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# Real-Time Ai-Based Ppe Compliance and Safety Intelligence for Construction Sites

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**Abstract- The construction site is considered a risky place for employees, and the risks are associated with falling objects, machines, and exposure to harmful substances. Monitoring the implementation of Personal Protective Equipment (PPE) standards, including helmets, vests, gloves, boots, and masks, is of critical importance in preventing accidents and injuries. The conventional approach to monitoring the implementation of these standards is through manual observation, which is associated with time delays and human error. This study proposes an intelligent framework for the implementation of PPE standards and safety monitoring using an improved YOLOv11 deep learning model for the detection and classification of different types of PPE in real-time construction site video feeds. The model is trained on a diverse dataset to cater to complex backgrounds, lighting, occlusion, and multiple PPE pose angles, ensuring the model performs well in diverse site environments. The framework helps improve workplace safety by ensuring compliance, reducing the probability of accidents caused by negligence, and promoting regulatory compliance, thereby creating a culture of consistent PPE usage and safe work practices across the construction industry.**

**Keywords- Compliance, Construction sites, Deep learning, Personal Protective Equipment, Real-time monitoring, Safety management, YOLOv11.**

## I. INTRODUCTION

The construction site is a dangerous environment where workers are often exposed to various hazards. This includes falling objects, machinery, and dangerous substances. Therefore, it is important to ensure that workers are complying with Personal Protective.

Equipment (PPE) policies, including helmets, safety vests, gloves, boots, and masks. In addition, traditional monitoring techniques rely on manual supervision, which has its own limitations. This includes human error, delayed responses, and limited site conditions. With the help of recent developments in computer vision and deep learning, it is possible to automate the process of safety monitoring. This includes the detection of any violation of compliance rules. By using the advanced version of the YOLOv11 algorithm and video feeds, this study provides an intelligent system that can recognize different types of PPE. The system not only improves adherence to safety regulations but also generates actionable data for site management, supporting proactive safety measures, minimizing risks, and fostering a culture of consistent PPE usage across construction sites.

Figure 1: Smart PPE detection in workerplace

### i). Problem statement

The construction site offers a wide array of hazards that pose a risk to the safety and well-being of the workers, including falling debris, the operation of heavy machinery, and exposure to hazardous materials. However, despite the inherent importance of Personal Protective Equipment (PPE), the majority of the industry relies on the most basic form of supervision to monitor the overall compliance of the workers. Such a method is, by its very nature, limited, which results in a situation wherein the overall detection of the violation is delayed, thereby increasing the probability of a mishap occurring due to human error or oversight. The lack of a real-time solution for the overall PPE compliance issue results in a situation wherein the overall management of the safety of the workplace is compromised. The current monitoring system is not efficient in the simultaneous detection of different kinds of PPE. It is also not capable of providing instant messages for corrective actions. This problem can be resolved by developing an intelligent system that can effectively classify and notify violations in PPE compliance. This will not only improve the enforcement of safety regulations but also help in adhering to regulations, reducing accident rates, and developing a safety culture.

**ii) Dataset details**

The dataset used in this study is a heterogeneous set of images collected from various construction sites, including different scenarios and activities of workers. The dataset includes images of different classes of Personal Protective Equipment (PPE), including helmets, safety vests, gloves, boots, and masks, among others. The images in this dataset have been carefully annotated to enable precise detection and classification. The dataset is also designed to handle various situations that may arise in a construction site, including partial occlusions, overlapping persons, and different orientations and backgrounds. Data augmentation methods, including rotation, scaling, and brightness, have been used to make the model more robust and capable of functioning effectively in different environments. The comprehensive dataset is used to train and fine-tune the improved YOLOv11 model to enable precise and reliable real-time PPE compliance monitoring.

**iii) Objectives**

The primary objective of this study is to create an intelligent framework for the detection and classification of Personal Protective Equipments (PPEs) on construction sites in real-time to ensure strict compliance with safety standards. Other objectives of the study are to develop a framework that minimizes the dependency on human supervision and human error in the process of monitoring, and to send instant alerts for corrective action through SMS, mobile notifications, and dashboards. The study also aims to develop a framework that is scalable and adaptable to different site conditions, including varying lighting conditions, occlusions, and complex backgrounds. In addition, the framework is intended to collect data on compliance over time, allowing for the analysis of safety trends and the implementation of proactive measures to enhance overall safety and compliance with safety standards.

## II. RELATED WORK

[1] Shanti, Mohammad Z., et al. proposed a deep learning-based framework for worker safety, focusing on the detection of helmets and harnesses using the DETR (Detection Transformer) model. The proposed framework detects the presence or absence of safety gear through real-time video feed collected from construction sites. The advanced object detection approach ensures the model performs well under changing lighting conditions, partial occlusions, and complex scenes. The research focuses on the accurate recognition of multiple safety devices. The proposed model uses the DETR transformer, which performs better for localization and classification compared to the CNN approach. The proposed framework sends alerts based on the violations detected. The proposed framework was tested on large datasets, including various construction site conditions. The proposed framework has high precision and high recall for detecting PPE violations. The proposed research has significant benefits for the construction industry, focusing on reducing accidents and ensuring regulatory compliance on construction sites.

[2] In the study conducted by Waqar, Ahsan, et al., the challenges associated with the adoption of IoT technologies in the safety management of small-scale construction projects in Malaysia are analyzed. In this study, the authors have applied the structural equation modeling technique to identify the challenges in the adoption of IoT technologies. The challenges identified in the study include the high cost of technology, the lack of technical knowledge, and the attitude of the employees towards the adoption of technology. The study has also identified the strategies to overcome the challenges in the adoption of IoT technologies. In the study, data have been collected from different construction sites to validate the proposed model. The study has provided insights into the relationship between the adoption of IoT technology and the safety of the employees. The study has also identified the role of IoT technology in the prevention of hazards in the construction industry.

[3] Hong, Younggi, and Jaeho Cho proposed a location safety check system for improving individual worker safety

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awareness within a work zone. The proposed safety check system is based on providing individual workers with real-time safety information regarding potential hazards within a construction site. The proposed safety check system is based on integrating GPS and safety information related to individual workers. The proposed safety check system is based on individual workers being provided with safety information regarding potential hazards within a construction site. The proposed safety check system is based on individual workers being provided with safety information regarding potential hazards within a construction site. The proposed safety check system is based on individual workers being provided with safety information regarding potential hazards within a construction site. The proposed safety check system is based on individual workers being provided with safety information regarding potential hazards within a construction site.

[4] In Baoju, Liu, et al., the researchers were concerned with safety helmet detection methods in heavy machinery factories using computer vision techniques. In the research, different object detection algorithms were implemented to ensure compliance in terms of wearing safety helmets by workers. The challenges that were identified in the research include different lighting conditions, machine occlusions, and the presence of multiple workers in one frame. The research has also shown that AI can be used to ensure the safety of workers in different industries. Accuracy, precision, and recall values were also used to check the effectiveness of different models. The results showed that using multiple algorithms and data augmentation can help in improving the accuracy and avoiding false negatives. In addition, warning signals can be sent to ensure that corrective actions are taken. It also helps in the analysis of compliance history.

[5] Al-Azani, Sadam, et al. suggested a framework for implementing a real-time PPE compliance monitoring system along with surveillance cameras to enhance safety at the workplace. The framework is based on deep learning concepts for detecting helmets, vests, gloves, and other equipment at once. The framework is designed to handle various issues such as overlapping workers, complex backgrounds, and varying distances from cameras. The framework generates alerts instantaneously via dashboards and notifications, thereby reducing reliance on traditional supervision. The framework is assessed based on metrics such as accuracy, precision, recall, and F1-score. The results show improved outcomes compared to traditional methods. The framework is designed to be implemented at multiple sites. The framework provides valuable insights to management to pinpoint areas of high risk and non-compliance. Overall, the framework proves to be highly beneficial for implementing AI-driven surveillance for PPE compliance.

[6] Investigate the factors that lead to the non-compliance of PPE among construction workers by using fuzzy logic theory, which was studied by Al-Bayati, Ahmed Jalil, et al. The research focused on the factors that affect the compliance of PPE, including the level of awareness, training, and workload of the workers, as well as the behavior of other workers and the level of supervision at the site. The research results identified the critical factors for non-compliance, including the lack of safety culture, lack of management enforcement, and lack of risk perception among the workers. The research emphasizes the fact that technical solutions can only be implemented to enhance the compliance of PPE, but human factors must be taken into consideration to improve the situation. The research results can be used to develop a better solution for improving the compliance of PPE by integrating the results of the research with the AI-based monitoring system to improve the compliance rate among the workers at the construction site.

Gallo, Gionatan et al.[7] developed an intelligent PPE detection system suitable for an industrial scenario that uses deep learning models in edge computing. The framework is capable of detecting helmets, gloves, vests, and other PPE in real-time directly on edge devices without needing cloud processing. The system is able to effectively handle issues such as occlusion, crowded spaces, and varying lighting. The use of edge computing in this context is beneficial in generating alerts in real- time in case of non-compliance. The study was able to achieve high accuracy, precision, and recall of various PPE types in an industrial scenario. The study also focuses on the scalability of the framework to deploy it in various plants without requiring major modifications in infrastructure. The study is beneficial in understanding the usage of edge computing in conjunction with deep learning in an efficient way. The study is beneficial in enhancing real-time occupational safety using intelligent systems.

[8] Sun, Lei, et al. proposed a novel YOLOv5s-CBCG algorithm for the detection of safety helmets in underground coal mines. The proposed algorithm uses a channel-based cross-grid feature enhancement method to improve the detection accuracy of the helmets, especially in low light and

visually complex conditions of the mining environment. The research addresses the problem of occlusion, the small size of the helmets, and the random location of the workers. The proposed system can process the video feeds in real-time, thus generating realtime alerts for non-compliance. The experimental results show a substantial improvement in the precision, recall, and F1-score of the detection of the helmets using the proposed algorithm over the standard YOLOv5 algorithms. The research demonstrates the utility of the proposed algorithm in improving the detection accuracy of the helmets, which can be very helpful for ensuring the safe mining of the coal mines. The framework can also help the mining supervisors to analyze the trends of the compliance of the workers, thus ensuring the safety of the workers.

[9] Curcuruto, Matteo, and Mark A. Griffin conducted a study on upward safety communication in the workplace, specifically on how team leaders contribute to workers' willingness to express safety concerns. The study points out empowering leadership and monitoring supervision as important contributors to stimulating proactive safety behaviors. Data collected from various sites in different industries showed that supervisors' active engagement is positively correlated with workers' PPE compliance and reporting. The study points out that organizational culture plays a role in supporting technical safety measures. The study's results indicate that safety systems should be implemented along with supportive management practices that promote workers' participation. However, it is also important to note that failure to implement upward communication may result in unreported hazards and low compliance levels. Overall, this study provides information on various ways to effectively implement PPE monitoring systems.

[10] A critical analysis of occupational safety and health practices in the construction industry of India was conducted by Samanta, Sasmita, and Jyotiranjan Gochhayat. The paper evaluates the regulatory aspects, compliance issues, and hazards faced by construction workers. The paper concludes with the gaps in the usage of PPE, inadequate safety training, and lack of supervision. The research paper also emphasizes the significance of incorporating technology, such as AI, with regulatory policies. The research paper also undertakes an analysis of the construction industry with international standards, which also concludes the significance of adapting the strategies based on the specific needs of the country, such as cultural, economic, and infrastructure conditions. The research paper concludes with the significance of adopting proactive strategies for ensuring the safety of the workers, as opposed to adopting reactive strategies. The research paper also concludes with the significance of adopting multi-faceted strategies for ensuring the safety of the workers, particularly in emerging economies.

## III. EXISTING METHODLOGY

In the conventional safety management of the construction site, the monitoring of the Personal Protective Equipments (PPEs) is done through the manual observation of the site managers or the safety officers. In this conventional approach, the site manager observes the workers on site and makes sure that all the safety protocols are followed. This includes the proper use of helmets, safety vests, gloves, boots, and masks. This conventional approach of monitoring the site has several disadvantages, as this process is quite time-consuming and the site manager cannot monitor the site at all times due to the extensive size of the site. Moreover, the conventional CCTV monitoring of the site is also done in several cases, but this process also requires the human observation of the site and the detection of the violations of the PPEs, which is quite time-consuming. In the conventional automated approaches, several attempts have been made to integrate the computer vision techniques and the object detection models like YOLOv3, SSD (Single Shot Detector), Faster R-CNN, etc. These models can identify objects within images with fair accuracy but find it difficult to function in complex situations found in construction sites.

These difficulties include dealing with changing lighting conditions, occlusion of workers, overlapping workers in images, and having two or more PPE in an image. Additionally, earlier models of these systems were designed to monitor one or two types of PPE in an image. This is problematic in practical situations because it is often required to monitor all PPE in an image simultaneously. These systems provide partial automation in construction site monitoring. However, there are significant disadvantages in existing systems. These disadvantages include human error in supervision, fatigue of workers in supervising sites, and inability of CCTV monitoring to provide proactive protection. CCTV monitoring is only effective after an accident occurs. Earlier AI-based solutions lack the robustness and speed required for live monitoring and fail to provide instant alerts, leaving potential safety violations unaddressed. Overall, the limitations of these existing technologies underscore the need for an intelligent, automated, and real-time PPE compliance system capable of accurately detecting multiple equipment types, providing immediate notifications, and supporting proactive safety management in dynamic construction environments.

## IV. PROPOSED METHODOLOGIES

The proposed system offers a smart and automated method for real-time Personal Protective Equipment (PPE) compliance checking at construction sites. The system uses the improved version of the YOLOv11 deep learning model, which is trained to recognize multiple classes of PPE, including helmets, safety vests, gloves, boots, and masks, among others. The system uses the real- time video feeds from the cameras installed at the construction site to analyze the activities of the workers to check for PPE compliance or non-compliance in real- time.

The improved version of the model has been trained on a dataset of images with different lighting conditions, occlusions, complex backgrounds, and varying PPE orientations, which helps to improve the accuracy of the detection of PPE at the construction site. Once the system is deployed, the system will classify the state of each worker's PPE, indicating if all the equipment is being worn. In the event of non-compliance, the framework will immediately send notifications through SMS, mobile apps, and/or dashboards, thus allowing the supervisors and site managers to respond to the situation in no time. This way, the need for manual supervision is reduced, and human error is also minimized. Furthermore, the system will offer the opportunity to monitor several sites at once, thus allowing the scalable deployment of the system in the context of the construction industry.

In addition to the aforementioned compliance detection, the proposed system will also record and save detailed information regarding the use of PPE. The data-driven approach will enable site managers to identify trends, areas of high risk, and take corrective actions to prevent accidents. The proposed system will improve the safety of the work environment through the use of object detection, proactive alerts, and thus improve regulatory compliance and promote the culture of using PPE. The inclusion of robust object detection, proactive alerts, and analysis makes the proposed system an improved version compared to the existing manual or semi-automated approaches for PPE.

## V. METHODOLOGY

### Data Collection and Dataset Preparation

Construction site images and video feeds are collected from diverse real-world environments to capture various worker activities and PPE scenarios. Each image is annotated to indicate the presence of specific PPE items, including helmets, safety vests, gloves, boots, and masks. To improve model robustness, data augmentation techniques such as rotation, scaling, flipping, and brightness adjustment are applied. This ensures the model can accurately detect PPE under varying lighting conditions, occlusions, and complex backgrounds.

### Model Selection and Enhancement

The enhanced YOLOv11 deep learning model is employed for object detection due to its superior speed and accuracy in real-time applications. The model is fine- tuned on the prepared dataset to recognize multiple PPE categories simultaneously. Network optimization techniques, including adaptive learning rate scheduling and advanced anchor box tuning, are applied to improve detection precision, especially in challenging scenarios with overlapping workers or partially visible PPE.

### Real-Time Camera Integration

Live video feeds from construction site cameras are continuously processed by the model. The system detects and classifies PPE compliance for each worker in real time, maintaining a high frame rate for instant analysis. Edge devices or cloud-based processing units are used depending on deployment requirements to ensure low latency and uninterrupted monitoring across multiple sites.

### PPE Classification and Compliance Detection

The model identifies whether workers are wearing the required PPE items and classifies each type. Compliance status is determined based on the presence or absence of mandatory equipment. The system can handle multiple workers in a single frame and accurately identify each PPE type regardless of orientation, occlusion, or distance from the camera.

### Alert and Notification System

Upon detecting non-compliance, the system immediately triggers alerts through SMS, mobile applications, or dashboard notifications. This ensures supervisors can take corrective action instantly, reducing response time and enhancing workplace safety. Historical data is also logged for future analysis and reporting.

**Data Analytics and Reporting**

Compliance data collected over time is analyzed to identify patterns, high-risk zones, and recurring safety violations. Insights derived from analytics help site managers implement proactive safety measures, optimize resource allocation, and ensure continuous adherence to PPE regulations.

**System Deployment and Scalability**

The framework is designed for scalable deployment across multiple construction sites. It supports integration with existing CCTV infrastructure and allows expansion with additional cameras or monitoring units as needed.

Cloud or edge computing solutions ensure efficient handling of real-time data while maintaining low latency and high reliability.

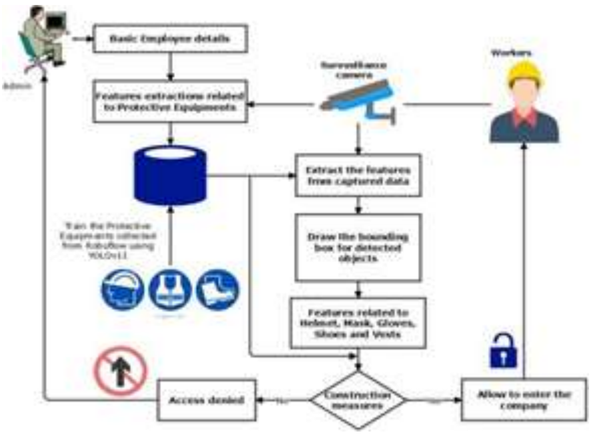


Figure 2: Diagram representation of the proposed methodology

**Algoritm**

- **Step 1:** Collect and prepare construction site images and live video feeds, ensuring all PPE types helmets, safety vests, gloves, boots, and masks are annotated.
- **Step 2**: Apply data augmentation techniques such as rotation, scaling, flipping, and brightness adjustment to enhance dataset diversity and model robustness.
- **Step 3:** Initialize and fine-tune the enhanced YOLOv11 model on the prepared dataset, optimizing anchor boxes and learning rates for accurate detection of multiple PPE categories.
- **Step 4:** Integrate live camera feeds to continuously capture worker activities and input the frames into the trained YOLOv11 model for real-time analysis.
- **Step 5:** Detect and classify each worker's PPE, determining compliance by checking for the presence or absence of required safety equipment in each frame.
- **Step 6:** Trigger immediate alerts via SMS, mobile applications, or dashboards upon identifying non-compliance, enabling supervisors to take corrective action instantly.
- **Step 7:** Log compliance data over time for analysis, enabling identification of high-risk areas, recurring violations, and the implementation of proactive safety measures.

## VI. EXPERIMENTAL RESULTS

The performance of the proposed PPE compliance detection framework was evaluated through its implementation on an exhaustive dataset of images and video feeds of construction sites. The proposed system was tested for its ability to achieve high accuracy in detecting different types of Personal Protective Equipment (helmets, vests, gloves, boots, and masks) under different conditions of illumination, occlusion, and complex backgrounds. The proposed enhanced YOLOv11 algorithm showed promising results in detecting PPEs with high accuracy and minimal latency.

The proposed system was compared with traditional manual supervision and other existing AI-based systems that used YOLOv3 and Faster R-CNN algorithms. The proposed system showed better performance compared to other existing systems in all aspects, including accuracy, precision, recall rate, and F1-score. The proposed system showed high accuracy in detecting different types of PPEs and minimizing false positives and false negatives. The proposed system showed high speed in processing video feeds compared to other existing systems.

Table 1: Performance Comparison of Existing Methods vs Proposed Framework

| **Method** | **Accura cy (%)** | **Precisi on (%)** | **Reca ll (%)** | **F1-Sco re (%)** | **Real- Time Capabil ity** |
|---|---|---|---|---|---|
| Manual Supervisi on | 65 | 70 | 60 | 65 | No |
| YOLOv3 -based | 82 | 84 | 80 | 82 | Partial |

| | | | | | |
|---|---|---|---|---|---|
| System | | | | | |
| Faster R-CNN | 85 | 87 | 83 | 85 | Partial |
| Proposed YOLOv1 1 Framewo rk | 95 | 96 | 94 | 95 | Yes |

The results indicate that the proposed framework achieves high accuracy and reliability in real-time PPE compliance monitoring. It significantly reduces human error, ensures consistent enforcement of safety protocols, and provides actionable data for site managers. These findings confirm the effectiveness of integrating advanced deep learning models with live monitoring systems for proactive workplace safety management.

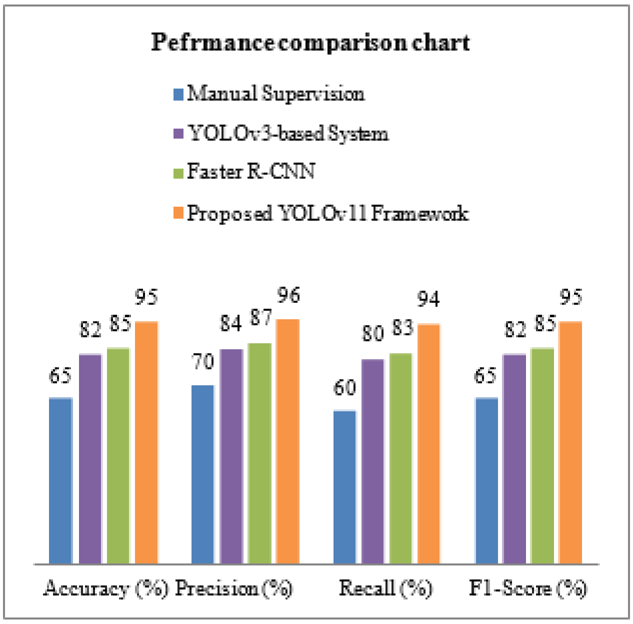


Figure 3: Performance metric chart representation

## VI. CONCLUSION

The implementation of the intelligent real-time PPE compliance monitoring system has significant advantages for the safety management of construction sites. This can be achieved by using the advanced YOLOv11 deep learning model for the accurate identification of different classes of Personal Protective Equipment, including helmets, safety vests, gloves, boots, and masks. The implementation of real-time camera and alert system has significant advantages in terms of providing immediate alerts for non-compliance. This approach can provide significant advantages for the safety management of construction sites by providing useful insights to site managers. In addition to real-time monitoring, the system can also be used for the collection and analysis of PPE compliance data. This can be useful for identifying potential improvements to the safety management system by using compliance records. Overall, the framework establishes a scalable and reliable solution for construction site safety, fostering a culture of consistent PPE usage and demonstrating the value of integrating advanced deep learning techniques with automated safety enforcement systems.

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