A BIM Integrated Hazardous Zone Registration Using Image Stitching

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Abstract –

Identifying hazardous zones is one of the priorities and duties of construction safety monitoring. With the emergence of vision intelligence technology, hazardous zones detected by AI algorithms can support safety managers in predicting potential hazards as well as making decisions. However, the risky area in images/videos continues to suffer from numerous issues as undetected or low accuracy. Further, there are many kinds of hazardous zones that need to be trained for computer vision. This study aims to develop a BIM integrated application of hazardous zone registration for the construction stage, which is represented as construction objects using image stitching. The methodology consists of two stages: (1) during the pre-construction stage, BIM-based safety planning extracts the virtual image with the danger region; and (2) during the construction stage, the hazardous zone may be recorded in the site image using a stitching algorithm. A proposed method has been validated by visualizing hazardous zones from the actual images of the ringlock scaffold systems installed at the ConTIL laboratory. As a result, the BIM integrated application is anticipated to assist vision intelligent warning systems in proactively predefining hazardous zones, ultimately reducing repeated accidents associated with other entities entering dangerous areas.

Keywords –

Hazardous zone; BIM application; Image stitching

1 Introduction

The construction work environment is deemed hazardous, as evidenced by industry-wide workplace incidence statistics. According to the annual report of the Occupational Safety and Health Administration, a total of 1061 of the 5333 worker deaths in the United States in 2019 happened in the construction industry, equating to one fatality for every five construction employees [1]. Additionally, 50% of all fatal incidents in Korea happened in the construction business [2]. In Europe, the construction industry ranks third in non-fatal injuries, and its total surpasses the average across all industries [3]. Specifically, over 90% of accidents are caused by reckless behavior and unsafe working situations [4]. Various research on construction safety stated that workplace safety might have helped reduce and avoid accidents. However, identifying and managing movement hazards and risks during the construction stage is a critical yet still challenging endeavor.

Technical advancements helped by computer vision have resulted in developing a very effective instrument for automatically detecting and predetermining dangerous circumstances in the construction workplace. It has been researched and may eventually replace existing manual observational techniques in building site OHS monitoring [5]. By analyzing the visual input data using an AI algorithm, it is possible to derive safety information. For instance, Kim [6] suggested a vision-based hazard avoidance system that alerts employees to potentially hazardous situations in real-time. Yan [7] addressed the monitoring of struck-by hazards in terms of the spatial relationship between a worker and a heavy vehicle by employing three-dimensional bounding (3D) box reconstruction and three-dimensional spatial relationship recognition techniques in conjunction with three-dimensional spatial relationship recognition. Additionally, other dangerous scenarios have been investigated continually, including failure to utilize personal protective equipment (PPE), failing to follow safety protocols. In particular, assessing a hazardous area is a priority for preventing a dangerous context.

By incorporating a building information modeling (BIM) methodology into construction planning, safety concerns may be addressed early in the process, such as and safety measures [8], visualizing current plans [9], camera position planning [10], and enabling safety communication. Additionally, workspace modeling has been investigated by adopting BIM. Therein, Getuli [11] defined terminologies of workspace's type (Worker's space, Hazard space, Equipment space, safety space) in the BIM model. As a result, the hazardous area could be detected prior to construction.

In order to overcome the above limitations, this paper aims to propose a BIM integrated application for hazardous zone registration using image stitching. The proposed method consists of two stages with pre-construction and during construction. The remaining of this work includes the following. Section 2 reviews the related study; the methodology is explained in section 3. A case study is implemented for evaluation following section 4. Finally, the author summarizes the method and discussion.

2 Literature Review

2.1 The current state of construction safety monitoring

Safety monitoring is critical in construction because it identifies and promptly corrects, ensuring safety concerns by eradicating them throughout the causative process. Traditionally, site observations and inspections have been widely utilized to assess the risk associated with ongoing work and context in construction sites [12]. However, these approaches are costly and time-consuming since they need supervisors or safety experts to do manual observations and paperwork. Additionally, manual observation is limited by the inability to obtain complete and accurate information in a timely manner. Recently, implementations enhanced surveillance camera performance to give the best monitoring of people, resulting in labor and cost savings. Nonetheless, identifying dangers such as dangerous circumstances and behaviors requires observers to use their perceptual and cognitive abilities. For instance, observers must examine the monitor system in order to comprehend the dangerous context and then evaluate it by comparing it to rules, guidelines, or the observers' prior experiences to detect unsafe circumstances and actions. Additionally, watching many contemporaneous displays dilutes the safety manager's concentration.

2.2 Hazardous zone monitoring using computer vision

Numerous studies have been conducted on computer vision-based construction safety. For instance, Seo [12] derived a general framework for computer vision-based safety and health monitoring. Zhang [13] reviewed the vision-based occupational health and safety monitoring of construction site workers. Mneymneh [14] presented a unique motion detection algorithm and human classifier for automatically detecting persons who are not wearing hard hats and identifying non-compliance with safety rules. Fang [15] developed a method based on deep learning for detecting non-hardhat users in far-field surveillance footage. Further, various studies focus on detecting unsafe behavior, unsafe contexts, such as the correlation between hazardous areas and workers [16]. However, there are many types of danger zone with different dimensions that are challenging in practically applying computer vision.

2.3 BIM-based safety planning

Construction safety planning is now being carried out using BIM-based approaches. Fall hazard identification techniques based on building information modeling were created by Zhang [17] to help workers become more aware of potential dangers by visualizing them. Tran [8] proposed a framework for hazard identification of spatial-temporal activities. Besides, BIM is integrated with other emergence technology to improve safety performance effectively. Deng proposed the idea for the assistance of indoor evacuation in fire scenarios, mainly including indoor positioning and rescue route planning by integrating BIM and computer vision. Further, BIM information can assist computer vision performance, such as automatic labeling construction site images [18].

3 Methodology

We proposed an approach for hazard zone registration using BIM, as illustrated in Figure 1. The BIM integrated application comprises two stages following the construction process. The input information is extracted from BIM-based safety planning. As a result, virtual images, including reference objects and hazardous areas, could be exported from the BIM model prior to the construction stage. After that, the virtual image will be matched with the site image. Through reference objects, the hazardous area from the BIM model would be registered in the actual image. The following sections would go into further detail on the structure and substance of the solutions given in this approach and the fundamental rationale for each of them.

3.1 Pre-construction stage

In this stage, existing construction safety-related information can be integrated into BIM to effectively develop safety planning. There are two types of information that are integrating into BIM, including geometry and non-geometry information. For instance, Table 1 shows an example OSHA regulation of an area around a scaffold. Rule 1926.451(h)(2)(i) required employees not to be permitted to enter the area under the scaffold to prevent falling items. Rule 1926.451(f)(6) asks for the clearance distance between scaffolds and

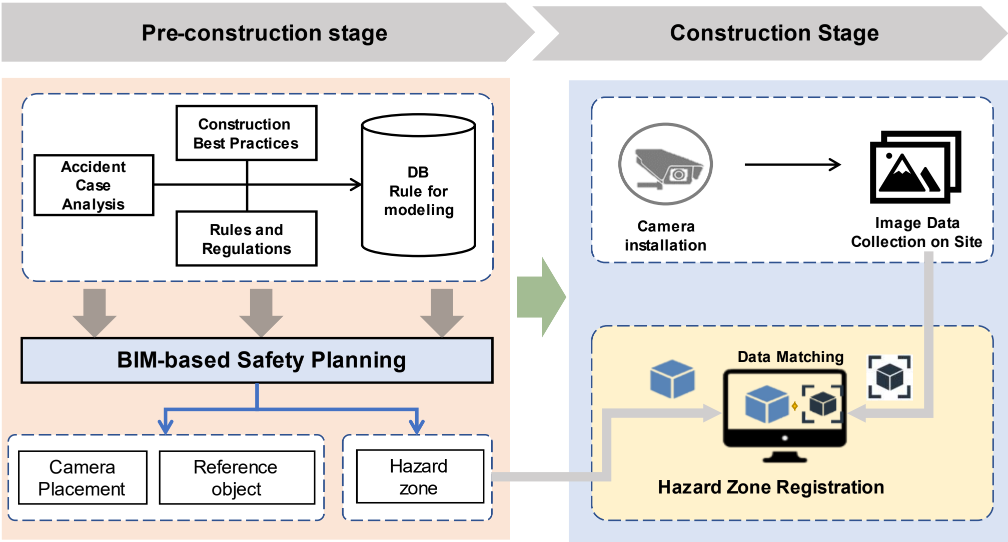

Figure 1. BIM-based Hazardous zone registration approach in construction site image

power lines. Through rule-based modeling, the hazardous zone can be simulated in a BIM environment. Continuously, the BIM model provides surveillance camera placements planning. The camera position, field of view (FoV) are visualized so that the hazardous area in the FoV can be extracted in the virtual image, as illustrated in Figure 2.

Table 1. Example of hazard area around scaffold following OSHA regulations

Regulation	Contents
1926.451(h)(2)(i)	The area beneath the scaffold where things might fall should be blocked, and no person shall be authorized to access the hazard area.
1926.451(f)(6)	The following distances should be maintained between scaffolds and electricity lines.

3.2 Construction stage

In order to realistically implement safety planning in the construction stage, there is a need for a robust monitoring system. Computer vision-based safety monitoring automatically supports safety managers to identify hazard conditions. Construction objects (worker, PPE, rail, opening, etc.) are detected using the CV algorithm. Besides, combining with BIM-based safety planning, the static hazardous areas can also be registered as objects that are used for CV. Hence, the hazard condition based on the correlation between hazard areas and other objects is identified.

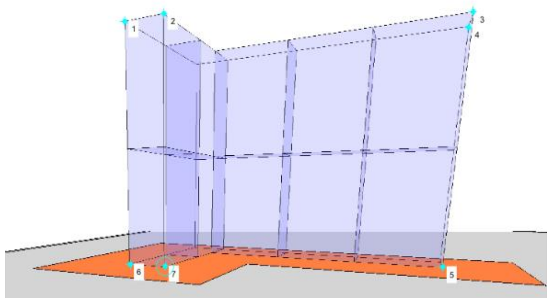

Figure 2. Control points in the virtual image.

3.2.1 Image stitching process

Image stitching is a process of composing two or multiple images with the overlapping region to create a new image with useful information from both images. In this case, the hazard zone will be determined after stitching the virtual image and the actual image. The virtual image was extracted from the BIM model (in Figure 2), and the actual image is the image was captured at jobsite by the camera (in Figure 3). The reference objects from the BIM model are employed as control points to stitch with control points from the actual image. The corresponding control points need to be identified from two of these images. As illustrated in Figure 2 and Figure 3, seven control points were selected; these control points need to be evenly distributed in images to increase accuracy. Then, based on the control points, the transformation matrix is estimated to warp the virtual images into the actual image. After blending the warping image and actual image, the hazard zone will be shown on the actual image.

Figure 3. Control points in the actual image

4 Case study

4.1 Introducing case scenario

To validate the applicability of the proposed method, the authors performed a case study for registering hazardous areas around scaffolds installed at the ConTIL laboratory, as illustrated in Figure 4. In the case study, BIM-based workspace planning is developed (Figure 5), including scaffold location and hazardous area. The hazardous area has been highlighted following OSHA regulation by using a visual programming language (Dynamo), as depicted in Figure 6.

Figure 4. Scaffold installation at ConTIL Laboratory

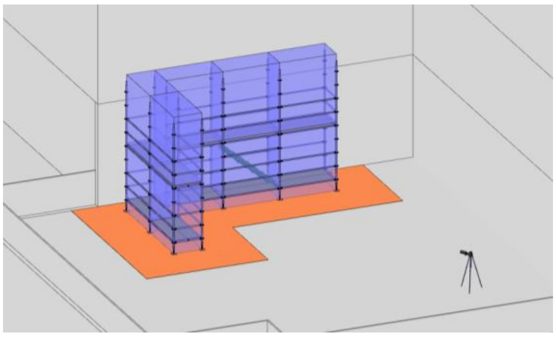

Figure 5. Installation planning scenario

Furthermore, the camera position is shown in a green circle as well as the reference object, which is in the yellow circle. After that, the camera and reference object are installed in the proper position on the actual site. Using a mapping algorithm in section 3.2.1, the hazardous area could be mapped to the actual image. It means the hazardous area is drawn as an object supporting computer vision.

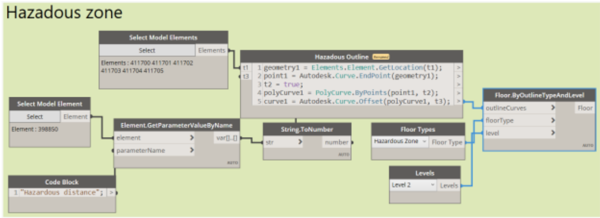

Figure 6. Highlighting hazardous zone using Dynamo

4.2 Results

After setting up a camera on the construction site, the images have been captured. To identify hazardous zone, the image from BIM-based safety planning is stitching with the site images. Through this, the hazardous zone is mapped with a site image. Figure 7 illustrated the results of the registration process. The orange area is presented as the hazardous zone. Hence, other entities entering this zone could be warned as risk actions.

Figure 7. Hazardous zone registration in reality image

5 Discussion and conclusion

Identifying hazardous zone plays a vital key in achieving safety monitoring success. Current research meets a gap between transforming hazardous zone from planning to the monitoring process. This study proposed a BIM integrated application for registering hazardous zone into construction site images using image stitching. First, the information from BIM-based safety planning (such as monitoring area, reference objects, virtual image exportation) is extracted. After that, the camera systems could be placed following the planning. Finally, the hazardous zone can be combined into the actual image.

The proposed method was tested in a lab environment. Test results illustrate the hazardous zone in the actual image. However, there are limitations yet to be addressed. First, the approach still has a manual effort that requires the employee to pick control points in the virtual and actual image. Second, the study has not investigated the number of control points need for image stitching and the registration accuracy. Third, the study assumes the camera placement base on the camera installation plans; however, the images captured by the camera may be partially occluded the control points by the dynamic obstructions.

For future studies, the authors would focus on the accuracy of stitching algorithms between virtual and actual images. Then, developing a correlation between hazardous zones and other objects (such as workers and mobile equipment). To reduce manual effort, automatic stitching between reference objects also needs to investigate. Control points from the BIM model would automatically stitch with control points from an actual image using pattern recognition..

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