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RAPID AUTOMATED MONITORING OF CONSTRUCTION SITE ACTIVITIES USING ULTRA-WIDEBAND

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ABSTRACT

Monitoring construction site activities is a critical concern to most stakeholders (owners, contractors, architects, engineers, suppliers, etc.) in a construction project. Successful projects are often determined by the level of awareness of project status or work task performance. Thus, information has inherent value for real-time or near real-time decision making. Good resource procurement and resource allocation of workforce, material, and equipment comes in play when job site conditions can be efficiently and effectively assessed. Semi- or automated technologies in the data collection and assessment process can assist in making fast and confident decisions. This paper introduces an emerging technology called Ultra Wide Band (UWB) for real-time location sensing and resource tracking. The technology, its use as data collection tool, preliminary data processing algorithms, experiments, and results are presented in the context of active work zone safety and material location tracking. Many more application areas exist where UWB might impact the field and project management level to overall benefit the construction industry's competitiveness.

KEYWORDS

Ultra-Wideband, Real-time, Sensing, Monitoring, Tracking, Emergency Response, Safety, Productivity

1. INTRODUCTION

Technological advancement in other industries strives for fast data collection and processing to enhance the flow of resources and to minimize logistical efforts. An example is the sophisticated tracking and progress monitoring of products during manufacturing and warehousing. In construction, however, adaptation or development of technologies last longer due to often required return on investment and benefit-risk analysis. Although this paper does not address the reasons of why few technologies get implemented in construction, it concentrates on how emerging technologies can help solve some of the problems construction field personnel face every day. The need for innovative technologies in construction becomes necessary when, for instance:

(1) Contacts resulting from struck-by events of heavy equipment and many other equipment related accidents need to be avoided. Thus, designing active safety tools is a particular application in construction that requires fast updates of machine location and its surrounding object positions in space.

(2) Resource tracking in the entire supply chain during construction and the life-cycle of the built environment to improve efficiency and effectiveness to overall benefit the construction industry and society.

Many different technologies have the potential to become a key element for solving these and other problems. In particular faster data acquisition and processing tools in construction are needed that allow real-time location detection and tracking of resources.

This paper provides a brief overview of recent technological innovations in construction resource tracking and progress monitoring, discusses the requirements of Ultra Wide Band technology that is needed for specific construction applications, and examines a few experiments conducted with the UWB systems in the construction field and inside the Real-time Automated Project Information Decision Systems (RAPIDS) research laboratory. Preliminary experimental results will be presented in the context to construction site resource location tracking and active safety. Finally, an outlook of future work ahead is provided.

2. BACKGROUND

In the last decade a number of reasons increased the interest in locating the position of resources. Worldwide competition, tighter schedules, and shrinking budgets demanded more accurate performance of work at an increased overall level of productivity. These drivers made the construction industry to adapt technologies such as Global Positioning System (GPS), laser tracking, and recently to support the development of active Radio Frequency Identification (RFID) in combination with GPS [1, 2]. Other semi-automated technologies, such as time-lapse photography in combination with a priori Computer Automated Design (CAD) information allow monitoring progress on construction sites [3].

A technology that might have answers for real-time locating systems is Ultra Wide Band (UWB). The origin of UWB technology dates back to the early 1960s when research experimented with the time-domain of electromagnetic-wave propagation. In a seminal paper Ross and Benet summarized UWB's early applications [4]. Ross was the first researcher to demonstrate an UWB communication system in 1986. Until 1994, the majority of the work was performed under US government programs. With rulings of the Federal Communications Commission (FCC), after 1994, there has been an increase in non-governmental related research and an increase in the number of UWB government agencies and companies that are greatly accelerating the development of UWB technology [5]. Since then, UWB technology has shown to possess unique advantages for precision localization applications. The use of short pulse radio frequency (RF) waveforms provides inherent precision for time difference of arrival measurements, as well immunity to multipath effects in indoor applications.

To measure larger distance and the locations of objects more efficiently and potentially identifying them at the same time, requires tagging the construction resources. UWB sensing has a particular advantage compared to RFID sensing, since it gives accurate 3D location values in real-time. Since GPS requires satellite or base station connection it is mostly limited to outdoor applications. UWB's main limitation at this point is a necessary measurement infrastructure, but once set in place can stay for at least the project duration. Material tracking or supply chain, however, does not stop once the shell structure of the building is erected. Many subcontractors come on site once the interior finishing of a building starts and even after the building is finished (e.g., maintenance). For example high-rise projects, often store materials and supplies in already built but unfinished building floors. If real-time tracking construction resources and progress should become a new tool in construction and project management, decision making at all levels (workforce, field manager, project manager) will require technology to record location and movement of construction resources at different time intervals, in three-dimensional space, at all times, safely, and at low cost and maintenance.

3. RESEARCH OBJECTIVE

The research objective is to assist the construction industry in determining the location and trajectories of resources (workforce, material, equipment). The purpose of this research is to demonstrate the applicability of Ultra Wide Band for construction and in particular to measure accuracies in field applications such as work zone safety, material and work task productivity tracking.

4. REQUIREMENTS FOR THE UWB SYSTEM

From an implementation perspective, the main points of the UWB system requirement can be summarized as follows:

- Accuracy: UWB must be better than existing solutions including GPS. An error in any dimension of less than 1m at update rates of at least 1Hz is acceptable for many construction applications, e.g., material tracking.
- Size and Cost: Depending on the application, the system needs to be affordable, small, and preferably offer full wireless operation, e.g. range between US$0.1-10 and a few grams per tag.
- Ease of use and cost: Fixed installation of hardware and antennas should require less setup and maintenance. Running cost should be minimal.
- Legality: Standards and regulations in each country differ and need to be developed and followed.
- Interoperability: Communication to other technologies must be likely, e.g. handhelds, but should not interfere and needs to co-habit with other signals in the radio frequent (RF) spectrum, e.g. inside and outside buildings.
- Range: To be practical in construction, signals must be useable over 150m between fixed and potentially mobile receivers, and need to work in object cluttered environments, e.g. walls, steel.
- Multipath: It must work well when there are multipath components at all delays from a few centimeters to several meters, similar in level to the straight path (and up to 10 dB higher in a few cases) [6].

5. EXPERIMENTAL SETUP

The experiments conducted inside the laboratory and on the construction job site used the following configuration of an Ultra Wide Band system (see principle layout illustrated in Figure 1):

- Central hub processor and computer interface
- Receivers (6 Mid Gain and 3 High Gain)
- CAT-5e shielded cables (several lengths)
- Tags (up to 30, including one reference tag)

The receivers/antennas are connected via shielded CAT5e cables to the hub. Each cable powers the connected receiver(s) as well as transmits the tag identification and time readings back to the hub. A reference tag in line-of-sight of the receivers or of receiver subgroups is placed preferably in the center of the space observed. The location of each tag is calculated based on synchronizing the arrival signal after the time-of-flight principle. Signals between receiver and tag can then generate real-time two-dimensional positioning data if at least three receivers are used. Real-time 3D location sensing requires at least four receivers, preferably at locations with significant difference in elevation.

The UWB tags come in form of a small badge (6.5x3.4x0.6cm), asset cube (2.9x2.9x2.5cm) or micro rectangular (1.3x2.5x0.6cm) form. The weight for each tag is less than 12grams. The update rate of the radio frequent (RF) signal of each tag is fixed and can be up to 60Hz, otherwise comes at 30Hz, 15Hz, 5Hz, 1Hz, or even lower frequencies. The range of the tags, depending on the receivers used, can be up to 200m (High Gain directional receiver).

Before measurements in the field or in the laboratory were conducted a Total Station recorded the 3D location of all receivers. This positioning data needs to be implemented in the hub's processing unit. Two initial experiments are presented to demonstrate the potential of the technology as well as preliminary results:

(1) Indoor tracking of humans within the laboratory. Evaluate UWB system under near optimal conditions to measure accuracy and precision.

(2) Job site tracking of workforce and steel erection. Evaluate the UWB system under realistic conditions with ambient influences, e.g. sunlight, metal interferences, at large scale of 60x60m.

6. EXPERIMENTS AND RESULTS

The condition and results of one indoor and one outdoor experiment are discussed in the following paragraphs.

A data processing and graphical user interface (GUI) exists that analyzes the RF signals inside the

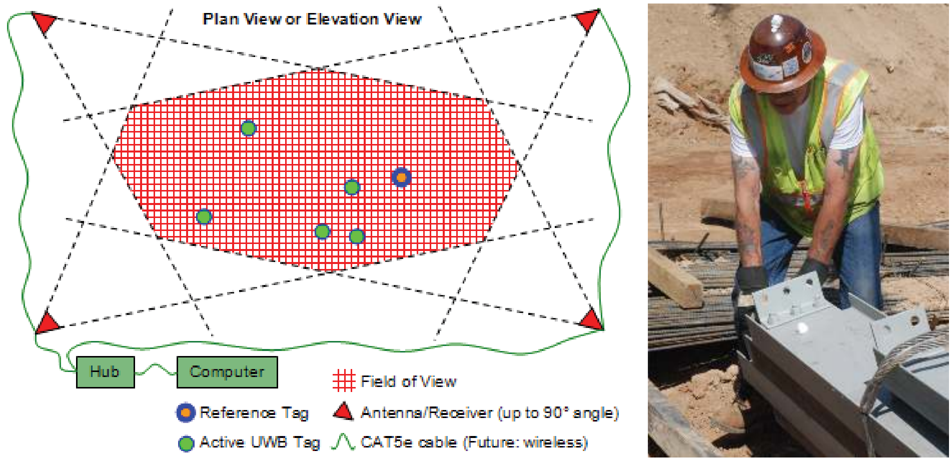

Figure 1 Ultra-Wideband Receiver and Hub Configuration, UWB Tags on Ironworker and Material

hub and displays the location of receivers and UWB tags in real-time. An example snapshot of the GUI with nine receivers and a few tags is illustrated in Figure 2. Preliminary data processing algorithms and visualization tools were developed to display the position data in a MATLAB environment.

The indoor experiment used four Mid Gain receivers and two asset tags at different update rates. The arrangement in rectangular form of 6x3 meters allowed placing the reference tag in the middle. Since only 2D data was collected, the (X, Y) position of single tags is displayed in Figure 3. The trajectories of two tags (two walking humans) are shown in form of a "Snake" (upper right image) as well as the overall trajectory in plan view (bottom right). The position accuracy was significantly better than 1m.

In a next step, the initial work on algorithm development included an obstacle avoidance algorithm that sends off an alarm whenever the tag (human) is in a predefined hazardous zone or when tags get too close to each other. User-defined values can be set, e.g. for the minimum allowable distance the tags can have to each other, or the location and size of the hazardous work zones. Once the criteria are not met an alarm window goes off (lower left in Figure 3). This has significant value for safe (and automated) machine operation when machine operators have limited visibility or workforce is unaware of dangerous situations. Overall awareness and safety can be increased by issuing alarm signals to workforce, operators, field safety personnel, management in form of acoustic, visual, vibration, or text messages. This basic proximity algorithm experienced a 100% detection rate, in real-time (in 3D), and at the same frequency as the tag with the highest update rate (60Hz).

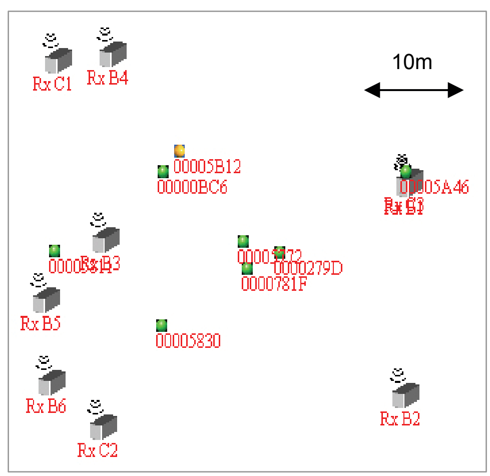

Figure 2 Receiver and Tag Layout in Field Trial

In a second experiment, the UWB system was used to track the material flow during the steel erection process of a three story research building. Upon truck arrival, the UWB tags were placed on the individual steel beams on the truck bed. The beams then were either moved temporarily to a laydown yard or hoisted directly into their final location using a mobile crane. Three-dimensional positioning data to each UWB tag was recorded and start and end point compared to a ground truth measurement using a Total Station. Tags were also placed on a few workers, materials, crane location, and crane hook. The layout of receivers and reference tag in the outdoor experiment is illustrated in Figure 2 (plan view). Three receivers were installed on already built structure at elevated level.

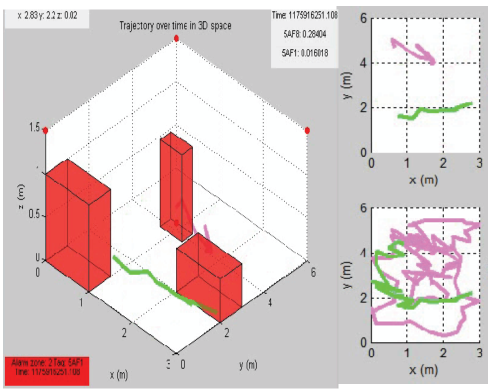

Figure 3 Active Work Zone Safety includes Predefined Hazardous Zones, Travel Paths, and Alarm Box

Figure 4 Sensor Field Setup, UWB Tag on Hook

An in depth experimental analysis is underway. Preliminary results can be determined as: (a) Installation time (1 day) was extensive for the short amount of time of the entire experiment (2 days), but once receivers, cables, and reference tag were installed the UWB system was easy to maintain and delivered positioning data that reflected the movements on site, e.g. tag on hook (Figure 4); (b) Although the UWB equipment is commercially available, it is predominantly used in manufacturing, distribution centers, or prototype evaluation projects; Field trial measurements in the rough construction environment were successful and the design of the equipment is robust enough to be placed on steel beams and withstand smaller punctual hits. (d) One tag had error readings due to a lose tag antenna and was removed from the experiment.

7. OUTLOOK

Ultra Wide Band positioning may offer many solutions to existing problems in construction and elsewhere. The Real-time Automated Project Information Decision Systems (RAPIDS) Laboratory in the School of Civil and Environmental Engineering at the Georgia Institute of Technology currently focuses on the following research and application areas in UWB [7]:

- Develop data collection and processing algorithms as well as user interfaces for accurate and precise positioning data in real-time.
- Determine the impact of UWB for the construction industry, e.g. accuracy, feasibility, and future UWB needs. Development of solutions to the following application areas that can expand the use of UWB.
- Improve simulation in construction by providing real-time and accurate positioning and time data, e.g. crane, truck-excavator.
- Increase motorist's and workforce awareness in transportation and construction work zones, i.e., during night road maintenance work using active real-time safety.
- Enlarge awareness of emergency responders in navigating through buildings, i.e., Georgia Emergency Responder test bed.
- Enhance existing supply chain and workflow productivity strategies and practices by locating and tracking resources (workforce, materials, equipment) on construction sites in real-time.
- Optimize sensor layout (and improve hardware for wireless and low power consumption).

8. CONCLUSION

This paper has demonstrated that a standalone or joint approach of using existing and emerging technologies such as Global Positioning System

(GPS), Radio Frequency Identification (RFID), laser tracking, and Ultra Wide Band (UWB) comes each with a variety of benefits and limitations. Tracking and monitoring construction resources (workforce, materials, and equipment) and activities in real-time, accurately, in indoor and outdoor situations is made possible using Ultra Wide Band technology. Preliminary research efforts conducted in the Real-time Automated Project Information Decision Systems (RAPIDS) Laboratory at the Georgia Institute of Technology show some benefits this emerging technology can offer to the construction industry. The results of this paper conclude that in particular the existing needs for real-time working applications such as work zone safety, job site monitoring, and resource tracking may offer a high return on the investment in UWB. Further research is needed to explore UWB's full potential for construction and other application areas. Investigations are pending and are currently under research in the RAPIDS Laboratory.

9. ACKNOWLEDGMENT

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