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Development of an Intelligent Control System to Integrate Computer Vision Technology and Big Data of Safety Accidents in Korea

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1. Abstract

Construction safety remains an ongoing concern, and project managers have been increasingly forced to cope with myriad uncertainties related to human operations on construction sites and the lack of a skilled workforce in hazardous circumstances. Various construction fatality monitoring systems have been widely proposed as alternatives to overcome these difficulties and to improve safety management performance. In this study, we propose an intelligent, automatic control system that can proactively protect workers using both the analysis of big data of past safety accidents, as well as the real-time detection of worker non-compliance in using personal protective equipment (PPE) on a construction site. These data are obtained using computer vision technology and data analytics, which are integrated and reinforced by lessons learned from the analysis of big data of safety accidents that occurred in the last 10 years. The system offers data-informed recommendations for high-risk workers, and proactively eliminates the possibility of safety accidents. As an illustrative case, we selected a pilot project and applied the proposed system to workers in uncontrolled environments. Decreases in workers PPE non-compliance rates, improvements in variable compliance rates, reductions in severe fatalities through guidelines that are customized according to the worker, and accelerations in safety performance achievements are expected.

Key words: Big data of safety accidents; computer vision technology; intellectual automatic control system; personal protective equipment

1. INTRODUCTION

With the increasing number of building construction projects, there is a heightened interest in safety management, one of the core elements of construction projects worldwide. For this reason, the Occupational Safety and Health Act, which was revised in 2020 by the Ministry of Employment and Labor, recommends that management officers of construction companies with more than 500 employees or a construction capacity ranked within 1000 companies must prepare an annual safety and health plan. Moreover, as part of the 'Fatal Industrial Accident Reduction Measures,' the Korean government advised that personal protective equipment (PPE) should be worn to reduce the risks of serious incidents, such as falls and jamming[1].

According to an industry report on the current state of disasters prepared by the Ministry of Employment and Labor, the construction industry had 567 deaths, which is the highest rate among all industries. Falls account for the largest number of deaths in the construction industry [2]. The use of PPE is recommended as a preliminary measure to minimize the number of deaths at construction sites. However, construction workers do not fully understand the importance of wearing PPE, and thus often do not wear PPE for a variety of reasons, including its inconvenience during work.

A construction company must appoint a safety manager at a construction site, depending on the type of business and the number of full-time workers. It also voluntarily appoints a safety supervisor to support the safety manager, if necessary [3]. However, it is almost impossible for a safety manager and a safety supervisor to inspect or patrol a large-scale construction site by themselves due to time limitations. If they do patrol or inspect the site, it might increase the potential risk of a disaster in risky or hard-to-access locations. To address this limitation, we examined the rates at which workers wear PPE at construction sites by collecting image data using CCTV and computer vision technology. This study is thus expected not only to reduce the number of safety incidents for safety managers and safety supervisors, but also to help ensure that more construction workers consistently wear PPE.

As part of this study, we developed a monitoring system to assess whether construction workers wear PPE. To achieve this aim, we carried out the following steps. First, we performed a literature review of existing computer vision studies. Second, we designed a monitoring system to verify whether construction workers wore PPE using an object detection algorithm. Finally, we analyzed the detection accuracy based on object distance or illuminance level in order to apply the results of the developed system to an actual construction site.

2. LITERATURE REVIEW

2.1. Computer Vision

Computer vision is a field of artificial intelligence (AI) that trains computers to interpret and understand visual information. It is applied in various cases, such as for object classification in images, as well as to identify and detect position, moving history and other elements. Object detection is utilized in various industries, including in autonomous driving, facial recognition, and augmented reality to distinguish a target object from the background by analyzing image data [4].

Whereas the existing image classification model for object detection assigns one class for one image, the newly developed image classification model not only assigns one class for one object but also simultaneously identifies the position of the bounding box in which the coordination is stored [5].

Object detection models are divided into two types. The first type performs regional proposal and classification simultaneously. In other words, it provides a simultaneous solution for object classification and localization. Although the results are not accurate, this first object detection type is fast and simple [5]. The YOLO series and SSD series are representative methods of the first type. The second type performs region proposal and classification sequentially. The R-CNN series (R-CNN, Fast R-CNN, and Faster R-CNN) is the representative method of the second type. CNN is a feed-forward network approach that extracts properties from an input image through a classifier. It has the advantage of providing position information around a pixel through the classifier and is limited when detecting a large number of objects [6].

2.2. Analysis of Previous Studies on Computer Vision

As mentioned above, the utilization of Smart technology has been studied in the construction industry. Among them are studies related to computer vision. One study conducted by Jeon Soyeon et al.(2020) analyzed the accuracy with which the wearing of hardhats, safety belts, and safety vests could be detected, based on the number of learning repetitions [7]. Another study performed by Kim Myeongho (2019) identified whether or not the wearing of hard hats could be detected using a deep learning object detection algorithm [8]. An additional study performed by Shuyuan Xu et al. analyzed computer vision studies conducted in the past 10 years to offer recommendations for practical applications [9]. In addition, another study conducted by Jeon Changwung (2021) detailed the development of an object recognition model that detected 12 small objects at a construction site, while considering the fact that computer vision is utilized only for construction workers [10].

Existing computer vision studies have primarily focused on the recent utilization, analysis, and accuracy of object detection of construction workers and objects. However, computer vision is difficult to apply to construction sites due to its low usability and scalability. Therefore, this study aimed to develop a computer vision technology-based monitoring system to verify whether a construction worker wears PPE, while analyzing detection accuracy according to distance or illuminance level for application at a construction site.

3. RESEARCH METHODOLOGY

In this study we developed a monitoring system to determine whether construction workers wear PPE, including hardhats or safety belts. The system consists of a dataset and an object detection algorithm, and attempts to analyze detection accuracy according to distance and brightness.

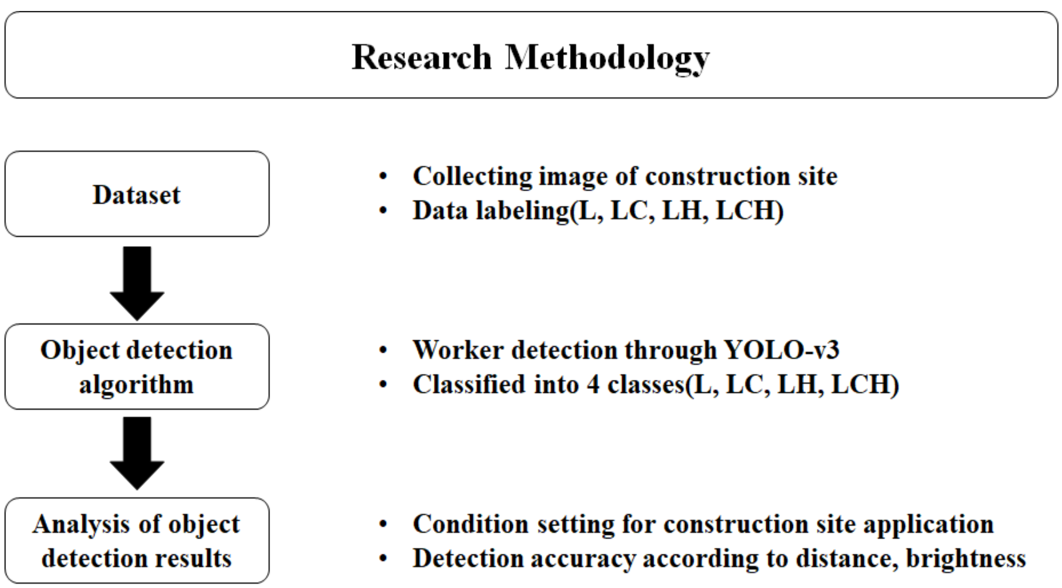

Figure 1. Composition of the detection system

3.1. Composition of a data set

The images that used as the dataset were collected using mobile cameras. A total of 11,607 images were collected based on work type (construction, engineering, others) from 12 domestic construction sites, as shown in Figure 2.

Figure 2. Images collected at construction sites

The images collected from domestic construction sites were processed using LabelImage provided by GitHub, so that they were converted appropriately for deep learning using the detection algorithm. A dataset was composed dividing image classes into L (laborer), LC (laborer wearing hard hat), LH (laborer wearing safety belt), and LCH (laborer wearing hard hat and safety belt) to determine whether or not a worker was wearing PPE.

3.2. Application of an Object Detetion Algorithm

The object detection algorithm was created using Python, based on the open-source PPE algorithm provided through YOLO-v3. Here, the overlap ratio between the actual detection target and the bounding box was set at IoU (intersection over union) $\geq$0.45; the threshold to determine the optimal value at 0.3; and the activation function at LeakReLU, and its parameter at 0.1, respectively. Using the algorithm set at the values above, laborers were first detected from the dataset, and then the class with the highest probability was selected and classified. The detection results of whether or not a worker wore PPE are shown in Figure 4.

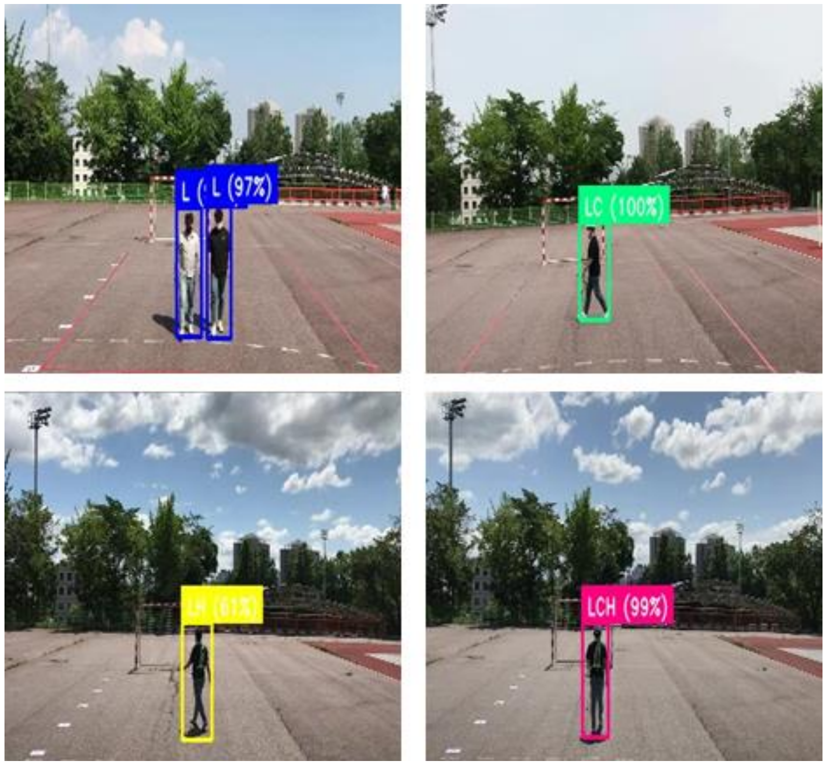

Figure 4. Detection results of wearing the personal protective equipment

4. ANALYSIS RESULTS

In this chapter, experiments were conducted to apply to construction sites based on object detection algorithms in the environment shown in Figure 5. Through the experimental results, the detection accuracy based on distance and illumination, which are fundamental factors for the application of construction sites, was compared and analyzed. After extracting the detection result every second, detection accuracy is calculated.

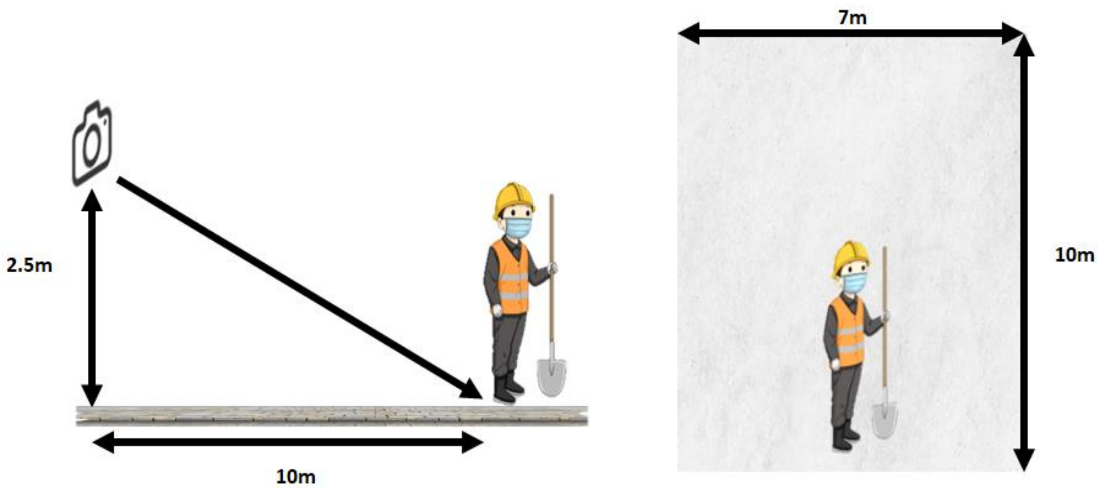

Figure 5. System applicablity experienment conditions

4.1. Detection Accuracy according to Distance

In terms of LCH, the detection accuracy results based on distance are provided in Table 1. The average detection accuracy for the LCH class was 86.13%. At farther distances, the number of false or null detections tended to increase. In the case of LC, false detections were not found at farther distances, while for LH, false detections were likely to occur at distances of 6 m, depending on the size and color of the safety belt.

Tabel 1. Detection accuracy according to distance

Division	Distance	Detection Accuracy (%)	Number of False Detection	Number of Null Detection
LCH	2m	89.38	0	0
	4m	86.95	0	0
	6m	85.60	2	0
	8m	84.79	4	0
	10m	83.90	4	0
	Subtotal	86.13	10	0

4.2. Detection Accuracy according to Brightness of Light

In terms of LCH, a comparative analysis of the detection accuracy was carried out at 20 lux and 50,000 lux, respectively. The analysis results are presented in Table 2. At 50,000 lux, if sunlight was reflected from the safety belt, it was found that the number of false detections increased or that the detection accuracy was low. Also, at 20 lux and at farther distances, the detection accuracy tended to decrease. Nevertheless, the detection accuracy was higher than 85% both at 20 lux and at 50,000 lux.

Tabel 2. Detection accurdacy according to brightness of light

Division	Detection Accuracy (%)	Number of False Detection	Number of Null Detection
50,000lux	86.13	4	0
20lux	85.90	5	0

5. CONCLUSION AND FUTURE RESEARCH

In this study, we developed a monitoring system to determine whether or not workers wore their PPE at construction sites in order to overcome the time and space limitations related to having safety managers and safety supervisors involved in large-scale construction projects. First, we collected images of domestic construction sites and constructed a dataset through a data labeling process. We then checked the detection results obtained through the YOLO-v3 algorithm. We subsequently determined the detection accuracy based on distance and illuminance level, as determined through an analysis of the object detection results. The highest detection accuracy based on distance was 89.38%; however, at farther distances, the detection accuracy tended to be lower.

In addition, the detection accuracy according to illuminance level was 85% or higher both at 20 lux and at 50,000 lux, meaning that it may be possible to detect whether a worker is wearing PPE between 20 lux and 50,000 lux. However, the number of false detections for safety belts was relatively high compared to that for hardhats. It may be the case that the number of images featuring different types, sizes, and colors of safety belts were comparatively low. To address this issue, the number of images containing dynamic conditions of construction sites should be increased, and the learning algorithm should be improved to obtain better detection accuracy.

Further studies should be conducted to explore the optimization and applicability of the detailed conditions for real-time monitoring. Since construction work is mostly done outside, real-time monitoring can be limited due to the dynamic nature of working conditions. Additional safety management studies are also needed to verify whether safety measures are implemented once managers are informed through the monitoring system that workers are accessing dangerous places or not wearing PPE.

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