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Using Active RFID for Automated Workforce Tracking

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ABSTRACT: The increased complexity of large construction projects has created a growing demand for collecting and monitoring job-site information in more efficient ways. Radio frequency identification (RFID) is one technology that could potentially address some of these demands through its ability to deliver data automatically in real-time. However, despite the documented success of using RFID by many industries with workplace issues similar to those in the construction industry, the use of RFID in construction, up to this point, has been limited primarily to material tracking on projects with large laydown yards.

This paper presents a review of existing RFID applications used on construction projects and a pilot project in which Active RFID technology was used to monitor the real-time location of workers on a large commercial construction project. The paper also recommends ways to use RFID technology to facilitate construction management decisions in daily workforce monitoring, safety, change management, and productivity.

1 INTRODUCTION

Commercial construction projects today are technically and contractually complex and are often awarded to construction management firms or general contractors (CM/GC) at very thin profit margins. In order to survive and prosper in this environment, the CM/GC must develop innovative ways to improve project management processes. One way to accomplish this would be to adopt new technologies that could produce consistent, reliable, automated data about current field operations.

Active Radio Frequency Identification (RFID) might be one such technology because of its ability to deliver data automatically, in real-time or near real-time. Accessibility to current data from field operations has the potential to improve standard practices and decision making processes for project level managers as well as enterprise level executives. This in turn has the possibility of improving the overall efficiency of the project.

Using technology to improve efficiencies in the construction industry has been a topic of much discussion. In 2008, the National Research Council (NRC) created an ad hoc committee of construction industry experts to provide advice for advancing the competitiveness and productivity of the U.S. construction industry. They recommended five "Opportunities for Breakthrough Improvements," with RFID specifically named as one of the technologies that could help to "improve job-site efficiency through more effective interfacing of people, processes, materials, equipment, and information." [NRC 2009]

Given that the NRC has recognized the potential of RFID to improve a project team's ability to interface with each other; a pilot project was conducted to test that hypothesis on the age-old practice of workforce tracking.

2 BACKGROUND

2.1 Workforce Tracking in Commercial Construction

Daily Construction Reports are the most common form of workforce tracking on construction projects today and consist of total headcounts, worker classifications, and a brief summary of activities and weather conditions. Reporting begins with each subcontractor's hand written account of work accomplished that day and the number of workers on site. These daily reports are then delivered to the general contractor for validation and inclusion in a project-wide report. Although this provides a relatively accurate accounting of worker hours and activities, the final version of the reports are rarely available in less than twenty-four hours. On large projects with hundreds of workers, this manual process can take days to collect, verify, and enter into a database before reports are available to the project team. This extended process takes information that has the potential to impact project decisions immediately and reduces it to historical data. Adding automation to the process can significantly improve a project manager's ability to respond to daily manpower issues as well as long term resource-leveling and safety concerns. Automated tracking, which has been successfully delivered to many diverse industries by RFID technologies, has the potential to deliver the same benefit to the construction industry.

2.2 What is RFID?

Simply put, Radio Frequency Identification (RFID) is a common term referring to automated technologies that use radio waves to transmit information wirelessly about people, objects, and locations to a computer system and/or the internet. The basic components of the technology are transponders, transceivers, and antennas. The most common transponders, referred to as the "RFID tags," consist of a silicon microchip connected to an antenna. Transceivers are called "readers" and are used to retrieve the information stored on the tag. Readers are also connected to antennas which allow them to send a radio signal to the RFID tag and receive signals back from the tag. When an RFID tag passes through the electromagnetic field produced by the antenna, it detects the reader's signal. The information embedded in the tag's microchip is then decoded by the reader and sent to a designated computer system for processing so the data can be used to create a business value. [RFID Journal. 1339]

2.3 Active vs. Passive RFID

The two types of RFID systems are known as Active and passive systems. Although they both use radio frequency (RF) to communicate between the reader and the tag the difference is that the tags in a passive system do not have a transmitter and rely upon the power from reader to energize the microchip. As a result the readers in the passive systems must be capable of transmitting a strong signal. In the Active system, the tags have an internal power source, usually a battery, to activate their RF circuitry. In this way, the Active tag not only initiates communication with the reader but can monitor other conditions such as motion and temperature. Battery power also gives Active tags the advantage of longer read ranges. The Active tag's range is up to 300 feet compared to the passive tag's maximum range of 30 feet. The disadvantage of the Active tag is its larger size needed to accommodate the battery and its higher cost, $10 - $50, compared to the typical passive tag cost of 20 - 40 cents. [AIM 2012]

2.4 RFID technology in construction

2.4.1 Active RFID to track construction materials

Up to this point, the most common use of Active RFID on construction sites has been to locate materials on industrial projects which tend to have large laydown yards where pre-engineered high-value materials are stored for long periods of time. Several GPS assisted Active RFID systems on the market can provide the real-time visibility, security, inventory identification and positional accuracy needed for this type of application. Research has proven that Active RFID systems can track the precise movement and location of materials on site and within laydown yards at less cost than a pure GPS system or other existing approaches to materials management. [Song 2006] Field tests have also proven that productivity can be significantly improved by using RFID automation to reduce the amount of time wasted on locating materials in large laydown yards. [Grau 2009]

2.4.2 Passive RFID for workforce tracking

There are many commercially available Passive RFID systems on the market, however, only a few small start-up companies offer proven applications specifically designed to track construction workers. Because of the tag's limited read range and inability to self-report, the use of Passive RFID technology is restricted to monitoring workers entering and exiting jobsites through designated portals or gates. Passive systems are often used in conjunction with facial recognition security which requires a guard posted at the point of entry.

Research has proven that passive RFID systems can be used in a built environment to track worker movements through monitored portals. In addition, the automated data gathered by RFID systems can provide project managers with well-timed information needed to analyze and potentially improve productivity of selected workers. [Costin 2012]

2.4.3 Active RFID for workforce tracking

Very few examples can be found in which Active RFID technology is being used to track construction workers. Unlike other industries with well-established Active RFID applications, most construction implementations are unique with stand-alone solutions specific to one client. Although some of the components used in these projects can be standard off the shelf hardware, the applications are not ready for industry-wide implementation. [Zoega 2006]

In 2009, one such implementation was installed on an existing tunneling project between Galicia and Madrid, Spain. The managing construction companies needed a system that could locate workers in the tunnel and provide bi-directional communication between the project headquarters and the workers. This was accomplished by using existing WiFi nodes connected with fiber optic cabling in the tunnels and badge tags that transmitted at the Wi-Fi 802.11 protocol in the 2.4 GHz frequency band. The badges were equipped with rechargeable batteries which allowed them to beacon a unique ID number at predetermined rates. Once inside the tunnels, the wireless access points picked up the unique ID number transmitted by the badge. The data was then sent from the access points to the back-end computer system where the positioning software calculated a worker's location based on the RFID tag's signal strength received from the access points. Due to the cost of the system, badges were issued only to those working in high hazard areas. [Swedberg 2009] Though this is an interesting RIFD application, the cost of fiber optic cabling makes this a one-of-a-kind implementation.

2.5 Active RFID Chosen for Pilot

While there are several forms of RFID technology to choose from, this paper introduces the potential of using Active RFID in lieu of the more commonly used Passive RFID technology to improve the process of collecting and monitoring worker movements within the changing environment of a commercial construction jobsite. The primary advantage of Active RFID over Passive RFID is its ability to provide accurate location based data for all workers over a large area, in real-time or near real-time, with limited equipment and infrastructure investments. Active RFID has the ability to monitor the entire project site as opposed to simply monitoring entry and exit gates. In addition, on project sites with multiple access points Active RFID can be implemented more cost effectively than Passive RFID which requires high powered readers at each entry and exit gate.

A second advantage of Active RFID technology is its ability to deliver worker location data as a three-dimensional rectangular coordinate (X, Y, Z). With the XYZ coordinates generated by the system, a worker's exact location within the building can be determined by floor and by the building plan grid. To date, Active RFID is the only available technology that delivers this level of detail to a built environment. If the location data from the pilot proves to be accurate and reliable, it has the potential to be used to update existing project management planning and scheduling tools such as Building Information Modeling (BIM), Lean Construction Plan, Critical Path Method (CPM) schedules, and Flowline location based schedules.

A third consideration for the pilot program was the need to minimize the high costs generally associated with implementing new applications. For that reason commercially available equipment and software were chosen for the pilot. It was important to prove that existing technology was sufficiently developed to provide accurate and reliable location data with little or no reengineering of either hardware or software.

3 RESEARCH OBJECTIVE AND METHODOLOGY

The original vision of the research evolved from Turner Construction Company's desire to improve the efficiency of various management processes by providing a means of automatically gathering real-time data on the location of a project's workforce and making that data readily available to the project team. Past research has shown that Active RFID can provide valuable location data for high value assets as well as reducing time lost on manual processes.

The goal of this research was to prove that commercially available Active RFID technology can be installed and remain operational on a construction project while delivering accurate and reliable information on the location of workers throughout the life of the project. To be considered a viable alternative to manual workforce tracking, these goals would have to be accomplished within the constantly changing environment of a commercial construction project.

There were several challenges associated with accomplishing this goal; the most significant was the fact that commercial construction uses a great deal of metal for the superstructure and interior framing as well as the mechanical and electrical systems. Past research has shown that radio frequency has difficulty navigating metal rich environments. It was for that reason a hospital project was chosen as a pilot, the worst case scenario. If an RFID system could be designed to handle one of the most metal dense building types, then it should be able to function well in other more common building types such as offices and schools.

The objective of the pilot project was to install an Active RFID workforce monitoring system and validate the accuracy of the location data collected by the system. The first step was to install the monitoring equipment and verify its ability to function consistently. With the system in place and stabilized the next step was to issue an Active RFID tag to be worn on the hard hats of the trades participating in the initial testing phase. Limited metadata would be collected from each worker at the time the tags were issued. For the first testing period the metadata would be kept to a minimum and would include the name of the contracting company, trade, and union classification. The workers would be given the option to have their names included in the metadata or to remain anonymous. The next step would be to validate the accuracy of the data. This would be accomplished by monitoring the computerized reports as well as the on-screen real-time views through a series of first-hand visual studies performed at regular intervals throughout the work day. The data would then be made available, via the internet, to all members of the project team. In this way practical uses of the information could be developed by the different management groups.

4 PILOT PROJECT AND PRELIMINARY RESULTS

4.1 Description of the project

The construction project chosen for the pilot was a new six-story, 362,000 square-foot patient bed facility in Northern California. The footprint of the building consists of 41 structural bays per floor measuring approximately 34'-0" x 32'-0". The superstructure of the facility consisted of a steel frame and metal deck with a reinforced steel and concrete fill. Floors three and four were used during the pilot to monitor the movements of workers involved in the interior framing and mechanical rough-in activities.

In choosing a pilot project it was important to find a construction setting that would push the limits of the RFID technology and its known vulnerability to metals. That made this project ideal for two reasons. First, this new bed building is a Seismic Safety Project (SSP) which means significantly more steel had to be used in the superstructure to meet California's mandated seismic safety requirements for hospitals.

Second, the inside of the building is a metal rich environment consisting of light gage metal stud walls, large sheet metal ductwork risers, large quantities of copper mechanical piping for medical gases, and extensive metal conduit for electrical raceways. If an RFID system could be designed so that an RF signal could successfully navigate the metal labyrinth of this hospital building, then the implementation of that system on a typical commercial construction site would pose very few technical or physical obstacles.

4.2 Selection and Implementation of Hardware and Software Technology

4.2.1 Selection Considerations

Background research supports the notion that the construction industry has a very low threshold for investing in the research and development phase of emerging technologies. Therefore, it was important to identify existing RFID hardware and software with successful implementations to avoid the added development costs typically associated with new or experimental technology. All preliminary research indicated that commercial RFID applications in industries with similar environmental considerations had matured sufficiently over the past decade to make this selection criterion attainable. Using equipment that had already been field tested in harsh environments equivalent to that of a construction jobsite had the potential to shorten the testing phase of the first pilot project.

4.2.2 Description of the System

A commercial RFID firm was chosen to provide a system that combined asset tracking devices, wireless infrastructure, and RFID software applications.

4.2.2.1 Asset tracking devices

The tracking devices used for the pilot were battery powered Active RFID tags operating over the 2.4GHZ frequency band. The devices were small, lightweight, and mounted on workers' hard hats. The tags had a 1,500 foot line-of-sight (LoS) range with two-way wireless communication and over-the- air programming capabilities. The tags used the signal strength of the beacons to define their location based upon an advanced triangulation scheme.

4.2.2.2 Wireless infrastructure

The wireless infrastructure was composed of beacons and wireless routing units. Forty beacons and two wireless routing units were used per floor. Beacons chosen were battery powered devices that signaled specific locations along a predetermined grid. The wireless routing units, also referred to as base stations, were stand-alone devices using the 2.4 GHZ frequency band to communicate with the tags. The unit's Ethernet connection to a WiFi access point sent tag location data to a dedicated onsite server for processing.

4.2.2.3 Software

Software programs associated with the pilot included a multi-instance location engine and a business process visualization program. The multi-instance location engine allowed the system to extract a worker's location based on multiple and mutually exclusive data sources. The program calculated worker locations based on the Received Signal Strength Indicators (RSSI) according to the location engine's predefined algorithms. The refined location data was sent to the cloud based business process visualization software. The visualization software allows for filtering of data from the location engine, managing of metadata, and generating of reports.

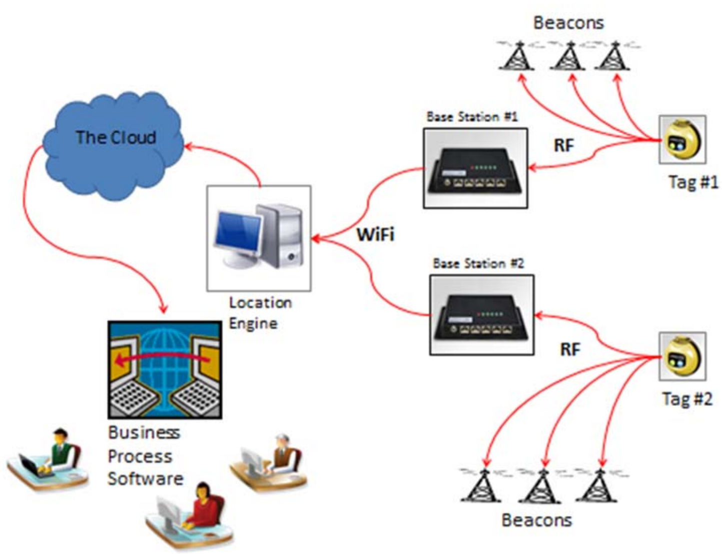

Figure 1. Workforce Tracking Application

4.2.3 System Deployment

The first step in implementing the Active RFID system was to install beacons, base stations and antennas on the 3rd and 4th floors of the pilot project. Beacons were mounted using wire hangers to suspend the beacons from the metal deck overhead in a consistent grid pattern on both floors and in a manner that would not interfere with the ongoing MEP rough-in.

The second step was to install the base stations and antennas in central locations on each floor. Each base station was linked to a WiFi access point using an Ethernet cable.

The third step was to install Active RFID tags on workers' hard hats. Preliminary testing proved that there was very little difference if the tag was on the front or back of the hard hat. The back was ultimately chosen as a convenience for the workers so that it would not interfere with other equipment they may use such as a light.

The final step to implementation was to collect the data automatically generated by the Active RFID system. The reports generated from the visualization software provided accurate, near real-time manpower counts traditionally derived from manually produced daily construction reports.

4.3 Preliminary Findings

It was evident early on that RF signal strength at the extreme edges of the building was diminished by the metal dense environment. In an effort to mitigate this issue, an additional base station was added to each floor as well as high gain antennas.

Initially beacons were located on structural steel columns; however, it was discovered that the RF signal was weakened by the beacon's proximity to steel. The issue was resolved by remounting them on wire hangers that suspended the beacons from the metal deck overhead allowing for maximum distance from the steel superstructure.

Periodically throughout the pilot, beacons were not able to maintain sync with the base stations which depleted the batteries. Several solutions were attempted including reconfiguration of the beacons firmware and disabling beacon's LEDs to conserve battery power. Additional firmware modifications are under development.

In the early implementation phase, it was discovered that tag read errors were frequently occurring around open shaft areas. These floor jumping errors were resolved by replacing the original nine beacons per floor configuration with forty battery powered micro-beacons per floor. The power signature of the original configuration was considered the primary issue.

The form factor of the tag used initially and the weight of its double battery was an issue with the workers. Consequently the tag was replaced with a smaller, lighter weight micro-tag that required a single battery.

Several issues of perception surfaced among both workers and managers. Workers' initial response was one concern; a system that could constantly monitor one's movements appeared to be too invasive until the safety aspects were explained. Project Managers in the pilot program were more inclined to see the value of automated workforce monitoring than Superintendents.

5 CONCLUSIONS AND RECOMMENDATIONS

Preliminary findings seem to indicate that Active RFID technology can be used to deliver accurate location data. The question of consistency and reliability of the equipment used in the pilot program remains unconfirmed. Early testing of this system did, however, confirm that

Active RFID can be used to locate workers accurately within a thirty foot range in a built environment. One advantage of using a commercially available RFID system is that industry has already developed flexible reporting tools so that unique reporting is easy. In addition, cloud-base solutions are already in place and are cost effective. Mobile applications for accessing RFID data are in development and will be available in the near future.

It appears that a metal dense environment poses a significant limitation on RFID systems but is not insurmountable with the right equipment, layout, and planning. Subsequent technical studies could focus on alternative Active RFID hardware and software solutions to improve system reliability. Subsequent studies of business solutions could focus on development of a standardized deployment scheme for the onsite installation of RFID equipment. Additional studies could develop methods of assessing worker perception and improving worker acceptance of workforce monitoring.

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