Journal of Electronics and Informatics (ISSN: 2582-3825)
www.irojournals.com/iroei/

Construction Site Worker's Safety Detection System

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Abstract

The construction sites are one of the most dangerous workplaces, due to the presence of machinery, tall buildings, and unsafe practices at work. One of the main factors leading to accidents is the incorrect use of personal protective equipment (PPE) like safety helmets, safety glasses, safety footwear, and reflective jackets by employees. Besides, there are cases of undetected health problems that lead to injuries. Traditional approaches to safety monitoring involve human inspection and periodical examination of workers, which are time-consuming, prone to errors, and do not work effectively on large-scale construction sites. The goal of this research is the development of an intelligent worker safety detection algorithm for the smart construction site that would incorporate machine vision–based detection of PPEs and Internet of Things (IoT) technologies for health monitoring. The algorithm detects safety helmet and reflective jacket using machine vision based on deep learning algorithms, while body temperature is detected using a DS18B20 sensor interfaced with an ESP32 microcontroller. A decision-making mechanism confirms safety of the conditions and sends a warning message in case any violation or abnormal situation is observed.

Keywords: Construction Site Safety, Personal Protective Equipment, Deep Learning, IoT, ESP32, Temperature Monitoring.

DOI: https://doi.org/10.36548/jei.2026.2.001
Received: 27.02.2026, received in revised form: 30.03.2026, accepted: 17.04.2026, published: 29.04.2026

1. Introduction

The fast-paced growth of the Internet of Things (IoT) technology has greatly changed the interaction between the physical world and digital technologies. IoT allows the implementation of real-time data collection, processing, and transferring by devices; therefore, automation, remote control, and advanced decision-making processes can be achieved. As IoT involves using sensors and embedded systems, there are different application domains like healthcare, agriculture, and construction site safety.

The construction industry is known to be among the most dangerous fields for professionals because it includes the usage of heavy machinery, high-altitude work, and the constant change of working conditions. However, despite all the safety rules implemented at the construction sites, accidents still occur frequently. The main reason for the numerous accidents is the noncompliance with safety procedures, especially wearing PPE (Personal Protective Equipment) like safety helmets and jackets [1], [8].

The conventional methods of safety monitoring mainly focus on the process of human supervision which can be inefficient, time-consuming, and error-prone. Moreover, it is often difficult for supervisors to monitor all workers constantly, resulting in violation of safety measures and posing possible threats [7]. With the rapid development of artificial intelligence, computer vision, and deep learning technologies, there are some advanced PPE monitoring techniques that help enhance safety compliance and management. This technique uses the technology of image processing and neural network models for PPE detection [2], [4].

Moreover, with the help of the IoT framework combined with intelligent systems, real-time data transmission and remote monitoring become possible [9]. Moreover, recent trends in safety monitoring include the use of deep learning with embedded systems like ESP32 for efficient real-world application [3], [6].

2. Literature Survey

Various scientific investigations have focused on safety monitoring within the construction industry and highlighted the significance of enforcing PPE regulations. The conventional methods used for safety monitoring rely entirely on manual observation, which is inefficient, inaccurate, and subject to errors, rendering consistent monitoring challenging [7].

With the emergence of computer vision and deep learning techniques, automatic PPE detection methods based on camera monitoring have become popular and effective. Such systems ensure efficient and accurate detection and monitoring [1], [2]. Moreover, deep learning models have been devised to efficiently monitor PPE compliance in various construction scenarios [3]. In addition, real-time PPE detection techniques applicable in construction sites have been established [4].

There have been advancements in the design of automatic helmet detection systems based on deep learning methods that have proven effective in improving workers' safety and minimizing accident risks [5]. Moreover, deep learning algorithms have been used to enforce safety standards by ensuring workers use the required PPE in construction sites [8]. Besides vision-based techniques, there have been developments in the design of IoT-based safety systems due to their ability to enable real-time data transmission and supervision [9].

Studies conducted to date regarding the application of computer vision systems in construction projects show an increasing trend towards automation systems and their effectiveness in promoting safety regulations [10]. Contemporary developments emphasize lightweight deep learning models and edge computing systems that facilitate real-time processing at lower costs [3], [6].

The literature highlights that a combination of deep learning, IoT, and embedded systems serves as an ideal solution to smart safety monitoring. However, there are challenges such as computational cost, environmental variability, and implementation in real-time. This research offers a solution to the aforementioned challenges by providing an affordable PPE detection system using IoT-based health monitoring.

3. Methodology

The proposed Smart PPE Detection System operates on a logical sequence of steps that incorporate image processing, deep learning, and IoT monitoring techniques to guarantee safe working conditions on construction sites. The overall workflow of the proposed system is illustrated in Fig. 1. First and foremost, the process starts with a camera unit, which continuously takes real-time pictures and/or videos of employees on construction sites. Once the input data is collected from the camera module, it is subjected to image preprocessing procedures, during which operations like resizing and normalization occur.

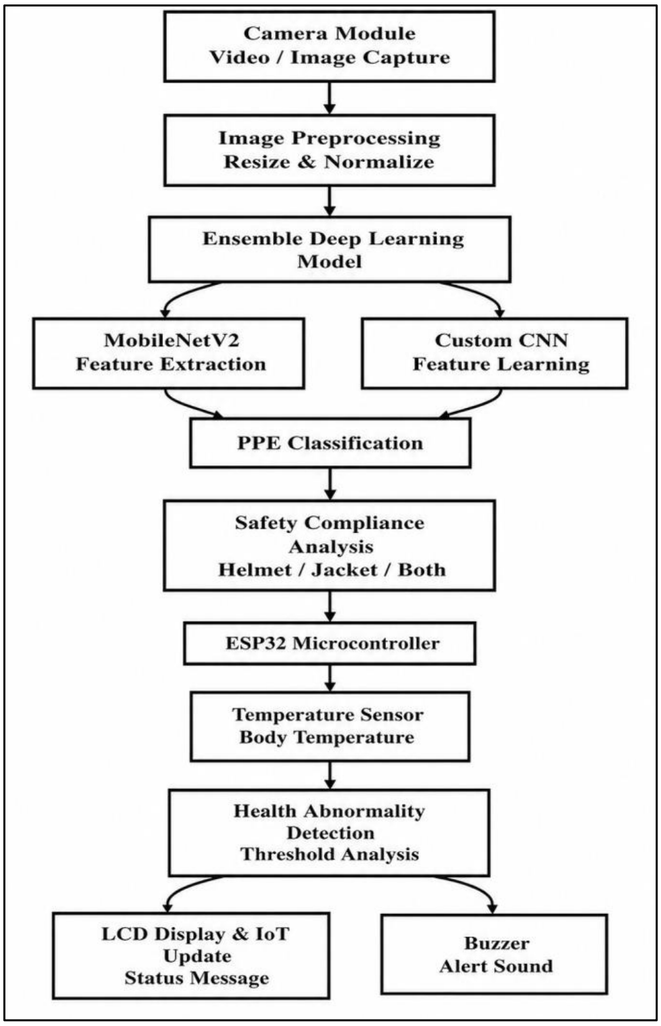

Figure 1. Workflow of the Proposed Smart PPE Detection System

An ensemble machine learning algorithm is employed for the purpose of detecting the presence of the PPE, combining both the abilities of the MobileNetV2 and a custom CNN. This allows for more accurate and efficient feature detection, as the lightweight nature of MobileNetV2 enables the efficient extraction of features, while the custom CNN aids in learning about particular patterns associated with PPE like helmets and safety jackets.

Once the features have been extracted, there comes the step of classifying the type of PPE that has been detected. The person could be wearing a helmet, a safety jacket, both, or none at all. This information is then used to carry out a safety assessment to check whether the employee meets the required safety levels. After feature detection, the data is transmitted to the ESP32 microcontroller, which becomes the control unit for the entire system. Furthermore, the system includes a temperature sensor, whose function is to measure the body temperature of the workers.

The threshold analysis method is used to find any discrepancies such as any hazards or abnormal temperature readings. The buzzer is triggered to give an audible alert, and there is a change in the status of the system either on the Internet of Things portal or the LCD screen. This approach will ensure real-time detection and constant monitoring, which makes it safer and reduces the chance of accidents occurring at the construction sites.

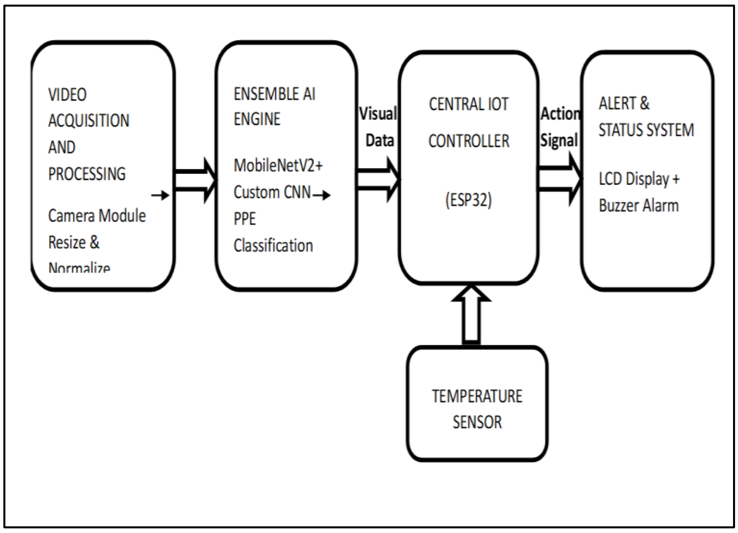

Figure 2. Block Diagram of the IoT-based PPE Detection and Monitoring System

A block diagram of the designed Smart PPE Detection System (Fig. 2) shows how data is acquired, processed, analyzed, and an alarm raised in case of any danger. The entire system comprises multiple components responsible for the execution of different tasks in order to achieve real-time monitoring for safety purposes.

The first step involves video acquisition and processing where a camera captures live videos/images of workers within the construction site. Preprocessing steps such as resizing and normalization transform the input data to ensure it can be analyzed by the next component. The next phase involves feeding the processed image/video to the ensemble AI engine that combines the functions of MobileNetV2 and a customized CNN for PPE identification. MobileNetV2 is effective in extracting features, whereas the custom CNN improves feature learning specific to safety equipment like helmets and jackets.

The result produced by the AI engine in terms of classified visual data is fed into the main IoT controller, which consists of ESP32 microcontroller. The ESP32 microcontroller serves as the central processing element of the module in charge of receiving the detection results as well as managing the operations of the module. It is responsible for communicating with other devices.

To enhance the system with health monitoring capacity, the temperature sensor is integrated. In addition to processing the PPE detection results, ESP32 also analyses the temperature information received from the sensor. Based on this information, it produces appropriate action commands to be sent to the alert system consisting of LCD and buzzer. The latter elements serve as the user interface, where the buzzer indicates audio alerts of hazardous situations.

4. Implementation

The execution of the suggested Smart PPE Detection System is achieved via the fusion of embedded hardware technology, vision processing through deep learning, and Internet-of-Things (IoT)-based communication. This system utilizes a hybrid approach that involves the execution of heavy computational image processing tasks with the help of a trained deep learning model and decision making through an embedded controller.

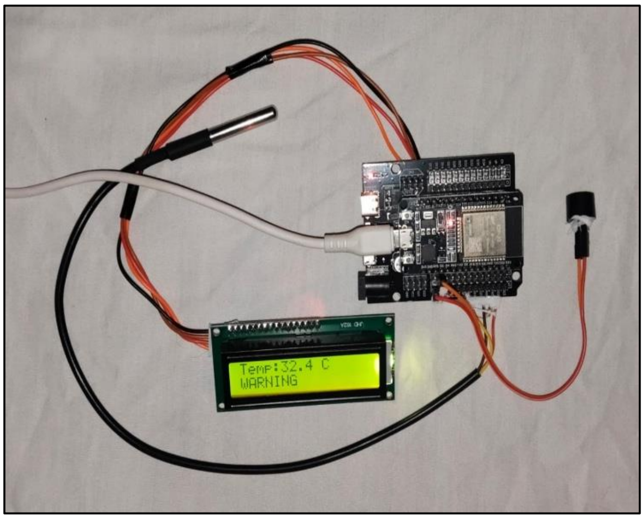

Figure 3. Hardware Implementation of the Smart PPE Detection System

Hardware Architecture (Fig. 3) includes a camera module, ESP32, DS18B20, LCD screen, and buzzer unit. Camera module is responsible for taking live videos of the construction site that are used in the detection process per frame. ESP32 is preferred because it acts as an IoT node as it has an integrated Wi-Fi feature, consumes less power, and suitable for real-time

ISSN: 2582-3825

applications. DS18B20 sensors will provide an accurate reading on temperature in the form of a digital format via a one-wire communication interface.

Software Implementation comprises three major processes: Preprocessing phase, feature extraction and classification, and decision-level fusion. During preprocessing, the images are normalized by resizing them to a certain predefined dimension (e.g., 224×224) to normalize the input distribution. Data augmentation like rotating, scaling, and brightness changes may be done when training the model in order to increase robustness to different environmental conditions.

For detecting the presence of PPE, an ensemble of deep learning models based on MobileNetV2 and customized Convolutional Neural Network (CNN) is used. MobileNetV2 acts as a backbone network to efficiently extract features based on depthwise separable convolutions that reduce the amount of computation involved in feature extraction. The obtained feature maps from the backbone network act as the input to the customized CNN network comprising multiple layers of convolution, ReLU activation functions, max pooling, and fully-connected layers.

Finally, the output layer employs the softmax function for classifying the input image as one out of the four classes, i.e., Helmet Only, Jacket Only, Both Helmet and Jacket, and No PPE. The trained deep learning model is put to use in an inference phase, during which prediction is made for the current video frame. The prediction information is sent to ESP32 through communication interfaces such as serial or network connections. After receiving the predicted class information, ESP32 analyzes the data using rule-based methods for checking the safety condition of the person. In case of violation of the safety rule, the buzzer alerts the worker, while LCD displays an appropriate message.

In parallel, the temperature sensor keeps track of the body temperature of the worker. The ESP32 uses a threshold-based analysis to check for any unusual health conditions, for instance, when the body temperature exceeds 37.5°C. In this situation, more alerts are sent, thus incorporating both safety and health checks into one system. With regard to the Internet of Things application, the ESP32 sends data to the cloud server using communication protocols that are easy to use, such as MQTT and HTTP. The data sent includes the timestamp, the PPE state, temperature data, and the alert state. Data storage and visualization using the cloud server take place from there.

5. Results and Discussion

The proposed PPE Detection System was subjected to a real-time evaluation for analysis of performance of detection and monitoring PPE compliance. The system successfully operated under real-time condition and classified each worker found in the scenes according to their PPE status. A sample detection output obtained from the system is shown in Fig. 4.

The PPE detection model successfully distinguished different states of workers according to their PPE, like helmet only, jacket only, helmet + jacket, and no PPE. The output classification result appeared alongside the captured images to provide visualization for the correctness of the detection. SAFE state occurred for workers who were wearing all required equipment whereas VIOLATION appeared for workers without complete protection equipment.

Detection model performed adequately in detection in controlled conditions with some variations in performance when encountering low illumination, occlusions, and motion blur conditions. The real-time feature of the system made it applicable in monitoring applications. Detailed logging was performed using Internet of Things and logged data included time stamps, prediction PPE category, and the system status. Data collected through logging process was sent to the cloud and users could access it remotely from the dashboard. Temperature detection was effectively executed in detecting anomaly temperatures.

The findings show that the system successfully applies the principles of deep learning and Internet of Things in order to build a safety monitoring application. Application of the MobileNetV2 as an extractor of visual features allows for minimizing computing costs thus making deployment on embedded platforms possible without loss of functionality. Integration of a custom CNN increases efficiency of feature learning and classification. One of the major benefits of the proposed system is its architecture, which separates complex vision processing from embedded control and makes the system scalable in terms of hardware capacity requirements.

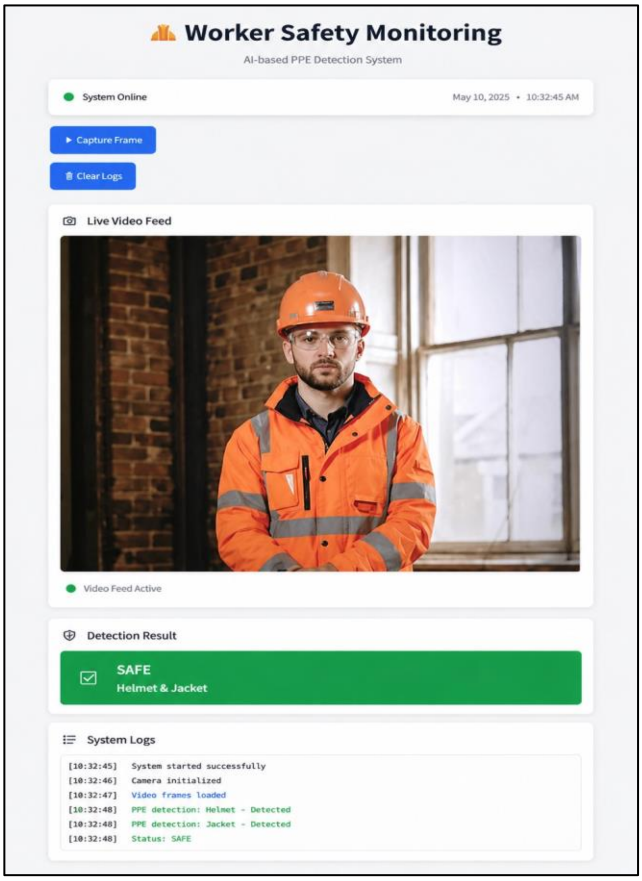

Figure 4. Sample Output Screen of PPE Detection Results

The implementation of an instant alert system that provides not only visual but also audible notifications allows for quick reaction to violations of safety standards and prevents possible accidents. Integration of IoT technologies contributes to increased efficiency of the system by providing remote monitoring, data logging, and analysis capabilities. Availability of such data allows to identify the frequency of accidents, patterns in workers' behavior, and other aspects related to workplace safety.

6. Conclusion

The smart PPE detection system based on IoT is a highly effective and intelligent way to enhance safety in construction environments by automating monitoring processes and analyzing data in real-time. With the help of the deep learning algorithms and an ESP32 IoT structure, the smart helmet and safety jacket detection system efficiently identifies when the workers wear personal protective equipment during their daily operations. Using a lightweight and effective model makes it possible to ensure the system's reliable functioning without wasting energy resources and time. The system features a real-time warning system, including a buzzer and LCD display, which helps detect all violations of security procedures immediately and take necessary actions to eliminate any threats. Moreover, IoT technologies enable the continuous transfer of data to cloud services, providing opportunities to monitor, log, analyze data, and make decisions. Thus, the implementation of the proposed approach proves its high efficiency and applicability to improve safety conditions in construction environments. Besides, this method is inexpensive, scalable, and convenient to implement in practice.

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