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Automating and scaling personalized safety training using eye-tracking data

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ABSTRACT

Research has shown that a large proportion of hazards remain unrecognized, which expose construction workers to unanticipated safety risks. Recent studies have also found that a strong correlation exists between viewing patterns of workers, captured using eye-tracking devices, and their hazard recognition performance. Therefore, it is important to analyze the viewing patterns of workers to gain a better understanding of their hazard recognition performance. From the training standpoint, scan paths and attention maps, generated using eye-tracking technology, can be used effectively to provide personalized and focused feedback to workers. Such feedback is used to communicate the search process deficiency to workers in order to trigger self-reflection and subsequently improve their hazard recognition performance. This paper proposes a computer vision-based method that tracks workers on a construction site and automatically locates their fixation points, collected using a wearable eye-tracker, on a 3D point cloud. This data is then used to analyze their viewing behavior and compute their attention distribution. The presented case studies validate the proposed method.

1. Introduction

Despite efforts to improve safety performance, fatal and non-fatal injury rates in construction are still alarmingly high. In the United States, the construction industry accounts for approximately 16% of all occupational fatalities, while employing less than 6% of the workforce [1]. Worldwide, more than 60,000 workers lose their lives on construction sites every year [2]. Over the years, the construction industry has been motivated to improve safety enforcement, training, and monitoring, which has resulted in significant improvements. However, desirable levels of safety performance are yet to be attained. Apart from the loss of human lives, construction accidents can also have an economic impact on companies, adversely affecting their profit margins [3]. Waehrer et al. [4] estimate that the cost of injuries exceeds $11.6 billion every year in the U.S.

To address this issue, researchers have attempted to identify the precursors of construction accidents [5–7]. Among others, workers' inability to detect hazards in dynamic and rapidly changing work environment [8–10] has gained significant attention. Recognizing hazards is the primary step in effective safety management as illustrated in Fig. 1. When hazards remain unrecognized, the possibility of accidents increases substantially. In fact, Haslam et al. [11] found that more than 42% of accidents involve worker-related factors including inadequate hazard recognition skill. Moreover, recent findings have demonstrated that a disproportionate number of construction hazards remain unrecognized in construction environments [10,12].

While researchers and practitioners have developed several training methods to improve hazard recognition, much of this effort has proceeded with the assumption that poor hazard recognition is mainly due to lack of knowledge. However, hazard recognition is a visual search process and is governed by psychological principles (such as in Feature integration theory [13] or the Guided search model [14].) Therefore, the process of hazard recognition is prone to human limitations. Jeelani et al. [15] identified 13 causal factors for poor hazard recognition levels among workers. Several of the causal factors were associated with how workers examine the environment for safety hazards and how their visual attention is distributed over the scene.

Jeelani et al. and Dzeng et al. [16,17] found a significant correlation between viewing patterns of workers and their hazard recognition performance. Hasanzadeh et al. [18] concluded that attention distribution of workers who detect more hazards are significantly different from those that detect fewer hazards. Further, Asadi et al. [19] found a close relationship between the amount of time participants spent looking at hazards and the number of hazards identified accurately. Hence, it is very important to study and analyze the viewing pattern of workers in order to understand what constitutes a good hazard search – a search that results in better hazard recognition performance. From the training standpoint, scan paths and attention maps can be used very effectively to provide personalized feedback to workers, by communicating search process deficiency to trigger self-reflection [9,20]. Although performance feedback alone (i.e., a hazard that were recognized or not recognized) is useful, data from eye-tracking can provide

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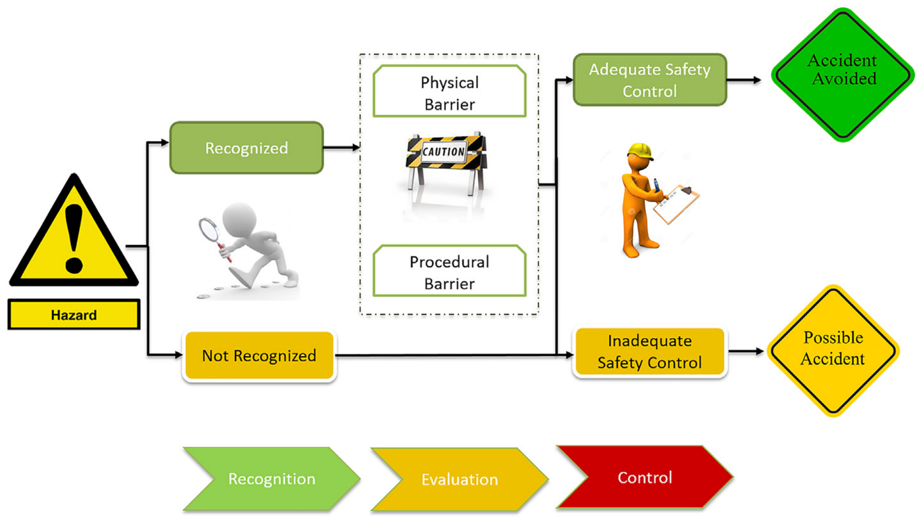

Fig. 1. Safety management process.

additional information on why certain hazards remain unrecognized. For example, eye-tracking can show that a worker did not recognize a hazard because they did not pay attention or did not fixate on a particular hazard (i.e., search error). Alternatively, the worker may have fixated on particular hazards but may not have recognized them as hazards (i.e., detection error). The workers may also prematurely terminate the hazard search process after a handful number of safety hazards are recognized.

Although the above studies [16–19] provide valuable insights about viewing patterns of construction workers and its impact on their hazard recognition performance, all of them examined hazard recognition using static images captured from construction workplaces. While beneficial, static images cannot capture the true dynamic nature of construction sites. They present fixed perspective views to the workers without the flexibility of moving around and observing the scene from different locations or orientations. As such, photographs do not represent the workers' viewpoints but rather represents the viewpoint of the photographer. Even if multiple photographs from a finite number of orientations and perspectives are obtained with additional effort, they still cannot cover all possible ways a worker may view a real scene. Hence, important information, which workers can derive while viewing a real scene, may not be available when photographs are used. As a result of this disconnect, the performance of workers during the experiments may not be reflective of their performance in real construction environments and can result in inaccurate assessments and non-representative viewing behavior.

Advancements in computer vision and wearable eye-tracking technology enable capturing and analyzing workers' actual views/perspective. An examination of the viewing patterns of workers in real work environments is expected to offer more benefits with superior validity. One way to achieve this objective is to record scan paths and fixation data of workers while they work, using a wearable eye-tracking device and later examine the data for each worker manually. Unfortunately, such an approach will be time-consuming, tedious and prone to human errors, which can result in inaccurate assessments and inefficient feedback. However, computer vision techniques can potentially automate, and thereby, scale the process of recording and analyzing eye-tracking data for a large number of workers.

Therefore, this study proposes the development of a novel computer vision-based system that can automatically analyze the eye-tracking data of workers and provide useful information about workers' visual search behaviors. This system can potentially automate and scale up personalized training for improving hazard recognition. Workers wear eye-tracking glasses that capture videos and eye movement data while they move in a construction site. The construction site is mapped in a 3D space and workers are localized in this space. Using the localized positions of the workers and the fixation data from the eye-tracking glasses, each worker's viewing behavior (i.e., attention distribution, fixation points, etc.) is recorded and analyzed automatically. The system is also used to predict the detectability of various hazards in a construction work environment.

The proposed system can be used to autonomously generate and provide personalized feedback to workers and safety managers for training purposes. It also generates the data to identify potential hazards that are more likely to remain unrecognized, which will assist the safety managers to proactively adopt remedial measures. The proposed work was tested and validated in two active construction sites.

2. Background

2.1. Technology in construction safety

Development in technology has influenced every domain of construction including safety. Skibniewski [21] has summarized the use of information technology for construction safety assurance over the past few years. Visualization technology has been shown to improve safety management by assisting construction professionals in safety training [22], job hazard analysis [23] and safety monitoring [24,25]. Similarly, different sensor-based technologies are also getting attention owing to their potential applications in safety management [26,27]. Technology has also played a part in improving safety by automating different construction tasks [28,29].

2.2. Hazard recognition and training

Heinrich et al. [30] argue that unsafe conditions and unsafe acts are two direct causes of accidents. Therefore, identifying such acts and conditions is the first step in taking corrective actions to eliminate them and prevent accidents [31]. The construction industry employs various hazard recognition methods and training interventions. These include predictive methods such as Job Hazard Analysis (JHA), pre-task safety planning, and task demand analysis [8,32,33]; and retrospective methods, such as safety checklists that include hazards gathered from past injury experiences to prevent future reoccurrences.

To overcome the issue of poor hazard recognition, the construction industry invests large amounts of resources in training the workforce to efficiently recognize and control hazards [34]. However, studies have demonstrated that workers lack hazard recognition skills despite having