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AN INTELLIGENT VISION-BASED APPROACH FOR WORK GROUP IDENTIFICATION THROUGH HELMET DETECTION

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Abstract. *Helmets are essential equipment to protect workers from danger during inspection and operation in almost all industries. There is a growing necessity of developing innovative methods to automatically monitor safety and work group identification at industry work sites. With the rapid development of artificial intelligence (AI) based image recognition technologies, computer vision-based inspections have been one of the most important industrial application areas for automation. Thus, in this paper, we propose an intelligent computer vision approach for work group identification through helmet detection by analyzing images collected from 4K camera installed overhead at work site. For this purpose, we attach a marker on the top of the worker's helmet to detect the helmet and identify the work group. This approach is tested on our data set through simulated experiments and the average accuracy of helmet detection is 92.9%.*
Keywords: Helmet extraction, Morphology operations, Circular object detection

1. **Introduction.** According to the Monozukuri White Paper 2019 [1] published by Japan's Ministry of Economy, Trade and Industry (METI) in June 2019, it has become increasingly difficult to secure human resources in the manufacturing industry every year since 2016. In this context, the number of companies for which the issue of securing human resources is a major challenge has risen every year, from 22.8% in 2016 to 32.1% in 2017 and 35.7% in 2018. In addition, less than 10% of companies have no issues with human resource shortages, with 5.8% of companies reporting no issues in 2017 and 5.2% in 2018, compared to 19.2% in 2016. Therefore, it is very important to train human resources and perform the same tasks as before with fewer people. In the case of the cell production system, which we will focus on this time, the product is assembled by one person or a small group of people, and unlike other systems, the workers have a wide range of responsibilities [2]. From this characteristic, eliminating the waste of walking leads to the improvement of work efficiency. In order to understand the waste of walking, it is important to detect and track the worker. Therefore, this research proposes a method to detect and identify workers, which is a preliminary step to tracking workers.

Extraction methods using sensors and cameras can be used to extract workers in a factory. Location measurement methods using sensors have been studied using portable wireless module [3] and acceleration and gyro sensor [4]. However, it is difficult to detect a worker using a sensor because the measurement device is attached to the worker, and it is difficult to detect the worker due to forgetting to attach the device or due to the influence of mixed wires. Therefore, in this research, we propose another method of worker detection using a camera.

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The purpose of this research is to detect and identify workers, which is a preliminary step to improve the efficiency of factory operations. 4K cameras installed above the workers record their movements, and the recorded data is used to identify employees and work groups. As a result, the precision and recall rates for helmet detection were 75.2% and 92.9%, respectively, despite the distance between the operator and the helmet.

This paper is organized as follows. First, Section 2 provides the problem statement and preliminaries; Section 3 describes the proposed methods; Section 4 deals with the experimental methods, and Section 5 concerns the experimental results. The conclusion is given in Section 6.

2. **Problem Statement and Preliminaries.** Next, we will compare papers. Currently, many previous studies on helmet detection have used computer vision and image recognition techniques. In a previous study [5], a helmet detector using a face-to-helmet regression model (FHRM) and a helmet detection model based on deep transfer learning (DTLHDM) was used to detect helmets at a construction site, and the detection results were 96.2% recall rate, 96.2% fit rate, and 94.4% average correct rate. However, this research was conducted on the condition that faces are detectable, and experiments were conducted only on images in which faces were photographed from the front to detect faces, not on images taken from above at an angle or images in which faces were not photographed from the front. To deal with the case where the face is not visible from the front, the work in [6] uses the skeletal extraction models OpenPose and YOLO v4 for helmet detection. This method was able to detect helmets when the face was not visible, but was not able to detect helmets with large numbers of people. Helmet detection using an improved version of YOLO V3 [7] and helmet detection using YOLOv5 [8] have been proposed to improve these problems. Although there are such helmet detection methods, other methods such as HSV color space instead of deep learning as in [9], and detection using occlusion between worker and helmet [10] are also considered. However, in most of these studies, the worker and the camera are relatively close. Therefore, in this study, we propose a method for worker detection in environments where the camera and the worker are far apart, which was not possible in studies such as [4-9]. Detection using machine learning requires a large amount of data as shown in [5-8]. Therefore, in order to enable detection even with a small amount of data, we use methods such as [9,10] for helmet detection without using machine learning.

3. **Proposed Method.** In this section, we summarize the process of helmet detection and group identification up to group identification. First, workers are detected from the input data, followed by helmet detection, mark recognition, and finally group identification.

3.1. **Helmet detection.** The general flow of detecting helmets is shown below. First, from the image in Figure 1(a), we extract yellow work clothes using color information as shown in Figure 1(b), and roughly locate the blue helmet from the original image as shown in Figure 1(c). Finally, a morphological transformation is performed on the extracted work clothes region, and the helmet region is extracted by taking the logical product of the helmet region and the work clothes region, as shown in Figure 1(d). The flowchart of this process is shown in Figure 2.

3.2. **Group identification.** The procedure for group identification is shown in Figure 3. Figure 4 shows the groups to be distinguished. As shown in Figure 5, the combination of red and black is designated as Group 1 (G1), black only as Group 2 (G2), and red only as Group 3 (G3). Those that cannot be distinguished by the image alone are classified as Group 4 (G4).

(a) Original image

(b) Work clothes extraction

(c) Helmet extraction

(d) Detected helmet area

FIGURE 1. Region extraction using color information

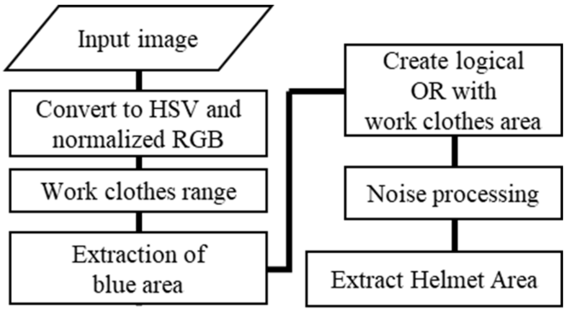

FIGURE 2. Process for helmet detection algorithm

First, mark detection is performed on the helmet area detected in Section 3.1 using the three colors information: normalized RGB and HSV color space hue and saturation. However, mark detection using only color information detects not only marks but also a lot of noise. Therefore, we use two types of noise processing: noise processing using Equation (1), and noise processing using occlusion of the helmet region and mark region to eliminate areas other than marks.

$$\text{circularity} = \frac{4\pi A}{L^2} \tag{1}$$

where A and L represent area and perimeter, respectively.

For group identification, the color is reinserted into the mark area detected by the process described in Figure 3, and the three groups are identified as shown in Figure 5. First of all, red is used as a reference, and when there is a red area RED, the black area BLACK is G2 when it exists, and G1 when it does not exist. Next, when there is no red region in the input image, the black region is designated as G3 when it is present and G4 when it is absent. Then, when the area of the detected red area (G2) is equal to or greater than the threshold value Th (= 200), it is determined as G3; when the area of the black area (BLACK) is equal to or less than Th, it is determined as G1; when BLACK is equal to or greater than Th, it is determined as G3; otherwise, it is determined as G4.

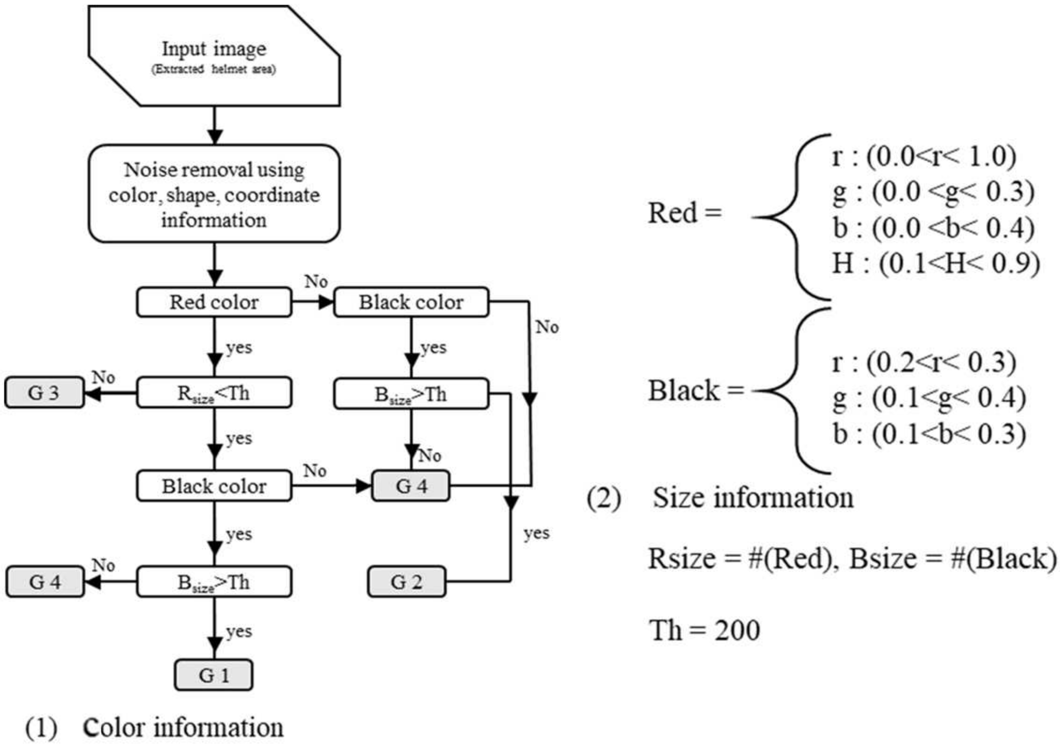

Figure 3. Algorithm for mark detection

Figure 4. Three actual groups used in this experiment

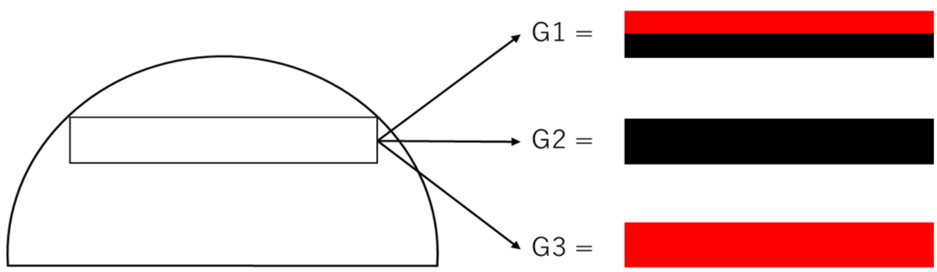

Figure 5. Three groups used in this experiment

Setting the material of the mark. In order to reduce the effect of light, the material of the tape was also examined. Five types of tape are available: bookbinding tape, vinyl tape, cloth tape, Velcro tape, and fluorescent tape. As a way to determine the material, color information was obtained at three different points in the environment, and a graph was used to select the tape with the least effect on specular reflectance even in different environments. The results of this process are shown in Figure 6. Figure 6 shows that the values of magic tape, plotted in black, do not vary as much as the other tapes, so magic tape is used this time.

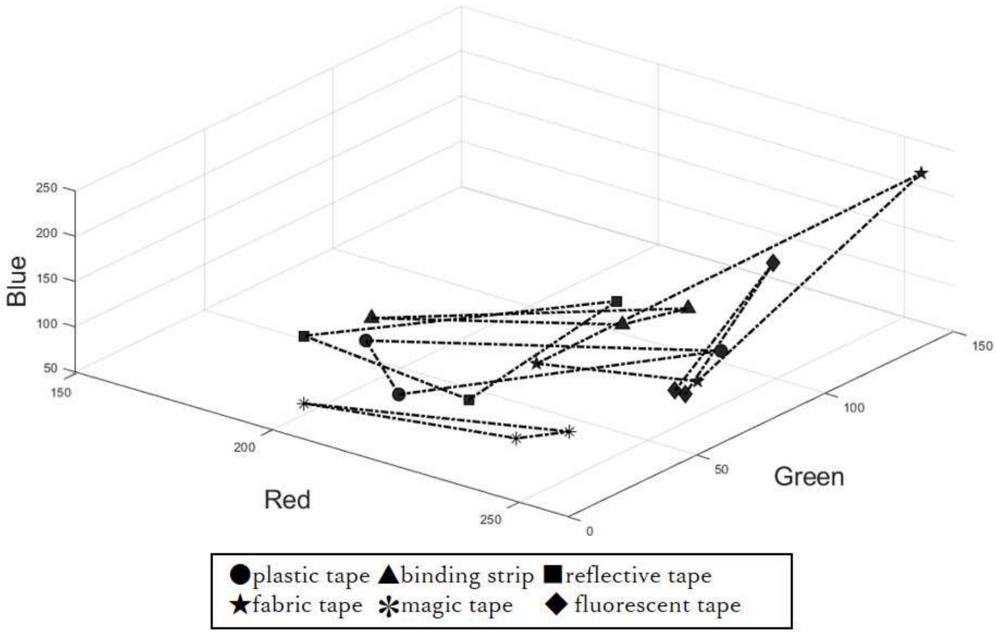

Figure 6. Reflections of the tape in different environments

4. Experiment.

4.1. **Experimental environment.** In this experiment, we use data taken at Kyoritsu Electric Manufacturing Co. The shooting environment was done with a camera height of 7.2 [m], a depiction width of 16 [m], a height of 17 [m], and a seal area of 5 [cm] × 100 [cm]. In addition, two cameras are set up for different locations, both in the same direction, and the work area is photographed from the upper part of the diagonal. We wanted to conduct this experiment using data of actual work being done, but since the delivery of the products was delayed due to COVID-19, we responded by having the participants simulate that they were working on the products that had already been created. In addition, the images used in the experiment were taken in a different experimental environment from the one in which the actual work was performed, as the products were detached. In this experiment, we asked the participants to simulate the work, but in actual work, they rarely walk around as in this experiment, so we used data from a more difficult environment. The AXIS 1448-Le was used to capture the images, and MATLAB 2020b was used to process the acquired videos. As an experimental method, we asked the cooperation of actual workers, 3 people in each of 3 groups, for a total of 9 people, to perform movements like actual work for 5 minutes. As a preparation before starting the experiment, we converted the acquired video data into 900 still images at 3 fps.

4.2. **Evaluation method.** The evaluation method is based on two accuracy evaluations: the accuracy of helmet detection and the accuracy of group detection. To check the accuracy of helmet detection, bounding boxes are manually created at the helmet locations, and the comparison with the experimental data is shown by the precision rate and the reproduction rate. To check the accuracy of group detection, we also compare the experimental data with the manually generated group discrimination data and show the reproduction rate and the precision rate using a confusion matrix.

5. Some Experimental Results.

For helmet detection, we used the method described in Section 3.1, and the results are shown in Figure 8, with an accuracy of 75.2% and recall of 92.9%. For group identification, we used the method described in Section 3.2, and the results are shown in Figure 9, with four different colored bounding boxes for each group. Examples of the results and their accuracy are shown in Figure 9 and Table 1.

(a) Only helmet visible (b) Two people are close (c) Mark not detected

Figure 7. Examples of undetected helmets

Figure 8. Results of helmet detection

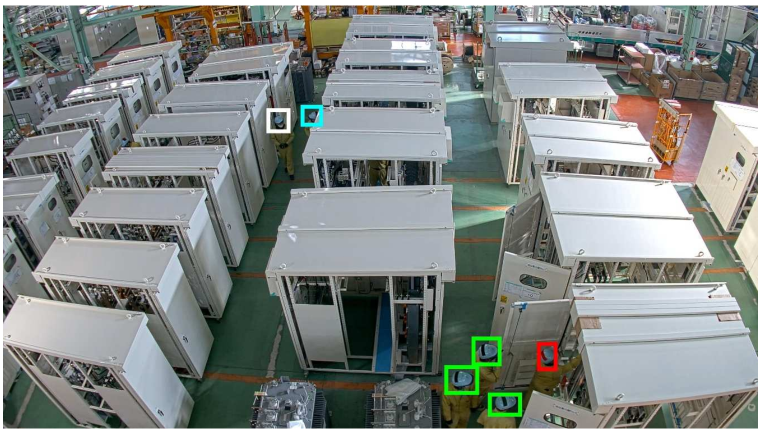

Figure 9. (color online) Results of group identification

For helmet detection, the precision rate was low, and the recall was high. The reason for this is that in Figure 7(a), the algorithm assumes that both work clothes and helmets can be detected, so if only the helmet is visible, but the work clothes are not, it may not be judged as a helmet. In the case of Figure 7(b), if two people are close to each other, they may be mistakenly detected as one person. Figure 7(c) shows an example of a case where group identification was not possible.

6. **Conclusions.** In this paper, we have proposed a method for group identification in order to create an index for efficiency improvement in factories. The precision and recall rates for helmet detection were 75.2% and 92.9%, respectively. On the other hand, the group identification rate was only about 50%. However, since the accuracy was more

Table 1. Results of group identification

		Experimental data				
		G1	G2	G3	Unknown	Recall
Correct answer data	G1	199	40	41	121	50%
	G2	52	914	59	653	54%
	G3	0	47	263	106	63%
	Unknown	2	14	1	55	
	Precision	79%	90%	72%		

than 85% when some of the correct data was selected, we can say that the purpose of this experiment was realized.

As an example of the challenges found in this experiment, the environment in which the experiment was conducted was to read a 100 cm^2 mark on the top of a helmet up to 17 m away. Even with the use of a 4K camera, there was a limit to how far we could go to achieve this, so we think that installing cameras on both sides of the helmet instead of only one side would improve the accuracy.

As for other problems, the Velcro tape we used this time was not available in a wide variety of colors, and we used red and black, which made it difficult to identify the groups. Therefore, we would like to consider reexamining the type of tape used.

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