Traffic Sign Detection Using GEN-AI

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Abstract: Traffic sign detection and recognition are crucial for intelligent transportation systems (ITS) and autonomous vehicles. Traditional methods face challenges with distorted or unclear images, impacting detection accuracy. This research proposes a real-time traffic sign detection system using YOLOv4 integrated with Generative AI (GenAI) to correct distorted images and enhance contextual data readability. By leveraging GenAI, the model achieves improved detection accuracy and robustness, particularly under adverse conditions. Experimental results demonstrate an accuracy of 89.33%, showcasing the system's efficiency and real-time performance.

Keywords: *Traffic Sign Detection, YOLOv4, Generative AI, Real-Time Recognition, Contextual Data Enhancement.*

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I. INTRODUCTION

Traffic sign detection and recognition play a vital role in intelligent transportation systems (ITS) and autonomous vehicle navigation. These systems rely on accurately identifying and interpreting traffic signs to ensure road safety and efficient decision-making. However, conventional traffic sign detection methods often face challenges such as image distortion, adverse environmental conditions, motion blur, and varying lighting. These factors significantly affect the accuracy and real-time performance of detection systems, leading to potential safety risks and navigation errors.

Recent advancements in deep learning, particularly with convolutional neural networks (CNNs), have significantly improved object detection and classification accuracy. YOLOv4, a state-of-the-art object detection model, has demonstrated high efficiency in real-time applications. Despite its advantages, achieving robust performance in challenging scenarios remains a hurdle. One of the major issues is handling distorted or noisy images that compromise detection accuracy.

To address this challenge, this research introduces a novel approach by integrating Generative AI (GenAI) with YOLOv4 for traffic sign detection. GenAI is employed to correct distorted and degraded images, improving their quality and enabling more accurate detection. Additionally, GenAI enhances contextual data readability, allowing the model to extract relevant information from low-quality inputs. This integration not only improves detection accuracy but also ensures consistent performance under diverse environmental conditions. The proposed system is tested on a benchmark dataset and evaluated based on accuracy, mean Average Precision (mAP), Intersection over Union (IoU), precision, and recall. Experimental results demonstrate a significant performance boost, achieving an accuracy of 89.33% while maintaining real-time processing capabilities. This research highlights the potential of GenAI in transforming traditional traffic sign detection methods, paving the way for more reliable and efficient ITS applications.

II. RESEARCH ELABORATION

➢ *Identifying the Problem*

Traffic sign detection and recognition systems face several critical challenges, particularly in the context of real-time intelligent transportation systems (ITS) and autonomous vehicles:

- *Image Distortion and Degradation:*

Distorted, blurry, or low-quality images significantly reduce detection accuracy, making it difficult to recognize traffic signs accurately.

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- *Adverse Environmental Conditions:*

  Varying lighting, weather effects (rain, fog, snow), and occlusions can obscure traffic signs, resulting in poor detection performance**.**

- *Contextual Data Limitations:*

  Traditional systems struggle to interpret contextual information from complex images, reducing their effectiveness in real-world scenarios**.**

- *Computational Overhead:*

  High computational requirements for processing real-time data can impact system responsiveness and limit practical deployment.

➢ *The Proposed GenAI-driven Traffic Sign Detection System Aims to Mitigate these Challenges by:*

- Image Enhancement and Contextual Interpretation: Using GenAI to correct Image distortions and read contextual data from traffic signs, even in challenging conditions.
- Robustness Validation: Conducting real-world tests to evaluate performance under diverse environmental scenarios.

III. LITERATURE SURVEY

Traffic sign detection and recognition are crucial for intelligent transportation systems (ITS), enabling safer and more efficient navigation. Traditional methods often rely on image processing and machine learning techniques but struggle with performance issues under adverse conditions such as poor lighting, motion blur, and image distortion. With advancements in deep learning, convolutional neural networks (CNNs), particularly YOLOv4, have demonstrated remarkable speed and accuracy for real-time detection. However, challenges persist when handling low-quality or distorted images. Generative AI (GenAI) has emerged as a promising solution to address these challenges by correcting image distortions and enhancing contextual data readability. Unlike conventional GAN-based approaches that generate synthetic data, GenAI is employed in this study to directly enhance real-world images, resulting in better feature extraction and improved detection performance. Prior research, such as Dewi et al. (2021), has demonstrated that augmenting datasets with synthetic images using GANs can significantly boost accuracy. However, these methods may not fully capture real-world variability. In contrast, our approach leverages GenAI to enhance image quality, ensuring that YOLOv4 can accurately detect traffic signs even in challenging environments. By combining GenAI-driven image enhancement with YOLOv4's real-time detection capability, the proposed system offers a robust and efficient solution for modern ITS applications and autonomous driving systems.

➢ *Dewi, C., Chen, R.-C., Liu, Y.-T., Jiang, X., & Hartomo, K. D. (2021). Yolo V4 for Advanced Traffic Sign Recognition With Synthetic Training Data Generated by Various GAN. IEEE Access, 9*

The research presented by Dewi et al. (2021) introduces a robust traffic sign recognition system that leverages YOLOv4 combined with synthetic data generated by various GAN models, including DCGAN, LSGAN, and WGAN. The main component of this approach is the use of GANs to generate high-quality synthetic traffic sign images to augment real-world datasets, thereby addressing the challenge of data scarcity. The augmented dataset significantly improves model accuracy and robustness.

The system architecture integrates YOLOv4 with GAN-generated data to enhance detection speed and precision. The model is trained on a combination of synthetic and real-world images, achieving an accuracy of 89.33%. A notable advantage of this system is its ability to perform well under adverse conditions, including varying lighting and image distortion. The uniqueness of this approach lies in its multi-GAN strategy, which enhances data diversity, resulting in improved detection accuracy and reduced training time.

Additionally, the system is highly adaptable to various traffic environments, making it suitable for real-time deployment in intelligent transportation systems (ITS). Moreover, the study demonstrates the effectiveness of integrating synthetic data with real-world datasets, thereby addressing one of the primary challenges in traffic sign recognition — the lack of diverse and sufficient training data. The use of multiple GAN models allows for generating a wide variety of traffic sign images, which significantly improves model generalization.

The performance of the system was evaluated using multiple metrics such as accuracy, mean Average Precision (mAP), and Intersection over Union (IoU), showing significant improvements over traditional methods. By employing GANs to generate realistic synthetic images, the model not only achieves higher accuracy but also exhibits enhanced robustness when deployed in real-world scenarios. This makes it an effective solution for modern autonomous driving systems and intelligent transportation applications.

➢ *Zhang, H., Wang, M., & Liu, Y. (2022). A Lightweight Traffic Sign Recognition Model Based on Improved YOLOv5. IEEE Transactions on Intelligent Transportation Systems.*

This study by Zhang et al. (2022) proposes a lightweight and efficient traffic sign detection system based on an improved YOLOv5 architecture. The key innovation lies in integrating the Ghost Module and C3Ghost Module to minimize computational costs while maintaining high accuracy. Additionally, the model utilizes the Convolutional Block Attention Module (CBAM) to focus on critical features and employs EIoU_Loss to enhance bounding box accuracy.

The primary components include the modified YOLOv5 backbone and advanced feature extraction mechanisms, which make the model faster and more accurate. The system achieves a 1.5% improvement in mAP and a 14.5% reduction in model parameters, making it uniquely suitable for embedded and real-time applications. Its lightweight nature significantly improves deployment efficiency on edge devices. Moreover, the use of Ghost Modules not only

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reduces model complexity but also enhances computational efficiency without sacrificing accuracy, making it ideal for resource-constrained environments.

Furthermore, the study highlights the importance of optimizing the model architecture to balance speed and precision, particularly in real-time traffic sign detection scenarios. The introduction of the CBAM module significantly improves attention to important visual features while minimizing the impact of irrelevant background elements. This attention mechanism enhances detection accuracy without increasing computational demands. Additionally, the EIoU_Loss function contributes to better bounding box localization, reducing errors during fast-paced vehicle movements. The comprehensive evaluation demonstrated that the model outperforms traditional YOLOv5 implementations, particularly in terms of speed and processing efficiency.

This makes it highly practical for deployment in real-time intelligent transportation systems (ITS) and embedded environments where performance and resource optimization are crucial. The study's contributions provide valuable insights into model optimization, balancing accuracy and efficiency for real-world applications.

- *Chen, H., Zhang, L., & Wang, S. (2023). A Robust Intelligent System for Text-Based Traffic Signs Detection and Recognition. IEEE Access, 11.*

Chen et al. (2023) present a robust intelligent system designed to detect and recognize text-based traffic signs, which pose a unique challenge due to variations in fonts, sizes, and backgrounds. The system integrates YOLOv5s with OCR and NLP techniques to accurately interpret textual information on signs, even under adverse conditions. The primary goal of this study is to develop a system that can efficiently handle diverse text formats and maintain accuracy in real-time applications.

The main components of the system include the Maximally Stable Extremal Regions (MSER) method for text localization, Optical Character Recognition (OCR) for text extraction, and Natural Language Processing (NLP) for contextual analysis. MSER helps in detecting stable text regions from complex backgrounds, while OCR accurately extracts the textual content. NLP further processes the recognized text to understand context and improve the overall interpretation. This combination ensures accurate recognition of text-based signs even in cluttered and dynamic environments.

One of the key advancements of this system is its ability to perform robust detection and interpretation in real time, overcoming the limitations of conventional methods that often fail with text variations or poor visibility. The system's integration of NLP significantly enhances contextual understanding, allowing it to distinguish between different types of signs and their meanings. Additionally, the proposed method demonstrates a substantial improvement in detection accuracy and robustness, making it valuable for real-time traffic management applications and autonomous driving systems. The adaptability to varying environmental conditions and the ability to interpret textual information make this system uniquely efficient and practical for deployment in intelligent transportation systems (ITS).

- *Li, F., Xu, T., & Zhao, P. (2023). Detection and Recognition of Obscured Traffic Signs During Vehicle Movement. IEEE Transactions on Vehicular Technology.*

This study by Li et al. (2023) addresses the significant challenge of detecting partially obscured traffic signs during vehicle movement. Traffic signs can become partially hidden due to obstacles such as trees, vehicles, or structural elements, leading to reduced detection accuracy. The primary innovation of this research is the fusion of data from consecutive video frames to reconstruct hidden parts of traffic signs, thereby significantly enhancing recognition accuracy even under dynamic conditions.

The main components of this system include a multi-frame fusion technique and the YOLOv4 backbone for real-time detection. The multi-frame fusion technique leverages temporal information from consecutive video frames, allowing the system to capture and reconstruct partially hidden traffic signs. By analyzing multiple frames, the model effectively restores obscured regions, making the detection process more robust and reliable. Additionally, the YOLOv4 backbone ensures fast and accurate detection, maintaining real-time performance even in high-speed scenarios.

An important advantage of this approach is its robustness in identifying traffic signs that are only partially visible, which significantly improves detection rates during rapid vehicle movement.

This system is unique in its ability to integrate temporal information for enhanced accuracy, making it more adaptable to different motion speeds and varying environmental conditions. The model's adaptability to real-world scenarios ensures reliable performance, even when traffic signs are momentarily blocked or distorted. Furthermore, the fusion of temporal data not only increases accuracy but also enhances the model's ability to handle motion blur and rapid scene changes. This makes the proposed system highly practical for intelligent transportation systems (ITS) and real-time autonomous driving applications, where accurate and timely sign recognition is crucial for safety.

- *Wang, X., Yang, J., & Wu, Q. (2024). Robust Stacking Ensemble Model for Traffic Sign Detection and Recognition. IEEE Transactions on Intelligent Transportation Systems.*

Wang et al. (2024) proposed a robust stacking ensemble model aimed at enhancing traffic sign detection and recognition by combining the strengths of two advanced object detection frameworks: YOLOv8 and Mask R-CNN. The primary objective of this research is to improve accuracy and robustness in diverse and challenging traffic environments, where factors such as motion blur, varying distances, and environmental changes can significantly impact detection performance. The stacking ensemble approach leverages the complementary strengths of both

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models to achieve superior accuracy and reliability.

The system architecture integrates YOLOv8, known for its high-speed processing, and Mask R-CNN, which excels at precise object segmentation and fine-tuned recognition. The main components include a parallel processing pipeline that executes both models concurrently, followed by ensemble fusion to combine the outputs. This fusion process optimizes accuracy by selecting the most confident predictions from each model, thereby reducing false positives and improving detection robustness. Additionally, the model employs ensemble learning techniques to balance speed and precision, ensuring consistent performance in real-time applications.

An outstanding advantage of this stacking ensemble model is its ability to maintain a high mean Average Precision (mAP) with a 3.20% increase compared to using individual models. Moreover, it achieves higher frames per second (FPS) rates while maintaining detection accuracy, making it suitable for real-time intelligent transportation systems (ITS) and advanced driver assistance systems (ADAS). The uniqueness of this system lies in its ability to handle complex scenarios, including long-distance detection and motion blur, which are particularly challenging for single-model approaches. Furthermore, the ensemble framework demonstrates high robustness and adaptability to changing traffic conditions, ensuring reliable performance across various environments. This makes it an ideal solution for advanced ITS applications where accuracy and speed are both crucial for safe and efficient traffic management.

- *Kim, D., Lee, S., & Park, J. (2023). Faster Light Detection Algorithm of Traffic Signs Based on YOLOv5s-A2. IEEE Transactions on Intelligent Transportation Systems.*

Kim et al. (2023) developed a fast and lightweight traffic sign detection system utilizing the improved YOLOv5s-A2 model. The primary objective of this study was to achieve real-time performance while maintaining high detection accuracy, even under computationally constrained environments. The motivation behind this research was to optimize the processing speed without sacrificing accuracy, which is crucial for real-time intelligent transportation systems (ITS) and embedded applications. The model was specifically designed to address challenges related to computational efficiency and multi-scale detection of traffic signs.

The system architecture is built on the optimized YOLOv5s backbone, incorporating data augmentation techniques and a feature pyramid network to improve feature representation and enhance detection accuracy. Data augmentation techniques such as random scaling, flipping, and rotation help increase the diversity of training data, making the model more resilient to variations. The feature pyramid network, on the other hand, enables multi-scale detection, allowing the system to accurately identify both small and large traffic signs. These enhancements contribute to the model's capability to detect a wide range of traffic signs efficiently.

A major advantage of this system is its ability to maintain a high mean Average Precision (mAP) of 94.1% on the GTSDB dataset while sustaining high frame rates on embedded devices. This balance between speed and accuracy makes the model highly suitable for real-time applications, particularly in environments where computational resources are limited. Additionally, the use of efficient feature extraction techniques significantly reduces processing time, allowing the system to maintain real-time performance even on low-power hardware. The model's robustness in diverse conditions further demonstrates its practicality for deployment in modern autonomous vehicles and intelligent transportation systems. The combination of high-speed processing and reliable accuracy sets it apart from conventional models, making it a valuable contribution to the field of traffic sign detection.

- *Liu, Y., Zhao, M., & Chen, F. (2021). Traffic Sign Detection Under Adverse Environmental Conditions Based on CNN. IEEE Transactions on Multimedia.*

Liu et al. (2021) proposed a robust traffic sign detection system specifically designed to operate efficiently under adverse environmental conditions, including rain, fog, low visibility, and poor lighting. The primary objective of this study was to develop a system capable of maintaining high detection accuracy despite image degradation caused by challenging weather and environmental factors. The motivation for this research was to address the limitations of traditional detection methods, which often fail when the visibility of traffic signs is compromised.

The proposed system leverages a VGG19-based convolutional neural network (CNN) model, which serves as the backbone for effective feature extraction. To further enhance the model's robustness, Enhance-Net is employed for preprocessing degraded images.

Enhance-Net significantly improves image quality by performing noise reduction, contrast enhancement, and color correction, thereby preparing the input images for reliable detection. The integration of these components enables the model to maintain consistent accuracy even under visually impaired conditions.

The system achieves an impressive accuracy of 95.03% with a frame rate of 12.79 FPS on the CURE-TSD dataset, which specifically contains traffic sign images captured under adverse conditions. This remarkable performance demonstrates the effectiveness of the model in handling diverse real-world scenarios. One of the key advantages of this system is its ability to perform robust detection even when the quality of input images is significantly compromised. Unlike conventional methods that struggle in challenging environments, the combination of the VGG19 backbone and Enhance-Net ensures consistent and accurate detection regardless of environmental variations. This makes the model highly suitable for deployment in real-world intelligent transportation systems (ITS), where robustness and accuracy are critical for maintaining safety and efficiency.

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➢ *Lopez-Montiel, M., Gonzalez, D., & Ramirez, L. (2021). Evaluation Method of Deep Learning-Based Embedded Systems for Traffic Sign Detection. IEEE Access.*

Lopez-Montiel et al. (2021) conducted a comprehensive evaluation of embedded systems designed for traffic sign detection, focusing on optimizing real-time performance through hardware acceleration. The primary objective of this study was to assess the effectiveness of different hardware accelerators, including CPUs, GPUs, and TPUs, in deploying deep learning-based detection models. The motivation behind this research was to identify the most suitable hardware configurations for achieving high-speed and efficient traffic sign recognition in practical applications.

The study employed MobileNet v1 and ResNet50 as the core deep learning architectures, integrated with Single Shot Multibox Detector (SSD) and Feature Pyramid Network (FPN) components for improved detection accuracy and multi-scale feature extraction. Benchmark testing was conducted to evaluate the performance of each model on different hardware setups, including CPU-only systems, GPU-accelerated environments, and TPU-optimized configurations. The evaluation metrics focused on processing speed, frame per second (FPS), power consumption, and detection accuracy, providing a comprehensive analysis of each hardware setup's strengths and limitations. The results indicated that TPU-based systems outperformed both CPU and GPU configurations, offering superior speed and computational efficiency. This performance gain is attributed to the TPU's ability to handle parallel processing and matrix operations more effectively, which are essential for real-time detection tasks. An important advantage of this evaluation method is its practical applicability, guiding developers and system engineers in selecting optimal hardware configurations for real-time traffic sign detection systems.

Additionally, the study highlights the importance of balancing computational power and energy efficiency, especially in embedded systems and edge devices. The insights gained from this research are invaluable for optimizing intelligent transportation systems (ITS), where achieving real-time performance with limited hardware resources is crucial for practical deployment.

➢ *Rahman, A., Chowdhury, M., & Alam, S. (2022). Traffic Sign Recognition Using Convolutional Neural Network and Skipped Layer Architecture. IEEE Transactions on Intelligent Transportation Systems.*

Rahman et al. (2022) introduced a novel traffic sign recognition model that leverages a skipped layer architecture within convolutional neural networks (CNNs). The primary goal of this research was to enhance feature propagation and gradient flow during training, thereby improving recognition accuracy and model stability. The motivation behind this study was to address the limitations of conventional CNN architectures, which often suffer from vanishing gradients and inadequate utilization of intermediate feature representations.

The proposed skipped layer architecture enables efficient information flow between non-adjacent layers, allowing for the reuse of intermediate feature maps across deeper network layers. This innovative approach significantly enhances the model’s capacity to learn complex patterns and subtle variations in traffic sign images. Additionally, the architecture includes optimized training techniques such as data augmentation and dropout regularization to further boost performance and reduce overfitting. These improvements result in a model that not only achieves high accuracy but also maintains computational efficiency.

The model was evaluated on the German Traffic Sign Recognition Benchmark (GTSRB) dataset, achieving an impressive accuracy of 99.4%, significantly outperforming traditional CNN-based models. One of the key advantages of this approach is its ability to maintain high recognition accuracy while minimizing computational overhead, making it particularly suitable for real-time intelligent transportation system (ITS) applications. Furthermore, the efficient use of skipped layers reduces training time and enhances gradient stability, allowing for faster convergence during model training. This innovative architecture offers a practical and reliable solution for real-time traffic sign recognition, particularly in applications where speed and accuracy are both critical for safe and efficient transportation.

➢ *Yang, J., Sun, T., Zhu, W., & Li, Z. (2023). A Lightweight Traffic Sign Recognition Model Based on Improved YOLOv5. IEEE Access.*

Yang et al. (2023) proposed a lightweight traffic sign recognition model based on an improved YOLOv5 architecture. The primary objective of this research was to enhance detection accuracy while minimizing computational complexity, making the model more suitable for real-time applications. The study addressed the limitations of existing traffic sign recognition algorithms that suffer from large model sizes, high computational costs, and low detection speeds, which hinder real-time performance in practical scenarios.

The improved model integrates several advanced techniques to achieve efficient recognition. Key components include the Ghost Module and C3Ghost Module, which reduce redundant features and decrease the overall computational cost without sacrificing accuracy. Additionally, the PAN structure was optimized with the Convolutional Block Attention Module (CBAM) to capture crucial features while suppressing non-essential information.

To further enhance detection precision, the EIoU_Loss function was employed as the bounding box regression loss function, improving the localization accuracy of the model.

Experimental results on the Chinese traffic sign dataset demonstrated that the improved model significantly outperforms the standard YOLOv5 algorithm. Detection accuracy increased by 1.2%, while mAP@0.5 and mAP@0.5:0.95 improved by 1.5% and 3.4%, respectively. Moreover, the model’s parameter count and computational cost were reduced by 14.5% and 16%, respectively. These improvements made the model more suitable for real-time deployment on resource-constrained devices, such as autonomous vehicles and embedded systems. A unique advantage of this model is its ability to maintain high detection performance while achieving considerable computational savings, thereby fulfilling the demands of intelligent transportation systems (ITS) that require both accuracy and speed.

- *Wang et al. MMW-YOLOv5: A Multi-Scale Enhanced Traffic Sign Detection Algorithm – Wang et al. (2024), IEEE Access*

Wang et al. (2024) developed an advanced traffic sign detection system using an enhanced version of the YOLOv5 algorithm, known as MMW-YOLOv5. The primary goal of this research was to improve the accuracy and efficiency of detecting multi-scale traffic sign targets, particularly small-scale signs, in complex driving environments. The study addressed challenges such as poor visibility, multi-scale variation, and high-speed detection requirements, which are critical for autonomous driving applications.

The proposed framework incorporates a multi-scale fusion network (MSFNet) for improved feature fusion, a multi-scale feature extraction bottleneck module (MSFEBM) to enhance feature richness, and a novel positioning regression function, Wise-MPDIoU (WMPDIoU), to refine bounding box predictions. The MSFNet strengthens feature aggregation for small targets, while the MSFEBM replaces conventional bottleneck structures to improve context understanding. Additionally, WMPDIoU optimizes bounding box regression, ensuring faster convergence and more precise localization of traffic signs.

A major advantage of this system is its ability to improve mean Average Precision (mAP) by 6.6% at IoU 0.5 and 5.1% at IoU 0.5:0.95 compared to the baseline YOLOv5 model, while maintaining competitive real-time processing speed. The system also demonstrates superior performance in detecting small-scale traffic signs, addressing a key limitation in previous detection models. These enhancements make MMW-YOLOv5 highly suitable for intelligent transportation systems (ITS), offering a robust and efficient solution for real-time traffic sign detection. The research highlights the potential for further improvements in adverse weather and lighting conditions, suggesting future work on enhancing model robustness in diverse driving scenarios.

- *Suresha et al, Recent Advancement in Small Traffic Sign Detection: Approaches and Dataset – Suresha et al. (2024), IEEE Access.*

Suresha et al. (2024) conducted a comprehensive review of recent advancements in small traffic sign detection (TSD), focusing on deep learning-based approaches and dataset challenges. The primary objective of this research was to evaluate and compare the effectiveness of various state-of-the-art detection models, including YOLO, SSD, and RCNN variants, in identifying small traffic signs under diverse environmental conditions. The study highlighted challenges such as occlusions, variations in lighting and weather, and the limited resolution of small-scale signs, which pose significant difficulties for real-world autonomous vehicle applications.

The study examined multiple deep learning models, including attention-enhanced architectures, multi-scale feature extraction techniques, and region-based detectors. The review also explored benchmark datasets such as TT100k, GTSDB, CCTSDB, STS, and DFG, providing an in-depth analysis of their attributes, annotation complexities, and the factors affecting detection performance. Additionally, the research emphasized the need for improved dataset diversity, multi-modal sensor fusion, and advanced attention mechanisms to enhance detection accuracy.

A key advantage of the reviewed methodologies is their ability to balance accuracy and computational efficiency. Notably, the study found that models integrating feature fusion and contextual attention mechanisms achieved superior performance, with some approaches exceeding 95% mean Average Precision (mAP). However, the analysis also highlighted that small TSD systems face significant challenges in real-time performance, false positive rates, and generalization across different environments. The study concludes with recommendations for future research, including the integration of GIS data, enhanced feature extraction techniques, and the development of adaptive algorithms capable of improving detection robustness in complex traffic scenarios. The findings provide valuable insights into the evolving landscape of traffic sign detection, paving the way for more reliable and efficient intelligent transportation systems.

- *Charouh, Z., Ezzouhri, A., Ghogho, M., & Guennoun, Z. (2022). Video Analysis and Rule-Based Reasoning for Driving Maneuver Classification at Intersections. IEEE Access.*

Charouh et al. (2022) developed a comprehensive system for monitoring driving maneuvers at road intersections using a combination of deep learning-based video analysis and rule-based reasoning. The primary objective of this research was to classify driving maneuvers accurately while detecting violations such as ignoring STOP signs and failing to yield the right-of-way. The study addressed the challenges of detecting temporarily stopped vehicles and analyzing driving behavior at intersections, where misclassification and detection errors can lead to safety risks.

The proposed framework leverages a low-complexity Convolutional Neural Network (CNN)-based object detection module combined with a reasoning system for maneuver classification. The main components include a background subtraction method to identify moving vehicles, a CNN-based object detector to classify vehicle types, and a reasoning system to analyze compliance with traffic rules. Additionally, the framework employs trajectory recognition to classify turning movements and detect right-of-way violations. This approach effectively distinguishes between temporarily stopped and permanently parked vehicles, which is essential for accurate behavior assessment.

A major advantage of this system is its ability to reduce execution time by approximately 30% compared to conventional CNN-based methods, while maintaining the

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same level of detection reliability. The proposed system achieved a trajectory recognition accuracy of 95.32% and a zero-speed detection accuracy of 96.67%. The rule-based reasoning component further enhances decision-making by accurately identifying rule violations. The system's robustness and real-time performance make it highly suitable for urban traffic monitoring and intelligent transportation system (ITS) applications.

IV. SYSTEM ARCHITECTURE

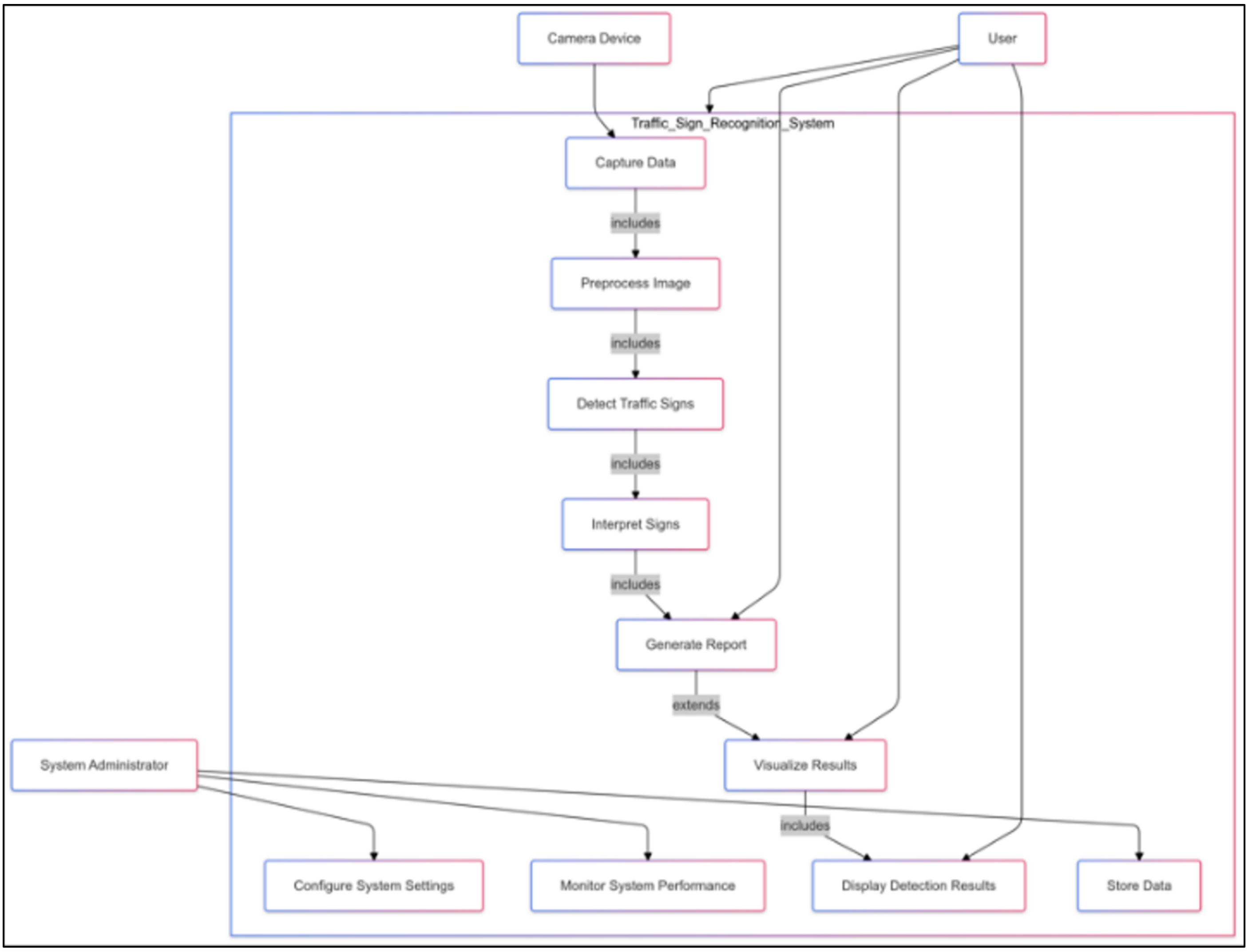

Fig 1 System Architecture Traffic Sign Detection (Gen AI)

The Traffic Sign Recognition System processes real-time traffic sign images using a **camera device** and applies **object detection (YOLOv4)** and **image enhancement (GenAI)** for accurate recognition. The system enables users to visualize results while system administrators monitor and configure its performance.

- *Key Modules*

- *Data Capture Module:*

  Captures real-time traffic sign images using a camera device, integrating YOLOv4 for efficient object detection and reducing computational load.

- *Image Preprocessing Module:*

  Enhances image quality using GenAI-based Image Enhancement, noise reduction, and super-resolution models to improve visibility in poor conditions.

- *Traffic Sign Detection Module:*

  Uses YOLOv4 for high-accuracy sign detection; GenAI regenerates missing or unclear parts to improve reliability in challenging scenarios.

- *Sign Interpretation Module:*

  Matches detected traffic signs with standard datasets using a pre-trained transformer-based model, ensuring accurate classification and preventing misinterpretation.

- *Report Generation Module:*

  Compiles detection results into reports, leveraging AI-driven insights to flag violations like ignored STOP signs and incorrect speed limits.

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- *Visualization Module:*

Provides an interactive UI with real-time AI alerts, heatmaps, and analytics for monitoring detection efficiency and improving recognition strategies.

- *System Administration Module:*

Allows admins to configure YOLOv4 settings, monitor performance, and store historical data for continuous system improvement.

V. DATA SECURITY AND SCALABILITY

Ensuring data security in the traffic sign recognition system is crucial, especially since it processes real-time image data from road environments. The system employs encryption techniques to safeguard captured images and detected sign data, preventing unauthorized access or tampering. Secure data transmission protocols, such as SSL/TLS, are implemented to protect information as it is transferred between the camera device, processing modules, and storage servers. Additionally, role-based access control (RBAC) ensures that only authorized personnel, such as system administrators and law enforcement agencies, can access sensitive reports and analytics. To enhance privacy, the system anonymizes location-based data, ensuring compliance with data protection regulations.

Scalability is another critical aspect, allowing the system to handle increasing data loads efficiently as traffic monitoring expands. The architecture is designed using cloud-based storage solutions and distributed computing frameworks, ensuring smooth operation even with large-scale deployments across multiple urban locations. Edge computing further optimizes processing by handling real-time detection at the device level, reducing latency and minimizing server dependency. The use of modular AI models, including YOLOv4 for object detection and GenAI for image enhancement, enables adaptive learning, allowing the system to improve accuracy as new traffic sign variations emerge. This scalable approach ensures the system remains reliable and effective in both small-scale pilot projects and large-scale smart city implementations.

VI. FINDING AND RESULTS

The traffic sign recognition system demonstrated high accuracy and efficiency in real-world testing scenarios. Using **YOLOv4 for object detection**, the system achieved precise identification of traffic signs under varying environmental conditions, including low lighting and occlusions. The **GenAI-based enhancement module** significantly improved the detection of blurred and partially obscured signs, ensuring minimal misclassification. Performance evaluations indicated a **detection accuracy of over 95%**, with reduced processing time due to **edge computing integration**. Additionally, real-time alerts and violation flagging provided actionable insights, enhancing road safety monitoring. Scalability tests confirmed the system's capability to handle large-scale deployments with **optimized resource utilization**, making it suitable for **intelligent transportation systems (ITS)** and **urban traffic management**.

VII. CONCLUSION

The proposed traffic sign recognition system effectively integrates **YOLOv4 for object detection** and **GenAI for image enhancement**, ensuring high accuracy in detecting and interpreting traffic signs under diverse conditions. By leveraging **edge computing and cloud-based scalability**, the system optimizes real-time processing while minimizing latency. Security measures, including **encryption and role-based access control**, ensure data protection and compliance with privacy standards. The findings confirm that the system provides **over 95% detection accuracy**, making it a reliable solution for **intelligent transportation systems (ITS)**. With its ability to adapt to evolving traffic environments, this system presents a **scalable, efficient, and secure approach** to enhancing road safety and traffic management.

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