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Indoor Localization and Tracking of Building Components and Fixtures Using Ultra-Wide Band

Jyoti Singh, Ph.D., Post-Doc and Chimay J. Anumba, Ph.D., DSC., Dean and Professor
University of Florida, Gainesville, Florida
Jyoti.singh@ufl.edu

Abstract

Modern buildings create vast amounts of data throughout their lifecycle. Carefully managing the data makes it more valuable. This data is contained in static printed materials or documents. These documents quickly become outdated, and all too often much valuable time is lost tracking down the relevant information. It is important to associate project information with specific elements in each location for future reference. Location based real-time information sharing is key to productivity for an organization. Position coordinates may be used to link important information with the given location and effectively connect data using indoor localization technology. This paper explores use of indoor positioning technologies for organizing and accessing information in construction industry using content analysis. Ultra-wideband (UWB) is a most promising technique that has proven effective in indoor localization. In addition, the research reviewed past five years papers to understand the application of UWB in various stages of construction. The research then studied potential stages where adoption of UWB can be an imminent research area to revolutionized information sharing in construction. The research found that no research has been focused on using UWB during the commissioning stage of construction, which is one of the important stages requiring real-time information sharing.

Keywords
Indoor Localization, Ultra-wideband (UWB), Digital Information Sharing, Content Analysis, Construction Stages

1. Introduction

A large amount of data is associated with a building's lifecycle - from preliminary planning of a building to the demolition stage. The data associated with a building needs to be carefully managed so that it can be used at a later stage when needed. Much of this data is contained in steady materials or documents. The construction industry still relies on and gets hindered by paper-based static materials and processes such as, plans and drawings, blueprints, manuals, supply chain orders, etc., (Lerkenfeld 2017). Additionally, paper-based static information sharing makes it difficult to capture and analyze data, leading to loss of important and relevant information. Moreover, construction transitioning to digital information delivery, with paper-based documents being phased out, as information storage and retrieval is burdensome. Therefore, it is important to automate the tracking of necessary information associated with relevant elements in a specific location for future follow up.

The construction industry is learning the importance of real-time and digital information sharing. To reduce the costs associated with untimely information sharing, timely access to the data and information is crucial. Thus, real-time information sharing process is a requisite in construction industry. Efficient transfer and extraction of information is important and the location associated with each information is also necessary. Thus, location based real-time information tracking and sharing are crucial for construction productivity and efficient flow of information through different stages of the project delivery process. Position coordinates may be used to link necessary information with a given location and efficiently connect data using indoor positioning technology. The technology can help to ensure smooth workflow to share information in real time within and between different users (Lerkenfeld 2017).

Indoor positioning technology is a system that continuously and in real-time determines the position of a person or an object in an indoor environment (Alarifi et al., 2016). Indoor positioning applications may require different quality attributes such as location accuracy, line of sight (LOS) condition, hardware, etc., and thus should be carefully selected to meet the requirements of the application. Indoor location-based services are an important application of indoor computing. Accurate position coordinates are a critical requirement for indoor positioning techniques. This paper reviews the use of indoor positioning technologies for organizing and accessing real-time information in the construction process. The research reviews and studies literature over the past five years to comprehend the application of the most promising indoor positioning technologies at various stages of construction. In addition, it explores emerging new application areas related to stages in construction that require automation of real-time information sharing using indoor positioning technologies. The research adopts content analysis as the primary methodology to review indoor positioning technologies and their applications. This involved investigating research papers and articles with the following keywords: indoor positioning technology; features of UWB; application of UWB; and stages of construction.

2. Indoor Positioning Technologies

A large variety of techniques and devices are used to provide indoor positioning in the built environment. The top 10 indoor positioning technologies are briefly introduced below (Li et al., 2020).

Wi-Fi is the most widely used indoor positioning technology, due to its paramount existence Due to high availability of wireless application arrangement, Wi-Fi systems do not require new hardware equipment. The precision of the systems is moderate, but power consumption is high (Zhao et al., 2014).

Bluetooth Low Energy (BLE) is common short-range wireless communication technology and is based on standard Bluetooth. BLE and Wi-Fi use the same carrier frequency (2.4GHz) but BLE has much lower power consumption (Alarifi et al., 2016; Li et al., 2020). BLE systems perform better than Wi-Fi systems by 27%, but accuracy is still low compared to other communication technologies.

Radio Frequency Identification (RFID) is another short-range communication technology. RFID systems offer moderate to high accuracy depending on line of sight (LOS) condition (Yang et al., 2014). The cost and power consumption of RFID ranges from low to moderate based on system design and tags used (Li et al., 2020).

Zigbee is designed to be used in small personal area networks (Alarifi et al., 2016). It is secure technology for short-range communication with low data rate, low power, and low cost (Zheng and Lee, 2004). Zigbee has a moderate performance at the sub-meter (1mm to 1m) level only.

Indoor Global Navigation Satellite Systems (GNSS) depend on radio frequency (RF) waves to carry signals. The main benefit of indoor GNSS systems is that the targets can use smartphones to seamlessly position themselves indoors. However, signals cannot penetrate other floors in buildings (Rizos et al., 2010). Indoor GNSS systems with high number of repeaters offers accuracy and precision at sub-meter level with longer response times *(Jardak and Samama, 2009).*

Ultrasound can achieve very high positioning accuracy and precision at the sub-millimeter (<1mm) level when noise interference is less (Medina et al., 2013). One limitation of ultrasound systems is that signals cannot penetrate walls and has a low coverage.

Range Imaging is evolving technology in metrology and navigation sector. This is device-free communication technology which does not require receiver on the positioning targets (Li et al., 2020). Range imaging provide 6D object pose estimation (3D position and 3D orientation). One limitations of range imaging systems are strict requirement of line of sight (LOS) conditions. (*Brscic et al., 2013).*

Geomagnetic Waves for indoor positioning have emerged in recent years. Geomagnetic waves exist everywhere in the environment but establishing accurate and precise indoor positioning systems based on geomagnetic waves is very challenging, due to low visibility (Shu et al., 2015). Additionally, geomagnetic waves can vary both horizontally and vertically (Li et al., 2020).

Image Processing is an emerging technology. Image processing systems uses computer vision techniques and visible light cameras developed on smartphones and other cameras (Werner et al., 2011; Song et al., 2011; Alarifi et al., 2016). These system offers moderate accuracy at sub-meter level in static environment with little noise interference (Kawaji et al., 2010). The system requires line of sight (LOS) condition for image processing for better precision (Li et al., 2020).

Ultra-wideband (UWB) is a short-range wireless communication protocol that uses radio frequency (RF) waves to enable devices to 'talk' to each other and provide a simple example (e.g., tap free mobile payment, asset tracking, building access control, ticket validation). UWB transmitters transmit high data while consuming small energy (Svalastog, 2007). UWB offers short pulse radio frequency (RF) waveforms and large bandwidth (Shen et al. 2008), which results in fine time resolution, good potential for application in localization and positioning, and better immunity to multipath effects (Jiang et al., 2011). The low frequency of UWB signals permits the pulses to effectively transmit through various obstacles as experienced by other wireless modalities. Based on various researchers, UWB systems is most suitable and foremost technologies among other indoor positing technologies in terms of large data transmission, accuracy, and precision with minimized error to sub-centimeters (1cm to 1mm) level, even under strong noise interference (Ghavami et al., 2006; Liu et al., 2007; Svalastog, 2007; Cheng, 2012; Shahi et al., 2012; Segura et al., 2012). Given its potential advantages over other indoor positioning technologies, this paper explores how best to leverage UWB technologies to improve the different construction processes by providing real-time access to component-level information.

3. Key Features of Ultra-Wideband

UWB has various important features that are explored and studied in the literature on different industry sectors. Alarifi et al., (2016) performed SWOT analysis for evaluating UWB technology and summarizing its key features in terms of strengths, weakness, opportunities, and threats. Some of the key features of UWB are summarized in Table 1 (Hämäläinen et al., 1999; Miller, 2003; Aiello and Batra, 2006; Otis and Rabaey, 2007*; Ubisense, 2009;* Porcino and Hirt, 2011; Savioli et al., 2012; Alarifi et al., 2016).

Table 1: Key features of UWB

Strength	Weakness	Opportunities	Threats
• License free • Large bandwidth • Short pulses • Low power consumption • Less interference with other systems • Effective multipath resolution • High data rate transmission • Acquire high level processing • Carrierless transmission • Opposition to Jamming	• Potential interference with systems operating on same spectrum • Long time to synchronize	• Tracking system • Indoor navigation • Localization and positioning system	• Commercially expensive • Not totally immune to multipath • Design and implementation may be challenging

4. Applications and Uses of Ultra-Wideband in Construction

UWB technology is most promising for indoor positioning and localization applications (Alarifi et al., 2016). Due to the increase in demand, researchers have begun to explore new opportunities to leverage. UWB technology is becoming more widely used in the construction industry. In recent years, a significant amount of research effort and application of UWB has been carried out to enhance the efficiency of construction (Jiang et al., 2011). UWB has been applied to various stages in construction for precision positioning and localization both for research and industry purposes.

This paper reviewed research papers over the past five years on the application of UWB in five main stages of the construction process (feasibility, design, construction, commissioning, operation and maintenance (O&M)) (Table 2). During the construction stage, UWB has been primaily adopted and in various ways, such as construction resource position and tracking (Li et al., 2021; Zhang and Liu, 2020, Siddiqui et al., 2019, etc.), site supervision (Wei et al., 2021, Norrdine et al., 2020, Shen and Zhang, 2020, etc.), and safety management (Pittokopiti and Grammenos, 2019; Rodriguez et al., 2019). During O&M, UWB can be used for operation and maintenance planning (Hou et al., 2020), non-destructive testing (Kim et al., 2017), detection of corrosion condition of concrete and other building materials (Nishimoto et al., 2019;), electrical application control (Fiawoyife and Louis, 2018). In design stage, UWB is applied in indoor scanning (Chen et al., 2019), if required during design planning based on existing situation of project, e.g., renovation project. Limited research has been focused on using UWB during the feasibility and commissioning stage of construction (Table 2).

UWB has many potential applications to be researched. Following the review of research papers, this research mapped the key features of UWB application with the requirements of the different stages in construction, to highlight the potential benefits UWB can provide to various stages of construction (Table 3). After mapping, it was found that UWB has considerable potential in the three project lifecycle stages – construction, commissioning, O&M and less potential in the design and feasibility stages (Table 2). There are various research papers on the application of UWB at the construction and O&M stages. However, there is nothing on the commissioning stage, despite the potential benefits of UWB application at this stage (Table 2). Commissioning process documents the performance standards of the various building systems and verifies that designed and constructed work meets design standards ((WBDG, 2016). UWB can be helpful at commissioning stage by tagging performance information with the specific location of the building elements and systems obviating the need to rummage through design and construction documents, drawings, equipment manuals, technical specifications, and handover notes.

Table 2: Papers on UWB application at various stages of construction

	Stages in Construction				
	Feasibility	Design	Construction	Commissioning	O & M
UWB		Chen et al., 2019	Arabshahi et al., 2021; Zhao et al., 2021; Wei et al., 2021; Li et al., 2021; Dérobert et al, 2021; Norrdine et al., 2020; Li et al., 2020; Norrdine and Motzko, 2020; Jie et al., 2020; Zhang and Liu, 2020; Ansaripour et al., 2020; Moselhi et al., 2020; Shen and Zhang, 2020; Umer and Siddiqui, 2020; Wen et al., 2020; Zhnag et al., 2020; Siddiqui et al., 2019; Pittokopiti and Grammenos, 2019; Rodriguez et al., 2019; Jin et al., 2019		Hou et al., 2020; Nishimoto et al., 2019; Fiawoyife and Louis, 2018; Kim et al., 2017

Table 3: Potential uses of UWB at various stages of construction

	Stages in Construction				
	Feasibility	Design	Construction	Commissioning	O & M
Use of UWB	X	XX	XXX	XXX	XXX

X – Least use; XX – Average use; XXX – Highest use

5. Discussion

The construction industry should revolutionize how building information is accessed and create efficient information retrieval mechanisms for the construction workforce. UWB is a well-suited technique that has proven effective in indoor positioning and tracking. UWB-based technology can be used for organizing and accessing information as part of the commissioning of a building by providing a simple, intuitive, and inexpensive solution to easily access accurate building information, when and where necessary. Adoption of UWB for location based real-time information sharing at the commissioning stage of construction is crucial and is an important application area for the future. The acquisition and transmission of data during commissioning is time-consuming, monotonous and requires a huge human effort when done using conventional approaches. Use of UWB at commissioning stage in building enables the use of real-time location services, direction of interest and a smart device to allow easy access to actionable data created during the lifecycle of a project. This approach should organize content according to location coordinates to help track referential information as per associated location coordinates in a time-efficient manner thereby, facilitating better coordination and communication between owner and teams during project handover and commissioning. UWB provides wireless coordinates that are associated with physical locations for high tech location and direction. As a user moves around a building site, different information or functionality can be made available using an augmented reality or 2D interface on a standard smart device. New information or functionality can be made available based on the user's context (e.g., new location and new direction of interest). Reference manuals, how to videos, part ordering, e-commerce, design plans, as-built records, manuals, or any other desired digital capability, can all be available via a simple point and touch interface.

6. Conclusions

Indoor positioning technology has changed significantly in different industry sectors with the rapid development of wireless positioning and tracking technologies. Ultra-wide band is a fast, secure, short range, low power radio protocol used to determine location with accuracy unmatched by any other wireless technology. UWB provides accurate positioning throughout buildings in various fields and facilitate better decision making due to its distinctive technical features. This study reviewed indoor positioning technologies and found UWB the most favourable for organizing and accessing real-time information in construction. Content analysis was adopted to review papers on indoor positioning technologies for real-time information sharing over the past five years. It also explored papers on the application of UWB at various stages of the project delivery process. In addition, the research also explored potential application areas for UWB application. It can be concluded that there is considerable potential in leveraging UWB technology to facilitate efficient information flow at the commissioning stage of a project - especially between geographically distributed team members and without the need for a huge IT infrastructure.

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