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Workplace Safety with Personal Protective Equipment Monitoring System using Computer Vision

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ABSTRACT

Workplace environments, particularly in manufacturing plants, are highly exposed to occupational hazards, emphasizing the need for effective and reliable safety monitoring systems. Traditional methods of enforcing Personal Protective Equipment (PPE) compliance rely heavily on manual supervision, which is often affected by human fatigue, inconsistent judgment, delayed response, and limited monitoring coverage. These limitations reduce the efficiency of workplace safety enforcement and increase the possibility of occupational accidents and injuries. To address these concerns, this study developed a Workplace Safety with Personal Protective Equipment (PPE) Monitoring System Using Computer Vision designed to provide automated and real-time PPE compliance monitoring in industrial environments. The developed system integrates computer vision and deep learning technologies to perform visual data curation, personnel facial image registration and identity verification, PPE detection, compliance assessment, and real-time reporting. The system utilized cameras, microprocessor, facial recognition, object detection, centralized database storage, and a web-based dashboard for monitoring and analytics. Functionality testing results revealed that the visual data curation module achieved 93.33% accuracy, personnel identity verification achieved 96.67% stability, PPE detection obtained 92.11% precision with a recall score of 0.95 and an F1-score of 0.93, while the compliance assessment module achieved 90.00% effectiveness. Furthermore, the reporting module demonstrated 96.67% reliability in event logging and monitoring operations. The acceptability evaluation using the extended Technology Acceptance Model (TAM) obtained an overall mean rating of 4.68 interpreted as Highly Acceptable. The findings indicate that the developed system has strong potential to improve workplace safety management through automated PPE compliance monitoring, personnel verification, and real-time safety reporting.

Keywords: Computer Vision, PPE Detection, Workplace Safety, Deep Learning, Facial Recognition

INTRODUCTION

Workplace safety remains a critical concern in manufacturing plants due to the constant exposure of workers to occupational hazards and industrial risks. Personal Protective Equipment (PPE) serves as one of the primary safeguards against workplace injuries, particularly in environments requiring head protection, face protection, protective gloves, and protective clothing. Despite the implementation of safety regulations and organizational policies, PPE compliance remains inconsistent because conventional monitoring approaches rely heavily on manual inspection and supervision.

Recent reports from the International Labour Organization (ILO) and World Health Organization (WHO) highlighted the growing number of work-related injuries and fatalities associated with unsafe work practices and inadequate safety compliance. In manufacturing environments, non-compliance with PPE requirements increases the probability of accidents, injuries, and operational liabilities. Manual monitoring methods are often limited by fatigue, human error, delayed response time, and restricted monitoring coverage.

Advancements in computer vision and artificial intelligence provide opportunities to automate safety monitoring operations. Deep learning-based object detection and facial recognition technologies enable systems to detect PPE usage, verify personnel identity, and generate real-time alerts. This study developed a Workplace Safety with Personal Protective Equipment Monitoring System Using Computer Vision capable of detecting PPE compliance in real time, logging violations, verifying personnel identity, and providing dashboard-based monitoring and analytics.

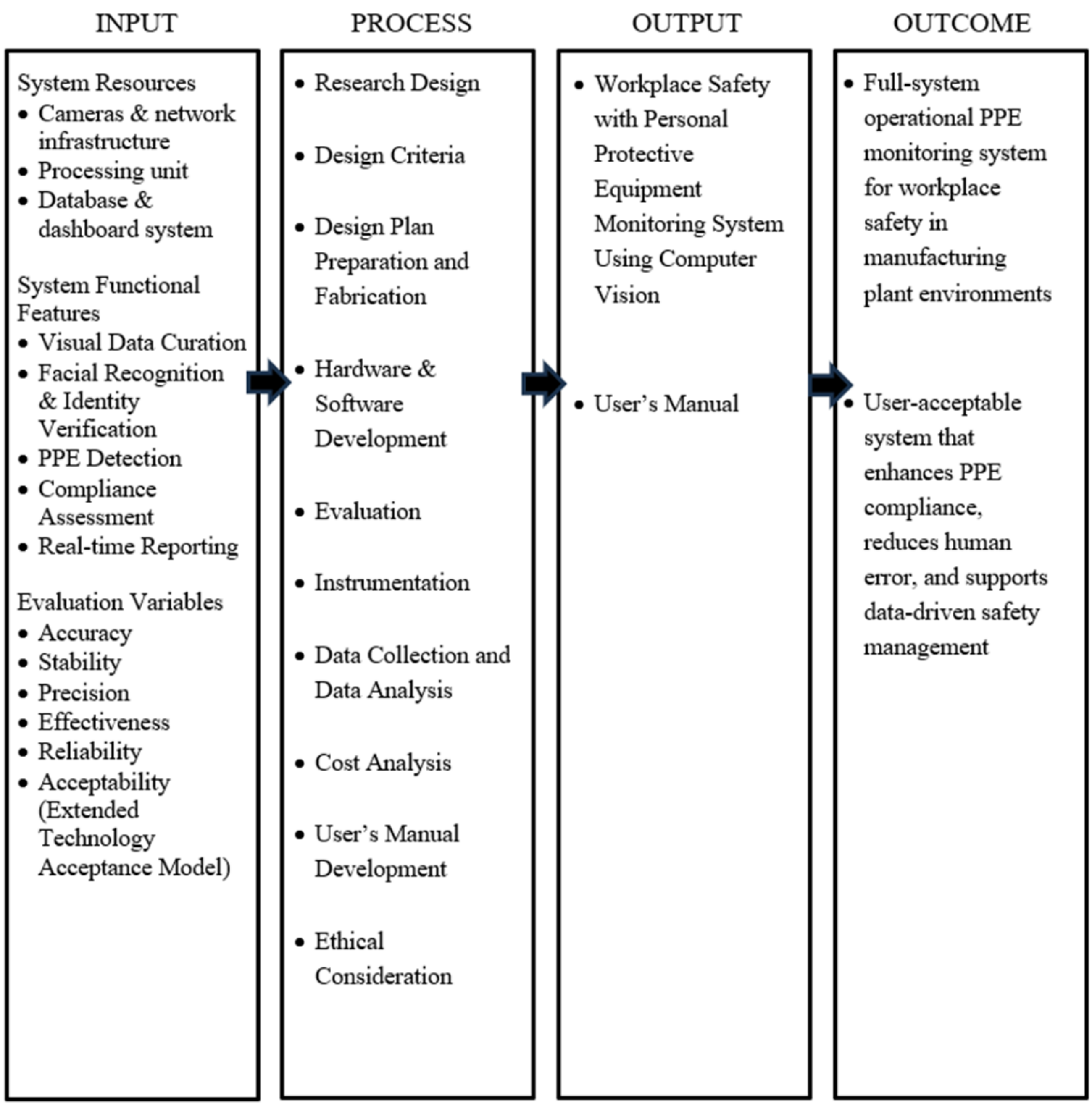
Objectives of the Study

The study aimed to develop a Workplace Safety with Personal Protective Equipment (PPE) Monitoring System Using Computer Vision capable of performing visual data curation, personnel facial image registration and identity verification, PPE detection, compliance assessment, and real-time reporting. Specifically, the study evaluated the functionality of the developed system in terms of visual data curation accuracy, identity verification stability, PPE detection precision, compliance assessment effectiveness, and reporting reliability. The study also evaluated the acceptability of the developed system using the extended Technology Acceptance Model (TAM). The evaluation focused on five key dimensions: Perceived Usefulness (PU), which measures how the system improves workplace safety monitoring and efficiency; Perceived Ease of Use (PEOU), which evaluates how easy the system is to operate; Attitude Toward Adoption (ATA), which assesses users' willingness to accept the system; Behavioral Intention to Use (BI), which determines the likelihood of continuous system usage; and Trust in the Proposed System (TR), which examines users' confidence in the system's reliability and accuracy. These parameters were used to determine the overall acceptability and potential adoption of the proposed system in workplace environments.

Framework of the Study

The conceptual framework of the study illustrates the operational structure of the Workplace Safety with Personal Protective Equipment (PPE) Monitoring System Using Computer Vision designed for manufacturing plant environments. The framework follows the Input–Process–Output–Outcome (IPOO) model, which explains how system resources and processes are transformed into functional outputs and intended workplace safety outcomes. The input stage includes the essential system resources such as cameras, processing units, network infrastructure, and database systems that support real-time monitoring and data storage. It also covers the major system features, including visual data curation, facial recognition and identity verification, PPE detection, compliance assessment, and real-time reporting, together with evaluation variables used to measure system performance and acceptability. The process stage involves system planning, design, development, testing, data collection, and evaluation. During this stage, computer vision technologies are integrated to perform PPE detection and personnel verification while ensuring accurate compliance assessment and reporting functions. The output of the study is a functional Workplace Safety with PPE Monitoring System capable of real-time monitoring, alert generation, logging, dashboard reporting, and user support through a manual. Ultimately, the study aims to provide a technologically acceptable and automated workplace safety monitoring system that enhances PPE compliance and supports data-driven occupational safety management.

Figure 1. IPOO Conceptual Framework of the Study



Scope and Limitations

This study focuses on the development of a Workplace Safety with Personal Protective Equipment (PPE) Monitoring System Using Computer Vision for manufacturing plant environments. The system is designed to monitor PPE compliance in real time through facial recognition at entry points, PPE detection, incident logging, image capture, and automated notifications to safety officers when violations occur. It also supports data transfer and centralized monitoring through a processing unit and database system. Testing and validation were conducted in controlled and semi-controlled environments using predefined workplace scenarios. However, the study is limited to selected PPE items such as head protection, face protection, protective clothing, and gloves. The system's performance depends on hardware capability, network stability, and environmental conditions, and it is intended only for prototype development and laboratory-scale testing.

Significance of the Study

The results of this study will benefit stakeholders in workplace safety and computer vision technology. Manufacturing plant management may use the system as a real-time and data-driven tool for monitoring PPE compliance, reducing workplace risks, improving efficiency, and supporting safety regulations. Safety officers and occupational health practitioners may benefit from automated monitoring, real-time alerts, incident logging, and reporting features that improve safety enforcement and corrective actions. Workers and plant personnel may gain improved protection and safety awareness through continuous PPE compliance monitoring. The study also contributes to academic institutions by providing a practical application of computer vision and artificial intelligence in workplace safety. Electronics engineering and information technology professionals, students, and future researchers may use the study as a reference for developing and improving automated occupational safety monitoring

METHODOLOGY

The study utilized a developmental research design in designing and developing the Workplace Safety with Personal Protective Equipment Monitoring System Using Computer Vision. The system architecture consisted of two major monitoring components: an entry facial recognition module and a PPE detection module for operational monitoring. The system utilized cameras, Raspberry Pi edge processing, centralized processing units, Flask-based web interfaces, and a MySQL database for real-time monitoring and data storage.

The developed system performed visual data curation, personnel registration, facial image embedding generation, PPE detection, compliance assessment, and automated reporting. The PPE detection process utilized deep learning object detection techniques capable of identifying hardhats, face protection, gloves, and protective clothing. Facial recognition was implemented using InsightFace technology for personnel identity verification.

Hardware Design and Development

Figure 2. System Architecture of the Developed PPE Monitoring System

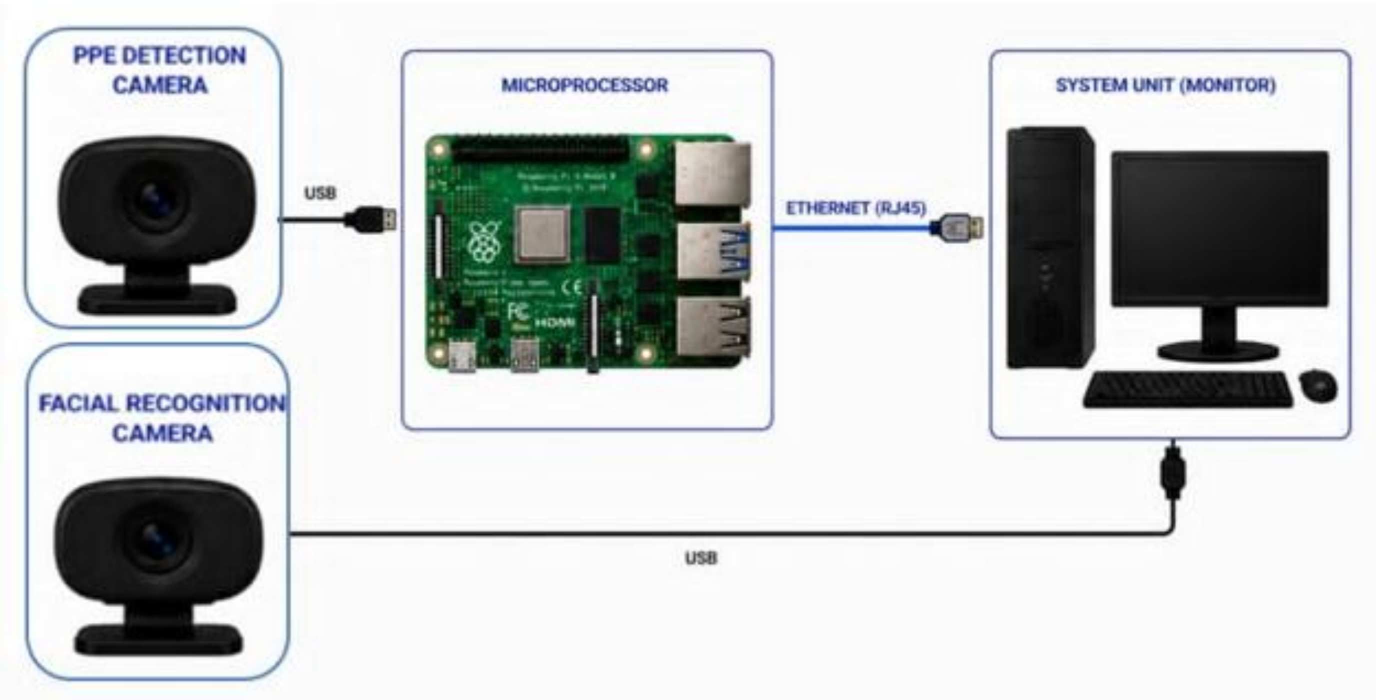


Table 1. Hardware and Software Components

Component	Type	Function
USB Camera	Hardware	Captures workplace images and video streams
Raspberry Pi	Hardware	Performs edge processing and detection
Flask	Software	Provides web-based monitoring interface
YOLO	Software	Performs PPE object detection
InsightFace	Software	Performs facial recognition and identity verification
MySQL Database	Software	Stores monitoring records and logs

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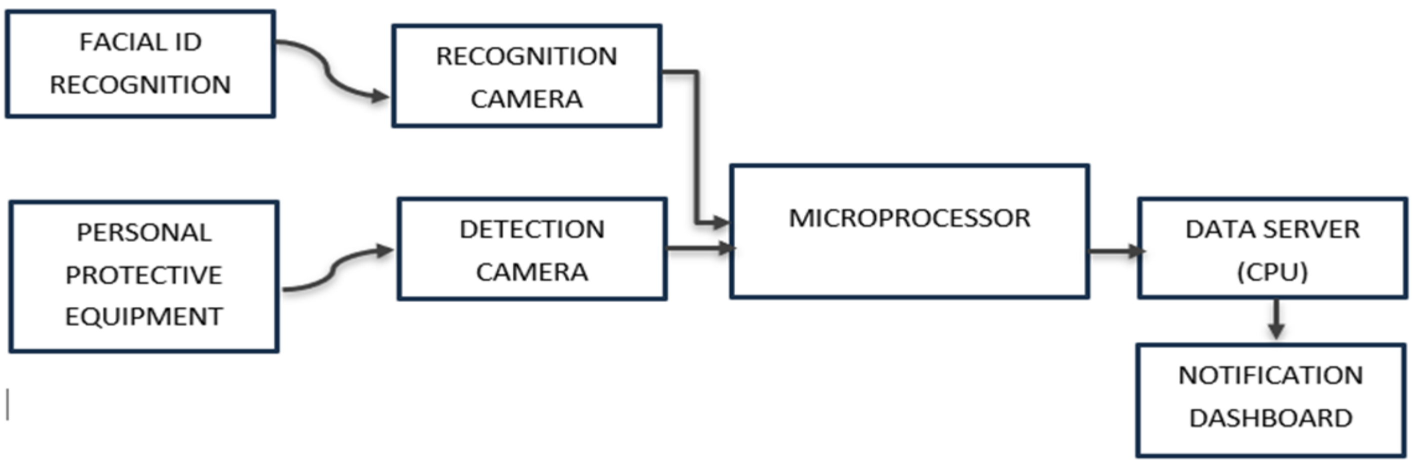
The developed Workplace Safety with Personal Protective Equipment (PPE) Monitoring System Using Computer Vision consists of integrated hardware and software components that work together to perform real-time workplace safety monitoring, personnel verification, and PPE compliance assessment. The USB camera functions as the primary image acquisition device, capturing real-time workplace images and video streams from designated monitoring areas. These visual inputs are transmitted to the processing unit for analysis and detection.

The Raspberry Pi serves as the edge processing and control unit of the system. It handles image processing, executes computer vision algorithms, and manages communication between the camera, monitoring interface, and database system. The Flask framework is utilized to develop the web-based monitoring interface and dashboard, enabling authorized users and safety personnel to access live monitoring feeds, view alerts, monitor violation logs, and manage system operations through a browser-based platform.

For intelligent visual analysis, the system uses YOLO (You Only Look Once), a deep learning-based object detection model designed to identify and detect required PPE components such as head protection, face protection, protective clothing, and gloves in real time. In addition, InsightFace is integrated into the system to perform facial recognition and personnel identity verification, particularly during entry-point monitoring. This allows the system to associate detected violations with registered personnel.

A MySQL database is used as the centralized storage system for maintaining personnel records, captured images, PPE detection results, violation logs, timestamps, and monitoring reports. This database supports efficient data retrieval, documentation, and reporting functions required for workplace safety management.

Figure 3. System Block Diagram



The system architecture diagram illustrates the operational flow from camera input, microprocessor preprocessing, facial recognition and PPE detection modules, centralized database storage, and dashboard-based reporting and notification.

The block diagram of the proposed Workplace Safety with Personal Protective Equipment (PPE) Monitoring System Using Computer Vision presents the interaction and flow of data among the major hardware and software components of the system. The design begins with two major input components: Facial ID Recognition and PPE Monitoring. The Facial ID Recognition module is implemented at the entry point of the workplace using a recognition camera that captures the facial images of personnel entering the operational area. The captured facial data are compared with registered records stored in the database to verify personnel identity and ensure that only authorized individuals are monitored within the system. This process also allows detected PPE compliance results and violations to be associated with verified personnel identities.

At the same time, the PPE Monitoring component uses a detection camera to capture real-time images and video streams of workers within the workplace environment. The system analyzes these images to determine whether the required PPE components, including head protection, face protection, protective gloves, and protective clothing, are properly worn by personnel. The captured visual data from both cameras are transmitted to the microprocessor, which performs preliminary preprocessing and synchronization of image data before forwarding them to the data server or central processing unit (CPU).

The data server serves as the primary processing and decision-making unit of the system. It executes computer vision and machine learning algorithms responsible for facial identity verification, PPE detection, and compliance assessment. In addition, the server handles data storage, violation logging, image recording, and report generation. Once processing is completed, the results are transmitted to the notification dashboard, which functions as the output interface of the system. The dashboard provides real-time monitoring, displays alerts for PPE violations, and maintains logs and reports for workplace safety evaluation and auditing. Through this integrated operation, the proposed system enables continuous, automated, and accurate workplace safety monitoring within manufacturing and laboratory environments..

Software Design and Development

Planning Phase

The planning phase established the overall direction, objectives, scope, and limitations of the Workplace Safety with Personal Protective Equipment (PPE) Monitoring System Using Computer Vision. During this phase, the system was conceptualized as an automated workplace safety monitoring tool capable of performing visual data curation, personnel facial image registration and identity verification, PPE detection, compliance assessment, and real-time reporting. The scope of the study was also defined, including the limitation of facial recognition only at entry points and the detection of selected PPE components such as head protection, face protection, protective clothing, and gloves. In addition, the required hardware and software resources, including cameras, processing units, computer vision models, facial recognition modules, and database systems, were identified together with the intended system users such as administrators, safety officers, and personnel.

Analysis Phase

The analysis phase focused on identifying and understanding the functional requirements, operational processes, and system capabilities of the Workplace Safety with Personal Protective Equipment (PPE) Monitoring System Using Computer Vision. During this phase, the researcher analyzed how the system captures, processes, and interprets visual inputs from workplace environments to support automated safety monitoring operations. The phase examined the sequence of operations involved in image acquisition, personnel identity verification, PPE detection, compliance assessment, and real-time reporting. It also identified how the system determines whether workers are compliant or non-compliant based on the detected presence or absence of required PPE components such as head protection, face protection, protective gloves, and protective clothing.

The interaction between major system components, including cameras, computer vision models, facial recognition modules, processing units, the monitoring dashboard, and the database system, was also analyzed to ensure proper integration and efficient data flow. In addition, workplace conditions that may affect system performance were considered, including multiple personnel within a frame, movement, varying lighting conditions, camera angles, and partial visibility of PPE. These considerations helped identify the necessary operational capabilities and limitations of the system to ensure reliable and effective performance within actual workplace environments.

Design Phase

The design phase defined the overall structure, architecture, and organization of the system. The system was designed to follow a sequential operational flow beginning with image acquisition through camera devices, followed by visual data processing, identity verification, PPE detection, compliance assessment, and reporting. The facial recognition module was positioned at designated entry points for personnel verification, while the PPE detection module continuously monitored workers within the operational area. The database structure was designed to store personnel information, facial data, detection results, timestamps, captured images, and violation records for efficient retrieval and reporting. In addition, the monitoring dashboard interface was developed to provide real-time monitoring, incident viewing, statistical analytics, and record management for safety officers and administrators. The design phase also included the preparation of system flowcharts, block diagrams, and interface layouts to clearly illustrate the interaction, communication, and operational sequence of the different hardware and software components within the system.

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Coding Phase

The developed PPE detection module utilized the YOLO26 object detection architecture for real-time workplace safety monitoring. YOLO26 was selected because of its high-speed inference capability, lightweight deployment compatibility, and strong object detection accuracy suitable for edge-computing environments such as Raspberry Pi-assisted monitoring systems. The model performs single-stage object detection, enabling simultaneous localization and classification of PPE components including hard hats, face masks, protective gloves, and safety vests within a single processing pipeline. Compared to traditional two-stage detectors, YOLO26 provides faster inference speed while maintaining reliable detection performance, making it suitable for real-time industrial monitoring applications.

The coding phase involved the development and integration of the software components of the system using the Python programming language. OpenCV was utilized for image acquisition, preprocessing, and real-time video processing, while the Ultralytics YOLO framework served as the primary object detection model for identifying PPE components such as hard hats, face masks, gloves, and protective clothing. InsightFace was integrated for facial recognition and personnel identity verification through facial embedding comparison. The system also incorporated a database for storing personnel records, detection results, timestamps, captured images, and violation logs, together with a monitoring dashboard for displaying real-time outputs, compliance status, incident reports, and statistical monitoring information. Additional coding procedures were implemented for data handling, system synchronization, error handling, and communication between modules to improve system reliability and operational stability. All system modules were integrated into a single operational platform to ensure stable and continuous operation.

Figure 4. Facial ID Recognition Flow Chart

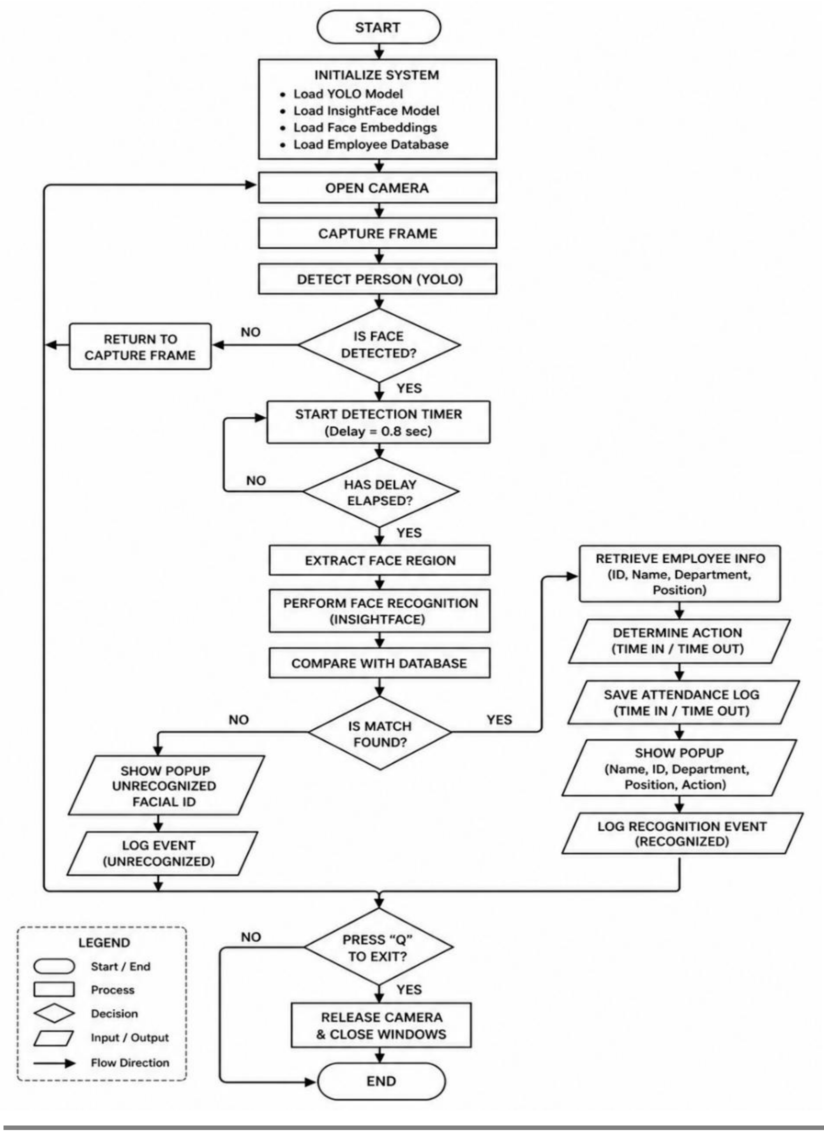

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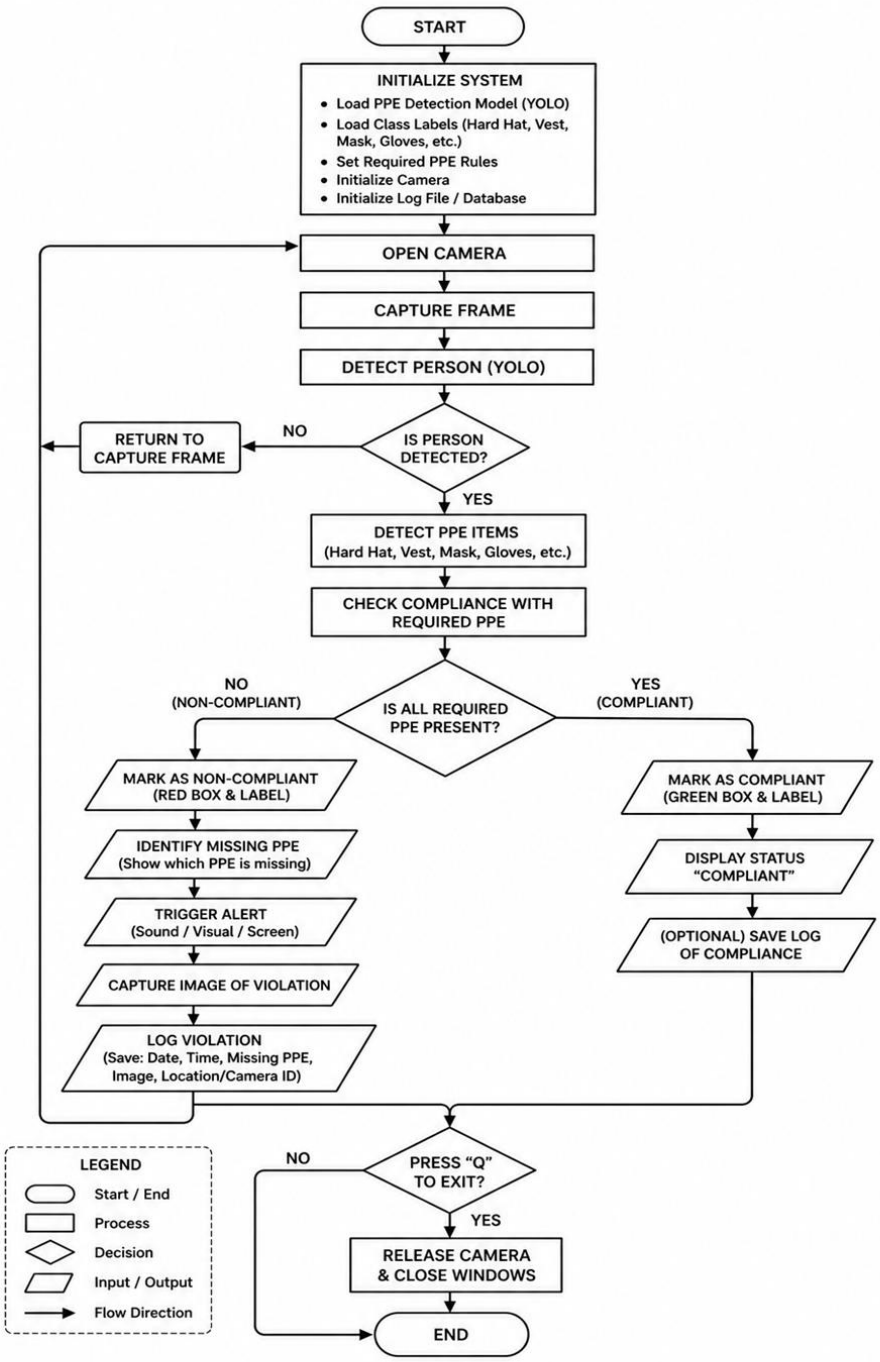
Figure 5. PPE Monitoring and Detection Process Flow Chart



Testing Phase

Environmental Robustness Evaluation

The developed system was evaluated under varying environmental and operational conditions to determine its robustness and reliability in real-world workplace applications. Testing was conducted under different lighting conditions including normal indoor lighting, low-light environments, and partially shadowed areas. Additional testing scenarios involved personnel movement, varying camera angles, partial facial obstruction, and the use of different PPE colors and vest styles. Results showed that the system maintained stable PPE detection and personnel verification performance under normal and moderately challenging conditions.

The testing phase was conducted to verify the functionality, reliability, and performance of the Workplace Safety with Personal Protective Equipment (PPE) Monitoring System Using Computer Vision. This phase ensured that all system components functioned properly both individually and as an integrated system. The evaluation focused on the major functionalities of the system, including visual data processing, facial identity verification, PPE

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detection, compliance assessment, and real-time reporting, to confirm that the developed system operates according to the objectives of the study.

Table 2. Testing Procedure

Test Items	Testing Scenario	Procedure	Expected Result
Accuracy of Visual Data Curation	Use prepared workplace images with different angles and PPE usage conditions	Check if the collected images are properly organized, labeled, and loaded into the system. Verify if the image files can be read and processed without errors before model testing.	The visual dataset is properly arranged, readable, and ready for use in PPE detection.
Stability of Personnel Identity Verification	Register sample personnel facial images and test recognition using live camera input.	Encode and save the facial images of registered personnel. Run the identity verification module separately and check if the system can match the live facial input with the stored record.	The system successfully registers and verifies personnel identity during repeated trials.
Precision of PPE Detection	Use sample images or live camera input showing hard hat, face mask, vest, and gloves.	Run the PPE detection module independently and observe if the trained model detects the required PPE components from the input image or video frame.	The trained model detects required PPE from images or video frames and displays the correct labels on the screen.
Effectiveness of Compliance Assessment	Use sample cases with complete PPE, incomplete PPE, and no PPE.	Run the compliance checking logic separately using detection results as input. Check if the system classifies the case as compliant or non-compliant based on predefined PPE rules.	The system correctly identifies whether the person is compliant or non-compliant.
Reliability of Reporting	Generate sample compliance and violation events during module testing.	Test the logging function by recording sample results, including personnel identity, PPE status, timestamp, and violation details. Check if the data are saved and displayed properly.	The system successfully records and displays monitoring results in the reporting module or dashboard.

RESULTS AND DISCUSSION

The developed Workplace Safety with Personal Protective Equipment Monitoring System Using Computer Vision successfully achieved the intended technical features including visual data curation, facial image registration and identity verification, PPE detection, compliance assessment, and real-time reporting. The system was capable of capturing and preprocessing workplace images, identifying personnel, detecting PPE compliance, generating event logs, and issuing alerts to safety personnel.

Table 3. Summary of Functionality Testing Results

Evaluation Area	Result	Interpretation
Visual Data Curation Accuracy	93.33%	Reliable
Identity Verification Stability	96.67%	Highly Stable
PPE Detection Precision	92.11%	Reliable
Compliance Assessment Effectiveness	90.00%	Effective
Reporting Reliability	96.67%	Highly Reliable

Table 4. Summary Testing Results for Accuracy of Visual Data Curation

Testing Category	Trial Condition	No. of Trials	Successful Output	Failed Output	Average Confidence Level	Accuracy Rate	Remarks
Image Organization Check	Prepared workplace images with different PPE usage conditions	30	29	1	0.91	96.67%	Passed
Image Clarity Check	Workplace images captured from different angles	30	28	2	0.87	93.33%	Passed
Image Upload and Processing Check	Image files loaded into the PPE monitoring system	30	27	3	0.82	90.00%	Passed
Dataset Preparation Check	Curated workplace images before PPE model testing	30	28	2	0.85	93.33%	Passed
Overall Result		**120**	**112**	**8**	**0.86**	**93.33%**	**Passed**

Table 5. Summary Testing Results for Personnel Identity Verification Stability

Testing Category	Trial Condition	No. of Trials	Successful Output	Failed Output	Accuracy Rate	Remarks
Normal Face Recognition Check	Registered personnel under normal facial conditions	12	12	0	100.00%	Passed
PPE and Face Covering Recognition Check	Registered personnel wearing PPE or partial facial obstruction	8	7	1	87.50%	Passed
Movement and Angle Recognition Check	Personnel under movement and side-angle conditions	5	5	0	100.00%	Passed
Unknown Personnel Rejection Check	Unregistered or unknown individuals	5	4	0	100.00%	Passed
Overall Result		**30**	**28**	1	**96.67%**	**Passed**

Table 6. Summary PPE Detection Testing Results for Precision, Recall and F1-Score

Testing Category	Trial Condition	Total PPE Instances	Correct Detection (TP)	Wrong Detection (FP)	Precision	Recall Score	F1-Score	Remarks
Hard Hat Detection Check	Personnel with and without hard hats	20	18	1	94.74%	0.95	0.95	Passed
Facemask Detection Check	Personnel with and without facemasks	20	17	2	89.74%	0.94	0.91	Passed
Vest Detection Check	Personnel with and without safety vest	20	18	1	94.74%	0.95	0.95	Passed
Gloves Detection Check	Personnel with and without gloves	20	17	2	89.74%	0.94	0.91	Passed
Overall Result		**80**	**70**	6	**92.11%**	**0.95**	**0.93**	**Passed**

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Table 7. Summary of Testing Results for Effectiveness of Compliance Assessment

Category	Count	Percentage	Description
True Compliant	25	60.00%	Correctly identified personnel with complete PPE and verified identity
True Non-compliant	11	25.00%	Correctly flagged personnel with missing PPE or unverified identity
False Compliant	2	7.50%	Incorrectly classified non-compliant personnel as compliant
False Non-compliant	2	7.50%	Incorrectly classified compliant personnel as non-compliant
Compliance Assessment Effectiveness	**36/40**	**90%**	**High Effectiveness**

Table 8. Summary of Testing Results for Reliability of Reporting

Parameter	Value
Total Events Generated	30
Successfully Reported Events	29
Failed Reported Events	1
Reporting Reliability	96.67%
Remarks	**Passed**

Table 9. Inference Performance Evaluation of the PPE Detection Module

Testing Parameters	Result
Average Processing Speed	24 FPS
Average Detection Time	90.7 milliseconds
Average Facial Recognition Time	0.55 seconds
Average Dashboard Update Delay	1.5 seconds
System Response Interpretation	Real-time Operational Performance

The inference performance evaluation demonstrated that the developed system is capable of real-time workplace monitoring operations. The PPE detection module maintained an average processing speed of 24 FPS during continuous monitoring tests, while detection latency remained below one second for both PPE identification and facial recognition operations.

Acceptability Evaluation

Table 10. Summary Results of TAM Evaluation

Evaluation Area	Mean	Standard Deviation	Interpretation
Perceived Usefulness	4.70	0.30	Highly Acceptable
Perceived Ease of Use	4.60	0.31	Highly Acceptable
Attitude Toward Adoption	4.65	0.29	Highly Acceptable
Behavioral Intention to Use	4.80	0.28	Highly Acceptable
Trust in the System	4.65	0.32	Highly Acceptable
Overall Mean	**4.68**	**0.31**	**Highly Acceptable**

The functionality testing results demonstrated satisfactory operational performance across all evaluation areas of the developed Workplace Safety with Personal Protective Equipment (PPE) Monitoring System Using Computer Vision. The system was able to perform visual data processing, facial identity verification, PPE detection, compliance assessment, and real-time reporting with consistent and reliable results during testing procedures. The PPE detection module achieved reliable detection capability with balanced precision, recall, and F1-score

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values, indicating that the system can accurately identify required PPE components while minimizing incorrect detections and missed classifications. These results demonstrate the effectiveness of the computer vision model in recognizing PPE under varying workplace conditions and monitoring scenarios.

The acceptability evaluation further revealed a high level of user acceptance toward the developed system. Respondents perceived the system as useful in improving workplace safety monitoring, reducing the need for continuous manual inspection, and supporting real-time compliance assessment. High ratings in Behavioral Intention to Use indicate that users are willing to adopt and continuously utilize the system in actual workplace operations, while strong Perceived Usefulness ratings suggest that the system is viewed as beneficial, efficient, and relevant for occupational safety management. Overall, the evaluation results indicate that the proposed system is both technically functional and acceptable for workplace safety monitoring applications.

CONCLUSION

The results of the study demonstrated that the Workplace Safety with Personal Protective Equipment (PPE) Monitoring System Using Computer Vision successfully achieved its intended objectives and functions as an effective automated workplace safety monitoring solution for manufacturing plant environments. The developed system successfully integrated visual data curation, personnel facial image registration and identity verification, PPE detection, compliance assessment, and real-time reporting into a unified monitoring framework capable of supporting continuous workplace safety operations.

Functionality testing revealed that the system achieved satisfactory operational performance across all evaluation parameters. The visual data curation and identity verification modules demonstrated stable and reliable performance, while the PPE detection component achieved high precision, recall, and F1-score results, indicating strong detection capability and balanced classification performance. The compliance assessment and reporting modules further demonstrated the system’s ability to automatically identify PPE violations, generate real-time alerts, record incidents, and support workplace safety documentation with dependable reliability. These findings confirm that the developed system can minimize dependence on manual supervision and improve consistency in PPE compliance monitoring.

The acceptability evaluation using the extended Technology Acceptance Model (TAM) showed that the system was rated Highly Acceptable in terms of Perceived Usefulness, Perceived Ease of Use, Attitude Toward Adoption, Behavioral Intention to Use, and Trust in the Proposed System. The results indicate that respondents recognized the system as practical, reliable, and beneficial for workplace safety management and real-time monitoring applications.

Overall, the study concludes that the developed system has strong potential for implementation in manufacturing plants and similar industrial environments. The integration of computer vision, deep learning, facial recognition, and automated reporting technologies provides an effective approach to improving PPE compliance monitoring, reducing human error, and supporting data-driven occupational safety management practices.

PRIVACY AND ETHICAL CONSIDERATIONS

Since the developed system utilizes facial recognition and personnel identity verification, proper data privacy and ethical considerations were incorporated throughout the study. Personnel facial images, facial embeddings, detection records, and workplace monitoring logs were stored within a centralized MySQL database protected through administrator-controlled system access and authentication procedures. Access to personnel records and monitoring logs was limited only to authorized administrators and safety officers.

RECOMMENDATION

Future researchers may improve the developed system through the implementation of Edge AI processing and distributed monitoring architectures. Instead of relying primarily on centralized processing and database operations, future versions of the system may utilize fully edge-based artificial intelligence models deployed directly on embedded devices such as Raspberry Pi or NVIDIA Jetson platforms. This approach may reduce system latency, minimize network dependency, improve operational speed, and strengthen privacy protection by limiting the transmission of sensitive biometric data across centralized servers.

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