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A deep learning-based method for detecting non-certified work on construction sites

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ABSTRACT

The construction industry is a high hazard industry. Accidents frequently occur, and part of them are closely relate to workers who are not certified to carry out specific work. Although workers without a trade certificate are restricted entry to construction sites, few *ad-hoc* approaches have been commonly employed to check if a worker is carrying out the work for which they are certificated. This paper proposes a novel framework to check whether a site worker is working within the constraints of their certification. Our framework comprises key video clips extraction, trade recognition and worker competency evaluation. Trade recognition is a new proposed method through analyzing the dynamic spatiotemporal relevance between workers and non-worker objects. We also improved the identification results by analyzing, comparing, and matching multiple face images of each worker obtained from videos. The experimental results demonstrate the reliability and accuracy of our deep learning-based method to detect workers who are carrying out work for which they are not certified to facilitate safety inspection and supervision.

1. Introduction

The construction industry is a high hazard industry and fatal accidents continue to occur [1]. According to the United States Occupational Safety and Health Administration (OSHA), approximately 900 workers lose their lives on construction sites in the US every year [2]. Furthermore, according to the findings of the case study research conducted by the Health and Safety Executive (HSE) in the United Kingdom, inadequate knowledge, competency and safety awareness are significant underlying causes of fatal accidents [3]. From a survey of 1241 construction laborers with reportable injuries, the US Bureau of Labor Statistics (BLS) found 26% of the injured laborers had not received any training before the injury event, and 74% of the injured had less than 1-year experience [4]. Similarly, Umeokafor, Evaggelinos, et al. [5] collected construction accident data over an 11-year period in Nigeria and found untrained or inexperienced worker-related accidents accounted for 40% of all the accidents resulting from unsafe human acts.

In the United States, the OSHA officially recognizes a work certificate as evidence that a qualified construction worker is equipped with sufficient knowledge, competency and safety awareness to conduct their job [6]. It is argued that a certified worker who has been fully trained pays more attention to safety and specific site safety requirements [7]. Thus, less accidents occur when workers are qualified and their qualifications are appropriately certified, since they have extensive knowledge of their trade and a deep insight of the consequences of their actions [8]. This is supported by a study conducted by California state OSHA, which found that the requirement for worker certification led to a 80% decrease in fatalities from crane accidents [9].

Therefore, more recently, Mainland China, Hong Kong and the United Kingdom have introduced policies to forbid non-certified workers doing construction work. In China, the AQSIQ [10] requires that Chinese special equipment operation staff must undertake rigorous training and pass certification examinations before operating special equipment, since the operation of special equipment can be difficult and its unsafe operation can cause serious accidents. To improve the quality and safety of construction projects, MOHURD [11] has specified that all construction workers in China must be appropriately trained and hold relevant certificates by 2020. Similarly, the related “Designated Workers for Designated Skills” policy provision in Hong Kong

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specifies that only registered skilled workers of specific trade divisions are allowed to independently carry out construction work on Hong Kong construction sites [12]. The principal objectives of this provision is to enhance the safety and quality of construction works by improving workers' skill levels [13]. Further, the United Kingdom's Common Minimum Standards for Construction [14] requires all workers to be registered with the Construction Skills Certification Scheme (CSCS), since CSCS cards are evidence of individuals' training and qualifications required by the specific trades they carry out [15].

In response to recent policy provisions, the Hong Kong Housing Authority (HKHA) has recommended that Radio Frequency Identification (RFID) contactless access monitoring and recording systems should be used at entrances of construction sites to prevent the entry of unauthorized persons [16]. Although this system can identify and restrict un-certified workers from entering construction sites, it is still unknown whether each worker is carrying out their appropriate work according to their certificate. This is a major problem, as construction safety statistics indicate accidents frequently occur as result of workers with weak safety awareness engaging in site activities they are not certified to carry out. For example, in the US, the Statistics in Fatality Assessment and Control Evaluation (FACE) program [17] identified that at least 10 of the 93 recent deaths as a result of electrocution involved uncertified and inadequately trained workers attempting to perform electrical work. Another study by the US Department of Labor revealed that fatal accidents frequently occur as a result of non-specialized workers operating tower cranes [18]. In this paper, we refer to 'non-certified workers' as workers who are carrying out trade work they are not certified to carry out on-site and does not include the checking of individuals who would be restricted from entering a construction site.

The accurate checking of certified workers is an important process to ensure construction site safety. This process involves trade certificate checking to determine if tradespersons (recognized by specific construction activity) match their certificates when queried for identifications. In previous related research, scholars have applied sensors [19,20] and handcrafted features based (such as Histogram of Oriented Gradient (HOG) [21]) methods for site worker identification. However, the sensor-based approach has recognition problems caused by sensor loss and the HOG technology is just a kind of handcrafted feature and acknowledged to have poor precision [22]. Although several researchers have contributed to activity recognition [23–30], few studies consider the relationship between activities and trades. Further, very few scholars have focused on solving certification-checking problems. Therefore, there is an urgent need to develop a suitable solution to automatically check for worker certification.

The field of computer vision has developed rapidly [31], and the vision-based approach to automatic security monitoring has made significant progress [32]. Therefore, we propose the combination of several advanced vision-based deep learning algorithms to check the certification of workers on construction sites and prevent workers carrying out work for which they are not certified. Once non-certified workers have been detected, they are alerted, and action will be taken to cease the activity. As such, a decrease in the levels of non-certified work is expected to reduce the occurrence of related accidents substantially.

In the rest of this paper, we firstly review the previous research related to the problem of construction site workers carrying out non-certified trade work, and the latest developments in computer vision technologies in addressing this problem. Secondly, we present our framework, which comprises three modules: key video clips extraction, trade recognition and worker competency judgment. Thirdly, we propose a set of rules for key video clips extraction and a new trade recognition method based on spatiotemporal relevance between workers and non-worker objects, as well as a multiple face images based on the improved identification strategy. Finally, we evaluate the performance of each module, discuss the causes of error analysis and present the knowledge contribution of this study.

2. Literature review

In recent years, methods of 'deep learning' have greatly progressed in the field of computer vision. Accordingly, computer vision-based safety behavior monitoring has also developed rapidly. This study focuses on identifying workers and matching their certified competencies with specific trades classified by activities. Because of the rapid advancements in deep learning-based object detection and tracking, and face detection and recognition, workers can be automatically identified Since few scholars have directly investigated automated solutions to enable the recognition of workers carrying out unauthorized work, we also review recent developments in activity recognition and worker identification problems in the construction industry to support this research contribution.

2.1. Related techniques in computer vision

Detecting non-certified work on site requires several techniques in computer vision. First, object detection and tracking methods are needed to classify and locate all the objects from the images and understand their actions from trajectories, which is the foundation of both trade recognition and identification. Second, face detection and recognition methods assist us to verify the workers' identities to determine whether they are certified to undertake the work.

Before introducing related algorithms, it is necessary to understand the functions and structure of Convolutional Neural Networks (CNN), which is the basic element of deep learning methods used in computer vision [33]. The purpose of CNN is to extract all the features from a resource image and then use all these features to classify the object in the image [34,35]. A complete CNN is consisted of multiple convolutional layer, rectified linear units, pooling layers as well as a fully connected layer. The parameters of learnable filters in these layers will be finetuned and optimized together with the classification components to minimize total classification error [36]. With the help of CNN, various objects in images can be recognized automatically, which is a fundamental step for ongoing research stages, mainly including object detection, tracking, face detection and face recognition.

The emergence of CNN has led to a rapid development of the object detection field [33]. Following the continuous improvement from RCNN [34] to SPP [35] to FAST RCNN [36] methods, the most recent advanced algorithms in the object detection field are Faster Region-based Convolutional Neural Networks (Faster R-CNN) [37], Single Shot Multibox Detector (SSD) [38] and You Only Look Once (YOLO) [39]. Despite the faster calculation speed of SSD and YOLO, Faster R-CNN has the highest accuracy and allows real-time detection for our purpose. Therefore, Faster R-CNN is argued to be the most suitable object detection method for this study.

Multiple object tracking (MOT) can be viewed as a problem to associate the same detected objects across multiple frames in a video sequence [40]. For most top-ranked MOT solutions [41–43], the speed is considered too slow and restrict their real-time applications. As the state-of-the-art online tracking algorithm, Simple Online and Real-Time Tracking (SORT) [40] is a much simpler framework that achieves favorable performance at high frame rates on the MOT challenge dataset [44]. Considering its compatibility with detection algorithms, advanced performance and short runtime, SORT is employed in our study.

Face detection is the pre-condition for face recognition [45]. Since computer face recognition requires close-up photographs with only the face visible for classification [46], there is a need to use face detection methods to extract the bounding boxes of faces before face recognition can commence. Recently, in response to the challenges in developing reliable face detection methods, researchers have made attempts to use generic object detection methods to solve face detection tasks, since face detection can be considered as a special type of object detection task in computer vision [47]. One of the most frequently used methods is Faster R-CNN [37]. Researchers have proposed new face detection