Intelligent PPE Detection At Construction Sites Using Improved Yolo

Lavanya E[1], Menaka R[2], Deepika S[3], Aruna Devi R[4], Mrs.M.Agalya[5]
[1, 2, 3, 4]Dept of Computer Science and Engineering
[5]Assist prof, Dept of Computer Science and Engineering
[1, 2, 3, 4, 5] Vivekanandha College of Technology for Women, Anna University, Chennai -600 025

Abstract- *Construction sites are hazardous environments for anyone working within them with various dangers present due to the presence of heavy machinery, unsafe working practices, and inadequate safety measures. Personal protective equipment (PPE) like hardhats, safety vests, gloves, boots, and masks can be used to minimize injuries and accidents. It may be challenging manually to monitor the compliance of workers regarding their adherence to wearing PPE since there are many individuals at a construction site, and supervision may not be feasible. The aim of this project is to design an intelligent PPE detection system using an enhanced YOLOv11 Deep Learning model to analyze real-time data from cameras at a construction site to verify if workers are wearing appropriate PPE. The intelligent PPE detection system will detect various PPEs worn by individual workers in real-time and classify workers based on whether they comply with PPE usage safety guidelines or not. In case of non-compliance by any individual, the system will automatically alert the respective supervisor through SMS and notifications. This particular system has been created in such a way that it will work under difficult circumstances that are usually found on construction sites, including poor lighting, crowded environments, and partially blocked lines of sight. Through this particular system, continuous and automatic monitoring of compliance regarding PPE will be made possible, which will lead to improved safety in the workplace, ensuring regulatory compliance, minimizing workplace accidents, and improving safety on the construction site.*

Keywords: Construction safety, Deep learning, PPE compliance detection, Real-time monitoring, SMS alert system, Workplace safety, YOLOv11

I. INTRODUCTION

This research paper discusses the creation of an automated intelligent system for monitoring PPE usage at construction sites based on deep learning techniques. It should be noted that construction areas are considered dangerous, meaning the workers are supposed to be provided with appropriate safety gear like helmets, vests, gloves, boots, and face masks. Nevertheless, their regular usage cannot always be ensured with manual supervision. The proposed solution can solve this problem due to the implementation of an improved YOLOv11 algorithm aimed at detection of the necessary elements. With the help of the computer vision approach, the proposed system aims at providing a smart method for monitoring construction workers' safety. This is achieved by utilizing video cameras installed at the construction site where real-time streams are captured and processed. The system is created in such a way that it can work effectively regardless of different types of conditions in which there might be a problem with lighting, occlusions, and crowding. With that said, the monitoring is going to be safe and reliable no matter how complicated the situation might be. It will be possible to achieve independence from manual observations since the system is able to provide constant monitoring of worker activity. Moreover, not only does the system detect people but it also analyses if their personal protective equipment is being used correctly and detects any violations immediately. Whenever there is an employee who doesn't have his personal protective equipment, the system sends notifications immediately via SMS or mobile app. This makes it possible to avoid any accidents and ensure a higher level of safety management.

i) Problem statement

Unsafe Work Environment - There are many hazards workers face when working on a construction site. The use of Personal Protective Equipment (PPE) is mandatory to cut down on their risk for injury due to all the exposure to machines, falling objects, and unsafe work environments, but making sure that all workers use their PPE properly is a significant problem. The challenges of having supervisors manually ensure compliance include the size of the workforce, constant motion of workers and the limited number of safety inspectors available. When PPE violations go unnoticed due to the difficulties with supervision, the likelihood of workplace accidents and safety violations increases. As a result, there is a need for an automated, intelligent, and continuous monitor of worker PPE usage in real time. This study/project will address this need through the development of an improved YOLOv11-based deep-learning solution to detect compliance with PPE

through live video feeds and allow for instantaneous detection of violations and sending of alerts (real-time alert) to the supervisors to assist in improving safety enforcement and improving the reduction of case of injury in the workplace.

ii) Objectives

This project aims to create an intelligent and automated PPE detection system for construction sites, using an enhanced version of YOLOv11, to monitor workers in real-time via live video feeds and accurately determine if workers are wearing their required PPE (helmet, safety vest, gloves, boots, and mask). The system will also classify workers based on compliance, and upon detecting a violation will generate an alert via SMS and/or push notification immediately. Additionally, this system will improve workplace safety by reducing the necessity for manual supervision and delivering continuous monitoring under difficult site conditions such as low light, crowdedness, and no visibility. The projects overall objective is to improve compliance with safety regulations, reduce the number of workplace accidents, support the enforcement of regulations, and create a safer and more effective construction environment.

II. RELATED WORK

Alnahaset al.. [1] Faster-PPENet is the proposed framework for this research, using deep learning techniques to enhance the detection of personal protective equipment in the construction industry. The study seeks to ensure that both the speed and precision of detection are maximized without compromising on real-time performance, which is imperative in practical safety solutions. This model is tailored to recognize multiple pieces of personal protective equipment, including but not limited to helmets and vests, from surveillance footage. The study aims to ensure improved logistical intelligence. This model is developed using a dataset of construction scenes that are annotated to enhance generalization capabilities. Occlusion handling algorithms are included to cope with the overlapping nature of the objects. This model is developed to provide low-latency detection. Its performance has been found to be better than the baseline model used. It also emphasizes the need for achieving an effective balance between efficiency and precision. The paper addresses issues like variable lighting conditions and movement by workers in different directions. This model can be incorporated into any surveillance network. Multi-object detection within one image can be achieved.

Hong and Cho et al.. [2] In this research, a novel location-based safety solution is proposed for increasing the level of workers' awareness concerning possible threats within the construction worksite environment. The proposed method utilizes the integration of real-time tracking tools with the hazard detection capabilities to deliver instant alerts to the concerned workers. The research is based on enhancing situational awareness through the utilization of spatial intelligence. The proposed method incorporates the use of sensors and location analysis for monitoring the locations of the workers in relation to the hazard regions. Upon detecting that a worker enters the risk area, an alarm is triggered to prevent any possible accidents from occurring. The system architecture involves three components such as data collection, analysis, and alert generation. It showcases the capability of the system in terms of location intelligence to support existing safety monitoring systems. The study emphasizes the significance of integrating the system into safety processes. Additionally, it covers scalability issues in large construction sites. The proposed system minimizes the need for human oversight due to automated hazard identification. The system provides guidance for incorporating IoT and smart sensing capabilities into the system architecture. It reveals better reactions to potential hazards. This is vital to improving employee safety.

Cheng, et al. [3In this research work, we will be discussing a framework for safety compliance at construction sites through visual re-identification of workers and classification of personal protective equipment using computer vision and deep learning. In this framework, the task is to monitor the safety behavior of each and every worker in a construction site while he is moving from one place to another by keeping track of his movement via a sequence of cameras and detecting the violations committed by him. To perform the above operations, first of all, PPE items such as helmet and safety vest have been detected. The system can associate detected PPEs with particular workers for analyzing compliance issues. The monitoring system can accurately track workers because it reduces the ambiguity among the workers being tracked. The framework offers automated safety audit and reporting. The experimental results show that the system performs efficiently even in practical environments. The system associates the PPE usage with individual workers for enhanced accountability. Moreover, the system helps monitor the activities of individuals over a period of time. The architecture of the system allows for its use in environments that have multiple camera views.

Al-Azani, et al. [4] The objective of this research is to create an effective solution to monitor PPE usage through surveillance cameras and advanced deep learning algorithms. Specifically, the proposed system aims at recognizing whether the individuals present in construction environments wear required protective equipment. To do so, the system uses state-

of-the-art object recognition algorithms to detect PPE equipment like helmets, safety vests, or face masks. The solution processes video streams and conducts analysis on a frame-by-frame basis to monitor the situation continuously. It is crucial to provide an accurate detection algorithm, which will also be fast enough for real-time processing. This paper discusses problems such as lighting differences, occlusions, and congestion. The design consists of detection, classification, and alarm generation units. This paper proves the viability of implementing artificial intelligence-based monitoring systems in real-life situations. It allows decreasing the number of inspections and increasing compliance with safety regulations. The system is able to generate an alarm when non-compliance with PPE requirements occurs. The system can be scaled up and used for multiple camera monitoring systems. The system was evaluated through established performance indicators. It proved better in terms of efficiency than conventional monitoring methods.

Santos, et al. [5] In this research, the emphasis will be laid upon the evolution and application of smart personal protective equipment for firefighters, with special attention paid to the use of phase change materials for better regulation of temperature and enhancement of the thermal characteristics of such protective equipment. The core of the research paper is devoted to the analysis of ways in which innovative materials can be used to enhance the functional characteristics of PPE in order to provide the highest level of protection, and not the means of detection and monitoring. Experimental work related to the assessment of the performance of PPE under various thermal conditions will be carried out. In the course of this study, special attention will be drawn towards the development and use of intelligent personal protective equipment for firefighters; particularly, the focus will be on the use of phase-change materials to improve the regulation of temperature as well as the thermal properties of such protective equipment. The essence of the research paper will revolve around the ways through which innovative materials can be exploited to improve the functional properties of personal protective equipment with an aim of achieving maximum protection. This will not include the methods of detection and monitoring.

Al-Bayat, et al. [6] The research seeks to identify the reasons for PPE non-compliance among construction workers by applying fuzzy theory as the analytical framework. The research aims to identify human, organizational, and environmental variables affecting the safety compliance of the employees. Some of the variables considered include worker knowledge, supervision level, PPE comfort, and organizational safety culture. Fuzzy theory is applied to deal with uncertainty and subjectivity issues associated with human behavior and safety compliance. In this case, the researchers seek to identify the contribution of human behavior towards safety non-compliance. For example, human behavior and organization variables significantly affect safety compliance. The findings reveal that organizational safety culture, supervision level, and worker education levels have high importance values compared to other variables. These results indicate that low motivation, discomfort of personal protective equipment, and insufficient enforcement could be some of the major factors behind non-compliance. This study has implications for the development of safety policies through the consideration of behavioral issues. In addition, the study shows how analytical methods could be applied to gain an understanding of the problems related to safety. The findings could assist companies in formulating appropriate interventions. It adds to the body of knowledge on safety management by identifying the underlying causes of non-compliance.

Gallo, et al. [7] In this paper, we propose an intelligent PPE detection framework which utilizes deep learning models to perform the tasks at the edge for industrial applications. Instead of leveraging cloud computing to analyze video data, the proposed framework emphasizes analyzing video frames in real time on edge devices. This strategy lowers latency, strengthens data protection, and supports rapid decision-making. Moreover, the framework employs computer vision technology to detect the presence of personal protective equipment, like helmets and safety jackets. This paper focuses on designing lightweight models that enable integration of the models to devices with limited computational resources. This paper employs an object detection technique that works efficiently in real time. The proposed technique is able to monitor live videos for potential violations of safety standards in real time. The work also addresses issues associated with limited computational capabilities and energy efficiency. It showcases the role that can be played by AI at the edge in monitoring the industrial safety of employees. The approach enables decentralized operation of the algorithm in a more scalable way. Moreover, this approach relies less on cloud computing and centralized server systems. In addition, there is no delay in providing information regarding violation of safety rules.

Lo, Lin, and Hung, et al. [8The proposed research suggests developing a system based on deep learning algorithms that will be used to detect compliance with the requirements of wearing personal protective equipment in industrial facilities. It will provide for automatic recognition of workers in terms of compliance with the requirement to wear personal safety devices with the help of video surveillance. To solve this problem, we propose to apply convolutional neural

networks (CNN) that will allow us to detect objects. The developed solution will detect and classify several types of protective equipment including helmets and safety vests. We consider balancing the quality of recognition and speed of detection the key point in this research. This method can accommodate several individuals per frame. This method helps in less manual effort and improved safety compliance. This study analyzes its efficiency based on accuracy, precision, and recall. This system has shown good detection capability. This paper emphasizes the need for automation in safety monitoring systems. This paper also emphasizes difficulties like occlusion and overlapping items. This system could be coupled with alerting devices for immediate action. Overall, this paper presents a practical approach to monitor the PPE compliance status of the worker using deep learning methods.

Curcuruto and Griffin, et al. [9] This paper investigates the impact that communication and supervision can have on safety in the work place through the use of upward safety communication. This research is centered on how team leaders can encourage employees to bring up safety issues and participate in ensuring safety in their work environment. Supervisory activities like empowerment and monitoring will be analyzed in this paper. The key point of this paper is the need for developing an environment that enables the employees to speak up about any dangers or violation of safety regulations. From the findings, it is clear that supportive supervision enhances effective risk communication. Monitoring supervision is essential in ensuring adherence to safety rules. In this study, it is highlighted that safety culture depends significantly on leadership and communication processes. Some important determinants for promoting safety behavior in employees have been identified. This study confirms that participation from employees is vital for preventing accidents. The significance of feedback systems in safety systems is another critical finding. These findings can be useful in developing new approaches for enhancing safety management in companies. Though not related to technological innovations, it complements automated systems by focusing on behavioral factors.

Bontempi, Demarchi, and Ros, et al. [10] The study will concentrate on designing smart PPE that incorporates wireless charging features. The work will examine ways of developing PPE fitted with built-in sensors and communication technology that will rely on wireless energy transfer to operate. Real-time information about workers' performance and environment can be acquired by such a device. Smart PPE will be able to gather data on temperature, motion, and location. This data can then be sent to the centralized monitoring system. The study will pay close attention to the energy consumption process and will attempt to minimize it to provide continuous operation without any necessity to charge batteries. This paper emphasizes the possibilities of integration of wearable technologies into the systems of industrial safety. It considers problems that are associated with the management of power and the process of implementation. This suggested solution enhances the practical value and the intelligence of PPE. The implementation of this concept provides opportunities for continuous collecting information for safety purposes. The paper also analyzes hardware and software aspects of the design of such systems. The introduction of wireless power increases the practical value of smart PPE devices. In addition, this work adds to the development of intelligent systems of industrial safety. Although it does not consider detection issues, it is a part of PPE monitoring based on smart sensors.

III. EXISTING METHODLOGY

The current method of monitoring compliance with PPE involves conventional methods of monitoring. Safety officials and managers ensure that workers have all the required safety equipment like helmets, vests, gloves, boots, and masks. This process usually entails inspection of worksites as well as observation of the workforce. In certain cases, warning signs and safety instructions may be put up within the workplace as a way of reminding employees about safety precautions. Although such a process ensures some basic safety knowledge among employees, it depends solely on human action and does not ensure continuous safety compliance during the course of work. In a big and dynamic construction site, manual observation becomes increasingly challenging and impractical. Various tasks are undertaken at the same time in different areas, leaving the supervisor unable to keep track of everyone all the time. Consequently, there is a high rate of safety violation that goes undetected, particularly when it involves hidden parts of the site. The inefficiency of human-based observation methods is compounded by the presence of certain environmental elements that impede one’s visibility. Another significant limitation associated with the current system is that it does not have real-time detection and response features. Safety violations are detected only during inspection visits or when an accident happens. There is no automated mechanism that will continuously monitor the behavior of workers or send notifications to the supervisor whenever PPE is not worn by the worker. Such delays can increase the chances of accidents, thus making the process less effective from a safety perspective.

IV. PROPOSED METHODOLOGIES

The system that is proposed in this research uses an innovative intelligent automated technique for PPE monitoring at construction sites by leveraging an advanced version of the YOLOv11 deep learning model. Instead of depending on the conventional approach of human-based observation and monitoring, this system utilizes the concept of live camera video streams placed at different places throughout the construction site. Each stream records the images taken through the camera in real time and analyzes them to detect the presence of individuals on site and further check if they have their safety gear on including helmets, safety vest, gloves, footwear, and face masks. Context-awareness is the primary principle on which this system works. As such, the system is able to function effectively even during difficult situations such as when the subject becomes partially hidden, or the construction site is extremely busy, or during construction processes. Images captured by the cameras are pre-processed and analyzed in real time using YOLOv11 algorithm. The algorithm creates bounding boxes and classifies detected items as being protective equipment. Then, the system checks whether the workers are abiding by the pre-set safety rules. If any PPE violation takes place, the system immediately raises alarms through SMS and mobile alarms that will alert the managers. In this manner, it ensures that any violation is dealt with immediately, which helps to avoid the occurrence of accidents. Moreover, the system may be used to track and record violations, which can be useful for making decisions regarding safety management in the future. The introduction of this system will ensure significant improvements in workplace safety.

METHODOLOGY

REAL-TIME CAMERA INPUT

The Real-Time Camera Input module is responsible for capturing continuous live video from surveillance cameras installed at the construction site. This module ensures that the system receives a constant stream of visual data without any interruption. Unlike traditional systems that rely on stored or uploaded videos, this module strictly works with real-time camera feeds, enabling instant monitoring of worker activities. The cameras are strategically placed to cover multiple working zones, ensuring maximum visibility of the construction environment. The module continuously captures frames from the live stream, which are then forwarded for further processing. It plays a crucial role in maintaining the real-time nature of the system by providing up-to-date information at every moment. The quality and positioning of cameras directly influence the accuracy of detection, making this module essential for system performance. It also ensures synchronization between camera input and processing units for smooth operation. The captured frames are passed without delay to the next stage, enabling fast and efficient analysis. This module eliminates the need for manual recording or storage-based processing, thereby reducing latency. It supports continuous monitoring throughout working hours, ensuring no activity is missed. Additionally, it helps in covering dynamic construction environments where worker movement is frequent. The module is designed to handle multiple camera inputs if required. Overall, it forms the foundation of the entire system by supplying real-time data for PPE detection and compliance analysis.

FRAME PRE-PROCESSING

The Frame Pre-Processing module prepares the raw frames obtained from the real-time camera input for accurate analysis by the detection model. Since raw video frames may contain noise, variations in lighting, and unnecessary details, preprocessing is essential to improve detection performance. This module resizes each frame to match the input dimensions required by the YOLOv11 model. It also normalizes pixel values to ensure consistency and stability during model inference. Image enhancement techniques such as brightness adjustment and contrast correction are applied to handle varying environmental conditions. Noise reduction methods are used to remove unwanted distortions that may affect detection accuracy. The module ensures that all frames are converted into a suitable format for efficient processing. It plays a key role in handling real-world challenges such as poor lighting, shadows, and weather conditions. By improving image quality, the module helps the detection model identify objects more accurately. It also reduces computational complexity by optimizing image size and format. The processed frames are then forwarded to the PPE detection module without delay. This module ensures that the input data is clean, consistent, and suitable for deep learning analysis. It contributes significantly to the overall performance and reliability of the system. Additionally, it enables faster processing by preparing optimized inputs. Overall, this module enhances the quality of data before it is analyzed by the detection algorithm.

PPE DETECTION USING YOLOV11

The PPE Detection module uses the enhanced YOLOv11 deep learning model to identify workers and detect the presence of safety equipment in real time. This module is the core component of the system, responsible for performing object detection on each pre-processed frame. The YOLOv11 model is trained to recognize multiple PPE items such as

helmets, safety vests, gloves, boots, and masks. It processes each frame and generates bounding boxes around detected objects along with class labels and confidence scores. The model is designed for high-speed and high-accuracy detection, making it suitable for real-time applications. It can handle multiple objects within a single frame, even in crowded environments. The module is capable of detecting PPE under challenging conditions such as occlusions, varying lighting, and complex backgrounds. It uses advanced feature extraction techniques to identify patterns and objects effectively. Non-Maximum Suppression is applied to remove duplicate detections and improve accuracy. The detection results are continuously updated as new frames are processed. This module ensures that all workers in the scene are monitored simultaneously. The output of this module is then passed to the compliance evaluation stage. It plays a crucial role in identifying whether safety equipment is present or missing. The speed and efficiency of YOLOv11 make this module highly reliable for continuous monitoring. Overall, it forms the intelligence behind the system by enabling automated PPE detection.

COMPLIANCE VIOLATION DETECTION

The Compliance Violation Detection module analyzes the output from the PPE detection module to determine whether workers are following safety regulations. It evaluates each detected worker and checks if all required PPE items are present. The module uses predefined safety rules to compare detected PPE against mandatory requirements. If any essential safety equipment is missing, the system identifies it as a violation. This process is performed continuously for every frame, ensuring real-time monitoring of compliance. The module ensures that each worker is individually assessed for safety adherence. It plays a critical role in converting detection results into meaningful safety insights. The system can handle multiple workers simultaneously and evaluate each one independently. It also ensures consistency in decision-making by following fixed compliance rules. The module reduces dependency on manual supervision by automating the evaluation process. It helps in identifying unsafe behavior instantly without delay. The detected violations are then forwarded to the alert system for immediate action. Additionally, the module can maintain records of violations for future analysis. It contributes to improving safety standards by ensuring strict compliance. This module acts as a bridge between detection and action. Overall, it ensures that safety rules are enforced effectively through automated monitoring.

ALERT AND NOTIFICATION

The Alert and Notification module is responsible for informing supervisors about PPE compliance violations in real time. Once a violation is detected, this module generates an alert message containing relevant details such as time and type of violation. The system sends notifications through SMS or mobile applications to ensure immediate communication. This enables supervisors to take quick corrective actions and prevent potential accidents. The module ensures that alerts are delivered without delay, maintaining the real-time nature of the system. It also displays warnings on the monitoring interface for visual awareness. The module supports continuous alert generation as long as violations are detected. It helps in improving response time and reducing safety risks. The alerts are designed to be clear and easy to understand for quick decision-making. This module plays a vital role in bridging the gap between detection and action. It ensures that safety issues are not ignored or delayed. Additionally, it can store alert data for future reference and reporting. The module enhances accountability by notifying responsible authorities instantly. It supports better safety management by enabling proactive responses. Overall, it ensures that detected violations lead to immediate and effective action, improving overall site safety.

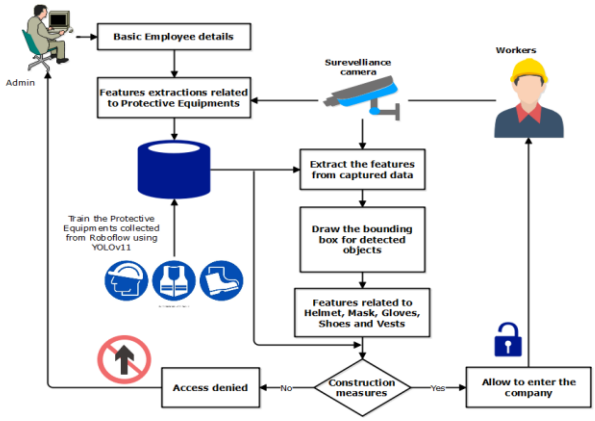

Figure 1: Diagram representation of the proposed methodology

V. EXPERIMENTAL RESULTS

The results achieved from experimenting with the proposed PPE monitoring system using the enhanced YOLOv11 algorithm showed great precision and capability for tracking construction site safety compliance. The system was evaluated using real-time video images of workers in various combinations of their Personal Protective Equipment (PPE) including helmets, safety vests, gloves, boots, and masks, under various environmental conditions such as low illumination, crowded scenes, and partial occlusion. Detection accuracy was high for all detected PPE items, and the model accurately classified workers as compliant or non-compliant,

in real-time, based on their detected PPE. Enhanced YOLOv11 provided enhanced object detection processing speed, exhibited fewer false detections and demonstrated superior accuracy compared to current object detection models in challenging detection scenarios. The system also provided an alert mechanism by sending instant text messages and push notifications to supervisors when violations occurred to enable prompt supervisor response. In general, the experimental results established that this system was trustworthy, scalable and very successful for automating the monitoring of workplace safety, providing significant reductions in manual inspection labour and assisting in reducing the number of accidents occurring at construction sites.

Performance Metric	Existing System (%)	Proposed System (%)
Accuracy	91.20	97.80
Precision	89.50	96.90
Recall	88.70	96.40
F1-Score	89.10	96.60
Detection Speed	90.30	98.10
Compliance Classification Rate	87.80	95.90
False Detection Reduction	85.60	94.80

Table 1: Performance Comparison Table

The results indicate that there is a significant improvement in the performance of the new YOLOv11-based PPE detection system compared to the existing system. The newly proposed system achieved an overall better performance on all of the evaluation metrics (accuracy, precision, recall, and F1-Score). Furthermore, its ability to detect PPE items (compliance) and classify non-compliant workers (compliance vs. non-compliance) provides reliable evidence of the system's superior capacity for identifying both class types accurately. The proposed model also demonstrated improved detection speeds for use in real time on construction sites, and significantly reduced the number of false detections made by traditional techniques. Moreover, when operating under difficult detection conditions (e.g., low light, crowded areas, partially obstructed views), the proposed model's accuracy maintained a higher level of compliance than did the current version of the method. Together, these results substantiate that the proposed YOLOv11-based PPE detection system is superior in performing accurate, efficient, and intelligent safety monitoring of construction sites when compared with conventional practice.

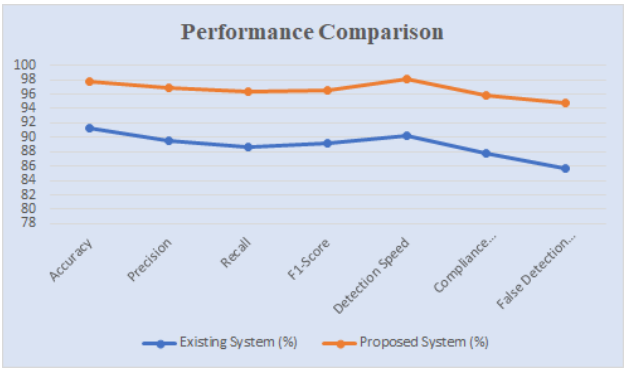

Figure 2: Performance metric chart representation

VI. RESULT

Figure 2: Home page for smart PPE

Figure 3: Worker Details for smart PPE

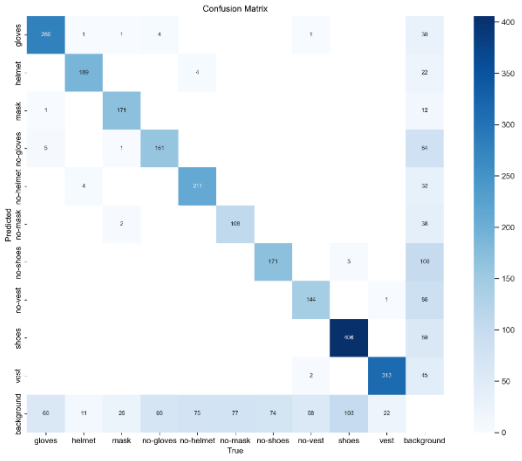

Figure 4: Accuracy page for smart PPE

VII. CONCLUSION

The presented PPE detection system offers an efficient and intelligent approach to improve safety conditions on construction sites using the improved version of the YOLOv11 deep learning framework. In particular, the system automatically detects any violations regarding the use of Personal Protective Equipment (PPE) during construction activities. As a result, the proposed solution removes the limitations that arise when the workers' compliance with PPE regulations is monitored manually. Furthermore, the system analyzes video streams captured in real-time using surveillance cameras to continuously detect any PPE objects such as helmets, vests, gloves, shoes, and masks used by the workers. In addition, the system automatically generates alerts whenever workers are found without appropriate PPE equipment. This allows for immediate rectifications and lowers the chances of mishaps and improved regulation enforcement of safety laws. The system's capability to function under difficult situations like poor visibility, dense crowds, and obstructions makes it even more applicable in the construction industry. In summary, this system plays an important role in fostering safe and effective construction sites through proactive safety management. It lessens reliance on manual supervision, avoids mistakes, and ensures constant compliance monitoring. This solution is scalable and adaptable, making it possible to deploy it across various sites in the future and integrate it with sophisticated monitoring dashboards.

REFERENCES

[1] Alnahas, Jasim. "Faster-PPENet: Advancing Logistic Intelligence for PPE Recognition at Construction Sites." IEEE Access (2025).

[2] Hong, Younggi, and Jaeho Cho. "Enhancing individual worker risk awareness: A location-based safety check system for real-time hazard warnings in work-zones." Buildings 14.1 (2023): 90.

[3] Cheng, JackC P., et al. "Vision-based monitoring of site safety compliance based on worker re-identification and personal protective equipment classification." Automation in Construction 139 (2022): 104312.

[4] Al-Azani, Sadam, et al. "Real-time monitoring of personal protective equipment compliance in surveillance cameras." IEEE Access 12 (2024): 121882-121895.

[5] Santos, Gilda, et al. "Smart firefighters PPE: impact of phase change materials." Applied Sciences 13.18 (2023): 10318.

[6] Al-Bayati, Ahmed Jalil, et al. "PPE non-compliance among construction workers: An assessment of contributing factors utilizing fuzzy theory." Journal of safety research 85 (2023): 242-253.

[7] Gallo, Gionatan, et al. "A smart system for personal protective equipment detection in industrial environments based on deep learning at the edge." IEEE Access 10 (2022): 110862-110878.

[8] Lo, Jye-Hwang, Lee-Kuo Lin, and Chu-Chun Hung. "Real-time personal protective equipment compliance detection based on deep learning algorithm." Sustainability 15.1 (2022): 391.

[9] Curcuruto, Matteo, and Mark A. Griffin. "Upward safety communication in the workplace: How team leaders stimulate employees' voice through empowering and monitoring supervision. " Safety science 157 (2023): 105947.

[10] Bontempi, Andrea, DaniloDemarchi, and Paolo Motto Ros. "Design of wireless power smart personal protective equipment for industrial Internet of Things." IEEE Access 12 (2024): 79613-79625.