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Computer vision techniques for construction safety and health monitoring ☆

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ABSTRACT

For construction safety and health, continuous monitoring of unsafe conditions and action is essential in order to eliminate potential hazards in a timely manner. As a robust and automated means of field observation, computer vision techniques have been applied for the extraction of safety related information from site images and videos, and regarded as effective solutions complementary to current time-consuming and unreliable manual observational practices. Although some research efforts have been directed toward computer vision-based safety and health monitoring, its application in real practice remains premature due to a number of technical issues and research challenges in terms of reliability, accuracy, and applicability. This paper thus reviews previous attempts in construction applications from both technical and practical perspectives in order to understand the current status of computer vision techniques, which in turn suggests the direction of future research in the field of computer vision-based safety and health monitoring. Specifically, this paper categorizes previous studies into three groups—object detection, object tracking, and action recognition—based on types of information required to evaluate unsafe conditions and acts. The results demonstrate that major research challenges include comprehensive scene understanding, varying tracking accuracy by camera position, and action recognition of multiple equipment and workers. In addition, we identified several practical issues including a lack of task-specific and quantifiable metrics to evaluate the extracted information in safety context, technical obstacles due to dynamic conditions at construction sites and privacy issues. These challenges indicate a need for further research in these areas. Accordingly, this paper provides researchers insights into advancing knowledge and techniques for computer vision-based safety and health monitoring, and offers fresh opportunities and considerations to practitioners in understanding and adopting the techniques.

1. Introduction

Due to hazardous working environments at construction sites, workers frequently face potential safety and health risks throughout the construction process. Even though the construction sector constitutes about 5% of the workforce in the U.S., fatal injuries in construction account for about 18% of all occupational deaths [1]. In addition, the incident rate for nonfatal occupational injuries and illness in construction is 30% higher than average industries [2]. These statistics obviously show an immediate need to reduce the prevalence of fatal and non-fatal injuries in construction. To address this issue, previous research has examined accident occurrence mechanisms to understand the causes of accidents, and the process and conditions leading to accidents. Notably, prior work demonstrates that nearly all such injuries are highly preventable by reducing or eliminating exposures that may contribute to detrimental safety and health effects to construction workers [3,4].

In the accident causation model [5], unsafe conditions and unsafe acts are considered the two direct causes of accidents. Monitoring unsafe conditions and acts in the construction process thus plays a key role in determining and taking prompt corrective actions to prevent resulting safety and health issues by eliminating them in the causal process. In practice, site observations and inspections are commonly used techniques to evaluate the risk involved in ongoing works and existing site conditions in construction [6]. However, observational methods are costly and time-consuming because they require human manual observations

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and documentations by supervisors or safety personnel [7]. In addition, manual observation suffers from the limitations of missing and inaccurate information in a timely fashion [8]. These limitations become more significant in construction projects because worker environments continuously change over time and skilled supervisory manpower is not always present at sites, thereby making it challenging to implement manual observation processes in daily practice [9].

Recently, computer vision has drawn attention because it can be used for the automated and continuous monitoring at construction sites. Computer vision can provide a rich set of information (e.g., locations and behaviors of project entities, and site conditions) about a construction scene by taking images or videos, which facilitates the understanding of the complex construction tasks rapidly, accurately, and comprehensively. These advances bring the operational and technical advantages over other types of sensing techniques (e.g., RFID, GPS and UWB) that require installation of sensors to all of project entities to be monitored and provide limited information such as location data, providing an opportunity to complement them [10,13,23,44,45,79]. Accordingly, computer vision has been applied to various areas in construction such as progress monitoring, productivity analysis, defect detection, and automated documentation [8,11,12,14]. Computer vision technologies have also great potential as field-based safety and health monitoring tools that can address limitations of current manual observational approaches, creating opportunities to automate the risk identification and evaluation processes by extracting and analyzing relevant information from images or videos [10,14,15]. Despite recent progress made toward computer vision-based approaches to safety and health monitoring, prior works have been infrequently applied to actual practice for technical and practical issues, or any other issues. Further studies are thus required to find out existing limitations and issues in the current body of knowledge in order to boost the adoption of the advanced techniques by practitioners as well as to address the identified issues in the future studies.

This paper reviews existing literature in computer vision-based safety and health monitoring: (1) to understand the existing state-of-the-art methods and their current progress; (2) to identify the major challenges and limitations commonly found in the prior studies; and (3) to offer potential problem-solving directions for future studies. To provide an overview on this review, this paper first presents current safety management practices relevant to field monitoring, and discusses potential roles and the general framework of computer vision for safety observation and inspections. We then present overall concepts, specific methods and applications of computer vision techniques that are directly or potentially used for safety and health monitoring in construction, specifically in the three groups categorized by computer vision methods and types of information extracted from imagery data (namely, object detection, object tracking and action recognition). Along with the overall review, this paper discusses technical challenges and potential issues when applying computer vision-based approaches in practice.

2. Overview of computer vision for safety and health monitoring

Compared with other industries such as automotive or manufacturing industries [62,63], the construction industry has many domain-specific issues in safety and health monitoring such as continuously changing and complex working environments, and non-standardized work procedures and designs, which may result in challenges for computer vision-based safety and health monitoring. In this section, current practices of safety and health monitoring in construction, and potential roles and approaches of computer vision to improve the practices are presented. Based on the potential roles, a general framework for computer vision-based safety and health monitoring is suggested.

2.1. Current practices of safety and health monitoring

The unique, dynamic, and complex nature of construction projects likely increases workers' exposure to hazardous working environments. Occupational hazards cannot be fully eliminated without systematic and comprehensive efforts for managing safety and health on construction worksites such as safety planning, worksite analysis, hazard prevention, and control or safety and health training [4]. The purpose of safety and health monitoring is to make sure that safety and health are being effectively managed by measuring health and safety practice against an organization's safety and health plans and standards.

Among safety and health monitoring activities, job safety observations and inspections are one of the common techniques used to evaluate ongoing tasks in construction [4]. The jobsite observation and inspection is typically conducted on a weekly or bi-weekly basis depending on the size of the project, and inspectors generally take the observation—without any other tasks at the time—for one to two hours at a randomly scheduled time during the week [16]. During the observation, the human observer then serves to detect and eliminate the potential causes (i.e., unsafe conditions and acts) of accidents by watching workers perform a specific task (i.e., safety observation) or visually examining the work area and work equipment (i.e., safety inspection) with a checklist [4]. To simplify the record keeping, for example, Reese and Eidson [4] identified unsafe conditions and acts that contribute to injury, property damage, or equipment failure, such as failure to wear personal protective equipment (PPE), improper lifting, improper use of equipment (e.g., excessive speeds, servicing moving equipment) or improperly stored explosive or hazardous materials.

2.2. Potential roles of computer vision-based approaches

As described in an earlier section, identification of risks such as unsafe conditions and acts calls upon observers' perceptual and cognitive capabilities [94]. For example, observers have to understand scenes using their perceptual capability such as object and scene recognition, or visual processing of spatial and temporal relations. Then, the perceptual information should be evaluated by comparing it with rules, guidelines, or observers' past experiences to identify unsafe conditions and acts. However, computer vision techniques themselves that aims to perform visual tasks accurately and reliably [17] are limited only to extract the perceptual information, not addressing evaluation of the information to identify unsafe conditions and acts. Therefore, computer vision-based approaches for safety and health monitoring should consider not only how to extract perceptual information, but also how to compare the information with existing knowledge on potential risks or hazards.

Types of perceptual information for safety and health monitoring vary depending on characteristics of unsafe conditions and acts, which requires different computer vision techniques. Based on the type of information, this paper classifies computer vision-based approaches into three categories: (1) scene-based; (2) location-based; and (3) action-based risk identification (Table 1). First, the scene-based approach pertains to understanding and evaluating any potential risk in a static scene by inspecting the scene in a safety context. For instance, required information for analysis includes whether unsafe objects are present in the scene, safety tools and equipment required are not present, workers are in unsafe areas, and so on. In Table 1, failure to wear PPE (e.g., safety vests and hard hats), congested work area, or improperly stored explosive or

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