Feasibility of location tracking of construction resources using UWB for better productivity and safety

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Abstract

There is a growing demand for accurate and up-to-date information in the construction industry. Ultra Wideband (UWB) Real-Time Location Systems (RTLSs) enable tracking and visualization of resources on site and give more awareness to the construction staff in real time. This research investigates how UWB technology can improve productivity and safety in construction projects. The requirements of the RTLS are identified in terms of safety and productivity management. The usability of RTLS in the construction industry is tested by the collection of data from a construction site and organizing them into useful information needed for management. It was found that UWB is an effective tool to monitor construction resources because it provides accurate information in real time. However, good understanding of the requirements and filtering the data are necessary in order to get the best benefit of the technology for productivity and safety purposes.

Keywords: UWB, indoor tracking, construction productivity, construction safety

1 Introduction

The construction industry can take advantage of the automated data capture, auto-ID technologies and Real Time Location Systems (RTLS) to achieve efficient management of projects. Available tracking and sensing technologies include Global Positioning System (GPS), Radio Frequency Identification (RFID), barcoding, video and audio monitoring, load gauges, accelerometers, and ladars (Navon and Sacs, 2007). Workers’ locations can be collected automatically at a regular time intervals and converted into labor inputs by associating activities with locations, and calculating the quantities of work of each activity (Navon and Goldschmidt, 2003). Recently, Ultra Wideband (UWB) RTLS technology has been investigated for automating data capturing and identifying, and for locating and tracking objects for productivity and safety management in the construction industry. Potential applications include work zone safety, material tracking and work productivity tracking (Teizer et al., 2008). In addition, UWB technology was successfully applied for accurate and real-time position tracking of workers and assets in construction sites for management purposes (Giretti et al., 2008). For safety purposes, active sensing technology is used in two ways: proactive safety technology which works in real time to alert personnel of the dangers occurring, and reactive technology which collects data to be analyzed in order to determine the best practices and to make process improvements (Fullerton et al., 2009). Safety management systems have been proposed for tracking workers’ trajectories to prevent accidents. Software was developed to graphically reproduce the travel patterns of workers, and to provide alerting signals in real time when the worker is within a previously defined...
dangerous area (Carbonari et al., 2009). UWB offers several distinct advantages over traditional tracking systems, such as long and reliable readability range, accurate real-time positioning, and better solution to the multipath problem. However, more investigation is needed to test the usability and identify the specific requirements of UWB in tracking indoor construction tasks. The objectives of this research are: (1) to investigate how UWB technology can improve productivity and safety in construction projects; (2) to identify the requirements of UWB RTLS in terms of safety and productivity management; and (3) to improve the usability of UWB RTLS in the construction industry by collecting raw data from a construction site and organizing them into useful information needed for real-time management.

2 Methodology

To achieve the objectives of this research, the proposed methodology starts by identifying the approaches to improve productivity and safety by using UWB technology. Then, the general requirements of UWB technology for location tracking of construction resources are defined. A further investigation of the specific requirements of UWB technology is done to establish its usability for improving productivity and safety. Considering these requirements, a case study is conducted in an indoor construction environment to propose improvements in the usability of UWB including data capturing, pre-processing, visualizing, filtering and analyzing the quality of these data.

2.1 Improving productivity

In a construction environment, there are dynamic changes in site layout due to the interaction of different contractors in the same space during the construction phases. Therefore, the use of UWB can lead to a better space management and productivity can be improved by assigning areas and resources more effectively. The following process improvement approaches are expected to improve productivity: (1) Measuring the percentage of the wasted time in unnecessary movements: The ratio between the time the worker is focusing on a specific task and the time used to move between different locations (e.g., searching for tools or materials) can be estimated based on the tracking data. (2) Automating repetitive processes: For example, by automatically driving the scissor lift to the position of the next operation (e.g., fixing studs for supporting the false ceiling in a large room), the time wasted to manually operate the scissor lift can be saved. (3) Optimizing the routes of workers in the building by using indoor navigation, which will help workers find the place where the work has to be accomplished and locate the required equipment. (4) Standardizing the work by re-playing and analyzing the recorded activities. Data collected for specific tasks can be analyzed to compare different methods and select better ones for future projects. (5) Determining the process of the project by linking location data with operations and schedules. (6) Reducing the conflicts for resources (e.g. space, tools, equipment) between different crews by predicting the location of moving objects in real time. The above mentioned process improvement approaches based on monitoring resources are an important step towards lean construction, which is a production management based approach to project delivery aiming to maximize value and minimize waste.

2.2 Improving safety

To improve safety of construction equipment operations and provide more awareness on site, several analyses could be done: (1) Identifying geometry of obstacles by using multiple tags attached to different components of equipment. Therefore, moving objects should be tracked, identified, and modeled in a way that the full geometry, speed, moving direction, and all the relative information of the task are used to prevent collision accidents. (2) Checking the compliance with safety regulations and engineering constraints to prevent accidents. For example, in some jurisdictions workers are not
allowed to move on the scissor lift to a new position unless the lift is down. (3) Achieving more advanced intelligent support by integrating path planning algorithms to generate a collision-free path. Once a potential collision is detected, re-planning of the equipment motion can be done based on updated environment information.

2.3 General Requirements

In the adapted UWB system (Ubisense, 2008), a sensor cell is constructed by several sensors connected together into a single operating unit. A master sensor is defined to receive and synchronize the timing data from the other sensors. Each tag registers with its containing sensor cell, and is inserted into the schedule for that cell. The schedule determines when the tag should emit UWB signals to be located by the cell. The schedule is optimized to give attention to each tag as close as possible to its requested quality of service, while maintaining enough space in the schedule for new tags to register. When a tag emits a signal, this signal is picked up by one or more sensors in the cell, as shown in Figure 1. The slave sensors decode the UWB signal and send the angle of arrival and timing information back to the master sensor through an Ethernet connection. The master sensor accumulates all sensed data and computes the location based on triangulation (Ubisense, 2008).

This research explores the following general requirements for the application of UWB in construction to improve safety and productivity: accuracy, visibility, scalability and real-time processing. The number of tags, number of sensors, and location and orientation of the sensors should be decided to meet these requirements.

**Accuracy requirements:** Accuracy is the most important requirement that needs to be fulfilled to guarantee that useful data are collected. Both angle of arrival (AOA) and time difference of arrival (TDOA) can be used to locate tags based on triangulation. It is normal for sensors to receive reflected signals from a tag, which generates different TDOA data for the same tag. Therefore, the combination of AOA and TDOA can be used to filter wrong data. As shown in Table 1, the combination of TDOA and AOA provides the highest accuracy by using two or more sensors (Ubisense, 2008).

<table>
<thead>
<tr>
<th>Location method</th>
<th>Number of sensors detecting tag</th>
<th>Other information required</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-sensor AOA</td>
<td>1</td>
<td>Known height of tag</td>
<td>2D horizontal position (+ known height)</td>
</tr>
<tr>
<td>AOA</td>
<td>2 or more</td>
<td>None</td>
<td>3D position</td>
</tr>
<tr>
<td>TDOA+AOA</td>
<td>2 or more</td>
<td>None</td>
<td>3D position (highest accuracy)</td>
</tr>
</tbody>
</table>

To gain accurate location data, the calibration of the sensors is essential. A local coordinate system is defined by the user, and based on that the coordinates of each sensor should be measured precisely using surveying tools, such as total stations. Each sensor should be levelled after the installation. One tag should be placed at a known location to complete the calibration process.

**Visibility requirements:** Sensors should be set in a way to utilize their antenna pattern which is ± 90° in the azimuth and ± 50° in the elevation. The maximum range of sensors can be potentially up to 200 ft (61 m); therefore, a reasonable monitoring area should be defined within these ranges considering the coverage of the sensor cell. In addition, multiple tags can be considered as a way to ensure the visibility of the objects. For example, tags can be attached to a worker on his hardhat, arms and waist.

**Scalability and real-time requirements:** Since there is only one single UWB channel, only one tag can be located at a time in each sensor cell. As mentioned in the visibility requirements, multiple tags are needed even for an individual object; therefore, the suitable number of tags attached to an object should be decided based on the frequency of the system and the number of tags to be tracked in a
sensor cell. Different update rates can be selected to determine how often the tags’ locations are updated. In the Ubisense system, the maximum update rate is 38 Hz with a small number of tags (Ubisense, 2009). Even with a large number of tags in a sensor cell, the sensed location of each tag can be updated in near real time. However, the update rate of the system may be insufficient for tracking moving objects with high velocity.

2.4 Specific requirements for productivity and safety applications

The general requirements discussed above should be specified more precisely for productivity and safety applications because the UWB system will be used as a part of a larger system that provides real-time safety feedback or post-processing productivity analysis. For example, in safety applications, the system should provide real-time feedback which sends an alarm in case of potential collisions. The data collected for safety need to be more accurate and more frequent compared with the data collected for productivity. Therefore, a high update rate and high visibility should be established.

3 Case study

The UWB RTLS was tested indoor in a real construction site on the 30th of April, 2009. It was conducted on the 7th floor of the new JMSB building at Concordia University during the installation process of heating, ventilating and air conditioning (HVAC) ducts. The captured data were processed, visualized, filtered and analyzed to study the quality of these data. The steps for this case study are described as follows:

(1) Scheduling. The schedule of the work was coordinated with the help of the construction company and the subcontractor for the HVAC system. Both companies collaborated actively in the development of the study providing information about the approximate schedule for the installation tasks and resources to accomplish the study without disturbing the construction operations.

(2) Test setting and requirements. The UWB sensors were placed on the construction site one day before conducting the test. All the system components were pre-tested on site. The calibration of the system took two and a half hours. A combination of AOA and TDOA was used in the test. The orientation of the sensors was selected considering the area of work to cover. The locations of the sensors and the switch have been designed considering the following issues: maximum coverage, minimum cable length, avoiding interference with workers and equipment (e.g. work zone of scissor lift), and avoiding gateway blockage. The same update interval of 865 milliseconds was used for all the tags. Ten tags were attached to two workers as shown in Figure 2 and eight tags were attached to a scissor lift. At the same time, video recording was used to compare the actual movements with those sensed by the system.

(3) Data visualization. The analysis of the data includes visualization of tags’ locations at a specific time in 2D and 3D. After collecting the information in a text file for four consecutive periods of time, the data were translated into a Geographic Information System (GIS) database. Using ArcGIS Tracking Analyst, it is possible to show the data as points or traces and to replay the movements. Figure 3 shows the traces in 3D of a tag attached to the hardhat of a worker, and Figure 4 shows the moving patterns around obstacles.
Data filtering. Some location points were sensed outside the space of the test or had errors caused by the reflection from metallic ducts or the lack of direct line of sight to most sensors. Accuracy errors can be found in patterns of movement where a sudden position change is not explained by a regular movement of workers or equipment. Missing points errors can be present when points at intervals between two locations are missing. In order to improve the quality of the data, a filtering process is required. For this process, timestamps are established for each period of time (865 milliseconds) to be analyzed. The timestamps with missing data were established as the points where there was no location data sensed. Then, the data were filtered based on the distance between consecutive points. If the distance exceeds 1.5 m for this study (assuming walking speed) the points were removed. The points that were sensed in the areas that are occupied by obstacles or outside the room were also removed. After filtering, timestamps with missing data were filled by interpolation. As a result, a new filtered data set was obtained.

Data averaging. As explained in Section 2, in order to analyze the movements of the workers and equipment, multiple tags can be used. Data averaging consists of obtaining average locations based on two or more neighboring tags that are attached to the same worker or equipment to better estimate the location. This averaging was done after the filtering process for each timestamp defined for the neighboring tags. The result of this process is a new data set with the average position for each worker and equipment.

Analysis of traces and speed. By comparing the traces of each worker over consecutive time periods, it is possible to analyze the work zones in 2D and 3D. These zones are in most of the cases non-overlapping, which means that although there is no pre-arrangement for using space, each worker reserves a certain area for a certain period of time. For example, one of the two workers moved along a narrow work zone while doing the measurements and the marking on the floor as shown in Figure 3. In addition to the visual analysis, the length of the path was calculated in 2D and 3D. This information can help to determine a layout of the workplace that minimizes the movements required to complete the task. Table 2 shows the length in 2D and 3D of the traces of tags attached to the hardhat of Worker 1 (tags 17 and 162). The difference between 2D and 3D traces indicates which period has more vertical movements (Period 2).
Table 2. Distance in 2D and 3D for two tags attached to the hardhat of Worker 1

<table>
<thead>
<tr>
<th></th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
<th>Period 4</th>
<th>All periods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2D distance (m)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tag 17</td>
<td>299.82</td>
<td>287.5</td>
<td>380.11</td>
<td>107.05</td>
<td>1074.48</td>
</tr>
<tr>
<td>Tag 162</td>
<td>304.47</td>
<td>300.26</td>
<td>389.02</td>
<td>74.91</td>
<td>1068.66</td>
</tr>
<tr>
<td>Average</td>
<td>302.14</td>
<td>293.88</td>
<td>384.56</td>
<td>90.98</td>
<td>1071.57</td>
</tr>
<tr>
<td>% Difference</td>
<td>1.55%</td>
<td>4.44%</td>
<td>2.34%</td>
<td>42.90%</td>
<td>0.54%</td>
</tr>
<tr>
<td><strong>3D distance (m)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tag 17</td>
<td>316.38</td>
<td>358.5</td>
<td>428.74</td>
<td>111.62</td>
<td>1215.24</td>
</tr>
<tr>
<td>Tag 162</td>
<td>321.53</td>
<td>357.17</td>
<td>436.28</td>
<td>76.71</td>
<td>1191.68</td>
</tr>
<tr>
<td>Average</td>
<td>318.96</td>
<td>357.84</td>
<td>432.51</td>
<td>94.17</td>
<td>1203.46</td>
</tr>
<tr>
<td>% Difference</td>
<td>1.63%</td>
<td>0.37%</td>
<td>1.76%</td>
<td>45.51%</td>
<td>1.98%</td>
</tr>
<tr>
<td><strong>Difference between 2D and 3D (m)</strong></td>
<td>16.81</td>
<td><strong>63.96</strong></td>
<td>47.95</td>
<td>3.19</td>
<td>131.89</td>
</tr>
</tbody>
</table>

In addition, the location data can be useful to verify the compliance with safety regulations. With the location data of the tags attached to the scissor lift, it is possible to identify its height and velocity at any time.

4 Conclusions

UWB is an effective tool for monitoring construction resources, such as workers and equipment, because it provides accurate information in real time. This research contributes by defining the requirements of accuracy, visibility, scalability, and real-time in order to accomplish the location tracking objectives to improve productivity and safety in construction sites. It also introduces a case study where the feasibility of applying UWB technology in a real construction site is tested. In addition, it is shown that filtering the data is necessary in order to get better results for productivity and safety purposes.

Acknowledgements

The authors would like to thank Mr. Bruce Harper and Mr. Marc Tardif from Verreault for facilitating the indoor case study.

References


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