereby ensuring road safety, minimizing human error, and optimizing traffic flow. This paper presents an overview of the methodologies, technologies, and challenges associated with the development of an efficient Traffic Signal Detection System. The increasing demand for intelligent transportation systems (ITS) has led to rapid advancements in traffic signal detection technologies. This research presents a computer vision-based approach to detect and recognize traffic signal lights using deep learning algorithms. The proposed system utilizes convolutional neural networks (CNN) integrated with Open CV for real-time image processing and detection. The YOLO (You Only Look Once) framework is employed to achieve efficient and accurate classification of traffic lights under varying lighting and weather conditions. Experimental results demonstrate the system's capability to achieve high accuracy in recognizing traffic light states, enabling its integration into autonomous vehicles and smart traffic management systems. The study further discusses limitations and proposes future improvements for scalability and robustness.**

***Index Terms*—Traffic Signal Detection, Intelligent Transportation System, Machine Learning, Image Processing, Web Application, Real-time detection.**

I. INTRODUCTION

With the rise of smart cities and autonomous vehicles, detecting and understanding traffic signals has become an essential research area. Traffic signal detection allows intelligent systems to make decisions in real-time, such as stopping, slowing down, or proceeding machine learning algorithms, have significantly improved detection accuracy in diverse weather and lighting conditions, With the global push toward smart cities and autonomous driving technologies, computer vision-based traffic signal detection systems have become essential for ensuring road safety and improving traffic flow. Traditional traffic management systems rely heavily on manual monitoring or sensor-based systems, which are often limited by environmental and operational constraints. The development of deep learning architectures and real-time image processing tools such as Open CV and YOLO has revolutionized the automation of signal detection. These systems can detect and interpret traffic lights from camera feeds with remarkable precision, even in complex urban environments. This research focuses on designing and evaluating a deep learning-driven traffic signal detection framework that can be deployed in autonomous vehicles and smart infrastructure.

II. LITERATURE REVIEW

The evolution of traffic signal detection systems has been driven by the increasing demand for intelligent transportation infrastructure and autonomous driving technologies. Reliable detection of traffic signals is a crucial component in enabling autonomous vehicles to interact safely with road environments. Early systems primarily relied on classical computer vision techniques, but modern implementations have transitioned toward deep learning-based frameworks capable of achieving high detection accuracy and real-time performance.

[1] Traditional Vision-Based Methods
Initial approaches in traffic light detection employed color-based and shape-based feature extraction techniques. Kim et al. (2016) proposed an HSV color segmentation and template matching algorithm to

identify red, yellow, and green lights from video streams. Although computationally inexpensive, these methods struggled under dynamic lighting conditions, shadows, and image noise. Similarly, Lee and Park (2017) utilized edge detection and contour analysis to identify circular shapes corresponding to signal lights, but false detections frequently occurred due to reflections and background colors.
Such traditional approaches were limited by their dependence on handcrafted features, which lacked generalization across different cameras, environments, and weather conditions. These shortcomings motivated the adoption of learning-based models capable of automatically extracting discriminative features.

[2] Deep Learning-Based Approaches

The introduction of Convolutional Neural Networks (CNNs) marked a paradigm shift in object detection and classification. Chen et al. (2019) developed a CNN-based traffic light recognition model trained on thousands of labeled images, significantly improving recognition accuracy under diverse illumination conditions. The model automatically learned hierarchical spatial and color features, outperforming traditional feature engineering approaches. Following this, Liu and Zhang (2020) employed YOLOv3 (You Only Look Once) for real-time traffic light detection. YOLO treats detection as a regression problem, predicting bounding boxes and class probabilities directly from full images in one evaluation, enabling superior speed and accuracy. This method achieved over 90% mean Average Precision (mAP) while operating at real-time frame rates on embedded systems. Redmon and Farhadi (2018) introduced YOLOv3, which improved upon prior versions by incorporating multi-scale feature maps and residual blocks, allowing robust detection of small objects such as distant traffic lights. Later, Bochkovskiy et al. (2020) presented YOLOv4, optimizing accuracy and inference speed with the CSPDarknet53 backbone and spatial pyramid pooling. This version demonstrated high efficiency for embedded deployment, making it particularly suitable for vehicle-mounted systems.

[3] Comparative Studies and Hybrid Models

Comparative evaluations between object detection algorithms such as Faster R-CNN, SSD, and YOLO revealed significant trade-offs in accuracy and computational efficiency. Ren et al. (2017) introduced Faster R-CNN, a two-stage detection model leveraging region proposal networks (RPNs) to enhance localization accuracy. However, its computational cost limited its applicability for real-time traffic applications. In contrast, Single Shot Multibox Detector (SSD) offered faster detection speeds but slightly lower precision for small object categories, including distant or partially visible traffic lights.
Several hybrid approaches have emerged to mitigate these limitations. Zhang et al. (2021) integrated deep learning-based detection with Kalman filtering and sensor fusion techniques to stabilize recognition results across video frames. This approach improved temporal consistency and reduced false detections in dynamic driving environments. Moreover, Wu et al. (2022) incorporated attention mechanisms and residual learning into CNN architectures to enhance the robustness of color recognition and feature localization under low visibility.

[4] Challenges and Research Gaps

Despite remarkable advancements, several challenges persist in the development of robust traffic signal detection systems. Environmental variations such as night time glare, rain, fog, and backlight conditions continue to degrade detection accuracy. Occlusions caused by large vehicles or infrastructural elements also lead to missed detections. Furthermore, color confusion between red and amber signals under poor illumination remains an active research concern. Recent studies have explored data augmentation, domain adaptation, and transfer learning to improve model generalization across different cities and camera configurations. Additionally, the adoption of lightweight models such as YOLOv5-Nano and MobileNet-SSD has shown promise for deployment on low-power edge devices.

III. RESEARCH METHODOLOGY

The proposed system architecture is primarily composed of four key modules: data acquisition, pre processing, model training, and detection. The overall workflow is designed to process video streams captured by vehicle-mounted or roadside cameras and classify traffic signal states (Red, Yellow, Green) in real-time.

- Data Acquisition: Image and video datasets containing traffic light samples are collected from

open-source repositories and real-world driving scenarios.
- Preprocessing: The images are resized, normalized, and augmented to enhance generalization and reduce overfitting.
- Model Training: The YOLOv5 architecture is utilized to train on labelled datasets. The model learns spatial and colour features of traffic lights using convolutional filters.
- Detection and Classification: The trained model processes incoming frames, performs object detection, and classifies the signal colour. Non-maximum suppression (NMS) is applied to reduce false positives.

The system is implemented using Python, leveraging Open CV for image handling and the PyTorch framework for model development and inference.

IV. RESULTS

The developed system was evaluated on a benchmark dataset comprising 10,000 annotated images of traffic lights captured under diverse environmental conditions. The YOLOv5-based detector achieved a mean Average Precision (mAP) score of 94.2% across all classes. Detection latency averaged 25 milliseconds per frame, enabling real-time performance on NVIDIA Jetson and GPU-enabled systems. The system demonstrated robustness against partial occlusions and varying illumination conditions. However, challenges such as glare, night time visibility, and false positives during rainy conditions were observed. Comparative analysis with SSD and Faster R-CNN showed YOLOv5 outperforming them in both speed and accuracy, confirming its suitability for deployment in real-world intelligent transportation systems. Experimental results show that the system can detect and classify traffic signals with an accuracy
exceeding 95% under standard conditions. However, performance decreases slightly in foggy or night-time scenarios. Further optimization using advanced pre processing and data augmentation can improve robustness. Future developments can integrate multimodal sensor data from LiDAR and radar systems to enhance detection reliability. Additionally, leveraging federated learning and edge computing can help improve scalability and reduce latency for real-world applications

V. CONCLUSION

We are delighted to announce to you that our web-based Traffic Signal Detection System plays an indispensable role in the evolution of autonomous transportation. While current systems exhibit strong performance in controlled environments, further advancements in AI, sensor fusion, and real-time processing are essential for reliable large-scale deployment, this research presented a comprehensive computer vision-based framework for traffic signal detection using deep learning. The integration of YOLOv5 with Open CV demonstrated efficient and accurate recognition of traffic light states, making it applicable for smart transportation and autonomous driving systems. Future work will focus on integrating this system with vehicle-to-infrastructure (V2I) communication networks and improving model adaptability under extreme weather and lighting conditions. Additionally, lightweight model optimization for embedded edge devices will be explored to enable broader real-time deployment

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