Automation in Construction 65 (2016) 21–32

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Automated hazardous area identification using laborers' actual and optimal routes

Hyunsoo Kim [a], Hyun-Soo Lee [b], Moonseo Park [b], BooYoung Chung [c,*], Sungjoo Hwang [d]

[a] Construction Engineering and Management Division, Charles Durham School of Architectural Engineering and Construction, University of Nebraska–Lincoln, W116 Nebraska Hall, Lincoln, NE 68588, USA
[b] Seoul National University, San 56-1 Shinrim-dong, Seoul, Korea
[c] ST Development Group, Samsung SDS Co., Ltd., 123 Olymic-ro 35-gil, Songpa-gu, Seoul, Korea
[d] Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI 48109, USA

ARTICLE INFO

Article history:
Received 1 February 2014
Received in revised form 18 January 2016
Accepted 30 January 2016
Available online 20 February 2016

Keywords:
Safety management
Hazard area identification
Automated data collection (ADC)
Real-time locating system (RTLS)
Building information modeling (BIM)

ABSTRACT

Approximately 20% of accidents in construction industry occur while workers are moving through a construction site. Current construction hazard identification mostly relies on safety managers' capabilities to detect hazards. Consequently, numerous hazards remain unidentified, and unidentified hazards mean that hazards are not included in the safety management process. To enhance the capability of hazard identification, this paper proposes an automated hazardous area identification model based on the deviation between the optimal route (shortest path)—which is determined by extracting nodes from objects in a building information model (BIM)—and the actual route of a laborer collected from the real-time location system (RTLS). The hazardous area identification framework consists of six DBs and three modules. The unidentified hazardous area identification module identifies potentially hazardous areas (PHAs) in laborers' paths. The filtering hazardous area module reduces the range of possible hazardous areas to improve the efficiency of safety management. The monitoring and output generation module provides reports including hazardous area information. The suggested model can identify a hazard automatically and decrease the time laborers are exposed to a hazard. This can help improve both the effectiveness of the hazard identification process and enhance the safety for laborers.

1. Introduction

The construction industry faces more risk factors than any other industry because each construction site has its own individual characteristics [1,2]. Compounding such complexity is the fact that construction accidents can be divided into two categories: those occurring while working and those occurring while moving to the working space. The fatal accident reports of the Korea Occupational Safety and Health Agency (KOSHA) [3] indicate that approximately 20% of fatal accidents in the construction industry occur when laborers are moving through a site. According to the Health and Safety Executive [4], 23% of all accidents in the construction industry occur while the worker is moving through a site. The risks that laborers face in their movement path are significantly different from the risks that laborers face while in their working places; this is due to the performance of other tasks, the piling of risky materials, the existence of openings in the floor, etc. Furthermore, since a construction schedule is established based on activities, safety management focuses on work spaces [5,6], which in turn means that the level of management for moving processes or paths is usually lower than for work spaces. The dynamic changes within construction sites also make it hard for safety managers to identify the beginning and the end of the overlap of hazards and the laborers'movement paths [7].

Carter and Smith [8] suggested that the hazard identification ratio of general projects is 66.5%. This means that the unidentified hazard ratio is greater than 30%. To detect unidentified hazards, additional resources (e.g., increasing the number of safety managers) are required to improve hazard identification under this current practice. However, even though unidentified hazards entail more risk than identified hazards, it is not economical to input additional efforts (i.e., increasing the number of safety managers) to identify more hazards. Additional resources may not be available for several reasons, such as financial limitations, lack of experts, etc. Regardless of why a site cannot add additional resources toward hazard identification, leaving risks unidentified means that the exposure time for a hazard can increase. For this reason, a method that can decrease the exposure time of hazards is required.

An automated approach—such as information technology (IT)—offers an alternative for identifying hazards promptly. A large amount of research deals with the IT-based location-tracking approaches that improve safety [9–11]. Hallowell et al. [12] used proximity sensors—consisting of radio frequency identification (RFID) and

---

* Corresponding author.
E-mail addresses: hkim13@unl.edu (H. Kim), hyunslee@snu.ac.kr (H.-S. Lee), mspark@snu.ac.kr (M. Park), booyoung.chung@samsung.com (B. Chung), nkkt14@snu.ac.kr (S. Hwang).

http://dx.doi.org/10.1016/j.autcon.2016.01.006
0926-5805/

ultra-wideband sensors—to prevent struck-by-vehicle accidents. Navon and Kolton [9,11] suggested a fall-prevention model based on the location tracking of safety equipment. In addition, Lee et al. [13] developed a laborer location-tracking-based system that warns laborers when they approach hazardous areas. Although these approaches offer value in risk mitigation, since they all focused on risk control and assumed that the hazards were already identified, they are not likely to accurately manage risks and hazards when such dangers are unidentified.

Therefore, the objective of this study is to develop a system that automatically identifies hazards in laborers' movement paths through laborer location tracking. The system identifies hazardous areas using the deviation between laborers' location logs and laborers' paths. By comparing existing hazardous areas and work spaces, previously unidentified hazardous areas can be identified. The proposed system uses real-time tracking to identify hazards that were previously unknown and to reduce the duration that such hazards remain without any safety countermeasures.

The rest of this study is organized as follows. First, this study investigates traditional hazard identification approaches. Then the related research for hazard identification is presented, and various methods are analyzed. From this analysis, assumptions for developing algorithms and a conceptual model are suggested. Finally, the detailed algorithms of the suggested system are explained with a validation of the system.

2. Literature review

To prevent accidents, hazard identification is necessary [3]. Unidentified hazards mean that hazards are not included in the safety management process. The traditional way of identifying construction hazards is through a rule-based checklist established based on accident cases and best practices. Traditional hazard identification methods have failed to identify all of the hazards that should have been identified [3] because hazards are generated by a combination of unexpected conditions in various times and places as a construction project changes dynamically and progresses. As a result, it is almost impossible to identify all of the hazards before the beginning of construction. Ineffective hazard identification can result in unsafe site conditions and construction processes [14].

Many researchers have attempted to identify construction hazards using various methods. Information retrieval-based methods have been suggested by Carter and Smith [8], Goh and Chua [15], and Kim et al. [16]. Carter and Smith [8] suggested a web-based application that includes knowledge and the experience level of all personnel within a company. Goh and Chua [15] developed a hazard identification model using case-based reasoning (CBR); their model was established based on accident cases. Kim et al. [16] introduced an information retrieval system that also used accident cases. Although this system can help to identify a hazard using accumulated accident cases, current accident cases are aggregated based on activities. Thus, the cases can indicate which activity is hazardous, but they cannot be used to identify a hazard in a laborer's path. The results of these various methods are mostly text-based cases about activities. It is difficult to determine the coordinates of a potential hazard using text-based cases since the cases are limited to illustrate a sequence of accidents. Therefore, managers would have to conjecture the coordinates of the expected hazards.

On the other hand, visualization—which can give obvious coordinates and visual information—has been applied to the design phase to help all construction participants identify hazardous activities or areas [14]. Recently, a building information modeling (BIM)-based 4-dimensional model was used to detect potential on-site safety hazards [14,17]. Despite the fact that some research has been conducted to improve construction hazard identification by using visualization technologies, there remains the problem of applying the visualization technologies to hazardous area identification in an ongoing project—it is difficult for an established visualization model to reflect the dynamic changes of a construction site when even a well-established BIM model does not fully depict changeable objects (e.g., piled materials, temporary equipment). Another problem is that a safety manager needs to check every visualized area in a computerized system to identify the potential hazards in a real site. This process can be a time-consuming task because there are enormous scenes, and the scenes are dynamically changing over time. Thus, in such systems, managers must examine extensive quantities of data. Moreover, these studies related with BIM are limited by the lack of the consideration for laborers..

Recent efforts on the integration of a real-time location-tracking system (RTLS) with BIM have been actively pursued for construction safety management [18]. This integration can be an alternative to solve these two problems. It can collect information that is generated on a construction site automatically and can give safety managers both visualized information and coordinates [19]. Laborers' location logs include extensive data that represent laborers' moving paths; if there is proper data processing, laborers' location logs can also be used in safety management [9]. Navon and Kolton [11] and Lee et al. [13] suggested RTLS-based safety management systems that track laborers' locations. Such systems generally use one of two tracking methods for tracking location: global positioning systems (GPS) and RFID [20,21]. Each of these approaches offers benefits to construction according to the sites' characteristics.

Construction sites can be broadly divided into indoor conditions and outdoor conditions. As the most widely used tool in the general population, GPS is an effective tool for outdoor conditions. However, this technique is difficult to apply to indoor construction sites because the received signal strength may be lower in an enclosed space. On the other hand, RFID has sufficient positioning accuracy in both outdoor sites and indoor sites so long as the receiver and transmitter devices are sufficiently installed.

Since construction hazards can be found in both indoor and outdoor settings, this study uses the RFID technique that can be applied to both conditions. By using the RFID technique, we can garner information such as the point where a laborer is currently located and a laborer's path. According to Chen et al. [23], the risk perception of laborers can be utilized to hazard identification. In this study, the risk perception of laborers can be represented by selection of laborers’ movement path. Based on this information, this paper suggests a hazardous area identification system.

3. Hazard identification model

This section presents the approach we used to organize the modules and related databases (DBs) to establish a hazard identification model. We begin by discussing the assumptions used when developing the model, then we cover the algorithms we developed for each module.

3.1. Conceptual model

Before developing a hazardous area identification model based on the usage of RFID, we suggest two hypotheses about laborers' moving characteristics. They are as follows:

(1) When laborers move to where they want to go, they have a tendency to move along an optimal route to minimize physical work [22] or time [24]. In this hypothesis, “optimal route” means the shortest path between two places—where laborers are coming from, and where they are going [25,26].

(2) When obstacles (activities, material, hazards, etc.) exist on an optimal route, laborers deviate from the route.

When laborers move to the work spaces, they normally select the shortest path [22]. If their actual path deviates from the optimal route, it can be assumed that there is likely an obstacle hindering their movement along the path. These obstacles could be piled-up materials, congested working spaces, or hazardous areas. If the deviation between the laborers' actual paths and the optimal route is calculated by using