THE AUTONOMOUS REAL-TIME SYSTEM FOR UBIQUITOUS CONSTRUCTION RESOURCE TRACKING

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ABSTRACT

With more and more industrial construction projects implementing RFID and other sensor-based technologies on fabrication and project sites, new innovative processes are needed to help automatically read and re-position RFID tags while reducing the cost to deploy RFID infrastructure over large areas. RFID tags are being used on construction sites to help identify the location of materials, equipment and personnel to aid in finding project critical materials and equipment required to construct the industrial facility on time and on budget. This research provides a cost-effective process for reading tens of thousands of RFID tags over large project sites from outdoor laydown yards, to warehouses to the workface where the materials and tagged equipment are installed. Based on the collected RFID and sensor data, localization mechanisms determine the most recent coordinates of the tagged components. The paper will cover analysis of RFID collected data and key lessons learned from a commercial deployment of the SiteSense® system with one Alberta-based industrial contractor, JV Driver Fabricators, at an 80-Acre module, pipe spool and structural steel fabrication site.

KEYWORDS

Construction, asset tracking, laydown yard, RFID, GPS, fabrication, pipe spools, modules, materials management, warehouse

INTRODUCTION

Construction projects have unique complexities and unpredictable nature that make successful management a very valuable asset, but an extremely difficult task. The importance of productivity improvements within the construction industry has been gaining significant interest (Park, 2005). Efficient management and monitoring of assets in a construction field is a significant contributor to overall achievement of the productivity (Song et al. 2006). Construction materials and equipment account for a significant portion of the total cost of an industrial project (Kini, 1999). Therefore, successful management of these resources is a vitally important factor leading to the success of a project. On a typical construction site, tens of thousands of components are delivered, inspected, stored, retrieved and installed (Caldas et al. 2006). The site tracking processes are usually error prone and inefficient since they are done manually by workers. Automated tracking techniques can provide the constant visibility and the immediacy within the construction supply chain to lend timely, relevant decision support to construction managers (Stone 1995; Kim and Haas 2002; Su and Liu 2007; Torrent and Caldas 2009).

Technological advancements have provided companies in different industries with more effective means for tracking and managing their assets. One such technology is Radio Frequency

Identification (RFID). With construction projects starting to implement RFID and other sensor technologies on project sites, new innovative processes are needed to help automatically read and re-position RFID tags while reducing the cost to deploy RFID infrastructure over large construction site areas. This paper focuses on the development of a cost-effective methodology for automated localization and identification of construction resources on a large industrial project. RFID tags are being used on construction sites to help identify the location of materials, equipment and personnel to aid in finding project critical materials and equipment required to construct the industrial facility on time and on budget. A cost-effective process is introduced for reading tens of thousands of RFID tags over large project site areas from outdoor laydown yards, to warehouses to the workface where the materials and tagged equipment are installed. Based on the collected data, localization mechanisms determine the most recent coordinates of the tagged components. The paper will describe analysis of RFID collected data and key lessons learned from a commercial deployment of the SiteSense® system with one Alberta-based industrial contractor (JV Driver Fabricators) at an 80-Acre module fabrication site.

MATERIAL MANAGEMENT PROCESS IN INDUSTRIAL PROJECTS

On large industrial construction project sites there are many areas around the site delineated to act as the laydown yards for construction materials, where they are stored before installation into the plant facility. The material management process entails tracking the location of thousands of components from the moment they are delivered to the site to the moment they are installed to the facility. As materials are received, truck drivers arrive with a packing list, which details the content of the shipment. Each component of material comes with an identification code which is written on the surface of the component (or barcoded in some instances). The received materials are unloaded into a laydown yard and manually entered into the materials management database system, so that construction managers can coordinate activities based on the availability of materials. In order to facilitate the retrieving process, materials are grouped according to their characteristics and ID code, assigned a color code, taken to the laydown yard which is divided into the smaller grids and placed within a specific grid. In this stage, the ID of the materials, grid and the color code are manually entered into the management system. Materials are stored in the laydown yard until they are needed for installation. However, they may be moved to different locations on the project site before installation. Therefore, workers need to update the location of the components manually upon every move of a material piece to aid in future location lookup when they are needed for installation (Torrent and Caldas 2009).

Current identification and localization processes of materials are labour intensive, time consuming and inefficient as it relies on the ability of personnel and paperwork. Therefore, it fails to accurately detect and record the movement of materials. Also, the large amount and out-of-order delivery of materials, harsh weather conditions negatively affect the identification and as a result the efficiency of the installation processes.

IDENTIFICATION AND TRACKING METHODOLOGY

In today's world of rising labour costs and labour shortages, advanced wireless technologies are utilized to automate material handling processes and improve efficiencies. The proposed ubiquitous tracking system is called SiteSense® which includes solar power RFID gate stations for receiving material, ROVER (vehicle mounted RFID reader), remote control cameras, Web-based and handheld software, and ultra-rugged active RFID Tags for construction. RFID tags and readers operate at 434 MHz. In this method, active RFID and GPS technologies are combined to facilitate the data collection and localization process. SiteSense® integrates with engineering and construction material and progressing software systems to provide automated reports for material receiving, locating and progressing. Figure 1 demonstrates the architecture of the SiteSense® ubiquitous tracking framework. SiteSense® was developed from the ground up for industrial construction projects with the main goal in mind to improve the construction process and reduce costs. SiteSense® takes the guesswork out of determining the physical location of the materials, tools and equipment.

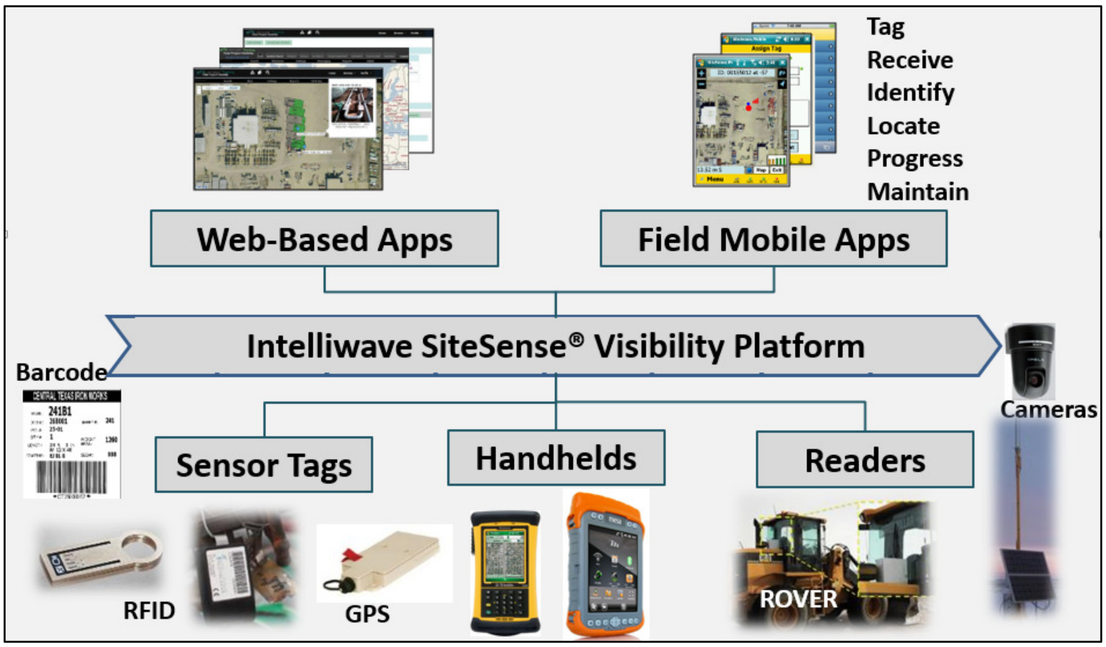

Figure 1. Overview of SiteSense® Components

In order to reduce manpower for receiving materials, delivered materials tagged with RFID can be read automatically via RFID gate station. Received materials are compared to electronic packing list and bill of ladings. Instead of using a dense network of fixed nodes to cover a large construction site, mobile anchor nodes are proposed. In this approach, a RFID Reader Unit which consists of RFID reader and GPS receiver is mounted and fixed to mobile equipment and vehicles as a means to track the location of tags on a site. Mobile readers are called RFID ROVERs. For optimal effectiveness, the RFID Reader Unit should be placed on equipment that is used frequently by materials management and other construction groups that will have the farthest reaching and coverage of the site. The goal is to detect as many tagged components as possible in a single scan, simplifying data collection processes and enabling more frequent data updates. Materials tagged with RFID can be tracked to their exact positions anywhere on the project site using the SiteSense® mobile reader infrastructure. If material moves, the new position will be known in SiteSense®. Material handlers can quickly find the position of the material using the SiteSense® site map and the handheld's built-in Geiger counter to direct them to the right material. The Geiger counter function on the rugged tablets can pick out the exact material in a laydown mixed in with hundreds of other identical looking pieces or even under the cover of snow. With the addition of SiteSense® remote control cameras, visual verification of tracked materials allows users to automatically zoom directly into the material, from anywhere in the world using the SiteSense® Website software.

When the SiteSense® ROVER vehicle turns on, the system is engaged through the ignition electrical line. The RFID reader powers up immediately. The vehicle PC boots-up in 30 seconds and initializes the SiteSense® ROVER software, which in turn initializes the GPS and RFID reader components. ROVER includes an IP address updater application that keeps the servers updated in case there is a need to remotely connect and perform maintenance. While the vehicle is in motion, the autonomous vehicle readers collect RF signal and sensor data from the RFID tags, filter out what would be considered superfluous data, and synchronize all relevant data back to the servers. While the vehicle is at rest, it only collects timestamp data and location improvement data. The vehicles maintain a temporary dynamic session database of what they collect that is shaped in part by the content on the servers. This temporary database allows the vehicle to heuristically determine whether or not incoming data is relevant or not. All data collected is packaged up into a data structure and synced with the servers. The time required to sync a package determines the interval of data transfers, usually 1 to 30 seconds. All data is synced over GPRS or WIFI. If any subsystem component is detected as not functioning, the system will restart itself and the whole process begins again.

The collected signal can be directly related to the component to which a tag is attached. As a mobile anchor node moves to a new position, its coordinates are determined and the surrounding tags are identified. The location of the reader (ROVER) is calculated by the built-in GPS device. RFID signal strength is converted into an estimated distance using the free path loss model. Both values together are then used to estimate the physical distance from the reader (vehicle) to the RFID tag. The identified tagged components are positioned somewhere within an ideal circle centered in the reader position. The radius of this uncertainty circle is the distance estimated using the free path loss model. Using the large amounts of data collected daily by the vehicles, the positioning system is able to iteratively approach more and more accuracy estimations, while also maintaining a very dynamic "Last Seen" timestamp for each RFID tag.

With material handlers and construction managers knowing exactly what materials, tools, and equipment are on-site and where they are located, they can ultimately get the material, tools and equipment faster to the work face. By reducing delays at the workface, the construction crew can be more efficient and increase their total productive time. Manual reporting of materials during receiving can lead to reporting errors. With less human intervention in material handling, data accuracy can be improved, thus saving time in error correction and ultimately in manpower. Progress reporting can be improved by integrating RFID tag status with construction progress. Once RFID tags are decommissioned then installation can be tracked with automated reports.

VALIDATION EXPERIMENTS AND SYSTEM IMPMENETATION

Industrial process plant construction projects consume enormous amounts of materials, equipment and specialist crews and involve multiple stakeholders who work closely towards delivering a project under a limited budget and a tight schedule. To improve project control, the SiteSense® ubiquitous tracking framework was implemented in a real construction scenario in JV Driver Fabricators module yard. JV Driver Fabricators undertakes mega industrial construction projects to construct complex pipe rack modules and electrical modules in Edmonton, Alberta that will later be shipped to northern Alberta for final installation into mining and plant facilities. Tens of thousands of module components and equipment pieces (such as pipe spools, valves, steel beams, grating, electrical equipment and mechanical equipment) arrive in Edmonton from all parts of the world via ocean shipping containers and heavy haul trucks. Each piece is destined to be installed in a specific module by a certain sequence and every module is to be shipped according to the installation schedule at the industrial or mining site. With so many components arriving in Edmonton in such a short timeframe, it is critical that the materials management team can account for each piece and easily find each component out of thousands of similar looking components in the warehouse or outdoor laydown yards in a timely fashion without holding up construction of a module. To make matters worse, Edmonton is covered in snow for about 6 months out of the year, making it even more difficult to locate materials.

To help the materials management team and work crews, JV Driver employed SiteSense® tracking system that utilizes rugged active RFID tracking tags , mobile and handheld RFID readers to help automate receiving and locating materials anywhere on the construction site spanning over 80 acres. Figure 2 shows the procedure of the application of SiteSense® in JV Drivers Fabricators' module yard.

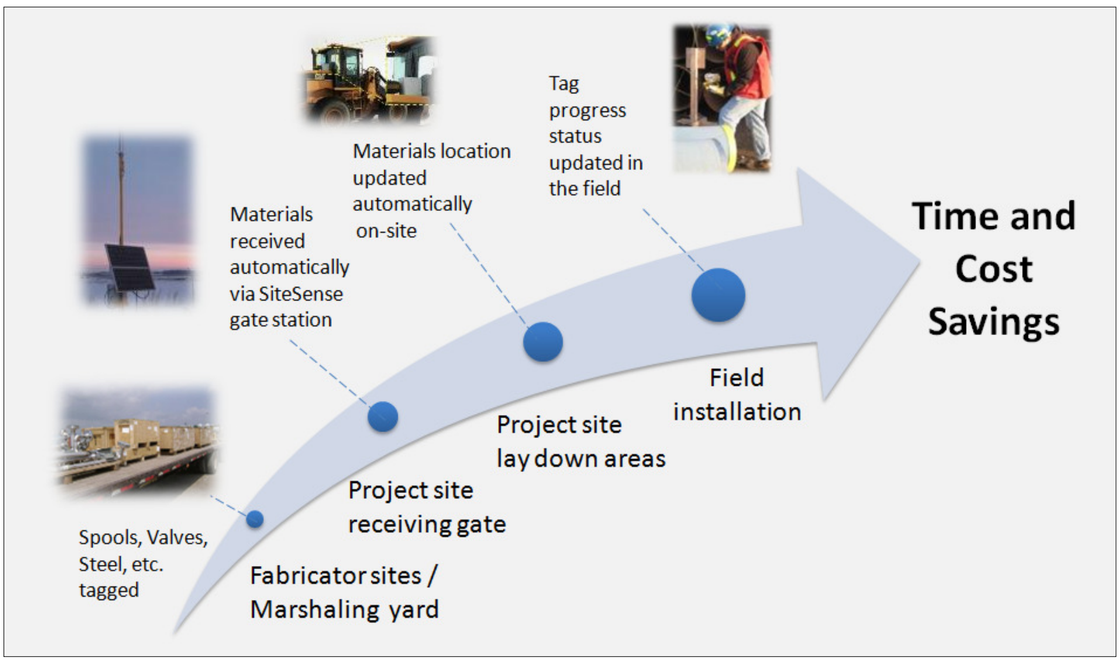

Figure 2. Overview of SiteSense® used in the construction process

Prior to materials being shipped to the fabrication yard, materials were tagged at vendor locations, other fabrication sites and marshaling yards. In order to reduce manpower for receiving materials, a RFID gate station was erected to automatically read tagged materials. Material handlers used SiteSense® Handheld Software to aid in receiving procedures by taking field notes on overages, shortages and damages that is automatically fed back into the materials management system to create the Material Receiving Reports. Ten-thousand material items along with 300 equipment items for constructing more than 100 modules were tagged with RFID tags. Two ROVERs were used frequently including 1 skid steer and 1 front end loader as the RFID mobile reader network for the 80-acre site. Figure 3 shows the mobile readers called RFID ROVERs. Figure 4 demonstrates the coverage area of the ROVER on the skid steer at the JV Driver Fabricator's module yard. Solid lines indicate vehicles' movement path over 24 hours tracked by the ROVER's GPS receiver module.

Figure 3: RFID Rovers for JV Driver fabricators' site

Figure 4: RFID Reader-Enabled Vehicles' (ROVER) movement tracks in JV Driver Module Yard

RESULTS AND DISSCUSSION

Remarkable results from field implementation were obtained, which are conducive to finding materials for the purpose of preservation and maintenance and issuing to the field for installation. More than 99% of the tagged materials were found in less than 5 minutes (where in the past it typically took an average of 30 minutes per piece), helping to create a very efficient work process for the field. The idle time for waiting for material and lost materials were reduced significantly. SiteSense® was also used as a secondary progressing system using RFID to automate material movement and report on the progress percentage completed for each module (Figure 5), awarding progress factors for receiving, storing, staging, issuing and installation in a timely, consistent fashion.

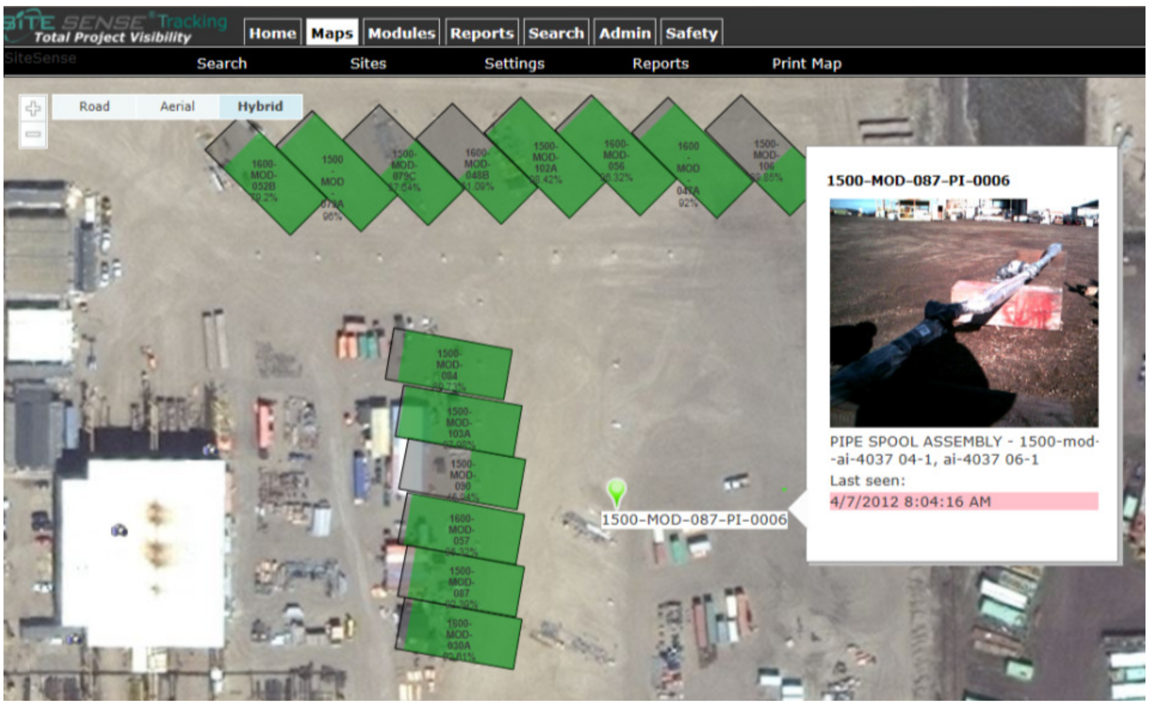

Figure 5: progressing system of the SiteSense® (Rectangles display modules)

The optical camera option with SiteSense® was also employed which integrates pan/tilt/zoom cameras and provides the capability of zooming directly into the location of the material for visual verification of material location in the yard. The cameras allowed management to remotely monitor the project site from anywhere in the world. JV Driver has consequently standardized on using SiteSense® for all future construction projects. SiteSense® increased their material handling productivity by 2.58 percent and equipment and tools productivity by 2.08 percent.

CONCLUSION

With more and more construction projects implementing RFID and other sensor technologies to help identify the locations of materials, equipment and personnel, new innovative processes are needed to help automatically read and re-position RFID tags while reducing the cost to deploy

RFID infrastructure over large construction site areas. This paper introduced a materials tracking platform called SiteSense® which integrates hardware devices and data from multiple construction applications to link the physical and digital worlds and turn materials management totally visible. SiteSense® ubiquitous tracking system incorporates advanced algorithms and information management support to track materials, equipment, tools and personnel at industrial job sites. In order to reduce manpower for locating materials in real- time, ROVERs are utilized as a means to track the locations of thousands of RFID tags across large sites. ROVERs are mobile equipment and vehicles that are equipped with a RFID reader unit. This cost-effective process enables reading tens of thousands of RFID tags over large project site areas from outdoor laydown yards, to warehouses to the work-faces where the tagged materials are installed. Building upon the SiteSense® Visibility Platform, specific web and mobile field application products and modules cater for focused user needs such as asset search and locate material pick-lists and progressing. Implementing the SiteSense® in JV Driver Fabricators' module yard has proved that SiteSense® framework has the potential to increase visibility within the construction supply chain. It is also concluded that this automated materials tracking system has a great potential to improve construction productivity and enhance project planning and control practices in the near future, ultimately leading to substantial time and cost savings on mega industrial construction projects.

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