INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

IJIE

Vol. 17 No. 6 (2025) 246-257
https://publisher.uthm.edu.my/ojs/index.php/ijie

Computer Vision-Based Security System for Monitoring the Use of Personal Protective Equipment (PPE) in Workplace Involving Production Machinery

M.Farrel[1], R.Winantyo[1]*, A.Kusnadi[2], E.E.Surbakti[2]

[1] *Electrical Engineering Department, Faculty or Engineering and Informatics, Universitas Multimedia Nusantara, Tangerang, Banten, 15810, INDONESIA*

[2] *Informatics Engineering Department, Faculty or Engineering and Informatics, Universitas Multimedia Nusantara, Tangerang, Banten, 15810, INDONESIA*

*Corresponding Author: rangga.winantyo@umn.ac.id
DOI: https://doi.org/10.30880/ijie.2025.17.06.020

Article Info

Received: 30 May 2025
Accepted: 13 September 2025
Available online: 30 December 2025

Keywords

OSH, machine learning, computer vision, tensorflow, SSD Mobilenet

Abstract

Occupational safety is crucial as workers' lives are directly or indirectly influenced by safety policies in the workplace. One significant cause of workplace accidents is the failure of workers to wear personal protective equipment (PPE). Advancements in technology now enable PPE monitoring through computer vision. This research aims to develop a computer vision-based security system to address the negligence of wearing PPE in work environments with production machinery. If the system detects that a worker is not wearing the required PPE, it issues a warning and shuts down the production machine. The system employs computer vision algorithms, specifically SSD MobileNet V2 FPNLite 320x320 and SSD MobileNet V2 FPNLite 640x640 models, trained to identify individuals, helmets, safety suits, and gloves. The system successfully detects the specified PPE, issues warnings, and deactivates the production machine, achieving the best accuracy and F1 score values of 0.538 and 0.479, respectively.

1. Introduction

Personal protective equipment (PPE) is equipment used by workers to protect themselves from external hazards [1] such as work accidents. Neglecting to wear complete PPE increases the possibility of workers experiencing accidents in the working area. Although PPE does not absolutely prevent workers from work accidents, at least PPE reduces the injuries that may be experienced. Research proves that PPE is effective in protecting workers from external hazards as realized by workers themselves as respondents to this study [2]. Checking the completeness of PPE use by workers can be done by other workers, but technological developments allow this to be done by computers through computer vision. Computer vision is an attempt to automate and combine various processes and representations to simulate vision with computers [3]. Computers are certainly more reliable than humans in doing repetitive work such as checking the completeness of workers' PPE. Considering the above, this study will focus on creating a security system against negligence in wearing PPE in a work environment with computer vision-based production machines. Especially for production machines that are operated directly by workers.

Computer vision has been shown to be effective in detecting shapes such as numbers on vehicle license plates, detecting color differences in different types of canola seeds [3], and detecting sizes such as differences in egg size [4]. Thus, computer vision is able to detect certain PPE that differ in shape, color, and size. This has been proven in research [5][6][7].

Computer vision detects and classifies masks, safety helmets, safety glasses, and safety headsets worn on workers' heads. The algorithms used are YOLOv3 to determine the location of the worker's head and Faster R-CNN for PPE classification because it is considered more accurate although slightly slower than YOLOv3. The algorithm managed to achieve an accuracy of 93.61% [8][9][10].

Technological developments allow computer vision to run on single-board computers (SBC) such as the Raspberry Pi which are cheap and portable [11][12]. Computer vision running on the Raspberry Pi is capable of detecting and classifying cars, motorcycles, trucks, buses, bicycles, and pedicabs. The algorithm used is Faster R-CNN with the TensorFlow framework. The algorithm managed to achieve an accuracy of 90.25% [12]. Computer vision running on the Raspberry Pi is also capable of edge detection to recognize the shape of the path followed by the line follower robot [14][15][16]. The results of the algorithm detection are used as motion commands for the robot. The algorithm used is Sobel with the OpenCV framework. The algorithm managed to achieve an accuracy of 96% [17][18]. Thus, computer vision applications become affordable and easy to apply anywhere.

Computer vision monitors in real time the entire work environment or room in a factory that requires workers to wear PPE. The computer can cut off the power supply to the machine in a particular room if there are workers who are negligent in wearing PPE in that room. However, a large-scale security system like this will certainly take a long time and cost a lot, beyond the resources owned by the researchers. Therefore, the researchers offer an alternative solution where the security system is made for only one room. The system's webcam will be placed at the end of the room in such a way that it can capture video of all production machines and the upper bodies of workers in the room. If in the future the security system wants to be applied to one factory, the security system can be installed in each room. The security system for each room can provide data access to one computer which will later become the main monitoring computer. The security system works independently for each room, but the results of all systems can be monitored from one computer only.

2. Methodology

The product to be created is a security system against negligence in wearing PPE in a work environment with computer vision-based production machines, especially for production machines operated directly by workers. This security system will use computer vision running on the SBC to detect the completeness of workers' PPE in a work environment with production machines constantly. If the worker does not wear complete PPE, the SBC will deactivate the production machine with a relay connected to it. Considering possible detection errors, the SBC will not immediately deactivate the machine but will wait for several further detection results to confirm the initial detection results. The security system is also equipped with a buzzer and LED bar lights as a warning system that will sound and light up if the SBC is going to deactivate the machine. In certain cases, the system can be set up to immediately deactivate the machine without warning. The system will also be equipped with an LCD touchscreen that shows video captures from the webcam along with the results of algorithm detection so that workers can ensure the system is working properly. The selection of mode without warning can also be selected in a simple GUI on the LCD touchscreen. The main components used are a webcam, Raspberry Pi 4B, LCD touchscreen, relay, buzzer, LED bar lights, and on/off button.

The computer vision algorithm uses the SSD MobileNet V2 FPNLite 320x320 model which will be retrained to recognize PPE according to the specifications described above. This model can detect objects from the COCO 2017 dataset at a speed of 22 ms per frame and gets a mAP of 22.2. This model is considered quite accurate and fast for the application in this study. The parameters used to assess the performance of computer vision algorithms are accuracy and F1 score [4].

Ideally, a security system is created for factories that are part of a single manufacturing company. Computer vision monitors in real time the entire work environment or room in the factory that requires workers to wear PPE. The computer can cut off the power supply to the machine in a particular room if there are workers who are negligent in wearing PPE in that room. However, considering the time and cost resources of researchers, a security system is more applicable if it is created for only one room. If in the future the security system is to be applied to one factory, the security system can be installed in each room and its output can be connected to one main monitoring computer.

The parameter used to assess the performance of a computer vision algorithm is accuracy. Accuracy is the number of correct detections divided by the total number of detections. F1 score is the harmonic mean of precision and recall. Precision is a value that indicates how likely an algorithm is to detect an object correctly. Meanwhile, recall is a value that indicates how likely an algorithm is to detect an object. The calculation method can be seen in the following formula:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

$$Precision = \frac{TP}{TP + FP} \quad (2)$$

$$Recall = \frac{TP}{TP + FN} \quad (3)$$

$$F1\ Score = 2X \frac{Precision\ x\ Recall}{Precision + Recall} \quad (4)$$

Based on previous studies [4][5], researchers determined that the minimum product computer vision algorithm must achieve a value of 0.9 for accuracy and F1 score. The aspects that determine the performance of this algorithm are the number of datasets (images of objects to be detected and their bounding boxes and labels) used for training, the number of training steps, and the quality of the dataset.

2.1 System Design in General

As seen in Figure 1, the webcam, LED bar light, and relay and branch outlet are separate from the enclosure containing the Raspberry Pi 4B, LCD touchscreen, buzzer, and on/off button. As for the cables connecting the components, the length is adjusted to the distance between the components that must be connected. For the enclosure, it can be installed on a wall, ceiling, table, or door according to the user's wishes as long as the information on the LCD touchscreen can be seen clearly. For the webcam, it can be installed at the end of the room in such a way that it can capture video of the entire production machine and the upper body of the worker in the room. For the LED bar light, it can be installed anywhere as long as it is still within the worker's line of sight. For the branch outlet, it can be installed close to the production machine.

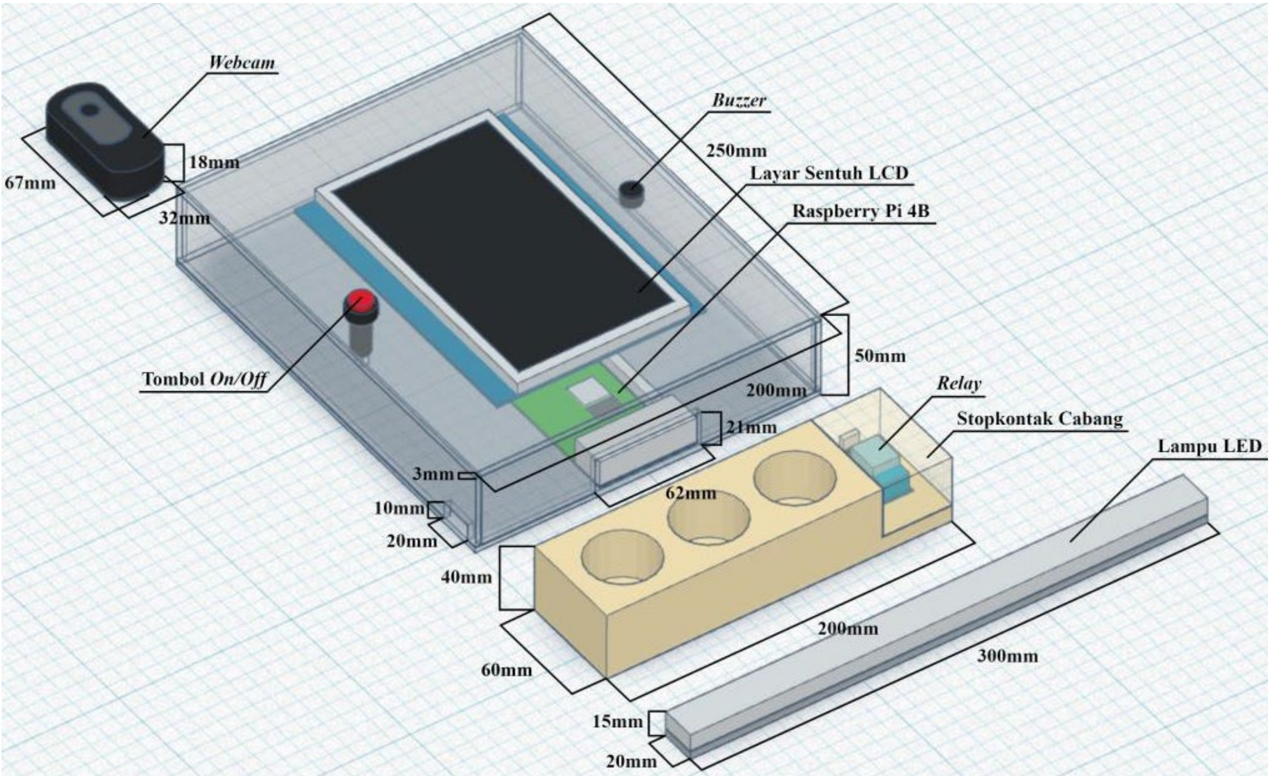


Fig. 1 *Physical design of the system*

Meanwhile, the wiring diagram can be seen in Figure 2. The physical implementation of the wiring diagram in Figure 2 can be represented in the form of an electrical circuit diagram as shown in Figure 3. There is a toggle button that is input to GPIO26 Raspberry Pi 4B as an on/off button to turn the system on and off. Connections D14 and D15 from Waveshare 7-inch HDMI LCD (B) (LCD touchscreen) to Raspberry Pi 4B are USB interfaces for touchscreen input functions. Connections D2 to D13 from Raspberry Pi 4B to LCD touchscreen are HDMI interfaces for display output.

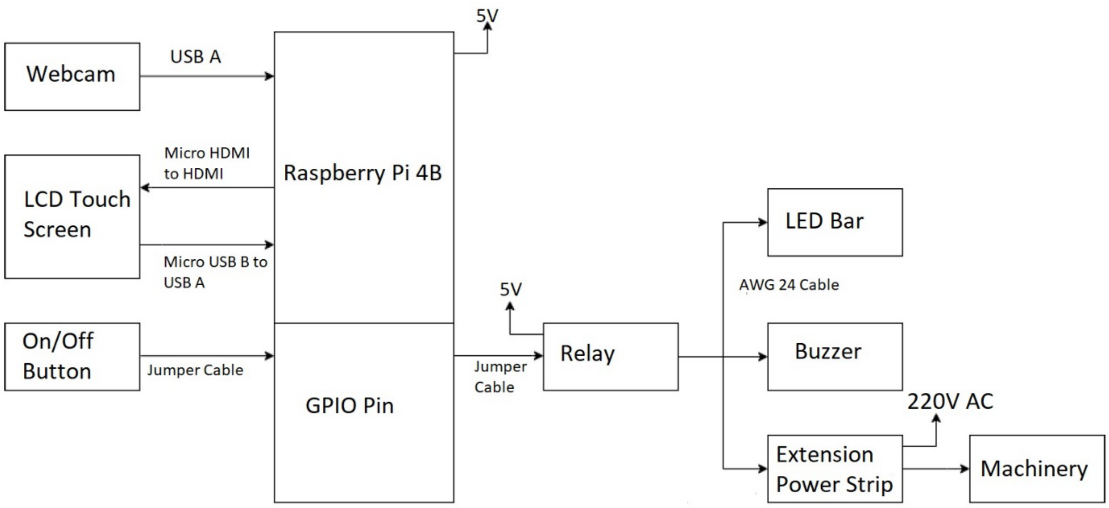
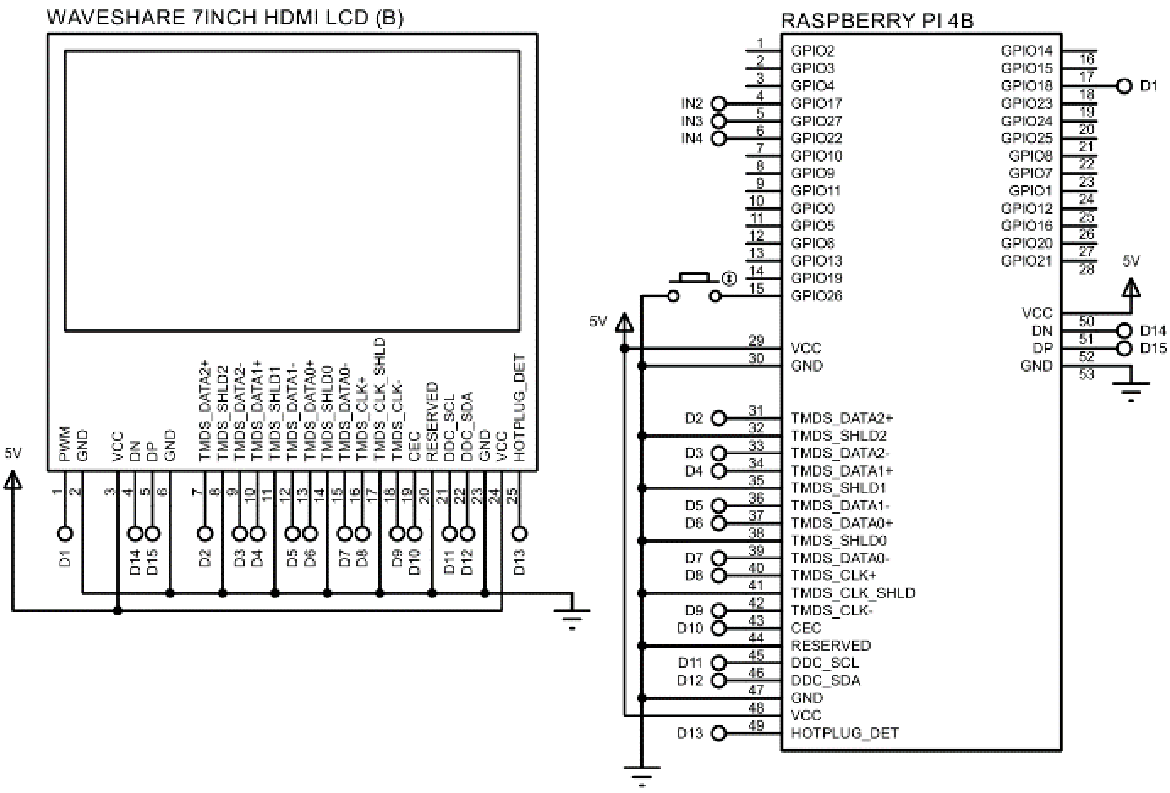


Fig. 2 *Wiring diagram*

Connection D1 from Raspberry Pi 4B to LCD touchscreen is to control the brightness of the LCD touchscreen with pulse-width modulation (PWM). Connections IN2, IN3, and IN4 from Raspberry Pi 4B to 5V Four-channel Relay Module (relay module) are to turn on and off BUZZ1 (buzzer), LAMP1 (LED light bar), and 220V AC power flow to the branch outlet for the production machine. Finally, a flasher is added to blink the LED light bar at a fast frequency. The final physical design can be seen in figure 4.



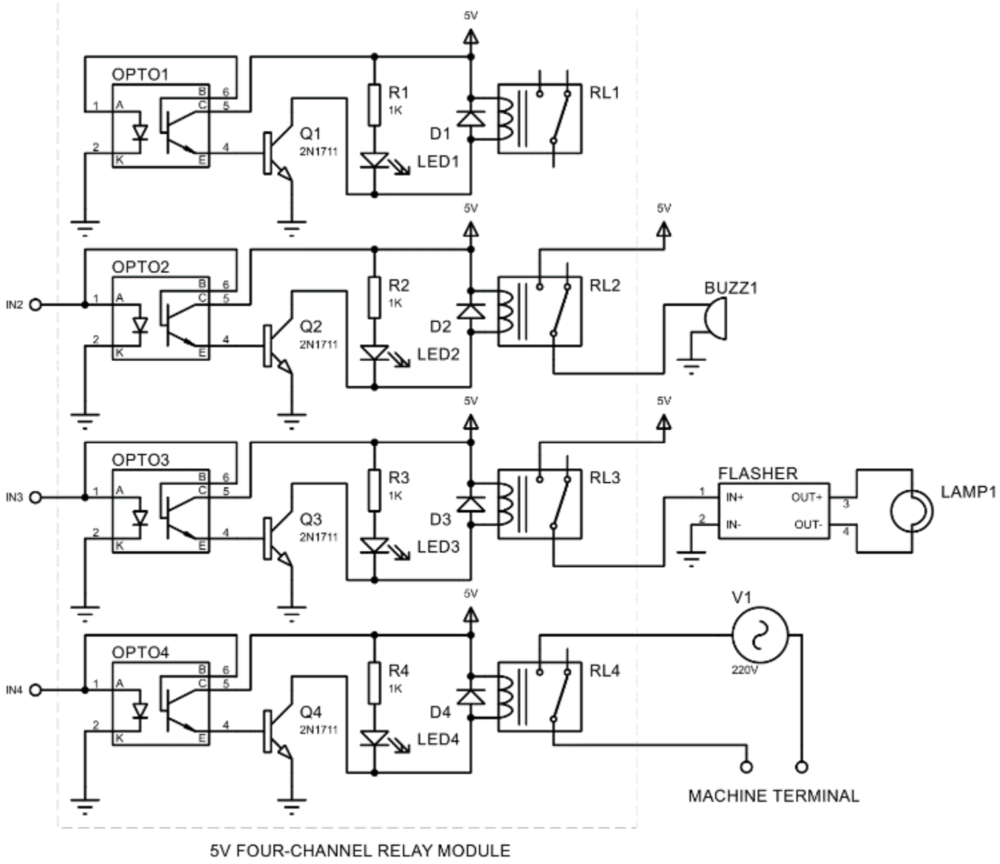
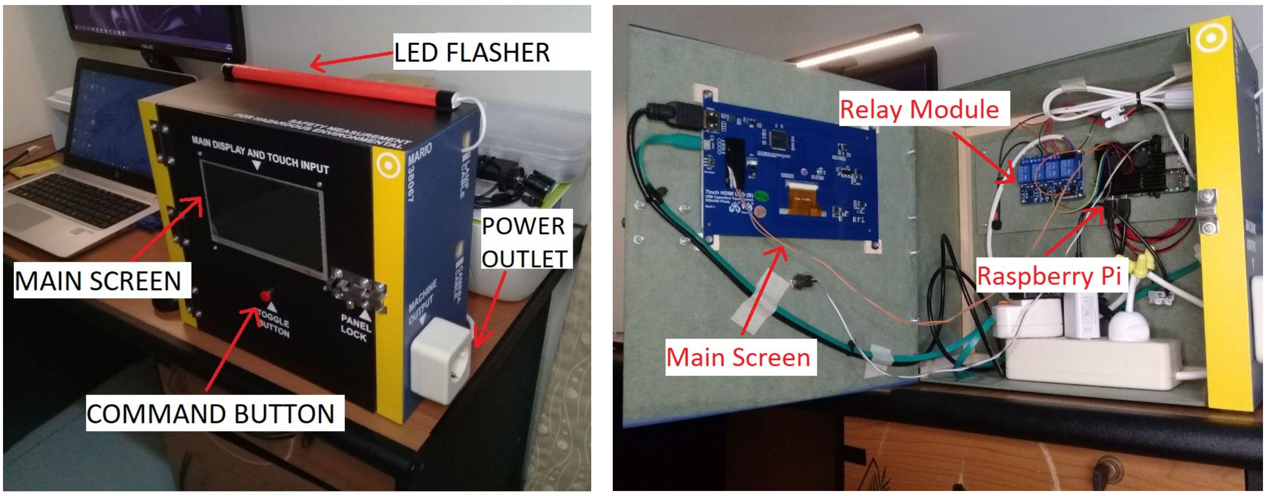


Fig. 3 *Electrical circuit diagram*



(a) (b)

Fig. 4 *Final product (a) External; (b) Internal*

2.2 Subsystem Design

The security system can generally be divided into three subsystems centered on the Raspberry Pi 4B, which can be seen on figure 5 and table 1. First, the video processing subsystem detects the completeness of workers' PPE with a computer vision algorithm so that the detection results can be displayed in the interface subsystem and become the determinant of the action of the production machine control subsystem. Second, the interface subsystem functions as a way for the system to communicate with the external environment or users, for example the use of buttons to turn the system on and off, an LCD touch screen to display the results of algorithm detection in real-time, and a warning system. Third, the production machine control subsystem functions as a way for the system to control production machines.

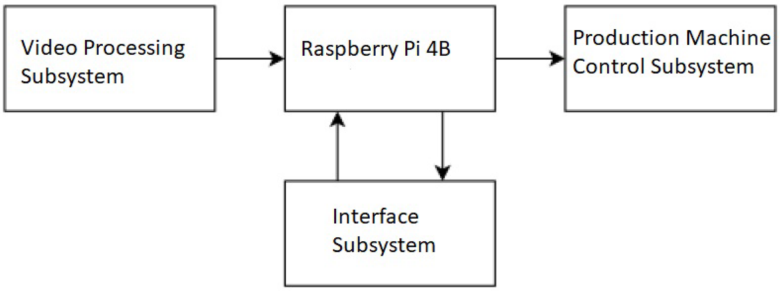


Fig. 5 *Subsystem design diagram*

Table 1 *Relationship between each subsystem*

Parameter	Description
Input	• Video Processing Subsystem • Interface Subsystem
Output	• Interface Subsystem • Production Machine Control Subsystem
Function	• Preventing workers from work accidents due to operating production machines

2.3 Video Processing Subsystem Design

The video processing subsystem functions to detect the completeness of workers' PPE with a computer vision algorithm from webcam video captures, which is shown in figure 6 and table 2. The video will contain workers operating production machines with PPE. The results of this detection are displayed in the interface subsystem and determine the actions of the production machine control subsystem.

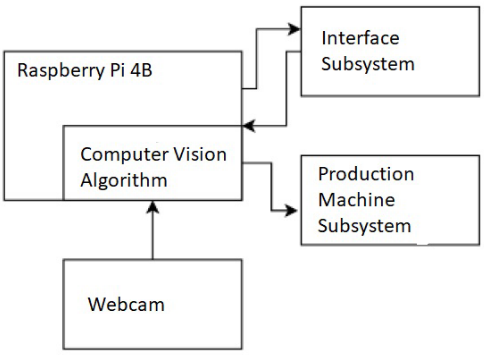


Fig. 6 *Video processing subsystem design diagram*

Table 2 *Relationship between each aspect of video processing subsystem*

Parameter	Description
Input	• Video capture by webcam. The video shows workers operating production machines with PPE.
Output	• Interface Subsystem • Production Machine Control Subsystem
Function	• Detecting worker PPE completeness with computer vision algorithms

2.4 Interface Subsystem Design

It can be seen in figure 7 and table 3 that the interface subsystem functions as a way for the system to communicate with the external environment or users. Examples include the condition of the on/off button that controls whether the system is on or off, the mode status of a simple GUI on the LCD touchscreen that controls whether the system uses a warning system or not, the LCD touchscreen that displays the results of algorithm detection by the video processing subsystem, and the warning system itself.

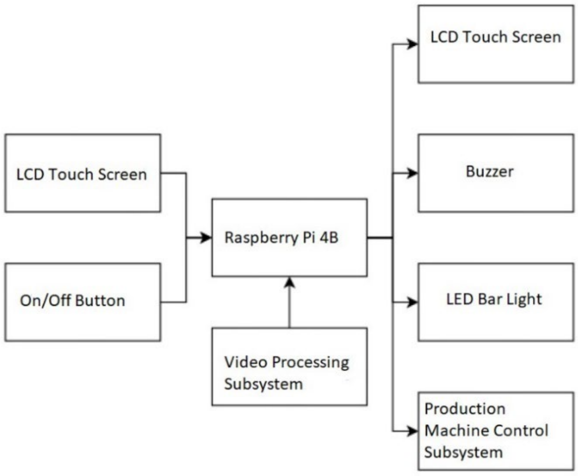


Fig. 7 *Interface subsystem design diagram*

Table 3 *Relationship between each aspect of interface subsystem*

Parameter	Description
Input	• On/off button state. • Status mode from LCD touch screen input to simple GUI. Mode B is selected to immediately turn off the machine without warning. By default, Mode A is selected, the system will still give a warning before turning off the machine • Video processing subsystem
Output	• LCD touch screen displays algorithm detection results from the video processing subsystem while the system is running • Buzzer sounds and LED bar lights up as a warning system if the worker is detected not wearing complete PPE by the video processing subsystem (only for Mode A, warning system is not active in Mode B) • Production machine control subsystem
Function	• As a way for the system to communicate with the external environment or users

2.5 Machine Control Subsystem

From figure 8 and table 4, it can be seen that production machine control subsystem functions as a system way to control the production machine. The algorithm detection results from the video processing subsystem and user input from the interface subsystem affects the action of the production machine control subsystem. If the worker which are detected by the video processing subsystem is not wearing complete PPE and the warning system from the interface subsystem has been running for a long time (Mode A, this step is skipped in Mode B), then the production machine will be turned off by the relay.

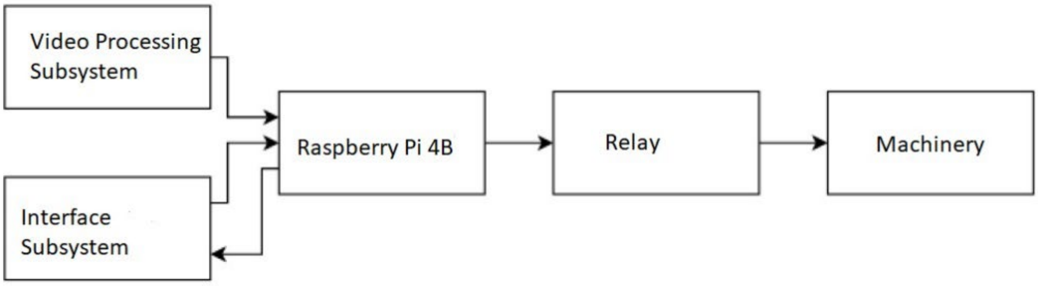


Fig. 8 *Machine control subsystem design diagram*

Table 4 *Relationship between each aspect of machine control subsystem*

Parameter	Description
Input	• Video Processing Subsystem • Interface Subsystem.
Output	• If the worker is detected as not wearing complete PPE by the video processing subsystem and the warning system from the interface subsystem has been running for a long time (only in Mode A, this step is skipped in Mode B), then the production machine will be turned off by the relay.
Function	• As a system way to control production machines

3. Results and Discussion

After categorizing the frame-by-frame detection results from the system display output recording into the object detection categorization quadrant, the accuracy and F1 score values were 0.538 and 0.479. Because the accuracy and F1 score values are one type of detection method, the testing of the computer vision algorithm model was declared successful. This system began having difficulty detecting objects, especially if the object is small (caused by the actual size of the object being small or the object being far from the camera), which can be seen in figure 9. In several experiments, the system was only able to detect 1 glove with a confidence score of less than 80%. Therefore, for current use, this system is more suitable for application in a room of 4 x 2 square meters.

(a) **(b)**

Fig. 9 *Detection accuracy on (a) near object; (b) far object*

It can be seen in figure 11 that the system gives a warning and turns off the light bulb if someone in the room is not using complete PPE. The system is also able to work perfectly even only 1 person is using complete PPE out of 2 people detected by the system, which is shown in figure 10. Then, the system turns off the warning and turns on the light bulb if 2 people detected by the system are using complete PPE, which can be seen in Figure 1. Thus, the PPE completeness detection test for more than 1 person was successful because it met the success parameters.

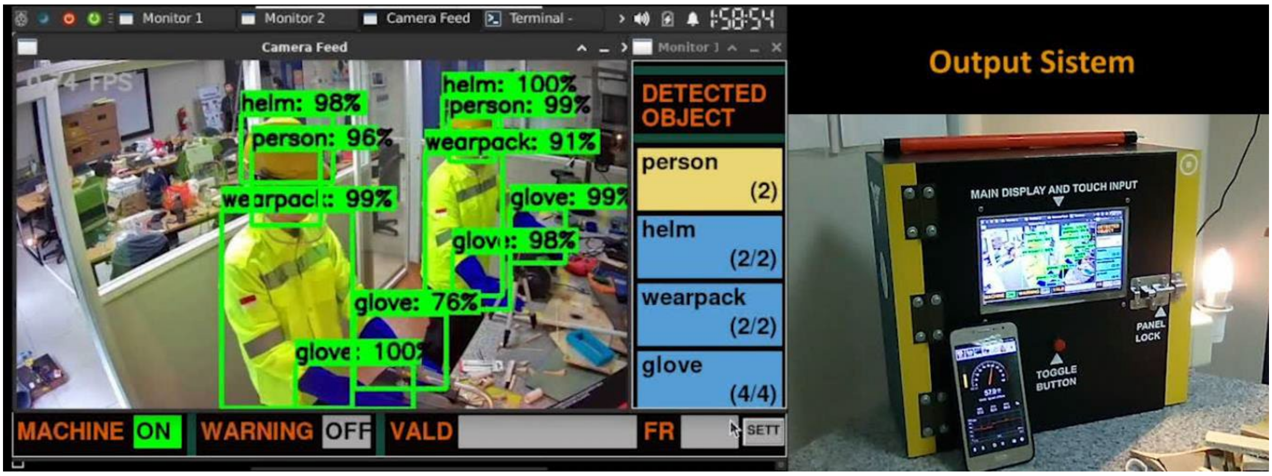


Fig. 10 *Detection of multiple workers wearing PPE*

Fig. 11 *Detection of multiple workers where there is only one worker wearing complete PPE*

Table 5 *Detection result*

Item	True Positive (frame)	True Negative (frame)	False Positive (frame)	False Negative (frame)
Person	50	0		409
Helmet	81	199		179
Safety Suit	122	199		138
Gloves	137	199		123
Sum	390	597		849

From the detection results in Table 5, the accuracy and F1 values obtained are:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} = \frac{390 + 597}{390 + 597 + 0 + 849} = \frac{987}{1836} = 0.538 \quad (5)$$

$$Precision = \frac{TP}{TP + FP} = \frac{390}{390 + 0} = \frac{390}{390} = 1 \quad (6)$$

$$Recall = \frac{TP}{TP + FN} = \frac{390}{390 + 849} = \frac{390}{1239} = 0.315 \quad (7)$$

$$F1\ Score = 2X \frac{Precision\ x\ Recall}{Precision + Recall} = 2x \frac{1x0.315}{1 + 0.315} = 0.479 \quad (8)$$

This system has one weakness. The computer vision used can only detect the presence of objects and cannot detect the condition of an object, in this context is the correct use of PPE. It can be seen in figure 12 when the helmet face shield is not lowered, in figure 13 when the safety suit is unbuttoned, and in figure 14 when the helmet and one of the gloves are not worn properly, but are still visible by the webcam, the system does not give a warning and does not turn off the light bulb. This means that the system still detects the user wearing complete PPE even though it is not used properly. Thus, the detection test for the use of inappropriate PPE was unsuccessful because it did not meet the success parameters.

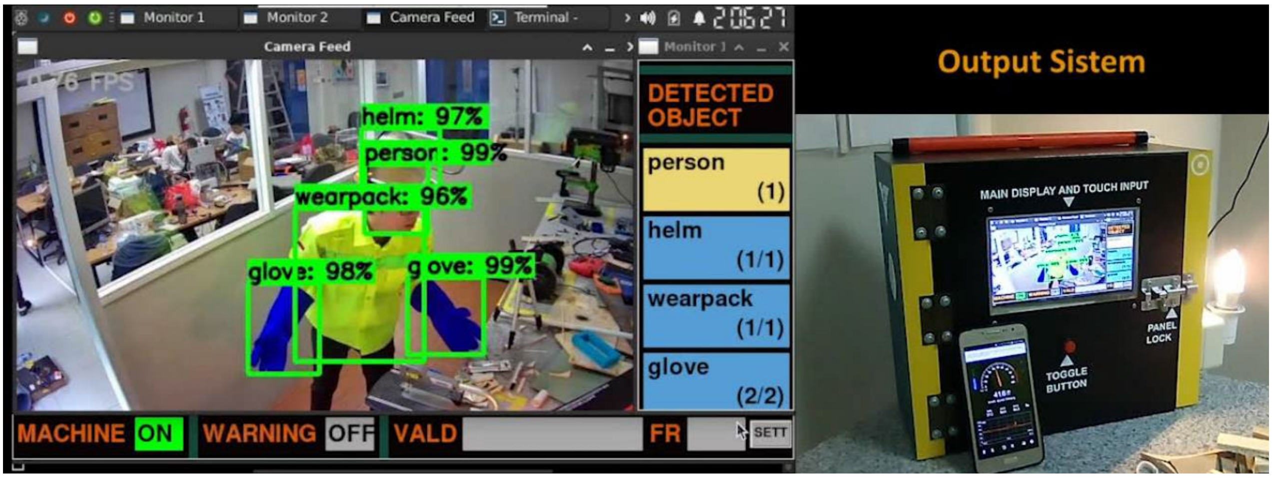


Fig. 12 *Worker is wearing helmet but not lowering face shield*

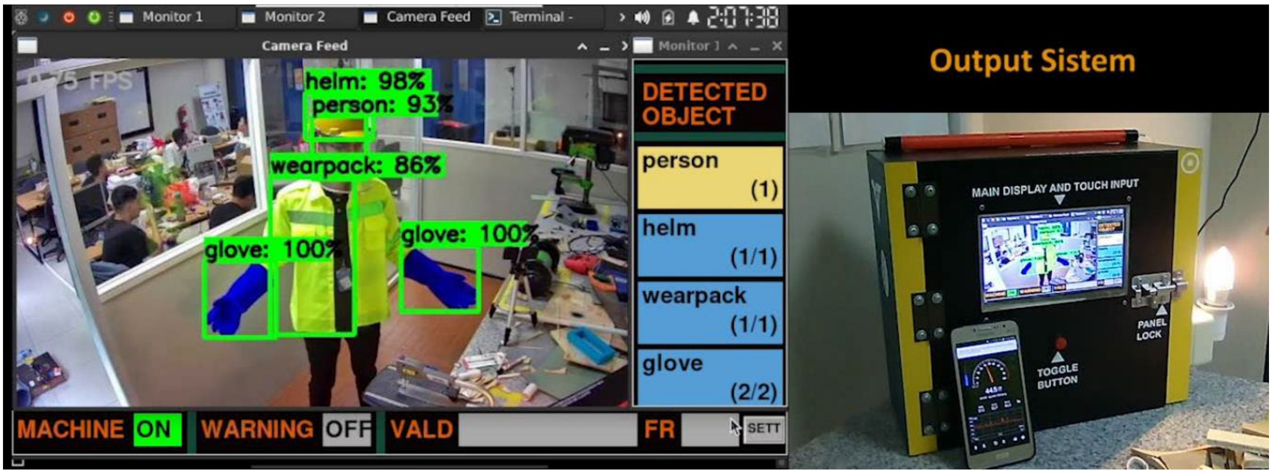


Fig. 13 *Worker is wearing unbuttoned safety suit*

Fig. 14 *Helmet and gloves are present but not worn by the worker*

4. Conclusion

The system is less able to detect objects in certain conditions, especially if the object is small on the camera due to the actual size of the object being small or the object being far from the camera. When the helmet face shield is not lowered, the wear pack is not buttoned, and the helmet and one of the gloves are not worn, but are still visible by the webcam, the system does not give a warning and does not turn off the light bulb. This means that the system still detects the user wearing complete PPE even though it is not used properly. Another factor that affects the detection accuracy is lighting level.

The F1 score is still lower than the target. The current system still manages to get F1 score of 0.479 from target score of 0.9. In other word, this prototype system manages to give 48% accuracy. In future research another method will be used to increase accuracy. There is a possibility that by reducing processor's workload through reducing framerate, we can increase the detection accuracy.

Using only 1 webcam also creates many blind spots, especially when several APDs are aligned with the webcam so that the APDs cover each other. This can be overcome by adding webcams to the system. Using 1 webcam, the fastest detection speed only reaches about 2.4 fps. Adding 3 more webcams to the system's detection module, namely the Raspberry Pi 4B, will burden the detection algorithm and make the detection speed even lower. Therefore, a detection module is also added for each webcam.

Acknowledgement

This research is made possible through monetary assistance by Universitas Multimedia Nusantara Research Department. Their funding played a crucial role in the successful execution of this study and the attainment of our research goals. Furthermore, I am grateful to my research team members and collaborators who have contributed their time, expertise, and efforts to this project. Their dedication and hard work have been instrumental in the successful completion of this research.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper. The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission and declare no conflict of interest on the manuscript.

Author Contribution

The authors confirm contribution to the paper as follows: ***conceptualization and methodology:*** *R. Winantyo, Author Y;* ***designing and testing:*** *R. Winantyo, M. Farrel;* ***image processing software:*** *A. Kusnadi;* ***Microcontroller programming****: E.E. Surbakti;* ***draft manuscript preparation:*** *R. Winantyo, A. Kusnadi. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Dickson, Eva. (2012*). Personal Protective Equipment for Chemical, Biological, and Radiological Hazards: Design, Evaluation, and Selection*. John Wiley & Sons. https://doi.org/10.1002/9781118422991.ch5

[2] Shinta Sabrina, Ichtiary & Winarko & Hermiyanti, Pratiwi & Suprijandani & Agus Ainur Rosyid, Muhammad. (2024). The influence of personal protective equipment (PPE) usage, age, work tenure on workplace accidents. *International Journal of Advanced Health Science and Technology*, 4(5). https://doi.org/10.35882/ijahst.v4i5.399

[3] Qadri, & Furqan Qadri, Syed & Razzaq, Abdul & Rehman, Muzammil & Ahmad, Nazir & Nawaz, Syed & Saher, Najia & Akhtar, Nadeem & KHAN, Dost. (2021) Classification of canola seed varieties based on multi-feature analysis using computer vision approach. *International Journal of Food Properties*, *24,* https://doi.org/10.1080/10942912.2021.1900235

[4] Yang, Xiao & Bahadur Bist, Ramesh & Subedi, Sachin & Chai, Lilong. (2023). A computer Vision-Based automatic system for egg grading and defect detection. *Animals*, 13(14), 2354. https://doi.org/10.3390/ani13142354

[5] Alexander, Leonardus & Kusnadi, Adhi & Wella, Wella & Winantyo, Rangga & Pane, Ivransa. (2018) Authentication System Using 3D Face With Algorithm DLT and Neural Network. *Joint 10th International Conference on Soft Computing and Intelligent Systems (SCIS) and 19th International Symposium on Advanced Intelligent Systems (ISIS),* 186-189, https://doi.org/10.1109/SCIS-ISIS.2018.00039

[6] Kusnadi, Adhi & Wella, Wella & Winantyo, Rangga & Pane, Ivransa. (2018) Evaluation of Feature Detectors on Repeatability Quality of Facial Keypoints In Triangulation Method*, International Conference on Smart Computing and Electronic Enterprise (ICSCEE),* 1-4, https://doi.org/10.1109/ICSCEE.2018.8538385

[7] Kusnadi, Adhi & Wella, Wella & Winantyo, Rangga & Pane, Ivransa. (2019) Removing DCT High Frequency on Feature Detector Repeatability Quality, *5th International Conference on New Media Studies (CONMEDIA)*, 238-243, https:/doi.org/10.1109/CONMEDIA46929.2019.8981817

[8] Delhi, Venkata & Lal, Sankar & Thomas, Albert. (2020) Detection of Personal Protective Equipment (PPE) Compliance on Construction Site Using Computer Vision Based Deep Learning Techniques. *Frontiers in Built Environment. 6, https://doi.org/*10.3389/fbuil.2020.00136.

[9] Chen, Leiyu & Li, Shaobo & Bai, Qiang & Jing, Yang & Jiang, Sanlong & Miao, Yanming. (2021) Review of Image Classification Algorithms Based on Convolutional Neural Networks. *Remote Sensing, 13*, 4712, https://doi.org/10.3390/rs13224712.

[10] Raju, A. & Maddileti, Telugu & J, Sirisha & Srinivas, Rayudu & Saikumar, Kampadandi. (2022) Pseudo Trained YOLO R_CNN Model for Weapon Detection with a Real-Time Kaggle Dataset. *International Journal of Integrated Engineering. 14,* https://doi.org/10.30880/ijie.2022.14.07.011.

[11] Chaki, Jyotismita & Dey, Nilanjan. (2020) *Texture Feature Extraction Techniques for Image Recognition*. Springer, https://doi.org/10.1007/978-981-15-0853-0.

[12] Saputra, Rezki & Surantha, Nico. (2021) Smart and real-time door lock system for an elderly user based on face recognition, *Bulletin of Electrical Engineering and Informatics, 10,* 1345-1355. https://doi.org/10.11591/eei.v10i3.2955.

[13] Akhand, M. A. H. & Roy, Shuvendu & Siddique, Nazmul & Shimamura, Tetsuya. (2021) Facial Emotion Recognition Using Transfer Learning in the Deep CNN*, Electronics. 10,* 1036, https://doi.org/10.3390/electronics10091036.

[14] Dewantoro, Gunawan & Mansuri, Jamil & Setiaji, Fransiscus.(2021). Comparative Study of Computer Vision Based Line Followers Using Raspberry Pi and Jetson Nano, *Jurnal Rekayasa Elektrika. 17,* 239-246, https://doi.org/10.17529/jre.v17i4.21324

[15] Pakdaman, Mehran & Sanaatiyan, Mohammad Mehdi & Rezaei, Mahdi. (2010). A line follower robot from design to implementation: Technical issues and problems, *The 2nd International Conference on Computer and Automation Engineering (ICCAE),* 5 – 9, https://doi.org/10.1109/ICCAE.2010.5451881.

[16] Jamatolail, Mohamed & Ambar, Radzi & Abd Wahab, Mohd Helmy & Isa, Khalid & Abdul Kadir, Herdawatie & Ahmad, Muhammad & Jamil, Mahadi & Mohammadian, Masoud. (2020) Development of a Mobile Robot with Camera-based Target Tracking and Obstacle Avoidance Systems*. International Journal of Integrated Engineering, 12*, https://doi.org/10.30880/ijie.2020.12.07.026.

[17] Dixit, Anjali & Kasbe, Tanmay. (2022). Multi-feature based automatic facial expression recognition using deep convolutional neural network. *Indonesian Journal of Electrical Engineering and Computer Science, 25(3)*, 1406-1419, http://doi.org/10.11591/ijeecs.v25.i3.

[18] Crossley, S. & Seed, N.L. & Thacker, N.A. & Ivey, P.A.. (2004) Improving accuracy, robustness and computational efficiency in 3D computer vision, *Image and Vision Computing, 22,* 399-412, https://doi.org/10.1016/j.imavis.2003.12.006.