Identifying unsafe habits of construction workers based on real-time location

Heng Li[1], Greg Chan[2]

Abstract: Unsafe behavior is one of the major causes of construction accidents. Managing the behavior of workers in real-time is difficult and requires huge manpower. In this paper, a new real-time locating framework is proposed to improve safety management by collecting and analyzing data describing the behavior of workers to identify habits that may lead to accidents. The aim of the study is to identify working habits of workers based on their location history. Location data is used to compare with that of other workers and equipment. The results indicate that the reuse of real-time location data can provide extra safety information for safety management and that the proposed system has the potential to prevent struck-by accidents and caught-in between accidents by predicting unwanted interaction between workers and equipment. This adds to current research aimed at automating construction safety to the point where the continuous monitoring, managing and protection of site workers on site is possible.

Keywords: Construction safety; framework; real-time system

I. Introduction

Worker behavior has been found to be a major cause of accidents since early studies in the 1940's (Heinrich, 1941), and has been identified as a major cause of construction accidents (Abdelhamid and Everett, 2000). One of the most difficult tasks is managing the behavior of workers. Aiming to improve the safety behavior of workers, the 'behavior-based safety' (BBS) technique was introduced in the 1970's. Chan and Tian (2012) define BBS as an operational learning theory that emphasizes the identification of the influencing factors of human behavior on safety through observation, rectification and analysis. Improved safety behavior is sought through interventions based on these factors. This process is termed 'reinforcement' in psychology (Chan and Tian, 2012). Komaki et al. (1978) have applied BBS techniques to enhance the safety of a food manufacturing plant by observing the behavior of workers and provided them with feedback three to four times a week. As a result, safety performance improved 26%, but performance returned to the baseline upon completion of the BBS program. This indicates that the continued use of BBS could effectively improve the safety performance of workers in the workplace. The successful application of BBS has been recorded in various industries such as the petroleum (Zohar and Luria, 2003), manufacturing (Ray et al., 1997; Chandler and. Huntebrinker, 2003) and nuclear power (Cox et al., 2004) industries.

Despite subsequent success in the transport and food manufacturing industries, recent attempts to apply BBS in the construction industry have not produced this same result. An exception is Lingard and Rowlinson (1998), whose trials of BBS on seven Hong Kong construction sites for nine months resulted in improved safety performance in some of the work activities involved.

While observation is one of the key functions of BBS, it is always difficult for the management team to observe the behavior of all construction workers at the same time due to both the numbers involved and the dynamic nature of construction site work. There is currently a lack of effective tools to monitor the behavior of all workers on site.

This study proposes a new method of monitoring the behavior of workers by using a real-time locating system (RTLS). The method aims to collect real-time location data of workers and equipment. The working behavior of workers and equipment is captured by analyzing the location data. By comparing the behavior of workers, equipment and the construction schedule of a construction project, the study aims to predict unsafe behavior or potential safety problems associated with construction schedule and location data. For this, a real-time locating system (RTLS) is developed. With the new system, the RTLS records the locations of construction workers, equipment and temporary works during working hours. Based on the result, the safety management team can then provide additional training to improve the safety knowledge and awareness of both individuals and groups of workers.

II. Previous studies

Observation and measurement, as a key procedure of BBS, has several limitations, with the observation process being a major problem. For example, the observation process of BBS is very time consuming (Levitt and Samelson, 1987), demanding a significant amount of

[1] Professor, Room ZS734, The Hong Kong Polytechnic University, Kowloon, Hong Kong, heng.li@polyu.edu.hk(*Corresponding Author)
[2] Postdoctoral fellow, Room ZN1002, The Hong Kong Polytechnic University, Kowloon, Hong Kong, g.chan@polyu.edu.hk

effort be dedicated to collecting reliable data (Johnson and Sackett, 1998). It also requires a large data sample to reduce observer bias (Levitt and Samelson, 1987). Since people have different opinions on the degree of safety involved in an activity, observations become inconsistent when the existing observer is replaced (Mattila et al., 1994). It was also pointed out by DePasquale and Geller (1999) that the frequency of observations is key to observing the response of the workers. It is also difficult for a single observer to collect a large amount of data at once. In short, field observation is too expensive for construction projects (Johnson and Sackett, 1998).

Meanwhile, the advanced development of real-time locating systems (RTLS) allows constant and live monitoring of the positioning of construction workers, equipment and materials. Carbonari et al. (2011) cite the four most promising technologies for construction use as: 1) Radio Frequency Identification Devices (RFID); 2) Global Positioning Systems (GPS); 3) Ultra wide-Band (UWB); and 4) Wireless Local Area Networks (WLAN). The accuracy of these construction systems has also been tested. Cheng et al.'s (2011), experiment of tracking resources at a construction pit, for example, found an average error of 41cm. Lee et al.'s (2011) case study involving the use of RFID technology for safety management, on the other hand, found an average error of 44.97cm. Previous studies have also shown the potential of RTLS in construction management, safety training and crane operation. For safety management, one of the most commonly used techniques is to create virtual fencing to prevent workers from entering hazardous zones (Carbonari et al., 2011). This method was also adopted by Giretti et al. (2009). A warning signal is sent to the workers to alert them when they have entered an area designated to be hazardous. Most previous work has used RTLS for real-time management, but the location data could also be used to predict the behavior of workers and equipment based on their working habits.

III. FRAMEWORK OF RTLS HABIT-BASED MONITORING AND ANALYSIS

As Petzold et al. (2005) mention, people have habits in their daily lives and usually follow routines in their working environment, so their position can be predicted by using previous position information. This study proposes a framework aimed at predicting construction accidents through the analysis of real-time location data of observed workers obtained by RTLS. By analyzing the location data, this paper aims to examine two habits of workers: 1) how the workers go to the work place and; 2) their working habits. After establishing the habits of the workers, the system then uses a virtual fencing (Hinze, et al., 2005) approach to fence off the hazardous area. The hazardous area is unique to every single construction site, depending on the requirements of the safety management team. Hazardous areas, for example, should include where working at height, confined spaces, using heavy equipment and toxic materials etc. A database of workers and equipment can be built by continuously monitoring the location of workers and equipment. Analysing the location data in the database has the potential to reveal the habits of workers and equipment. By so doing, it is possible to predict their locations. By comparing their habits and the construction schedule, this framework can identify the workers and equipment that may enter pre-defined hazardous areas.

IV. EXPERIMENT

Site experiments were conducted to demonstrate and test the system developed from the framework. The experiments aimed to test if the system could identify habits that may lead to accidents based on the information collected. The detailed implementation and results of the experiment are presented below.

a. Data collection

The system requires two types of data for BBS analysis. The first type is the location of the observed objects. This is used to analyze the location of the observed object during working hours. Chirp Spread Spectrum (CSS) based RTLS technology was selected in this study to obtain the location data of the observed workers, equipment and other required objects. CSS, as defined by IEEE 802.15.4a. Commercial module nanoPAN 5375RF by Nanotron Technologies GmbH was used in the experiment. A CSS based RTLS was built by the components as shown in Figure 1. This includes anchors, a tag, repeater, router, computer and database. Four anchors were required to set up the observed area of the RTLS. Any tag inside the observed area could obtain its own location by communicating with the anchors. The tag then passed the data to the repeater, which was first transmitted to the router and then to the computer. One repeater can transfer data up to a hundred meters. More repeaters are required if the distance between the computer and the tag is too great. The tag was attached to the observed worker or equipment to obtain its location. With RTLS, the real-time location of the observed object is obtained. The CSS based RTLS immediately obtains the ranging distances between the observed object and the nearby anchors and transmits the distances to the server. The server calculates the position of the observed object and presents it in three-dimensional format (X, Y, Z). Both the ranging distances and calculated position are stored in MySQL format.

b. Results of the experiment

The system was implemented on construction sites in both Hong Kong and China from November 2013 to April 2015. During this time, the system was setup on the construction site and experiments were carried out occasionally. More than fifty experimental trials were conducted during this period. The system setup proved stable during the experiments.

c. Identifying the habits of construction workers

Once the worker has entered the construction site, the worker was required to wear a tag, which was installed on the safety helmet. Once donning the helmet, the tag records the real-time location of the worker. The developed system captured the locations of workers within the construction site. The location of the worker is stored in three-dimensional format (X, Y, Z) plus time. Based on the 3D location data, a set of points can be plotted. The points represent the location of the worker during working time. By connecting the location points, the path of the workers to their working locations can be drawn (Figure 1). By repeating the whole process, the system can compare the path of different days and even the path of different workers.

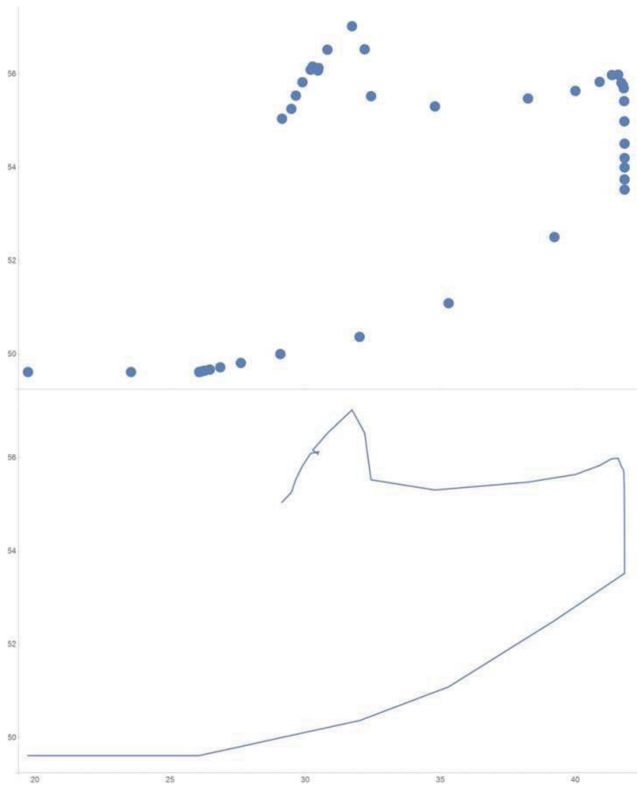

Figure 1. The movement path of one of the workers to the work place

The working location of worker was captured on site. For example, Figure 2 shows the working locations of one of the workers being observed on a construction site. The worker stayed in the same area during the working hours. The locations of the worker were similar in another working day. By comparing the locations of the worker on different days, it can be found that, when the worker is working on the same task, the working location does not change. Based on the schedule, the working location of the worker in the next few days can be predicted, if the tasks remain unchanged.

Figure 2. Working location of one of the observed workers

By using kernel mixture distribution analysis, the distribution of worker'locations is mapped by colors according to the density of the location points. The pink area refers to the area in which the worker stayed the longest. In Figure 3, the locations of the worker are plotted and analyzed. This Figure shows that the worker worked in five nearby areas during the experiment.

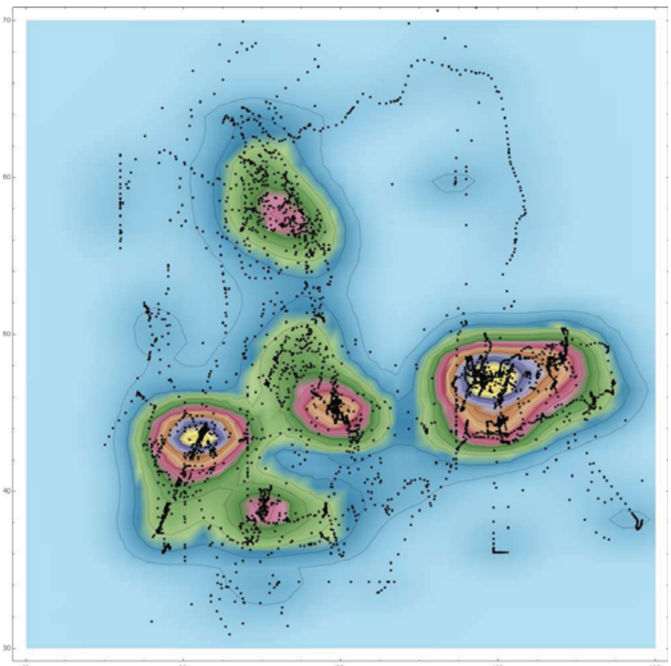

Figure 3. Location of workers during an on-site experiment

V. DISCUSSION

The traditional observation process is known to be time-consuming (Levitt and Samelson, 1977), resource intensive (Johnson and Sackett, 1998), biased (Levitt and Samelson, 1977) and inconsistent (Mattila et al., 1994). The results of the study suggest that the use of RTLS can accurately capture the real-time location of construction workers (i.e. providing quantitative information) inside the site area. Continuous monitoring the real-time location of workers can capture the location of workers over a full day. The location data of construction workers allows the identification of two possible habits of construction workers 1) the path on which they go to their workplace and 2) their working location. By comparing these two habits with the construction program, the proposed method aims to predict construction safety problems 1) unwanted interaction between workers and heavy equipment and 2) entry of prohibited areas. As mentioned in the experiment, it is possible to identify the movement habits of workers by observing their travel, such as the path to their workplace. If workers follow the same path for a few days, the path could be classified as a moving habit. Change in a habit can be caused by a change of environment or behavior of the worker. Early detection of such a change would allow the management team to investigate the reason and rectify the action if it is unsafe. The same applies to the entry of unauthorized areas. This is achieved by continuously monitoring the location of workers and comparing it with that of the equipment or pre-defined hazardous zones. Therefore, providing the hazardous zones are well-defined, unsafe worker behavior can be identified by this approach.

The same principle also applies when equipment is the source of the hazard. For example, an excavator was set as the hazard source in one of the experiments. A red zone was defined as the hazardous zone. By continuously updating the location of the excavator, it was possible to identify the working location of the excavator and thus defines a non-stationary source of hazard for the next few days before the same construction activity was completed. By comparing the habits of workers and equipment, it is possible to predict unwanted interaction between workers and equipment. This can clearly help reduce the number of 'struck-by' construction accidents, as a substantial number of accidents have been reported as being are caused by misjudgment of such hazardous situations (Hinze et al., 2005).

VI LIMITATIONS

There are several limitations in this study. First, the proposed method has been trialed several times on three different construction sites. However, it was very difficult to continuously monitor the movement of the same workers. We could only monitor the workers after obtaining their approval. Some workers changed their mind after the initial experiment while others refused from the beginning. Workers may also be present on a few construction sites at a time. For example, they may only attend the site for half day and come back a few days later. To avoid delaying construction progress, the research team can only visit the sites occasionally. As a result, in this study, the research team was not able to continuously monitor a group of same workers for a long period in order to identify their working habits. As a result, the system could only be verified by a series of experiments.

VII CONCLUSION

While previous studies focus on using data captured from the RTLS for real-time monitoring and management, this paper is concerned with predicting unsafe scenarios by using the same set of captured data to enable the management team to predict unsafe scenarios before the start of construction and prevent accidents as a result. The use of RTLS is examined to collect quantitative data for analyzing the working habits of construction workers. The approach provides an automatic, statistical and consistent means of finding two of the working habits of construction workers: the path of the worker to the work place and the working locations. To validate the concept, an operational system was developed and applied to two construction projects in Hong Kong and one construction project in Shanghai, China. The trials aimed to show that the system could obtain information from workers to analyze their habits. From the two trials, it is shown that the system can trace the movement paths of workers and heavy equipment (such as the excavator in the case study). Through the analysis of their locations, the two working habits of construction workers can be identified. This confirmed the expected outcome of the study in predicting that the worker may enter the working area of an excavator. The safety manager used the provided information to correct the workers' unsafe behaviors through safety talks, training or both. The results of the study also indicate that the system has the potential to identify unsafe behavior by using "spatial reasoning" (Lee et al., 2011). The method analyses the data to show the distribution of worker' locations for predicting possible unsafe scenarios. The method is new and was not considered in previous studies. The re-use of the large amount of data, which was originally captured for real-time management, is proved to be possible to identify safety problems that are yet to happen. The method therefore has a clear potential for enhancing the safety performance of construction projects and has especial advantages for large sites where it very difficult and expensive to simultaneously monitor hundreds of workers by conventional means.

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