

RFID Readability Test for Construction Materials: A Senior Project

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Radio Frequency Identification (RFID) is a globally accepted technology that can provide real-time information visibility and traceability for supply chain management. The introduction of RFID for automating tracking and locating activities promises to greatly improve material handling and productivity on construction sites. However, as yet the data acquisition process is imperfect due to the readability limitations associated with various materials. This study investigated the readability of tags on general construction materials and the integration of the information they contain with Construction Specifications Institute (CSI) MasterFormat division lists to determine the utility of real-time information during the construction process. The measurements were performed by students majoring in construction management as part of their senior project. An active 433.92 MHz RFID system was utilized for the readability test, with a typical reading range between the tag and reader of up to 450ft and long-life batteries lasting up to 5 years. The results revealed the reading range of the active RFID system tested to be from 37ft to 450ft, depending on the scenario tested. These findings represent the first step towards understanding how RFID readability varies for different types of material and supports more effective utilization of existing equipment and technology in the construction industry.

Keywords: RFID, Readability, Senior Project, Material Management

Introduction

The objective of the research reported here was to test the readability of tags on different material types using a Radio Frequency Identification (RFID) reader to determine the feasibility of applying RFID technology as a material management tool on construction sites as part of a senior research project. RFID is a globally accepted technology that has enjoyed great success in the area of supply chain management, particularly for inventory management (Kathawala & Tueck, 2008). Materials management approaches that use RFID for automated tracking and locating activities are promising to greatly improve productivity on construction sites by utilizing sensor technologies and sensing systems to help contractors continually monitor the precise locations of different materials as they are moved around the site (Razavi & Hass, 2011). However, although the application of RFID for automated tracking and locating activities is expected to greatly improve material handling and productivity on construction sites, as yet the data acquisition process is imperfect due to readability limitations caused by factors such as the type of antenna, the height and displacement of the tag, and the antenna-tag distance (Kim, Yook, Yoon, & Jang, 2008). To examine how the range of RFID readability can vary for different construction materials, for this study construction materials were classified into four main types, namely metal, concrete, plastic, and wood, based on the categories used in the Construction Specifications Institute (CSI) MasterFormat division lists (2014). Our findings revealed that the readability for different material varied considerably, with the reading range of the active RFID system tested ranging from 37ft for embedded concrete to 450ft for unobstructed tags. This research represents the first step towards improving our understanding of how

RFID readability varies for different material and supports better utilization of existing equipment and technology in the construction industry.

Study Objective and Overview

This study was designed to help students learn how to identify and evaluate appropriate tools for material management in construction. Four students enrolled in a university construction management program participated in the study as part of their senior project. An active 433.92 MHz RFID system (Wavetrend Technologies, Chantilly, CA) was utilized for the readability test; according to the specifications provided by the manufacturer, the typical reading range between the tag and the reader is up to 450ft for battery operation, with an expected battery life of 3-5 years. Before conducting the readability test on different construction materials, the 4 students were each assigned a different RFID application as background research: personnel, equipment, material inventory, and site layout. For the experimental component, the RFID material test was performed three times each for six different scenarios: the tag itself, and tags embedded 2" deep in concrete, enclosed inside 2" of wood, inside a plastic food container, wrapped in a single layer of aluminum foil, and in a person's pocket. This hands-on experiment conducted under real-world conditions helped the students appreciate how various factors impact the effectiveness of RFID technology from both a theoretical and a practical standpoint and facilitated their learning about material management. Two faculty members were involved in this undergraduate research activity and meetings with the students were held on a regular basis throughout the semester at two or three week intervals. The main objective of the readability test conducted as part of the senior project was to provide efficient and effective learning related to the introduction of a new technological tool in construction. This paper presents the readability results for distance only based on the six scenarios and includes the students' assessment of to the method's effectiveness in helping them to fully appreciate the utility and limitations of RFID technology on construction sites.

Background

Traditionally, a senior project is designed to be an exercise in estimating and scheduling using construction documents from an actual building project utilizing major elements of the construction management program and follows American Council for Construction Education (ACCE) guidelines. The project typically includes developing a fictitious construction company organization, producing a project estimate and schedule and preparing a construction bid and construction documentation. In addition to the traditional approach, on the first class day of the semester faculty members offer students the option of participating in an original research project as part of their senior project. A student chooses between two options to complete the senior class: 1) a traditional approach that focuses on estimating and scheduling and 2) a hybrid approach that incorporates an applied research project based on an individual student's interests. A faculty member will then provide individual supervision for those students who choose to participate in a research topic to help them complete their research activities in conjunction with a traditional senior project.

Radio Frequency Identification (RFID) provides a means of identifying unique items using radio waves (Arnold, Chapman, & Clive, 2010). An RFID system consists of two main components: a reader (or interrogator) and a tag (or transponder). Typically, the reader interrogates the tag, which consists of a small microchip and an antenna. Data are stored in the tag, generally in the form of a unique serial number (Wang, 2008). RFID is currently being introduced in three main application areas: transportation and distribution, manufacturing and processing, and security and law enforcement (Singh, McCartney, Singh, & Clarke, 2007). For instance, E-Z Pass systems that utilize active RFID technology have been introduced to collect payments from vehicles travelling along toll roads or in congestion charge zones in cities in the US and around the world. Railroads in North America also use RFID tags on all their rolling stock and locomotives because RFID devices do not require an unobstructed line of sight between label and reader, unlike bar codes (Arnold et al., 2010).

In construction, RFID technology has been widely applied in many areas. The most common uses include tracking materials en route to the jobsite; locating bulk materials, plant and equipment on construction sites; and security and access control. To understand this technology's general utility for the construction industry, this study utilized the RFID Development Kit shown in Figure 1, consisting of a reader, personnel tag, micro tag, key fob tag, and software. The total cost of this RFID development kit was $800, including a free trial of the home automation software. In general, four different types of RFID tags are used for material management in construction: to facilitate inventory control by scanning materials as they are delivered to the site; to tag metallic materials to help minimize loss and support the assembly sequence during installation; to tag non-metallic material to provides information for material management; and to control site access of personnel for security and/or safety. The reader is connected via a USB port to a microprocessor controller with onboard firmware that communicates directly with the radio frequency receiver module.

FIGURE 1: RFID Development Kit (Wavetrend Technologies)

The research suggestion guiding the senior research project involving RFID technology was initiated by faculty members, who wondered if it would be possible to utilize a tower crane as a platform for mounting an information scanner capable of tracking tagged equipment, personnel and materials across an entire construction site. In general, a tower crane covers the whole construction and is installed in a central location on the jobsite. The students performed preliminary research to investigate this possibility by examining the effect of site layout on different material types on a typical construction site.

Background Research by Students

This section presents extracts from the students' background research in four areas: personnel, equipment, materials, and site layout.

1.1.1 Personnel and RFID

With the boom in technology beginning to have an impact on the construction industry and the constant pressure to improve the efficient use of resources, the ability to track equipment, materials, and employees is a growing focus for the industry. Using RFID technology to track employees as they move around a job site has both positive and negative aspects. On the positive side, this ensures payroll accountability and enables managers to track the crews on site at any time, the precise locations of the personnel and crew productivity, while some of the negative aspects include RFID limitations, the life span of the equipment, and personal privacy issues.

The application of RFID for payroll accountability is a very practical and legitimate reason for issuing personal RFID chips to employees. If a general contractor or subcontractor knows exactly when their employees come onto the jobsite and leave for the day and their breaks, the exact amount that individual employees should be paid can be better recorded. This avoids the problem of employees forgetting to clock in or out and prevents time sheet fraud because the system records exactly when and where they were working on the jobsite.

Another benefit is grouping the individuals to show which crews are working on the site. Creating “divisions” of labor and assigning individual personnel tags into those divisions reveals when the crews are there and what type of work is being done at a given time. This information can be combined with scheduling software such as P6 to show owners and other stakeholders what has been done. The divisions can be broken down into groups such as concrete workers, iron workers, rebar workers, carpenters, electricians and so on to mirror the CSI divisions for estimating, making it possible to tie the two together using an RSMeans guide for crew divisions.

Knowing which employees are on the job site and where they are also contributes to safety. In the event of a major accident such as a structure failure or a crane collapse, the ability to rapidly locate every worker on the site allows rescue teams to identify those who are missing and focus their retrieval efforts on their last known location. It also allows managers to identify employees who are not pulling their weight. For instance, if the same one or two individuals keep visiting a remote corner of the site and spending an extended amount of time there, the foreman can investigate. This all ties back to knowing who is on site and accountability. Finally, crew productivity can be tracked. If managers know when a crew is working and when they are waiting for more work, the construction manager can adjust material deliveries and phase start dates accordingly.

A major issue with RFID technology is that it is primarily limited to data storage. As yet, it does not constantly relay information but only provides it when scanned. This limits the scanners to a schedule as opposed to a constant feed from the chips. The tags provide only a tag number and it is therefore necessary to assign employee data to individual tag numbers. Another limitation is the range. Depending on the materials, material thickness, number of obstacles and distance from the scanner, this can vary greatly so multiple scanners would have to be set up. Another limit is the lifespan of the equipment, primarily the battery life of the tag. Depending on whether the system is active or passive, the battery life may vary considerably and as battery replacement is expensive, it is often simpler to purchase new tags if using an active system. Finally, there is a major issue with employees’ privacy, as employers would know exactly where they are at all times and employees could potentially be vulnerable to stalking, harassment, and unwanted contact from other employees if the RFID information fell into the wrong hands.

1.1.2 Materials and RFID

RFID tags can have a big impact on inventories and material handling. In addition to their use with materials in stockyards, RFID tags on materials enables site managers to always know where materials are, ensuring that items do not get lost or forgotten about once they arrive on site. Items will be checked in and placed in the stockpile and then easily located and checked off when they are needed. Using RFID tags on materials also helps keep the project on schedule, as contractors will know when all the materials needed for an activity are on site and can adjust the flow chart to take into account the available materials. It also helps keep materials from sitting on site unused for too long. When using RFID tags, contractors will have to be mindful of the materials they are used on, however. Aluminum and steel are known to impede the function of RFID tags, but there appear to be fewer problems with materials such as concrete, plastic and wood. Most projects involve many different types of materials and this must be kept in mind when using RFID tags in this context.

1.1.3 Equipment and RFID

Good organization on the jobsite is vital for an efficient site and thus a profitable project. The RFID system must be incorporated in the jobsite layout plan because this shows the movement of materials, where they are stored, and the equipment used to handle them. All these factors should be included in the overall plans established by the general contractor. Material handling and equipment constraints are two of the four areas that must be considered in the layout plans. A good RFID system can help with both of these tasks. RFID can support material handling operations by showing how much material was moved and when, as well as where it was stored, either in a remote location or placed for immediate use. Once the materials are delivered, a tag from the site RFID system can be placed on the materials to be tracked. Most materials are only moved once, but these RFID tags will be especially useful if the materials are to be moved more than once. This ensures the materials cannot be moved or stolen without the system flagging it up and will also help ensure the provision of adequate delivery routes in remote areas of the jobsite.

Construction companies must keep track of a wide range of information and equipment on jobsites if they are to be profitable and successful. RFID allows the entire inventory to be tracked, including equipment that is owned by the company as well as equipment that has been leased, grouping it by accounting and different classifications. A good tracking system makes it possible to transfer inventory to and from different jobs and issue work orders to help manage the equipment if it is moved to another site, as well as showing maintenance schedules by month, mileage or hourly usage. It also makes it easier to keep up with repairs, costs, extra parts needed, fuel, and other factors involved in running the equipment. The use of rental equipment can be tracked to make sure it is fully utilized and thus reduce unnecessary costs. Managing hand tools is often difficult because of their size and the number present on a typical construction site. Tracking software makes it possible to place either a bar code label or an RFID tag on any piece of equipment and use the software to designate a named individual who is responsible for that piece of equipment. Depreciation can also be tracked, informing managers when it is time to either switch out or replace a piece of equipment.

1.1.4 Site Layout

Construction sites are everywhere, from far out in the middle of nowhere to the heart of our largest urban centers. The use of RFID tags in these very different areas to keep track of materials entering and leaving the site can be problematic, however, depending on the site’s surroundings. In an area with no congestion such as a greenfield site RFID systems will not suffer the inference problems that often plague sites in highly congested areas. In a high population density environment such as a city, there may be many other broadcast signals at frequencies that interfere with the on-site RFIDs and the other buildings surrounding a job site may also block the signals from tags. Open areas also have their problems: wind may blow tags off and rainstorms could wash them off. Wet surfaces also interfere with signals. These factors need to be taken into account when designing an RFID system for a specific jobsite. Ways to counter interference include testing the RFIDs signal to identify potential problems due to interference, ensuring that all the signals are assigned to the same frequency and the signal strength will be adequate, and making sure the suppliers have this information ready as needed.

Understanding Major Materials

Construction is inherently multidisciplinary as it requires various materials to be integrated together to produce the final product. To understand materials management in construction, students are required to distinguish the different materials most commonly utilized based on the 16 item CIS MasterFormat division list. MasterFormat is the specifications-writing standard used for most commercial building design and construction projects and lists titles and section numbers that can be conveniently used to organize data related to construction requirements (CSI, 2014). Table 1 shows how 13 different types of materials are assigned to these divisions. The configuration of the materials with the different divisions was selected based on the students' judgment and experience. The use of RFID technology is one of the material managements utilizing a state-of-art information technology. Therefore, the identification of the main materials according to MasterFormat ensures students understand and anticipate the RFID technology for the specific construction application. The recognition of major material types also helps students to select appropriate materials for an RFID readability test for construction materials based on those most widely used on U.S. construction sites.

Table 1: Matrix of Material Types and their CSI MasterFormat Divisions

Division	steel	aluminum	wood	plastic	concrete	dirt	bricks	slate	marble	plaster	ceramics	glass	asphalt
1													
2			■			■							■
3	■		■	■	■	■							
4	■	■		■			■	■	■				
5	■	■											
6			■	■									■
7		■	■	■	■		■				■		■
8	■	■	■									■	
9		■	■	■	■		■	■	■	■	■	■	
10													
11	■	■		■		■						■	■
12	■	■		■	■		■					■	
13	■	■	■	■	■		■		■	■	■	■	

14	■	■	■	■	■	■	■	■	■	■	■	■	■
15	■	■		■									
16		■		■						■			

Methodology

Students performed the readability test three times for each of the 6 different material scenarios at the university's athletic field, well away from major campus buildings. Although the background research on equipment and RFID presented in the previous section was performed by the students, they were not able to execute the readability test for the equipment. The 6 different material scenarios consisted of the unobstructed RFID tag itself, and RFID tags embedded under 2" of concrete, sandwiched between two 2" sheets of plywood, inside a plastic food container, wrapped in a single layer of 0.2 mm food-grade aluminum, and carried in the pocket of one of the personnel involved. The unobstructed RFID tag, which was not attached to any material object, was included to confirm the basic readability distance of 450 ft. provided by the manufacturer. The RFID reader was located in a fixed position and connected to the laptop through a USB cable. As each different situation moved an additional 50ft. from the reader, the connectivity of the reader and the tag was checked to determine whether or not the tag remained within the readable range. Once a material was out of the range, the material was then returned to the previous readable range and moved out ft. by ft. In the case of the embedded concrete, the material was moved in 10 ft. increments due to the unwieldy nature of the sample to measure the readability.

Results

In general, there are three types of UHF RFID interference: tag interference, multiple reader-to-tag interference and reader-to-reader interference (Kim et al., 2008). The type of antenna, height of the tag, displacement of the tag, and antenna tag distance are also factors. The distance measurement for RFID readability used here considered displacement of the tag only on a level grade, but UHF RFID interference might also influence the distance. The results of the distance measurements are shown in Table 2. The distance at which a tag was readable with no obstructions was around 450 ft., which supports the manufacturer's claimed distance of 450 ft. The RFID tag embedded under 2" of concrete was readable for distances less than 40 ft. on average. This poor performance was compounded by the necessity to wrap the tag in a thin layer of plastic to deal with water leaking into the tag when embedding it in the concrete, which may have affected its readability. In the plastic material test, placing the tag in a plastic food container reduced the readable distance considerably compared to the no material case.

Table 2: RFID Readability Test Results

Types of Material	Test Number			Average (ft)
	Test 1	Test 2	Test 3	
Unobstructed (No Material)	450	425	443	439.33
Embedded: 2" Concrete	34	37	42	37.67

Embedded: 2” Plywood	211	209	215	211.67
Plastic container	280	284	283	282.33
0.2 mm Aluminum	177.5	178	160	171.83
Pocket (Personnel)	200	190	198	196.00

Discussion: Comments by Students

The results of the materials tests were very interesting. The most surprising finding is that the RFID scanner picked up the tag wrapped in foil. Our preliminary research indicated that RFIDs do not work with aluminum, but these results showed otherwise. The most severe effect was for concrete, which clearly impeded the signal and shortened the range by an order of magnitude. While testing the pocket/personnel tag, the signal was erratic, possibly due to interference from personal cell phones. This would be important in the field if RFIDs were to be used as personnel tags on construction sites.

Conclusion

New technologies are constantly being introduced to improve every aspect of construction, including productivity, material handling, estimating and inspection. Students in construction management programs, especially undergraduate students, have little experience in using and evaluating newly available technologies and their potential application for improving the construction process except for software in the form of computer applications. Including this type of research as part of the senior project course has helped both faculty members and students enlarge their knowledge by engaging in hands-on trials of new and innovative technology of the type that will become commonplace on tomorrow’s construction sites. Based on this activity, students learned how to recognize the capabilities and limitations of RFID technology designed to accurately identify materials stored within containers or otherwise hidden from view. Above all, the students learned how to develop and establish the basic concepts involved in integrating new technological applications into the construction process, especially those related to material handling.

RFID technologies will have a major impact on construction in the future, especially for scheduling and tracking materials. The students who carried out this project concluded that it could indeed be helpful to mount an RFID reader on a crane on large sites to facilitate tracking the location of specific tags and monitor the movement of material and personnel around the site. The use of RFID tags can also help ensure the accuracy of a site’s material and equipment inventories by checking in material and equipment as it arrives and leaves the job site.

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