PROACTIVE FIELD MATERIALS MANAGEMENT USING INTEGRATED LOCATION AND IDENTIFICATION SENSING TECHNOLOGIES

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ABSTRACT

Commonly, field materials management still relies on traditional practices. Previous research efforts showed that proper materials' handling operations have the potential to enhance construction productivity. This paper describes a study that focuses on the integration of on-site materials' data with project management systems. Automated data collection technologies are used to keep track of materials' location and identification information. This data is proactively integrated with management tools in order to forestall future issues ahead of time. Using this method, managers may be able to take action to prevent materials-related problems before they actually happen.

KEY WORDS

construction management, construction materials, data collection, global positioning, identification, information technology, integrated systems

INTRODUCTION

Field materials management has a high potential for improvement. An early study by the Construction Industry Institute (CII) (CII, 1986) showed that adequate management of on-site materials handling operations would result in a conservative 6% increase of craft labor productivity. Since the publication of this primary study, the technology industry has accelerated its development of innovative and sophisticated products; the construction industry works to adapt these applications to improve or to substantially change traditional on-site practices. Indeed, a recent industry survey showed that more than 80% of the surveyed field supervisors and project managers believed that new technology developments would have a critical impact on materials handling operations, and consequently on construction operations (Vorster and Lucko, 2002).

Several sensing products are ready to support field construction processes. These devices coupled with mobile computing solutions are able to collect on-site materials' data in a timely, accurate, and automated fashion. In fact, technology stands ready to easily become

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the foundation for re-engineering traditional construction practices. This emerging reality can also validate the perception by Garret et al. (2003) that technologies could change some of the industry's basics.

Commonly, project managers can only react to field events. The traditional manual data collection process is intrinsically error prone and slow, requiring a considerable amount of time to detect deviations from planned conditions. This implies after-the-fact and late responses to field events. Frequently, deviations are only noticed at the moment when the implicated components need to be handled for construction operations; this last minute awareness makes addressing the problem quickly and efficiently unlikely. Thus, the unnoticed absence of even a single construction component in the critical path can delay a whole project. Such delays can greatly reduce the chances for project success.

However, significant competitive advantages could result from the integration of current materials' data into management processes. Applications able to continuously process sensed field data, so that they can automatically denote deviations, can trigger the appropriate messages to the right project players. Using such methods of data integration, project managers could significantly reduce the amount of time between field event and corrective action, and hence facilitate the process of controlling materials' status as planned. For instance, managers could reliably elaborate short-term plans based on the actual materials and their status.

In addition, a proactive integration method could help avert future materials-related problems. Managers could prevent potential issues when detected by taking the appropriate actions. For instance, the absence of a component would automatically be reported to the management the moment it goes missing, thereby initiating its opportune field search. In such a case, the integration procedure facilitates the flow of proactive information back to the field.

BACKGROUND

Sensing technologies coupled with data communication protocols are ready for identifying and locating components on construction job sites. Some of the available technologies are barcodes, smart labels, active and passive RFID, real time locating systems (RTLS), contact memory buttons, wireless and ultra wide band (UWB) communications, and mobile and handheld computers. Other solutions are laser scanners, LADARs, micro-electro-mechanical systems (MEMS), webcams, digital cameras, Bluetooth and ZigBee standards, and cell phones.

Appropriately collecting materials' data from construction job sites has some intrinsic needs. First, data should be automatically captured once and at the source. Second, sensed data should be updated and meaningful to the materials management system. Third, data should be accurate so as to guarantee full advantage of its use. While other solutions can also fulfill these requirements, RFID and GPS were better suited for the objectives of this research as explained later in this paper.

The communication between the coupled reader and receiver (tag) is the generic basis of the RFID technology. Both reader and tag communicate via radio signals emitted through their respective antennas. The tag detects the incoming reader's signal, processes it, and sends it back to the reader. Tags can be powered either by batteries (active) or by the reader's incoming signal (passive). Active tags can communicate from much greater distances than can passive solutions. Even though cost and lack of commercial standards still prevent radio frequency solutions from their broad implementation within the construction industry, researchers early on adopted active RFID technology for data collection processes due to its non-contact and non-line-of-sight nature. Jaselskis et al. (1995) primarily suggested RFID applications for on-site construction processes. Akinci et al. (2002) analyzed the use of the technology in order to track pre-cast concrete members while storing their life-cycle information. Umetani et al. (2003) combined sensors with databases and robots to identify, position, and locate construction components. Navon et al. (2005) used the sensors to semi-automate and visualize materials throughout the supply chain (purchasing, delivering, and dispatching materials for installation). Song (2005) implemented the technology to locate on-site materials based on a grid pattern using proximity techniques. Finally, Song et al. (2006) determined the feasibility of active RFID to automatically track spool pieces and read additional spools' information during delivery and receipt processes.

GPS, in its generic form, is an outdoor and worldwide radio-navigation system composed of a constellation of 24 satellites. Ground receivers determine their own position by using triangulation techniques, which require the incoming signals from at least four satellites. The resulting position accuracy is usually better than 15 meters (raw data). Differential correction of this raw data results in a more accurate position. For instance, OmniSTAR and Wide Area Augmentation System (WAAS) usually improve the data to sub-meter accuracy in real-time and by means of additional geographic references (OmniSTAR, 2006; Garmin, 2006). Raw data can alternatively be corrected using ground stations as a fixed reference. Despite the GPS need for line-of-sight between satellite and reader antennas, its worldwide coverage and its wide range of off-the-shelf solutions are the predominant characteristics that have attracted research efforts. Navon and Goldschmit (2003) analyzed the feasibility of a ground-based locating station that, coupled with project models, monitored on-site labor. Brown (2004) used micro-electro-mechanical systems (MEMS) and miniaturized GPS receivers to position and to track moving objects. Caldas et al. (2005) determined the time savings gained on one field locating operation of an industrial project when using GPS.

PROACTIVE FIELD MATERIALS MANAGEMENT USING IDENTIFICATION AND LOCATION DATA

Effective materials' tracking on the job site provides an answer to the question "Where is it?" To respond, one should know the material's *location* data and, by default, its *identification* data. Moreover, to satisfy an effective response, these data should be accurate, prompt, and updated.

Proactive integration of location and identification field data with project management tools requires four basic steps: technology selection, data collection, sensed data fusion, and data integration with project management tools. The next sections explain these steps and discuss the future research steps.

TECHNOLOGY SELECTION

There were many available sensing and computing technologies that could theoretically collect on-site data, offering a vast range of technology characteristics, data communication protocols, implementation architectures, and costs, among other features. Indeed, the lack of industry standards among similar sensing solutions frequently resulted in incompatible core technologies. In addition, the commercial pressure intrinsic to the high technology market resulted in an ever-growing puzzle of new and promising products that, in reality, might or might not essentially differ from what already exists.

The researchers of the present study had the opportunity to obtain construction and technology feedback by interviewing industry members. The interviews, although informal, allowed the researchers to determine some of the fundamental opportunities for technology solutions within current field materials practices. The main challenges found were the number of lost items, the availability of materials when needed, and the construction time lost, among others. In addition, interviews also addressed a variety of other topics such as technology opportunities and feasibility, field practices, or costs issues.

DATA COLLECTION

Two different sets of field experiments determined the feasibility of GPS, RFID, and mobile computing solutions to collect field data. The experiments integrated these technologies with construction processes.

Technology Used

Standard handheld computer models were used during data collection processes. They stored the information read by the sensors and controlled the sensors' settings. Handheld computers and sensors were always physically connected.

The GPS reader determined its own location at any given time. The receiver was embedded in the antenna, which was mounted on a backpack. A unique position was defined by latitude, longitude, height, and time. The reader allowed for sub-meter precision using WAAS.

Reader, antenna, and tags were the fundamental elements of the active RFID solution. The reader with antenna was inserted in a PC card slot in a handheld computer. When communication between tag and reader had been successful, the reader sent the tags' identification numbers to a software application that stored them in the handheld computer. Later on, the same information could be transferred to a host computer.

Field Experiments

The authors conducted two different sets of experiments to determine the feasibility of GPS, RFID, and mobile computing solutions to track pipe spools under real construction scenarios. Results of these experiments were reported by Song (2005) and by Caldas et al. (2005).

The first experiment determined the feasibility and reliability of active RFID technology to automatically track spool pieces during materials' receipt and delivery. In that approach, long read-range tags were individually attached to metallic pipe spools lying on a flat-bed truck that passed through a portal equipped with fixed antennas. In the course of delivery antennas potentially read the identification of each tag, which were collected through the reader in a mobile computer.

The analysis of the results showed that it was feasible to track spool pieces using active RFID solutions for delivery and receipt processes. Indeed, the study demonstrated that the reader could identify 100% of the tags when the truck speed was lower than two miles per hour. The parameters analyzed were truck speed, number of antennas and their location, and the on/off timing sequence of the reader relative to the truck. Finally, the study identified process time reduction, accurate and updated information, and minimization of misplaced pipes and searching times as the potential drivers to leverage portal system applications.

The other experiment analyzed the impact of GPS when tracking and locating pipe spools on lay down yards. A GPS unit and a handheld computer were integrated into the current process. This was broken down into five different steps, one of them establishing the baseline for the analysis. Then, the test measured the workers' time to accomplish this locating step, with and without GPS.

The authors quantified important time savings when using GPS. Craft workers only spent an average of fifty five seconds to locate a spool with GPS. In fact, the sensor saved five minutes and forty seven seconds per spool piece when compared to current practices. These savings could potentially justify the technology deployment. Other potential benefits derived from the GPS deployment were the reduction in the number of lost items and the positive impact on construction operations. Additionally, the authors stated that GPS could enable re-engineering the current process into a more standardized practice with a more steady and predictable outcome.

However, there were two important limitations. First, the locating process was still highly dependent on human nature and, as a consequence, error prone. Workers had to intensively use handheld computers to introduce data and to control the GPS functions. In addition, spools were visually identified by means of written marks on their surface; in reality, some spool pieces could not be identified. Second, when a spool was moved its new position was not automatically tracked. This resulted in the misplacement of those pieces that were moved to different locations without notice to the system. These issues set the basis for a new approach that combined the two types of sensors used during the field experiments described above.

The combination of active RFID and GPS readings had the potential to offset these limitations by automating the tracking process. When used together, they determined their own position and identified tagged spools in a prompt and reliable manner. The collected data was automatically stored without human direct involvement. In this approach, a worker equipped with both readers and a handheld computer would facilitate the data collection by moving around the site.

SENSED DATA FUSION

The data collected with active RFID and GPS sensors needed to be adequately merged into a common source of information. The RFID reader identified the surrounding tags at any given time. Similarly, the GPS reader processed its own position at any given time. So, sensors' synchronization eventually depicted the tagged spools around a GPS sensor position and for a particular time frame.

However, this approach alone would bring a great uncertainty in the true location of a tagged spool. The coordinates of the GPS sensor would be used instead of the actual tag's location; this would be somewhere within the sensor's communication range (Figure 1). This fundamental simplification would prevent from efficient tracking processes.

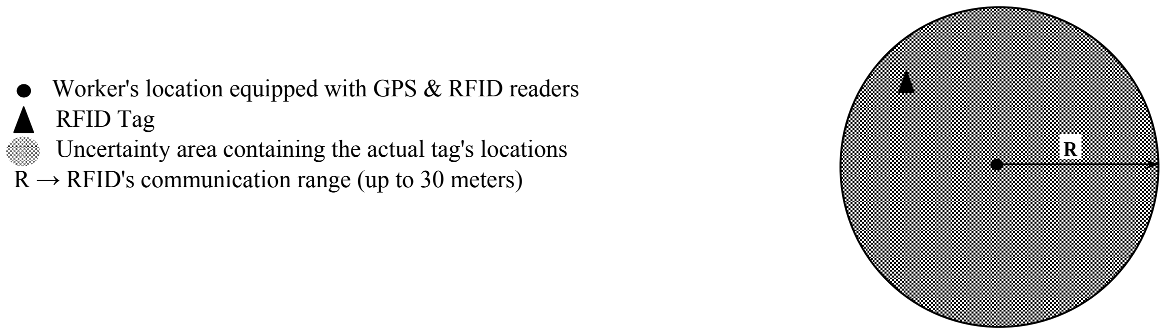

Figure 1: Tag's location uncertainty based on the GPS sensor position

To determine the actual tagged spool's position, both technology architecture and proximity models were concurrently addressed. Proximity models mathematically estimated tag's position with a measurable degree of uncertainty, while technology design optimized these results. For instance, shorter RFID communication ranges increased tag's positional accuracy but reduced the probability to read them. Optimally, several readings for each tagged spool intersected and minimized location uncertainty (Figure 2).

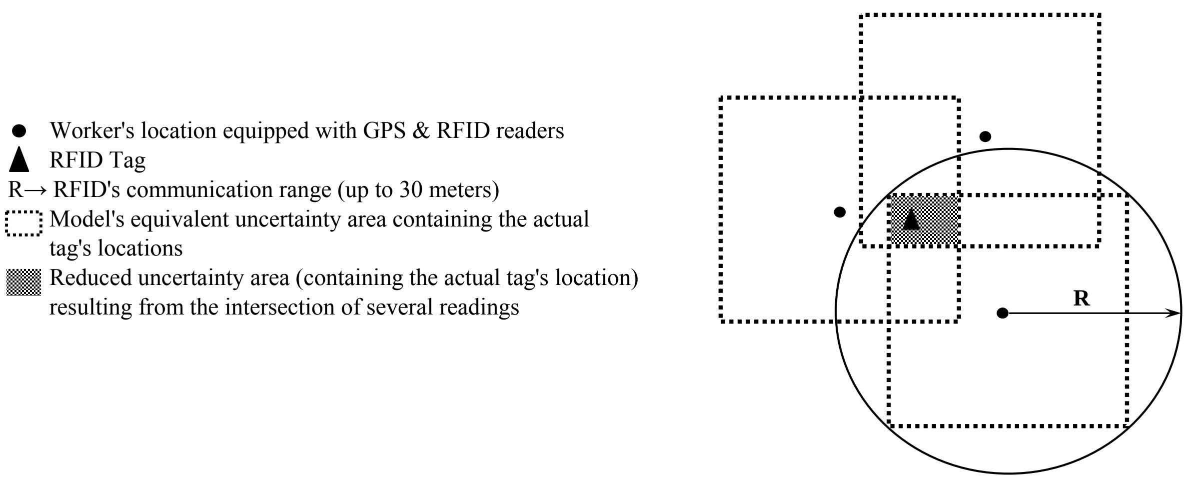

Figure 2: Several readings intersect and decrease the location uncertainty for a particular tagged spool

GPS Data

Every reading was represented by four parameters: longitude, latitude, height, and time. Longitude and latitude situated the sensor in a 2D plane on the surface, while the height quantified its elevation. Time made each position identifiable and unique.

A WAAS real-time differential correction was enabled. Since WAAS accuracy depends on the changing position of the satellites above, its use was limited to configurations that would result in position accuracies approximately better than +/- 1 meter. In reality, accuracies were usually better than +/- ½ a meter.

The reader was set to calculate its own position every second and used the following timing schema HH:MM:SS:mmm (hours:minutes:seconds:milliseconds). Then, each collection of position was synchronized to happen when the “seconds” field was integer number (i.e., when the “milliseconds” field was null). So, the resulting schema can be written as HH:MM:SS:000.

RFID Data

A communication protocol to control the RFID reader was built on top of a commercial software development kit (SDK) using C++. The tool moduled the sensor’s settings (e.g., power level and sensitivity threshold, among others) while synchronizing the readings with those of the GPS. The RFID reader collected the time reference (according to the HH:MM:SS:000 schema) and the tags’ identification numbers that had successfully communicated with the reader.

An adequate data structure needed to be identified in order to store and manage the large amounts of collected information. In fact, it should offer effective search functions for large sets of data. In addition, the nature of the collection process required an expandable storage structure capable of efficiently adding data sets while keeping a particular order. With this in mind, double linked lists turned out to be the most appropriate structure.

Double linked lists were a fundamental data programming structures. Data was stored in nodes, each node containing three fields. In particular, the data field stored tag identification numbers and each time reference, while two other reference fields pointed to the next and to the previous nodes in the list. Needless to mention, the sequence of the nodes followed the temporal order of the collection. In order to improve search functions, the head node was referenced to the tail node and hence the structure became a circular linked list (in other words, the list was a closed loop).

INTEGRATION WITH PROJECT MANAGEMENT TOOLS

Now that the previous research steps have been completed, the research team will focus on the integration of the collected data with project management tools. Based on previous results, the researchers are collecting and integrating new sets of field data. Further research efforts are also working on additional sensing designs, algorithms, and formalisms.

CONCLUSIONS

This paper summarized the results to date of a study that aims to proactively integrate automated identification and location technologies with project management tools. The proposed solution involves collecting pre-fabricated pipe spools' location and identification data from RFID and GPS readers installed on handheld devices used by construction workers. Then, both sets of data are integrated based on matching time references. Data related to GPS positions and surrounding RFID tags are stored and used as input to proximity techniques that determine the tagged spools' positions. Additional research efforts are under development to complete the proactive integration of the actual location of tagged objects with scheduling software systems.

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