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Detecting non-hardhat-use by a deep learning method from far-field surveillance videos

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ABSTRACT

Hardhats are an important safety measure used to protect construction workers from accidents. However, accidents caused in ignorance of wearing hardhats still occur. In order to strengthen the supervision of construction workers to avoid accidents, automatic non-hardhat-use (NHU) detection technology can play an important role. Existing automatic methods of detecting hardhat avoidance are commonly limited to the detection of objects in near-field surveillance videos. This paper proposes the use of a high precision, high speed and widely applicable Faster R-CNN method to detect construction workers' NHU. To evaluate the performance of Faster R-CNN, more than 100,000 construction worker image frames were randomly selected from the far-field surveillance videos of 25 different construction sites over a period of more than a year. The research analyzed various visual conditions of the construction sites and classified image frames according to their visual conditions. The image frames were input into Faster R-CNN according to different visual categories. The experimental results demonstrate that the high precision, high recall and fast speed of the method can effectively detect construction workers' NHU in different construction site conditions, and can facilitate improved safety inspection and supervision.

1. Introduction

Construction is a high-risk activity requiring construction workers to operate in awkward postures, excessive lifting and high-intensity operations [1], which are key factors leading to occupational injuries. According to the United States' Bureau of Labor Statistics, the number of fatalities in the US has gradually increased from 849 to 985 between 2012 and 2015 [2]. Similarly, according to the UK Health and Safety Executive (HSE), 38 construction workers suffered fatal injuries in Great Britain between April 2014 and March 2015, while this figure rose to 45 [3] during the same period the following year. Such statistics reinforce the need for greater safety measures to reduce the occurrence of construction accidents.

The consequences of head injuries are the most serious of all construction accidents. Although accidents involving legs, feet and toes most lead to some injury, those involving head and neck are often fatal [4]. Many head and neck injuries are caused by falling from height or being stuck by vehicles and other moving plant and equipment. From 2003 to 2010, 2210 construction workers in the United States died as a result of traumatic brain injuries [5,6], accounting for 24% of the total number of deaths from construction accidents.

Wearing a hardhat is an effective protective measure for minimizing the risk of traumatic brain injury. In construction accidents, hardhats protect workers by resisting penetration by objects, absorbing shock from direct blows to the head by objects and reducing electrical shock hazards. The United States Occupational Safety & Health Administration (OSHA) has two standards requiring workers to wear hardhats when there is a potential for head injury from "impacts, falling or flying objects, or electrical shock" [7]. Despite the vital role of hardhats in protecting life, a survey conducted by the US Bureau of Labor Statistics (BLS) suggests that 84% of workers who had suffered impact injuries to the head were not wearing head protection equipment [8].

An automated monitoring method helps to improve the supervision of construction workers to ensure hardhats are appropriately worn. It is argued that traditional safety management methods, such as risk analysis and safety training, are not sufficient to protect construction workers, as it is difficult to accurately predict the prevention of all kinds

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of accidents at the design stage [9]. An automatic monitoring method is conducive to the realization of real-time site monitoring, which cannot only save labor costs but also enhance site security.

However, previous research into non-hardhat-use (NHU) detection methods is still beyond practical applications. Although existing methods perform well in near-field pedestrian recognition, they are less effective in far-field surveillance video detection. This is because the image resolution of construction workers is high enough to extract the facial features that are clearly visible in near-field image frames [10]. Additionally, most scenes captured by near-field cameras have a minimal change of background, which is inconsistent with the common ever-changing background of a construction site.

Most construction site surveillance cameras are installed on the site boundary at a high altitude. The location of cameras determines the far-field nature of their shoot. A far-field surveillance video is distinguished from other videos by the small pixel size of workers (as small as 30-pixels tall), broad background and the various postures of individuals [11,12]. Therefore, the continuous movement of equipment, resources, people and the environment is all captured in a far-field video, which is a major challenge to the detection of NHU on a construction site.

This paper proposes an object recognition method for NHU detection in far-field surveillance videos on construction sites. With the aim of verifying the adaptability of the method to the construction environment, this research analyzes the various visual conditions of construction sites and classifies image frames according to their visual conditions. The image frames are then input into the Faster R-CNN model according to their different visual categories. The precision and recall rates of the results are verified to judge how much the Faster R-CNN method is suitable for different construction conditions. The experimental results demonstrate that Faster R-CNN is highly robust for various backgrounds and worker posture changes in NHU detection. The precision and recall rates are all above 90%, which is sufficient to improve construction site safety supervision.

2. Literature review

2.1. Necessity for safety monitoring NHU

A survey conducted by the United States Bureau of Labor Statistics found the proportion of up to 90% traumatic brain injuries as a result of NHU [13,14]. Previous research demonstrates that wearing a hardhat can significantly reduce the probability of skull fracture, neck sprain and concussion [14,15]. As such, it is a statutory requirement to wear hardhats in construction activities all around the world [16,17]. Unfortunately, not all construction workers are aware of the importance of wearing a hardhat. In practice, many workers tend to take off their hardhats [18–20] because of discomfort due to weight and to cool off in high temperatures. If not rectified, this reinforced negative behavior can continue in the future until an accident occurs. Clearly, it is necessary to enhance monitoring of the hardhat use of construction site workers.

The ratio of NHU in a construction work group is related to two conditions [21,22]: 1) the workers' safety awareness and attitude towards construction risk and 2) safety supervision. Effective external supervision can not only prevent unsafe behavior in the first instance, but can also gradually improve the level of safety awareness and attitude of workers [23]. Therefore, an automated supervision method to detect construction workers NHU is required to minimize the risk of accidents and improve their safety.

2.2. Related research into the detection of NHU

At present, research into NHU detection can be divided into sensor-based detection and computer vision-based detection methods.

Sensor-based detection primarily relies on positioning technology to locate workers and hardhats. Kelm, et al. [19] designed a mobile Radio Frequency Identification (RFID) portal for checking Personal Protective Equipment (PPE) compliance of personnel. The RFID readers were located at the construction site entrance, and therefore only those who enter the construction site are checked, while workers in other areas are not. Additionally, the tagging of PPE with a worker's identification card only indicates that the distance between the worker and PPE is close, but unable to determine whether the PPE is being worn, held or has been placed on the ground. Barro-Torres, et al. [24] introduce a novel Cyber Physical System (CPS) to monitor how PPE is worn by workers in real time. Rather than being located at the construction site entrance, their sensors were integrated into the clothing of workers for constant monitoring. However, again, this system is unable to determine if a worker is wearing their hardhat or is just near it. Dong et al. [25] use a location system with virtual construction technology to track whether a worker should be wearing a hardhat and transmit a warning. A pressure sensor is placed in the hardhat to collect and store pressure information to indicate whether the hardhat was being worn, and then transmitted via Bluetooth for monitoring and response. However, if a worker exceeds an acceptable range from the monitoring center for long durations, information on the worker can be lost, making it difficult to identify whether they have been wearing their hardhat when out of range. Further, the Bluetooth devices are required to be regularly charged after a period of use. The need to regularly charge the Bluetooth transmitter can limit its use and practicability on site and can be detrimental to the long-term and widespread use of this technology. In general, the use of existing sensor-based detection and tracking techniques is limited by the need for each construction worker to wear a physical tag or sensor. This can be seen as intrusive to workers and generally requires a large up-front investment in additional equipment, including the physical tag or sensor. Many workers are unwilling to wear such tracking equipment because of health and privacy concerns.

In comparison to localization techniques, image recognition is receiving increased attention on construction sites for its enhanced monitoring abilities. RGB-D cameras, such as Kinect and VICON are one kind of popular tools to collect workers' unsafe behaviors [26–28]. Whereas, RGB-D sensors are limited in the range of around 1 to 4 m [29]. Also susceptibility to interference from sunlight and ferromagnetic radiation, making them unsuitable for NHU detection on construction sites [30]. In this regard, the use of regular cameras, particularly a single camera has a competitive advantage for practical application. However, several problems still exist in automatic NHU detection. For example, Du et al. [31] present a NHU detection method based on facial features, motion and color information. Facial feature and color information recognition methods have two important assumptions: 1) all workers turn their face towards the camera while working and 2) all hardhats are of the same color. These two assumptions can be inconsistent on an actual construction site. Further, Shrestha, et al. [32] use edge detection algorithms to recognize the edge of objects inside the upper head region where a hardhat may be recognized. This method also relies on the recognition of facial features, where workers who turn their face away from the cameras cannot be recognized. Rubaiyat, et al. [33] propose another automatic NHU detection method for construction safety by mixing a Histogram of Oriented Gradient (HOG) with Circle Hough Transform (CHT) to obtain the features of workers and hardhats. Again, this method relies on the detection of facial features and has similar limitations to previous algorithms. Park and Zhu et al. [8,34]develop a new NHU detection algorithm based on HOG that does not rely on the detection of facial features. They can contrast objects captured in images by developing a HOG feature template of a human object. Thus, it will be recognized as a worker if the detected object is similar to the previously proposed template. Compared to previous methods that rely on facial recognition, this method depends on the application of the HOG feature template. However, a limitation of this method is that they will not be recognized by the algorithm if workers, while working, act in different ways from the HOG feature template. Accordingly, this paper presents a