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Chirp-spread-spectrum-based real time location system for construction safety management: A case study

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ABSTRACT

Observing the working procedure of construction workers is an effective means of maintaining the safety performance of a construction project. It is also difficult to achieve due to a high worker-to-safety-officer ratio. There is an imminent need for the development of a tool to assist in the real-time monitoring of workers, in order to reduce the number of construction accidents. The development and application of a real time locating system (RTLS) based on the chirp spread spectrum (CSS) technique is described in this paper for tracking the real-time position of workers on construction sites. Experiments and tests were carried out both on- and off-site to verify the accuracy of static and dynamic targets by the system, indicating an average error of within 1 m. Experiments were also carried out to verify the ability of the system to identify workers' unsafe behaviours. Wireless data transfer was used to simplify the deployment of the system. The system was deployed in a public residential construction project and proved to be quick and simple to use. The cost of the developed system is also reported to be reasonable (around 1800USD) in this study and is much cheaper than the cost of other RTLS. In addition, the CCS technique is shown to provide an economical solution with reasonable accuracy compared with other positioning systems, such as ultra wideband. The study verifies the potential of the CCS technique to provide an effective and economical aid in the improvement of safety management in the construction industry.

1. Introduction

Construction accidents are one of the major sources of workplace fatalities. In Hong Kong for example, there were 46 fatalities in the construction industry or around 24% of the total fatalities in all workplaces in 2011 [17]. In investigating the causes of construction accidents, Abdelhamid and Everett [1] found unsafe site environments and unsafe working attitudes (workers deciding to work in dangerous conditions) to be the major causes of construction accidents. During the last five years, numerous researchers have suggested new safety training modes. These include e-Learning [16], peer-led participatory training [37], tracking and visualisation [36], virtual safety training systems [21] and immersive virtual reality training platforms [30]. New training approaches may have improved the attitude of some workers, but there are additional factors such as work pressure, co-workers, intrinsic attitudes and other psychological variables involved [11]. To deal with unsafe behaviour, observing safety procedures is one of the seven safety management approaches suggested by the OSHA handbook [29]. However, due to the high worker-to-safety supervisor ratio, it is difficult, if not impossible, for the safety management team to supervise the work of every single worker on site. In Hong Kong for example, only one safety officer is required to stay on a construction site when there are more than one hundred construction workers. The construction industry in general is lacking a tool to collect useful data for construction management [7]. This means that there is no tool to assist the safety management team in collecting real-time data of construction workers for their real-time behaviour monitoring on site. As a result, accidents exist when construction workers act in an unsafe manner, even after they have received safety training.

Recently, the advanced development of real time locating systems (RTLS) has prompted their application in construction research. An example of previous studies into the use of positioning systems to improve management is given in Fig. 1 [2,3,5,7,14,18,35,36,39,40]. The abovementioned research shows that these systems have the potential to improve construction management through: 1) materials management [2,14]; 2) equipment management [5,18,39]; and 3) worker management [3,7,35,36,40]. Previous studies have obtained either the approximate position (e.g. [14]) or accurate position [3] of an object (e.g. worker, equipment or materials) to achieve different management goals.

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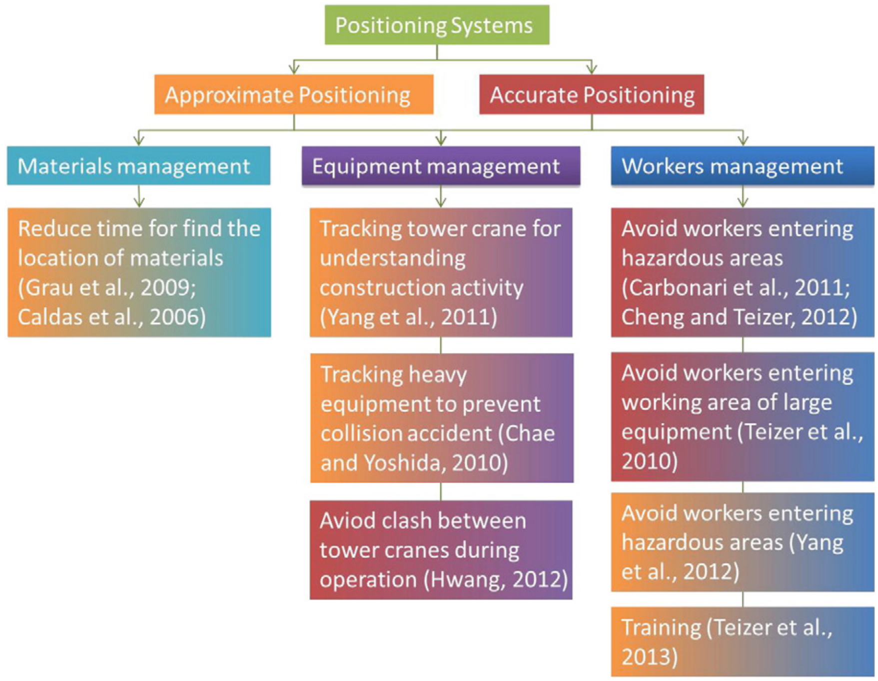

Fig. 1. Positioning systems for construction use.

Previous research [35,40] has demonstrated the potential of positioning technologies in safety management. Despite this, each study has different limitations, such as accuracy, cost and difficulties in deployment. Vaha et al. [43] summarised the range, accuracy and cost of ten positioning systems. As the positioning systems have different characteristics, each may be suitable for some application but not all.

This paper describes an approach to improve this situation by developing a proactive safety management system to monitor the real-time location of construction workers and equipment by a new RTLS. This RTLS provides reasonable accuracy with affordable cost and relatively simple deployment. A prototype system was developed based on the approach. A case study of a public housing project in Hong Kong is used to illustrate and test the performance of the method.

2. Review of previous studies

Fig. 1 gives some examples of the previous studies, in which researchers have covered materials, equipment and workers management. To prove RTLS are suitable for the construction industry, researchers have different approaches to their validation. For example, some researchers examine the accuracy of the RTLS to see if reasonably accurate data can be collected to achieve their purposes. For example, Schipperijn et al. [31] report that the average error of GPS is 70 cm in open areas and 520 cm in urban areas in Denmark. Qi et al. [27] use iterative Taylor-series estimation to further improve the accuracy of 3D UWB, finding the positioning error of the system to be only 1 cm in an indoor experimental environment. The latest development of these systems may provide highly accurate results, but they may perform differently in a construction environment.

Peyret et al. [26] use real-time kinematic (RTK) GPS to track the location of equipment in open areas. The accuracy of the system is better than that of GPS alone, but varies depending on its environment. Chae and Kano [4] and Woo et al. [38] suggest adopting radio frequency identification (RFID) for tracking workers in indoor environments by using a received signal strength index (RSSI) technique. Using this technique, Woo et al. [38] recorded an average error of 2.93 to 5.92 m. Razavi and Haas's [28] case study of the use of RFID for tracking materials found that accuracy could be improved by using reference RFID tags, with an average accuracy varying from approximately 7 to 10 m. More recent studies [13,25] show that RFID has the potential to improve facilities management during the operation phase. Motamedi et al. [25] study the effect of increasing the number of data collection points within a building, obtaining an average error of 1.59 m by using a cluster-based movable tag localization approach. In the construction environment, a similar result was also reported by Ding et al. [12], with an average error of 1.37 m and 2.56 m in stairways and tunnels within a metro tunnel construction site in China. Montaser and Moselhi [24] also compare the triangulation and proximity methods, finding that the triangulation method can provide better results (mean error of 1 m and 1.9 m for user location and materials tracking respectively).

Others suggest integrating UWB, Zigbee and RFID to improve accuracy. Carbonari et al. [3], for example, located construction workers by using UWB technology while Lee et al. [19] report an average error as low as 45 cm when using the RFID method. The tracking of construction workers is also proposed for visualisation integration [8], education and safety training [36]. Rather than locating the workers within a site, Lee et al. [20] suggest using ultra-sonic and infrared to prevent them from entering prohibited areas. Therefore, these studies indicate that RTLS has the potential for use in managing materials, equipment and workers on site. Teizer et al. [34] and Cheng et al. [6] use UWB technology to track the location of construction equipment, with Cheng et al.'s [6] system having an accuracy as high as 0.34 m.

Some researchers have also proposed the integration of different RTLS to improve performance, such as coverage and accuracy. For example, early work by Song et al. [33] advanced the notion of integrating GPS and RFID for locating construction materials on site through proximity techniques using RFID and GPS to obtain the two dimensional (2D) and three dimensional (3D) positions of an object. More recently, Majrouhi Sardroud [23] proposes the use of GPS to locate construction materials, RFID for identification and a general packet radio system (GPRS) for data transmission.

Another way of determining the success of an application is to measure the effects of its use. For example, in Caldas et al.'s [2], although the accuracy of the system was not mentioned, a field trial showed that the time required to determine the yard and colour codes (recalling step) and location (flagging step) of a pipe spool was dramatically reduced from 6 min 42 s to a mere 55 s. Teizer et al. [36] tracked the location of workers during training to analyse the working and waiting time of