Fire and Smoke Detection System

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Abstract — Fire and smoke detection is a critical component of early warning systems aimed at preventing the rapid spread of fires in both urban and forest environments. Traditional detection methods, such as thermal sensors and manual monitoring, often suffer from limitations including delayed response times, environmental dependencies, and high maintenance costs. In this study, we propose a real-time fire and smoke detection system utilizing the YOLOv8 deep learning model. The system is trained on a dataset of over 11,000 annotated images sourced from Roboflow, enabling high-accuracy detection in diverse scenarios. The proposed method incorporates a structured pipeline comprising image preprocessing, normalization, model training, and alert generation. Experimental results demonstrate that the YOLOv8 model achieves a mean average precision (mAP@50) of 0.926, with a precision of 0.954 and recall of 0.848, outperforming previous YOLO variants. This system offers a robust solution for real-time fire and smoke detection, with applications in forest surveillance, urban safety, and industrial monitoring.

Keywords: Fire Detection, Smoke Detection, Deep Learning, YOLOv8, Object Detection, Computer Vision, Real-Time Monitoring, Forest Fire, Image Processing, Emergency Response

I. INTRODUCTION

Fire and smoke pose serious threats to both natural ecosystems and human-built environments. Forest fires alone destroy millions of hectares annually, leading to loss of biodiversity, property damage, and significant environmental impact. Traditional fire detection systems, such as satellite imaging, thermal sensors, and manual surveillance through towers or patrols, often suffer from limitations including delayed response, high operational costs, and poor performance under adverse weather conditions. In urban settings, conventional smoke alarms and thermal detectors are generally reactive, triggering only after a fire has already spread to a dangerous level. These challenges underscore the urgent need for a faster, more accurate, and automated approach to early fire detection.

Recent advancements in computer vision and deep learning have enabled significant improvements in object detection tasks, especially with the advent of convolutional neural networks (CNNs) and real-time detectors such as the YOLO (You Only Look Once) series. YOLOv8, the latest version of this model family, offers enhanced accuracy, faster inference, and a lighter architecture, making it suitable for real-time applications. This research leverages YOLOv8 to develop a fire and smoke detection system capable of analyzing live video feeds and issuing timely alerts. By training on a diverse dataset of over 11,000 annotated images and incorporating preprocessing and decision-making logic, the proposed system aims to provide a scalable, accurate, and real-time solution for mitigating fire-related disasters across multiple environments.

II. LITERATURE SURVEY

A. YOLO-SF: YOLO for Fire Segmentation Detection

- Reference Paper: Cao, X., Su, Y., Geng, X., & Wang, Y. (2023). *"YOLO-SF: YOLO for Fire Segmentation Detection."* IEEE Access.
- Key Findings: This study proposed YOLO-SF; an updated YOLO-based model capable of detecting fire regions accurately across various fire scene types. It demonstrated high robustness and stability in identifying fire objects in both large and small scales.
- Review: The paper showcases the practicality of YOLO-SF for real-time fire segmentation. Despite high performance, the authors suggest future work to improve recall rates and enhance model sensitivity in complex environments.

B. EfficientNet for Wildfire Smoke Detection

- Reference Paper: Fernandes, A. M., Utkin, A. B., & Chaves, P. (2022). *"Automatic Early Detection of Wildfire Smoke with Visible Light Cameras Using Deep Learning and Visual Explanation."* IEEE Access.
- Key Findings: This study introduced a mosaic-like output using EfficientNet-B0 for smoke detection, achieving an AUROC of 0.949 with low false positives.
- Review: This work effectively addresses attention mismatches in neural networks, showing how tailored output layers can improve smoke localization. The EfficientNet-B0 model is highlighted as both lightweight and precise.

C. YOLOv8-FEP for Enhanced Fire and Smoke Detection

- Reference Paper: Zhang, T., Wang, F., Zhao, Q., Ning, W., & Wu, H. (2024). *"Research on Fire Smoke Detection Algorithm Based on Improved YOLOv8."* IEEE Access.
- Key Findings: YOLOv8-FEP introduced a multi-scale attention mechanism and a large-target detection head, improving both precision and recall over standard YOLOv8.
- Review: The proposed enhancements significantly improve robustness in complex fire scenes. The study also highlights future plans for improving detection in extreme environments by expanding the dataset diversity.

D. Spatio-Temporal Attention for Fire Detection in Video

- Reference Paper: Shahid, M., Virtusio, J. J., Wu, Y. H., Chen, Y. Y., & Hua, K. L. (2022). *"Spatio-Temporal*

Self-Attention Network for Fire Detection and Segmentation in Video Surveillance." IEEE Access.

- Key Findings: Introduced a two-stage architecture combining spatial and temporal features using attention modules, aimed at small fire detection.
- Review: This method offers effective early detection through minimal annotation and semi-supervised learning, though future work targets a more lightweight design for deployment on low-power devices.

E. Bayesian Neural Networks in Active Learning Fire Systems

- Reference Paper: Kim, Y. J., & Kim, W. T. (2022). *"Uncertainty Assessment-Based Active Learning for Reliable Fire Detection Systems."* IEEE Access.
- Key Findings: Introduced Bayesian FNNs and LSTMs with MC Dropout for uncertainty modeling in fire detection, achieving an F1-score of 0.952 with only 700 informative samples.
- Review: The active learning strategy is proven effective in reducing labeling costs while maintaining accuracy. It also demonstrates how BNNs can handle uncertainty in real-world detection systems.

III. System architecture:

The proposed fire and smoke detection system is structured into multiple interconnected modules, forming a pipeline that processes live video input into actionable alerts. The system is designed around the YOLOv8 deep learning framework, which is renowned for its speed and accuracy in real-time object detection. The architecture follows the traditional waterfall model, encompassing sequential phases such as requirement analysis, system design, implementation, deployment, and maintenance. Each phase ensures that the model operates efficiently from data input to final detection and alert generation.

At the core of the system lies the YOLOv8 model, which receives preprocessed and normalized image data. The input to the system comes from a high-resolution live video stream, which is first segmented into individual frames. These frames undergo preprocessing steps including resizing, color normalization, and noise reduction. Once the images are prepared, they are fed into the YOLOv8 object detection module. The model then performs bounding box regression and classification to identify regions with fire and smoke with high confidence levels.

The system also includes a decision-making module, which interprets the results generated by YOLOv8. If fire or smoke is detected, the module triggers an alert mechanism. This alert can take multiple forms, such as a visual warning on the user interface, a sound alarm, or a mobile notification. The flexibility in output design ensures that the system can be adapted for various environments such as forests, industrial areas, or buildings. Additionally, integration with messaging APIs allows alerts to be sent to emergency services or users via platforms like WhatsApp.

The architecture is built using open-source technologies to ensure easy maintenance and cost-effectiveness. The development stack includes Python 3.8 with TensorFlow and Keras for deep learning, OpenCV for image processing, and Tkinter for GUI design. The entire system runs efficiently on a standard laptop configuration (Intel Core i5, 8 GB RAM), making it suitable for deployment in edge computing scenarios. Overall, the system architecture balances performance, scalability, and ease of integration, making it a practical solution for real-time fire and smoke detection.

IV. Conclusion:

In this study, we developed a real-time fire and smoke detection system utilizing the YOLOv8 deep learning architecture. The system was trained on a large dataset comprising over 11,000 annotated images, allowing it to achieve high detection accuracy across various environments such as forests, buildings, and industrial areas. The YOLOv8 model demonstrated superior performance with a precision of 0.954, recall of 0.848, and mAP@50 of 0.926, outperforming previous YOLO versions. The modular system design includes preprocessing, normalization, object detection, and decision-making components, ensuring efficient and robust detection from live video input.

The results of this research validate the effectiveness of deep learning in fire and smoke detection applications. The system's lightweight design, ease of deployment, and use of open-source tools make it highly adaptable for real-world implementation, particularly in resource-constrained or remote areas. Future enhancements will focus on model optimization for edge devices and improving accuracy under extreme conditions, such as low lighting or occluded views. The proposed solution holds significant potential for enhancing emergency response systems and minimizing the impact of fire-related disasters.

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