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Review

Real-time locating systems applications in construction

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ABSTRACT

Real-time locating systems (RTLSs) are considered an effective way to identify and track the location of an object in both indoor and outdoor environments. Various RTLSs have been developed and made commercially available in recent years. Research into RTLSs in the construction sector is ubiquitous, and results have been published in many construction-related academic journals over the past decade. A succinct and systematic review of current applications would help academics, researchers, and industry practitioners in identifying existing research deficiencies and therefore future research directions. However, such a review is lacking to date.

This paper provides a framework for understanding RTLS research and development in the construction literature over the last decade. The research opportunities and directions of construction RTLS are highlighted. Background information relating to construction RTLS trends, accuracy, deployment, cost, purposes, advantages, and limitations is provided. Four major research gaps are identified and research opportunities and directions are highlighted.

Contents

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1. Introduction

In the past decade, there has been a surge of interest in the use of real-time locating system (RTLS) technologies in the construction sector. RTLS is an application used to locate the current geographic position of a person, materials, or equipment, facilitating data tracking and management, and is considered as one of the innovations that have changed traditional practices in the construction industry over the last two decades. There is no standard definition of RTLS, but it is defined in this study as a combination of hardware and software systems to automatically determine the coordinates of an object in real time within an instrumented area. The data collected by RTLSs may be used not only for real-time purposes but also for further analysis after a set of data is collected. Some types of RTLS consist of location sensors (e.g., receivers) and tags. The tag communicates with the receivers by a signal. The location of the tag is calculated by different algorithms, such as the received signal strength indicator (RSSI) and the time of arrival (TOA). Other types, such as vision-based positioning systems, do not require tags. Recent developments in RTLS have also extended its application from outdoor positioning to indoor location tracking [48,49]. Research has shown that indoor positioning has the potential to be applied in the construction industry [96,102]. While the use of RTLS is well documented in other industries, including the logistic and healthcare industries, such as in the operation of container terminals [69] and hospital security management [6], there is a lack of a systematic review of the use of RTLS technologies in the construction industry. Therefore, this paper provides such a critical review of the literature and suggestions for further research. In doing so, the paper (i) identifies key construction RTLS research, (ii) discusses the advantages and disadvantages of the main RTLS technologies available, and (iii) identifies a research agenda and opportunities for further research.

2. Research method

A two-stage literature review method after Tsai and Lydia Wen [101] and Ke et al. [39] was used to identify the journal articles that describe and investigate the use of RTLS technologies in the construction industry from 2005 to 2014. First, a comprehensive literature search based on "title/abstract/keyword" was conducted through search engines such as Scopus and the SCI database. Keywords included, but were not limited to, "RTLS," "construction engineering," "construction site," "construction planning," "building design," "building repair and maintenance," "building retrofitting" and "building demolition." A long list of papers obtained in this way was generated for consideration for possible review. However, the inspection of the long list revealed that different journals generally have different publication interests and that the selection of the journal had a substantial effect on the research topics involved. The investigation was therefore recommenced and restricted to research articles published in first-tier construction journals only.

Following Xue et al.'s [110] selection criteria, five well-known academic journals within the area of construction engineering and information technology were selected from the SCI database. The five selected journals are *Advanced Engineering Informatics* (AEI),*ASCE Journal of Computing in Civil Engineering* (CCE), *Automation in Construction* (AIC),*Journal of Construction Engineering and Management* (CEM), and *Journal of Computer-Aided Civil and Infrastructure Engineering* (CACIE). These journals are accepted by the research community as being prominent and high quality and with an important impact in the construction engineering and management field [14]. In the second stage of the literature search, a more focused and comprehensive search within the five targeted journals was conducted with the support of the Scopus/SCI search engine.

Based on Gu et al.'s [33] survey and Deak et al.'s [24] review, 10 RTLS technologies and components were selected for review. These are composed of one outdoor positioning system (GPS) and nine indoor positioning systems (IPS) comprising *infrared* (IR), *ultrasound*, *radio frequency identification* (RFID), *wireless local area network* (WLAN), *Bluetooth*, *ultra-wideband* (UWB), *magnetic signals*, *vision analysis*, and *audible sound*. Papers using RFID technology for data transfer were excluded, as were editorials, book reviews, letters to editors, discussions/closures, and comments. Articles and review articles were searched within the same publication period (2005–2014). This involved scanning 3791 publications over the 2005–2014 period, resulting in a sample of 75 relevant articles being identified for analysis (Table 1).

3. Overview of construction RTLS-related publications

As Table 1 indicates, AIC covers around 60% of the identified literature, with 43 (3.92%) of the 1097 articles published by the journal over the period. Apart from CCE (3.07%), other journals contain proportionally much less coverage. Table 2 also indicates an increase in volume of articles in recent years, most significantly since 2009. RFID is by far the most widely discussed (36 times), with infrared technologies (2 times) being the least mentioned in the literature.

Over half (55.8%) of the articles are based on experimental studies, many of which were carried out off-site – in an existing building for example, or on the campus of a university – while only 33% tried to test or apply their work on a real construction site. The majority of articles focus on verifying the accuracy of the developed RTLS-related technologies: 20% relate to construction process management and 17% to site safety management, the remainder suggesting RTLS technologies could improve property management (5%), maintenance (3.7%), site productivity (2.5%), cost control (1.2%), and the health management (1.2%) of construction projects.

3.1. Classification by specific RTLS technologies

The results in terms of most frequent RTLS technologies included in the sample of journals follow.

3.1.1. Radio frequency identification (RFID)

RFID is a technology that stores and retrieves data by using electromagnetic transmission and a radio frequency (RF) compatible integrated circuit [68]. The use of RFID is common in complex indoor environments such as in office buildings and hospitals, as it provides a considerably cheap and flexible approach to identifying individual people and devices [22].

Although RFID is neither the most accurate nor the most conveniently deployed RTLS, its application in the construction industry has been researched intensively, with 36 positioning studies in our sample. Previous studies of RFID are summarized in Table 3. In 2006, Song et al. [91,93] found that using RFID for tracking the location of pipe spools speeded up the installation process. Tracking materials in this way proved to be useful in other studies too [29,32,81,83]. RFID has also been used for tracking workers or equipment (e.g., [26,54]). Further studies simultaneously track the location of both workers and