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Design and implementation of an identification system in construction site safety for proactive accident prevention

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ABSTRACT

Identifying accident precursors using real-time identity information has great potential to improve safety performance in construction industry, which is still suffering from day to day records of accident fatality and injury. Based on the requirements analysis for identifying precursor and the discussion of enabling technology solutions for acquiring and sharing real-time automatic identification information on construction site, this paper proposes an identification system design for proactive accident prevention to improve construction site safety. Firstly, a case study is conducted to analyze the automatic identification requirements for identifying accident precursors in construction site. Results show that it mainly consists of three aspects, namely access control, training and inspection information and operation authority. The system is then designed to fulfill these requirements based on ZigBee enabled wireless sensor network (WSN), radio frequency identification (RFID) technology and an integrated ZigBee RFID sensor network structure. At the same time, an information database is also designed and implemented, which includes 15 tables, 54 queries and several reports and forms. In the end, a demonstration system based on the proposed system design is developed as a proof of concept prototype. The contributions of this study include the requirement analysis and technical design of a real-time identity information tracking solution for proactive accident prevention on construction sites. The technical solution proposed in this paper has a significant importance in improving safety performance on construction sites. Moreover, this study can serve as a reference design for future system integrations where more functions, such as environment monitoring and location tracking, can be added.

1. Introduction

Construction's safety record is unenviable, as the fatality and injury records in construction continue to plague the industry across the world (Gibb et al., 2006; Aneziris et al., 2008; Manu et al., 2010). In order to prevent fatal and injury accidents on construction sites, various existing research have been carried out to identify and analyze the causes of safety hazards and risks from an integral perspective of accidents (Cheng et al., 2010; Aneziris et al., 2010). On the other hand, there were also studies that concentrate on the causes of specific safety hazards, such as study on falling accidents (Goh and Love, 2010), human–machine conflictions (Teizer et al., 2010a), electrical fatalities (Chi et al., 2009), steel erection fatalities (Beavers et al., 2009) and 'struck-by' injuries (Hinze et al., 2005). Among those studies, the accidents of falling from height on construction sites are the most commonly identified safety hazard (Chi et al., 2005; Aneziris et al., 2008; Saurin and Guimaraes, 2008).

It has been widely accepted that accidents are just the tip of an iceberg and henceforth understanding the cause of the accidents is of great significance for accident prevention. However, simply learning from the accidents that have already happened is not enough. For each particular incident, it is not acceptable to identify and record a specific hazard only after a related accident has already happened. It is therefore useful to study the near-miss accidents, which are deemed as another effective learning source and tracking method for accident prevention. Near-miss accidents were usually referred to as precursors of accidents (Bier and Mosleh, 1990), indicators of potential accidents (Brazier, 1994) or imminent signals of accidents (Jones et al., 1999). Phimister et al. (2004) identified a near-miss accident as a special kind of precursor and defined it as an event in which no damages or injuries actually occurred but, under slightly different circumstances, could have resulted in great harm. In construction, the modified statistical triangle of accident causation described the same process from near-miss accidents to fatal accidents (Carter and Smith, 2006). Cambraia et al. (2010) adopted

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the concept of a near-miss accident as an instantaneous event that involved the sudden release of energy and had the potential to generate an accident.

Many organizations have attempted to develop programs to identify and benefit from accident precursors, which were defined as the conditions, events and sequences that preceded and led up to accidents (Phimister et al., 2004). Similarly, Suraji and Duff (2001) explained this concept as an undesired event, which was an unwanted incident immediately preceding and leading to an accident that did, or could have caused injury to construction personnel or the general public, or damage to property or the environment. When adopting a broad definition of precursor, it is not difficult to find that a near-miss accident is an important kind of precursor (Jones et al., 1999; Phimister et al., 2004). However, some organizations have chosen to limit the use of the term 'precursors' to near-miss accidents that exceed a specified level of severity (Phimister et al., 2004). Similarly, the objective of this research has also confined precursors to events that exceed a specified level of severity. It should be pointed out that a near-miss accident is identified in a much wider range of severities and may include all defects and abnormal events.

Though focusing on precursors and near miss-accidents on construction sites has been recognized as one of the important ways to improve safety on construction sites, its potentials have not been fully realized (Wu et al., 2010a). Recent research outcomes have shown that the information of identity about on-site staff, machine and material is highly related to accident precursors and near-miss accidents on construction sites (Wu et al., 2010b). In the meantime, investigation by Lu et al. (2010) also reveals that information which is crucial for safety management, such as labors' IDs, photos, access authorities, time of inspection, access control, personnel who conducts the checking, conditions of the machines, repair work done and so on. Such information can be handled by radio frequency identification (RFID) based automatic technologies. RFID refers to a branch of automatic identification technologies in which radio frequencies are used to capture and transmit data from a tag, or transponder (Ergen and Akinci, 2007). The potentials and benefits of applying RFID technology in construction site safety have been given much attention but the construction industry is slow in adopting the RFID technology in spite of its great potential (Wu et al., 2010b; Lu et al., 2010).

The development of numerous emerging information technologies has prompted research into their application to construction. Compared to other automatic identification systems, RFID is the most promising technology that does not require line-of-sight communication between tags and readers. Besides, RFID has inexpensive yet reliable tags, which provide more comprehensive tagging information and fast-speed reading. Chae and Yoshida (2010) applied RFID technology to the prevention of collision accidents with heavy equipment such as hydraulic excavators and cranes. Teizer et al. (2010b) introduced radio frequency remote sensing and actuating technology to improve construction safety, warning or alerting workers-on-foot and equipment operators in a proactive real-time mode when the equipment comes close to other objects or equipment. Navon and Berkovich (2005) have developed a model based on automatic, or semiautomatic, data collection for materials management and control. Navon and Sacks (2007) discussed the monitoring of automated data collection needs and the potential technologies to satisfy them. Ergen and Akinci (2007) highlighted the potential of RFID technology in enabling automated tracking of components/materials in dynamic and uncontrolled environments. WSN is a self-organized wireless network consisting of a large number of sensor nodes that interact with the physical world (Li and Liu, 2007). Compared to other existing networking technologies, WSN is a low-power, low-cost, reliable and easy-to-implement wireless technology. It can accommodate a large number of nodes and can be deployed in a complex environment readily. In the construction industry, WSN has been applied in structural health monitoring (Sazonov, 2004; Paek et al., 2005; Li and Liu, 2007). Furthermore, Jang and Skibniewski (2009) created a framework for integrating the latest innovations in wireless sensor networks that automate tracking and monitoring construction assets using a combination of radio frequency and ultrasound signals.

One way to achieve RFID based applications for construction site safety is to implement the proposed systems proposed by Lu et al. (2010). Nevertheless, little research has been done in both the integrated analysis of automatic identification requirement and its technological solutions based on real time information on construction sites. Similar lack of research also applies to the investigation of the integration of RFID technology for automatic tracking of identity information in construction safety. In this paper, the integration of RFID system in sensor network architecture is investigated to enable an autonomous identification system in construction site safety for proactive accident prevention. Thus the objective of this paper is to address this challenge by designing and implementing an identification system in construction site safety for proactive accident prevention. This study will provide the technical solution, which is based on a dedicated RFID sensor network system, for tracking identity information for proactive accident prevention. It is therefore of great significance and importance in improving the safety performance on construction sites.

The paper is organized as follows: firstly, following the detailed background introduction, we briefly describe our case study methodology and the main technologies involved in our system design. The case study is then carried out with key information required for tracking near-miss accidents on construction sites that are being identified. Based on this outcome, the system is then designed, with system network architecture, database structure and implementation illustration being presented. A demonstration system is designed and tested to show the feasibility of our system design. Finally, a discussion and conclusion of this work is given.

2. Methodology and enabling technologies

2.1. Empirical methods of case study

Darbra and Casal (2004) indicate that useful information can be provided by the historical analysis of the accidents about the most frequent accidents, their origins and causes. At the same time, this analysis can also provide rich information about the precursors of accidents (Wu et al., 2010a; Phimister et al., 2004). In order to conduct an integrated analysis of automatic identification requirement about the identity information regarding on-site staff, machine and material, the historical records in USA from 1995 to 2008 are analyzed. The cases used in this research come from the U.S. Department of Occupational Safety and Health Administrative (OSHA). They are in database form, created by the software Microsoft Access. Moreover, in order to focus on common and conventional types of construction sites, accident events are limited to residential, commercial building and manufacturing plant in the statistical analysis. In total, 4640 cases in residential, commercial building and manufacturing plant from 1995 to 2008 are analyzed.

2.2. RFID and WSN technology

2.2.1. RFID

The development of promising information technologies, such as RFID and WSN has prompted research into their application to construction. Automatic identification (Auto-ID) technologies are a broad term of technologies that enable the machines to identify