Integration of Passive RFID Location Tracking in Building Information Models (BIM)

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Abstract. Emerging wireless remote sensing technologies offer significant potential in advancing the management of construction processes by providing real-time access to the locations of workers, materials, and equipment. Unfortunately, little is known regarding the reliability and practical benefits of emerging sensing technology integrated with Building Information Modelling (BIM) within an indoor building environment. This limitation effectively impedes widespread adoption of sensing technology. This paper introduces and evaluates the framework that integrates commercially-available Radio Frequency Identification (RFID) technology for real-time, mobile resource location tracking in a BIM model. The need will be explained with potential applications in construction and facility management. Algorithms to process RFID signals and integrate the generated information in BIM will be presented. Furthermore, to demonstrate the benefits of location tracking technology and its integration in BIM, the paper provides a preliminary demonstration on tracking valuable assets inside buildings in real-time.

1 Introduction

Real-time access to the locations of workers, materials, and equipment has been a significant advancement to the management of construction processes. There have been a variety of technologies (Ultra Wideband, GPS, laser scanner, etc.) utilized to produce visualizations of the locations of resources on a construction site. However, there is a lack of real-time visualization of such technologies within an indoor environment to determine one's location inside the facility, as well as to aid navigation. The need for such technologies in an indoor setting is crucial since 85% of the total project cost is spent in operation and maintenance (Taneja et al., 2010). One solution is the integration of emerging wireless remote sensor data with Building Information Modeling (BIM), which allows for the real-time visualization of the locations of workers, materials, and equipment. Unfortunately, little research has been conducted regarding the reliability and practical benefits of the integration. The lack of integration impedes widespread adoption of the current outdoor approaches to an indoor environment.

Sensors of different types have been tested and proven in the construction industry. Global Positioning System (GPS) technology does not require any pre-installed infrastructure location determination (Behzadan, 2008). However, it cannot be used in indoor environment (Ogaja, 2011). Similarly, Ultra Wideband can be implemented to track and determine the location of resources in a jobsite (Bohn and Teizer, 2010), but it requires a careful installation of multiple readers at known locations. The UWB utilizes multiple readers to identify the location of tags in (Cheng et al., 2011). However, UWB cannot be used when the tags are stationary and the reader is mobile. In case of passive RFID, a single reader can be utilized to read the tags in range (Costin et al., 2012). The technology has also been successfully tested in construction environment for inventory management, material tracking, on-site security and productivity analysis (Jaselskis and Misalami, 2003; Goodrum et al., 2006).

Liu et al. (2010) proposed an indoor localization and visualization environment using 2D laser scanner and inertial measurement units (IMU). A human-operated backpack system and
image based rendering was used to process the location. Bernoulli et al. (2010) also utilizes an IMU and an algorithm to map indoor travel to a simple computer aided design (CAD) model. Rüppel and Stübbe (2008) proposed an indoor navigation system that utilizes RFID, ultra-wide-band (UWB) and a wireless local area network (WLAN) for emergency response and recovery. However, testing has not been conducted to evaluate the accuracy and reliability of the system. Indoor localization using RFID can even be used to pin-point current position of the reader and lead the worker with the RFID reader to the correct utility (Pradhan et al., 2009). Active RFID tags were implemented for localization and fingerprint map of strength signals were used as the basis. Another approach of localization using an array of passive RFID tags placed on the floor of experimental bed has been implemented by Park et al. (2009) for indoor mobile robot movement. Signal strength control was used for improving performance of position estimation. Simultaneous Localization and mapping (SLAM) algorithm has also been evaluated for 2D trajectory tracking using passive RFID tags (Yang et al., 2008).

Facility management requires a robust database linked to the items and a visualization environment for identifying the items as well as locating oneself in the model. Currently, BIM has been used as a digital copy of the facility which is independent of the actual facility. Real-time correspondence of the model with actual facility has not been studied. Hence, BIM appears to create a promising platform if equipped with sensing technology which can facilitate real-time update of the facility. Few studies have been conducting involving RFID and BIM. Xie et al. (2010) focused on using GPS and RFID for tagging steel components and using the same unique tag for each component throughout the BIM model in the project. Updating the status in the BIM model would automatically keep track of the components from delivery to installation. Integration of RFID and BIM has been proposed for life cycle information management of open-buildings (Cheng and Chang, 2011). It discusses the integration in planning and design, manufacturing, construction, maintenance as well as recycle and refuse phase. A pilot study has been performed on using RFID for facility management based on BIM database (Meadati et al., 2010). The objective of the study was to be able to reduce the identifying items in the facility and searching, retrieving and validating information required for any facility management operation. However, research focusing on using a building model for facility management with indoor localization has been lacking.

This research focuses on creating a platform that encapsulates both integration of passive RFID and BIM for facility management and visualization for indoor tracking. BIM and RFID possess immense potential and implementation. BIM has evolved as a ground-breaking concept in its own and RFID has proven to be next generation in tagging. However, amalgamation of these two technologies can open up an enormous field in which they can be implemented and perform tasks that have been limited due to the lack of knowledge.

2 Background
2.1 Passive RFID Technology and Database
Radio Frequency Identification (RFID) is the communication via radio waves that uses three main components in this system: a computer, reader, and tag. The reader sends a signal, which is then received by the tag, and then returned back to the reader, along with any data stored on the tag, such as its identification number. The reader then transfers the information to the computer where it is stored in data files, including the time of being read, what reader it was read by, and signal strength. Although there are active and semi-active RFID tags, passive tags are shown to be the most suitable for an indoor application of tracking workers, materials, and equipment due to their small size, low cost, and low maintenance requirements (Costin et al., 2012).
The data that the reader transfers to the computer can be utilized in many ways. A database can be used to link that data to additional data. For instance, a tag’s unique identification number can be linked to further information regarding that tag (i.e. unit name, installation date, manufacturer etc.). Queries can then be developed to make the information that has been tracked by the RFID readers easily accessible to the user, such as the project manager.

2.2 Building Information Modelling

Building Information Modelling (BIM) drives the traditional design approach a step ahead, adding more dimensions to the current 3D model. BIM integrates the geometric and parametric properties of the 3D model of a building with all the information and properties of that building, such as product information, site schedule sequencing, owner histories etc. In addition, each component of the model, their relationship with other objects in the model and logical classification of objects in the model, are stored directly within the model. By the use of BIM, an accurate virtual digital model of a project is constructed and it has been found to be one of the most promising advancement in the Architecture, Engineering and Construction (AEC) industry (Eastman et al., 2008). Integration of all the aspects on the projects like structural, architectural, mechanical and electrical plumbing (MEP), energy etc. into the same platform has enabled a new era of collaboration for better design and optimized performance.

As the objects in BIM hold their properties with the capability of parametric modelling, it finds enormous implementation in fields (estimating, scheduling etc.) which were based on more or less manual techniques to date. BIM provides a platform to obtain real time estimation and scheduling based on the 3D model of the project. It has literally changed the way different actors work on the project and also the way a traditional project has been categorized into stages. Every possible effort has been made to enhance the capability of BIM and, as a result, it has developed into a robust and sophisticated tool for project design and construction process. However, in terms of time and money, design and construction phases constitute a minor proportion of the total project cycle for the owner. In fact, the whole intention of designing and constructing a project is for its operation phase. From an owner’s perspective, design and construction constitute only 15% of the total project cost while the remaining is spend in operation and maintenance (Taneja et al., 2010). Operation and maintenance is an on-going process that continues throughout the project life cycle.

3 Research Purpose, Scope, and Methodology

Radio Frequency Identification (RFID) technology has been selected to be the most suitable wireless remote sensing technology to be deployed in an indoor environment. The purposes of this research are to (1) develop a framework that utilizes the integration of commercially-available Radio Frequency Identification (RFID) and a BIM model, and (2) evaluate the framework for real-time resource location tracking within an indoor environment.

The scope of this research focuses on facilities management. This paper only deals with passive RFID location tracking based on utilities located inside a facility. An approach will be discussed on localization based on permanently located utilities, as well as different algorithms currently used for precision and accuracy of localization. The position of the reader can be visualized in real-time in the BIM model. This will aid in the determination of current location of the facility as well as facilitate navigation. Testing is conducted within the Sustainable Education Building (SEB) located at the Georgia Institute of Technology, Atlanta, Georgia. Current facilities management include the manual location of a utility using a paper map of a facility (see Fig. 1a), which is shown to be time consuming and error prone. One of the objectives is to automate this process.
This research uses Trimble ThingMagic Astra Readers for the RFID technology and Tekla Structures to develop the BIM model. Besides combining these two technologies, a software application was developed in this preliminary research stage to store all the details of tags within a Microsoft (MS) Access database. In addition to storing all parametric and geometric information (the standard 3D model), a BIM model also has the capability of storing all the attributes for each of its elements, such as part number, material type, histories etc. However, the operation and maintenance phase of a project is very long and could be as long as 50 years and, as a result, large amount of data will be needed to be stored for each element during this period. Hence, a database has been implemented instead of saving the data directly into BIM model to avoid overwhelming the model with data. The database also allows for efficient storage and retrieval of the maintenance data. The object IDs in the BIM model were linked to unique RFID tags and the relation was also stored in the database. So, whenever a tag is read, corresponding object ID in the model was retrieved from the database. This BIM object ID was used to query the model to retrieve location information of the element.

![Figure 1: Facilities Management: (a) facilities manager locating utility on a paper map; (b) facilities manager’s cart and equipment; and (c) mobile RFID cart and RTS.](image)

![Figure 2: Utilities with Passive RFID tags (from left): (a) door sign; (b) fire extinguisher; (c) electric outlet; (d) fire alarm; and (e) door sign.](image)
There are two approaches to the deployment of an RFID system. The first is when the readers are stationary (e.g., over doorways) and resources that are mobile are tagged (e.g., workers, equipment, and material). The second is when the tagged utilities are stationary (e.g., light fixtures, door frames, etc.) and the readers are mobile (e.g., cart) in order to find the current location of the readers within the building. Facility management generally deals with the second approach in order for indoor locationation, and therefore is the focus of this paper. Having the location of the building’s utilities and assets stored in the database sets the stage to the facilities management phase. After the completion of construction, all data and information (drawings, database, BIM model, etc.) are turned over to the owner in order to keep up with operation and maintenance of the building.

Preliminary testing was conducted to validate the accuracy and reliability of the developed software application. In order to test the second approach of the deployment, a mobile cart with wireless RFID readers was created to mimic the cart used currently by the facilities manager (Fig. 1b & 1c). A variety of utilities within SEB were tagged with passive RFID tags (Fig. 2). Data was collected as the cart was pushed around the facility. Unique tag IDs were read of each passive tag. To assess tracking accuracy, location error rates for selected RFID track signals were obtained by automatically tracking a single entity using a Robotic Total Station (RTS) for ground truth. The data from the readers was analysed and filtered for any error reads. A localization algorithm then located the cart position within the building model using BIM as a visualization platform. The details of the approach have been discussed in following section.

4 Field Trial and Results

4.1 Details to implementation of hardware and software

The first step was to integrate RFID and BIM. The application programming interface (API) of a software/hardware component allows direct communication to others. Therefore, a prototype software application was developed in Visual C# 2010 to connect the Thing Magic API (RFID) and Tekla API (BIM), in addition with MS Access database. The success of this software lies with the ability to link RFID tracking technology and a BIM model for the lifecycle of a building, from pre-construction planning through the operation and maintenance (O&M) phase. The software works in a two part phase; (1) project management (PM) during construction and (2) facilities management (FM) after completion of construction. The PM phase uses real time visualization to track the resources (workers, tools, equipment etc.) on the job site, as well as storing the location of the building’s utilities and assets (light fixtures, doors, toilets etc.) in the database. The tracking of the resources is useful for the project manager to optimize productivity and safety (Costin et al. 2012). Any resource that contains an RFID tag can be read essentially anywhere on the job site and be shown in the BIM model in real-time. The FM phase utilizes the stored tag location of the utilities in order for facilities management, including automated scheduling for maintenance, automated summary and reporting, and indoor localization.

A prototype mobile cart (Fig. 1c) was assembled with four wireless readers; one on top, front, and two sides. Ideally, the cart would be extremely light, compact and battery powered. However, during preliminary testing, power would be supplied by an extension cord. The data reads were transmitted wirelessly from the readers to a computer that stored them in the database.

4.2 Capabilities of Software Application

Real-Time Feed. Knowing what resources are on site at all times, as well as their location, is essential for a Facility Manager (FM) to optimize safety and productivity. Resources include
workers, tools, equipment, and materials used for the construction and maintenance of the building. Real-time tracking allows a FM or observer to see which utilities are located in vicinity and to obtain automated maintenance history of the utilities. It can help in eliminating the need for manual record keeping, or at least in assisting in this labour intensive and error-prone task. There is an array additional benefits that come with knowing the approximate location of resources at all times. Other important applications tied into automated time-clocks include site security and emergency response. Since the location of all the tags are known beforehand, by identifying misplaced or missing tags in the system, hazardous conditions can be identified and necessary measures can be taken.

**Localization and Visual Display in BIM Model.** The ability to connect to a BIM model is what distinguished this approach from any ordinary RFID tagging system. Each tag is placed in a known location in the building and the BIM model. Therefore, when a tag is read, an approximate location of the reader is known based on location of the tag. This takes visualization to a new level, in which the ability to visually see where the tags are located within the BIM model creates additional capabilities. When two or more tags are read simultaneously, a triangulation method can be used to locate the location of the reader in the building. Currently the primitive approach implements simple mean of the coordinates of the tags being read for determining the location of the reader. However, a better way would be to consider signal strength of the RF signal and determine the location using weighted mean based on signal strength and coordinates of the tags.

**Data Analysis.** The data analysis portion of software generates the important information that is needed to for a facility manager. Different queries can be utilized to access certain data which is stored in a database. For instance, the FM can search data based on any combination of the specific date, time, location, type, trade, etc. The value of producing a database is evident from the ability to select specific data from a variety of options for data analysis. The best practice is to give a FM or staff member adequate time to find valuable resource mobility or status data and prepare the necessary steps to implement changes for improvement. Automating the analysis of recorded data saves significant time when examining labour productivity.

**Status of Utilities.** The status of worksite resources function allows the facility manager to automatically identify utilities that require maintenance. Every time a utility is read, its maintenance history is retrieved and if the utility has been lagging in maintenance, the FM can be notified and a maintenance request can be filed (Fig. 3). Similarly, based on other tags in vicinity, an oddly placed tag or missing tag can be identified and hazardous conditions can be identified.

**Maintenance History and Scheduler.** The maintenance history for each utility is stored in the database, along with frequency of maintenance. Each day, a report would be generated explaining what utilities need servicing along with the list of tools needed to complete the job. Then the location of the utility will be shown in the BIM model. This function automates the maintenance servicing and location, which would save time from doing it manually. Moreover, an RFID scanner would allow the ability to know if all the tools are there before going to the utility location. The time saved from not having a tool at the utility is also important, especially in a large facility.
4.3 Preliminary Testing and Results

Tests were conducted that consisted of 20 unique tags, each representing a different utility in a facility. Each item is different, but similarities were made to see if we can mix up the application. For instance, two light bulbs are identical, except they are at different locations and have different installation dates. The first part of the experiment was to show that the application can successfully link to the readers and database. The application was deployed, and the tags were first placed one at a time to see if the correct information would pop up on the screen. Once they all passed, a couple of tags at a time were placed in front to see if all their correct information would show. Finally, all tags were placed in front and all the correct information was there. Thereafter, to test the connectivity of the application with Tekla, objects were assigned to each of the tags and different trials were done storing and retrieving the objects corresponding to the tags and vice-versa. For those limited tags tested in the lab, the application seems to work fine.

A corridor of SEB was modeled in Tekla Structures (Fig. 4). The cylindrical object on the left represents the position of the mobile cart in this case. It can be assumed that a FM is walking on the corridor with an RFID reader and the cylinder indicates the position of the FM at any given time. The cubes mounted on the wall represent different utilities located in the corridor. The cubes have been made big to make it obvious for demonstration purpose. In reality, only the object ID and coordinates of the cubes will be retrieved from the Tekla model for localization purposes. For preliminary testing, the objects were generally created. However, a more elaborate model will be needed for a more accurate and reliable representation of reality. The exact locations and dimensions of the objects will be measured and supplied by the RTS.

Figure 5 provides a demonstration of how the developed application can be used to determine one’s location with the help of BIM model. In this stage of the research, the tags were not actually mounted into the utilities but for demonstration purpose, appropriate tags were brought into the reading range of the readers and the algorithm was tested for correctness (this represents the results of the tags being localized by the algorithms). The preliminary research work used a triangulation algorithm to locate the mobile cart base on tag reads. For instance, when tag 1 and 2 are read (Fig. 5a), the mean distance is calculated and placed in the correct location between the tags (Fig. 5d). A more elaborate algorithm is being developed that
utilizes various current techniques (e.g., signal strength, SLAM, etc.) Field implementation needs to be done with large number of tags and performance of the application should be tested in real world condition. The application still possesses huge potential to be developed and more debugging is required. The various existing indoor localization algorithms still need to be tested and implemented with this system.

Figure 4: Building model of SEB corridor

Figure 5: Demonstration of localization: (a) tags 1 and 2 being read; (b) tags 1, 2, 3 and 4 being read; (c) tags 3 and 4 being read; (d) localization based on tag reads 1 and 2; (e) localization based on tag reads 1, 2, 3, and 4; and (f) localization based on tag reads 3 and 4.
5 Conclusion and Recommendations

The integration of real-time location tracking data in BIM provides many useful applications to optimize safety, security, and productivity. Productivity analysis is important for a project manager to maximize productivity and minimize wastes and cost on jobsite. Integrating RFID technology and BIM into a single application and deploying it for indoor settings is a significant accomplishment in the AEC industry. A software tool was developed in order to help project managers to optimize productivity and safety, which ultimately affects the way the construction process is conducted. The data fusion between RFID technology and BIM serves to be an invaluable accomplishment that can be utilized for future research and applications.

The system will extend the use of current wireless remote sensing technologies and BIM from being limited to design and construction phase to throughout the project. Design and construction hardly constitute few years but operation and maintenance span for many years. The system does not demand any new model but just makes use of already existing model for a much longer period of time. This will help in maintaining an up-to-date digital copy of conditions of utilities in a facility. Required data can be easily retrieved and new records can be easily inserted and maintained. Databases can be modified and the system can be made to work on cloud so the system can be monitored from any corner of the world. Automated maintenance history and maintenance schedule can be generated from the application. Reporting tools can be developed and implemented so as to produce an automated maintenance schedule for all the utilities in the facility.

To date, RFID tags are used ubiquitously for tagging products and materials. This application can be easily implemented to utilize those tags that were used during material tracking and installation during the construction phase to work as a reference for this maintenance management system. Hence, neither a new BIM model nor new tagging system will be required. Needless to say that automated recording and reporting system helps in avoiding potential errors of manual entry and paper filing. Retrieving required data can take huge effort in paper system and moreover, manual entry can be erroneous, which is avoided with this system. Passive tags are detected wirelessly using radio frequency. Based on the schedule of maintenance, optimum and shortest distance can be calculated, which help in saving time.

This research can extend to the fire and rescue community because it offers an invaluable tool for saving lives in an event of an emergency. In addition to finding tagged utilities, the location of medical personnel or equipment in hospitals, police dogs trained to find explosives in a building and evacuation routes can be found using indoor localization. Since RFID tags do not rely on a power supply from the facility, they keep working in an event of a power outage. This is crucial since the rescue team can still use the tags to guide them through the facility (heat and fire resistance of tags still need to be researched). Additionally, Passive RFID tags provide the ability to allow access to certain areas to only those with the authorized permission, which can be determined from their tags. Moreover, the system can track if there are any unauthorized workers in sections of the job site that are either restricted or off limits. This is important when in the case of workers wondering into hazardous or dangerous areas, in which an alarm or warning sign will notify the workers and managers.

The preliminary results provided the feasibility of integrating passive RFID with BIM for indoor settings. The next step is to test the integration for indoor localization, and utilize the current localization algorithms specifically for passive RFID technology. More defined testing will be needed.
References


