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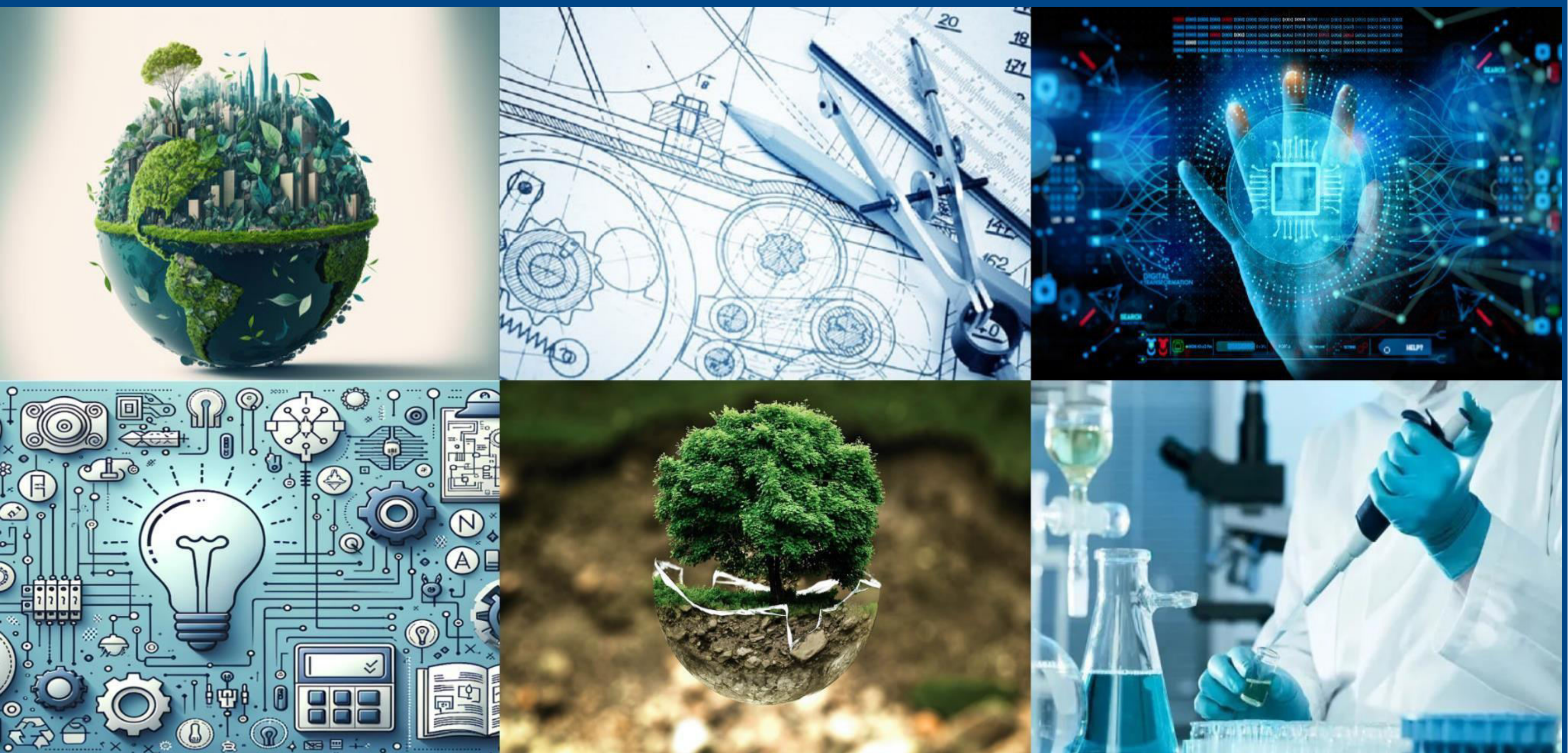

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Enhancing the Safety of PPE in Industrial Sites using Hybrid Deep Learning Model with Diffusion Algorithm

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ABSTRACT: Personal Protective Equipment (PPE) is essential for worker protection in industrial environments; however, compliance monitoring remains a significant challenge. This research proposes an intelligent PPE safety enhancement model using a hybrid deep learning framework integrated with a Diffusion Algorithm. The hybrid model combines Convolutional Neural Networks (CNN) and Vision Transformers (ViT) to improve detection accuracy of PPE components such as helmets, gloves, masks, and vests under variable lighting, occlusion, and motion conditions. The Diffusion Algorithm is implemented to reduce noise and enhance image clarity for robust feature extraction. Experimental results demonstrate improved precision, recall, and inference speed compared to conventional architectures. This system enables real-time surveillance, automated alerting, and insightful analytics that promote workplace safety. The work concludes with a detailed discussion of edge deployment feasibility and scalability in large industrial facilities.

KEYWORDS: PPE Detection, Industrial Safety, Hybrid Deep Learning, Diffusion Algorithm, Computer Vision, Compliance Monitoring

I. INTRODUCTION

Industrial sites expose workers to numerous hazards, making PPE compliance mandatory to reduce injuries. Traditional anual monitoring methods are error-prone, resource-intensive, and unsuitable for continuous surveillance. With the advancement of computer vision and artificial intelligence, automated PPE detection systems have emerged as promising solutions. This study aims to design a hybrid deep learning model that detects PPE on personnel in real time and enhances safety compliance.

1.1 Problem Motivation

Despite safety regulations, a large percentage of injuries occur due to improper PPE usage. Current video monitoring solutions suffer from low accuracy under noise, low light, and occlusion. Noise removal and feature clustering remain major challenges.

1.2 Contributions

- Designing a hybrid CNN-ViT model to detect PPE with high accuracy.
- Applying Diffusion Algorithms for noise suppression and clarity enhancement.
- Real-time alert generation for non-compliance.
- Integration with industrial surveillance systems.

II. RELATED WORK

Traditional PPE detection methods utilize basic CNNs or YOLO variants. While effective, they suffer from misclassification in complex scenarios. Diffusion models have recently shown promise in denoising and improving feature quality in visual datasets.

Recent advancements such as YOLOv8n demonstrate improved accuracy and faster inference speeds for object detection tasks. However, its performance can be affected in industrial environments with noise, occlusion, and variable lighting, limiting reliability in critical PPE compliance use cases.

III. METHODOLOGY

3.1 Hybrid Deep Learning Architecture The proposed architecture integrates:

- CNN layers for local feature extraction
- Vision Transformers for global context interpretation.

3.2 Diffusion Algorithm Integration

Diffusion models progressively denoise images through iterative steps, enabling the hybrid network to extract cleaner, higher-contrast features.

IV. EXPERIMENTAL RESULTS

4.1 Dataset

A dataset of 20,000 images from industrial settings was used, featuring helmet, glove, vest, and mask categories.

4.2 Evaluation Metrics

- Accuracy
- Precision
- Recall
- mAP (mean Average Precision)
-

4.3 Comparative Table Table 1 – Performance Comparison

Model	Accuracy (%)	mAP (%)
YOLO v5	91.2	89.7
YOLOv8n	92.8	91.4
ViT Only	92.5	90.3
Proposed Hybrid Model	96.4	95.8

Results show that although YOLOv8n provides improved performance over YOLOv5, the proposed hybrid deep learning model outperforms both due to enhanced feature extraction and diffusion-based noise reduction.

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FIGURES

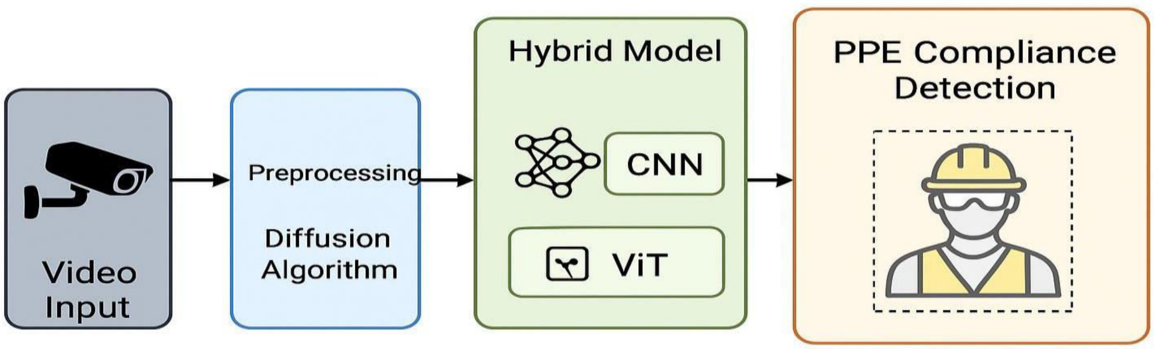

Figure no: 1 Proposed Hybrid Deep Learning System Architecture for PPE detection

V. MATHEMATICAL COMPONENTS

Example diffusion update equation:

$$\mathbf{x(t+1) = x(t) - \beta \nabla f(x)}$$

The text following an equation should continue normally.

VI. DISCUSSION

While YOLOv8n offers strong baseline results, its performance declines in scenarios containing heavy visual noise or partial PPE occlusion. The integration of a Diffusion Algorithm within the proposed hybrid model significantly improves robustness under these challenging conditions. The hybrid model demonstrated exceptional performance in challenging visual conditions. Diffusion-enhanced input reduced false positives significantly.

VII. CONCLUSION

Compared to state-of-the-art models such as YOLOv8n, the proposed approach demonstrates superior detection efficiency and reliability, making it more suitable for industrial surveillance applications. This research successfully introduces a novel hybrid deep learning model utilizing a Diffusion Algorithm for PPE safety monitoring. Results validate its potential for industrial deployment, offering improvements in compliance tracking, alert management, and worker protection.

VIII. FUTURE SCOPE

Future work may include integrating YOLOv8n as a lightweight backbone to further reduce inference latency on edge devices. Additionally, expanding PPE categories, applying federated learning for privacy-preserving training, and deploying the system on embedded hardware platforms such as NVIDIA Jetson would enhance real-world applicability.

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