Feasibility Study of UAV use for RFID MaterialTracking on Construction Sites

Bryan Hubbard, Heng Wang, Michael Leasure, Tim Ropp, Tamara Lofton, and Sarah Hubbard
Purdue University
West Lafayette, Indiana

Shiyuan Lin
North China Electric University
Beijing, China

The use of Radio Frequency Identification (RFID) technology has been successfully deployed in construction to provide identification of both materials and workers entering a construction site and in other supply chain management areas. Unmanned Aerial Vehicles (UAVs) are also being tested on construction sites for tasks such as inspection, documentation of construction work progress, and safety visualization. The ability to locate specific materials on a construction site in order to allow quick retrieval is important to improving job site productivity on large and complex job sites. This paper presents the findings of an initial feasibility study on combining RFID technologies with UAV technologies to improve construction project supply chain management. The study provides proof of concept and addresses technology issues such as frequency interaction between the UAV telemetry and RFID scanning frequencies. Test results indicate that an RFID reader equipped on a UAV can identify and provide location of tagged materials. Notable technical restrictions include RFID reader weight and detection range between RFID reader and tags. Results of this study indicate that the RFID equipped UAV can be used to provide data that can be implemented in supply chain management systems and connected with Building Information Models (BIM).

Keywords: RFID, UAV, UAS, Supply Chain Management, BIM

Introduction

Radio Frequency Identification (RFID) has been successfully demonstrated to improve supply chain logistics in manufacturing and transportation industries (Zhu, Mukhopadhyay & Kurata, 2012; Sarac, Absi & Dauzère-Pérès, 2010). This technology offers considerable promise in the construction industry. The effective movement of materials on a construction site is critical to efficient construction operations. The use of Unmanned Aerial Vehicles (UAV) are being examined for many types of inspection applications in the construction industry. The paper provides a review of both RFID applications and UAV applications in the construction industry. A feasibility study is performed to determine the effectiveness of utilizing an RFID reader on a UAV for determining material location on a construction site. Factors determining the selection of equipment are provided along with data from an initial test of the combined system. The goal of the research is to utilize these technologies to improve worker productivity by identifying location of materials for construction work crews.

Background

RFID Technologies in Construction

RFID technologies have many potential applications in construction, as was noted two decades ago by Jaselskis, Anderson, Jahren, Rodriguez and Njos (1995). The normal working conditions of a typical construction project involve harsh outdoor environments in which many construction processes have to be completed on time. They indicated that RFID technology could have a positive impact on improving normal construction work. RFID
technology is a wireless communication technology, typically utilizing a tag and reader configuration. Circuit chips are imbedded in both tag and reader; the tag is attached to the subject and the reader is supposed to read and identify the subject with corresponding pre-written information on the tag. Many technical aspects of RFID such active or passive tag, fixed or portable reader, radio wave length applicable and so on need to be carefully considered when setting up for a particular application. However, there are no requirements on line-of-sight, direct contact or close proximity, and they are typically durable in all weather and harsh conditions; these capabilities provide RFID huge advantages over other technology like bar code. Jaselskis et al. (1995) proposed conceptual ideas of taking RFID into the construction project processes such as labor, material receiving and tracking, concrete delivery and quality control. But neither empirical data nor experimental results were offered or discussed.

Later studies began to identify the specific processes and industrial areas that could utilize RFID for improvement, typically feasibility studies and field test studies as the application. Jaselskis and Ei-Misalami (2003) had a workshop to identify ideas with construction practitioners and found applicable areas in spool tracking, mechanical machinery handling, material management and field operations. Despite the simplicity of the field tests and technical issues remaining, RFID technology showed promise for construction project improvement, especially in the material tracking area at that time.

Song, Haas, Caldas, Ergen and Akinci (2006) provided an overview of industrial construction processes and believed that automation of site material management and more specifically pipe spool tracking with RFID would have huge potential improvement for these projects. The research team evaluated whether all materials being delivered automatically could be tracked while the truck drove through the gate of site. They conducted their technical feasibility study and field tests in two phases with positive results. Some of the questions raised by Jaselskis et al. (2003) were no longer problems any more due to technological advances. RFID tags could be easily detected and read with metal surfaces nearby with some system configuration methods. The field tests essentially indicated that current RFID technology could automate the identification and tracking process for pipe spools with statistical significance. Provided time and further development of RFID technology, the trucks could go through the gate of site and all shipping information of the delivery would be automatically entered into the computer.

A more sophisticated study conducted by Ergen, Akinci and Sacks (2007) using prototype RFID and GPS combination system on precast panel identification and tracking confirmed the technical feasibility of RFID technology. Field tests were conducted in the laydown yard of a precast plant where precast panels were temporarily stored, and in some cases relocated multiply times before being finally shipped to site according to site erection progress. The field tests results showed 60% success rate due to restricted accuracy of GPS and limited system integration. It was suggested that further research with more data and refinement of this system would validate it as a reliable automatic identification and tracking system.

Demiralp, Guven and Ergen (2012) went on to study the potential cost savings along the supply chain and a potential RFID technology investment cost sharing ratio according to cost saving findings. The authors based their research on the precast and building industry along the supply chain. Three scenarios: manual, Semi-automatic (SA) and Full-automatic (FA) material tracking systems were developed along the same supply chain including precast manufacture, shipping and constructor on site. Probabilities of occurrence were obtained through interviews and previous studies. Simulation model were developed for multiply iterations. In normal construction cases, 3.1% of total construction costs could be saved after either SA or FA investment.

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_UAV Technology on a Construction Site_

Unmanned Ariel Vehicles (UAVs) are being implemented in construction sites for numerous applications. UAVs will be able to provide real-time visual information to monitor construction site safety. As noted by Gheisari, Irizarry and Walker (2014), in a constantly changing construction site the safety manager’s job of direct observation site work and interaction with workers continuously and in real-time are an excellent application for UAVs. UAVs have the ability to reach difficult positions on a construction site and provide live video streaming for safety managers. Hence it is possible for safety managers to interact with site workers if the situation arises. Similarly Irizarry, Gheisari and Walker (2012) also discussed some of the benefits of using drones for the construction jobsite safety management.
Wen and Kang (2014) combined the capability of a UAV with a high definition camera and Augmented Reality (AR) technologies to improve construction site management. UAVs can be flown to specific altitudes and locations to capture images. The images can be used to develop 3-D representations using AR technology. It would enable managers to plan the construction site such as material and worker flow and identify potential constructability issues. As many studies have noted, UAVs can perform many of the tasks that were typically performed by workers in the field. Karan, Christmann, Gheisari, Irizarry and Johnson (2014) examined how UAVs are being applied by the Department of Transportation of to track highway construction projects.

Methodology

The objective of this research was to perform initial proof of concept testing of an RFID reader on a UAV to evaluate the potential to join these two technologies on a common platform utilizing off the shelf technologies. The method being used was a functional test which focused on whether these two technologies would be able to work together as conceptually expected. A simple system was configured by installing a RFID reader on a UAV, both of which were off-the-shelf products readily-available. Tags with different reading ranges were spaced and arranged on a route along which the UAV would fly. The researchers flew the UAV along the route to see whether the system could acquire tag information as expected. These function tests were conducted multiple times and conducted in the indoor environment in Amory Building of a major research University to avoid potential interference from wind, rain or physical obstructions. In reality, a construction site would be much more hazardous than a pre-arranged indoor environment. However, the initial step was to prove the basic idea and find out major limitations. In this sense, the off-shelf equipment and indoor conditions suited our objective well. The methodology included identification of relevant equipment parameters and specifications, selection of an RFID reader, selection of a UAV, and testing the range and capabilities of the system with a variety of transponders.

Equipment Parameters

The equipment parameters evaluated during the design of the test apparatus included the following:

- Identification of the operating frequencies of both the RFID reader and the UAV
- Evaluation of potential interference between the RFID reader and UAV telemetry
- Assessment of the maximum equipment weight that could be carried on the UAV
- Assessment of the maximum range of the standard handheld RFID reader
- Assessment of the UAV flying time based on payload weight
- Assessment of the most appropriate RFID tag

Selection of RFID Reader

RFID options include both handheld and fixed units. The evaluation of alternate RFID readers for use in this study was limited to handheld units, which were preferable due to their lower weight, built-in power source, and rugged and self-contained data acquisition system which are suitable for the potentially harsh conditions on the construction site. Based on a review of the capabilities of available hand held units, the Trimble Juno T41 with integrated Thingmagic RFID reader was chosen to collect data (Figure 1). This RFID reader is approximately 21 cm x 8.1 cm x 3.2 cm and weighs 500g. This reader has a built-in processor for data acquisition, real-time GPS, and the ability to read multiple types of RFID tags. The UHF (Ultra High Frequency) RFID range for this model is 860 to 960 MHz, and it has a published range of 3.5 meters for 5 cm$^2$ UHF tags. The antenna has the ability to transmit up to 30 dB. The processor operates on the Android 4.1 platform. Although the weight of the unit is higher than desirable, this unit was selected due to the range, ruggedness, and built-in data acquisition platform (Cite Juno Data Sheets).
Selection of UAV

To select the proper UAV for the testing, researchers from XXX University’s Aviation Technology Department were consulted to provide assistance in the selection of the appropriate UAV. The department has an active UAV research program and courses to support UAV operation and UAV research activities. The major equipment selection criteria were the requirement to carry a heavy payload and the capability to operate on frequencies not used by RFID. The standard telemetry frequency for this type of UAV is 915 Mhz, which is in the same frequency range as a standard RFID reader; if both the RFID reader and the UAV operate in the same frequency range, there is a potential for interference, which would potentially affect the operation of both the UAV and RFID reader. The Trimble Thingmagic RFID reader operates in the range of 865-928 MHz. The UAV that was selected for this testing is the IRIS quadcopter from 3D Robotics, which operates at 433 MHz and is shown in Figure 3.

Key parameters for the IRIS quadcopter are as follows:

- Payload capacity 400g
- Real time GPS
- 6-22 minutes flight time based on payload and battery size
- Remote controller with on-screen telemetry

Results

RFID Testing of Reader Detection Range

Prior to testing the drone RFID combination, the RFID reader detection range was determined for nine different passive RFID tags, designed for a variety of applications in material control as shown in Figure 3. The detection range was determined by moving the reader towards the stationary tag until the RFID issued an audible signal indicating the tag was identified. The antenna power was increased to the maximum 30 dB to allow detection from the furthest distance. The read rate is the number of times the reader attempts to read a tag; this is an important parameter since a higher read rate will allow detection of tags more quickly, an especially important consideration given the potential UAV travel speed. In this test, the read rate was 10 times per second. Results from the stationary test are shown in Table 1. There were five tags that read at 1 meter or greater, however no tags were in the range noted in the specifications of 3.5 meters. Additional data transmitted is the Received Signal Strength Indicator (RSSI), a measure of the power of the RFID signal, time of reading and the read count (how many times the tag had been read successfully).
Table 1

Read Distance for Multiple Passive RFID Tag Types

<table>
<thead>
<tr>
<th>TagId</th>
<th>Time Stamp</th>
<th>Read Count</th>
<th>RSSI</th>
<th>Initial Read Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IWI68FYDITHJ83VN0G1</td>
<td>10/1/2014 17:24</td>
<td>87</td>
<td>-53</td>
<td>0.4</td>
</tr>
<tr>
<td>YBM58FYDITHJ83VN0G1</td>
<td>10/1/2014 17:24</td>
<td>49</td>
<td>-64</td>
<td>1.75</td>
</tr>
<tr>
<td>MIM58FYDITHJ83VN0G1</td>
<td>10/1/2014 17:24</td>
<td>95</td>
<td>-51</td>
<td>1.2</td>
</tr>
<tr>
<td>AUJ68FYDITHJ83VN0G1</td>
<td>10/1/2014 17:26</td>
<td>40</td>
<td>-67</td>
<td>0.7</td>
</tr>
<tr>
<td>AJI68FYDITHJ83VN0G1</td>
<td>10/1/2014 17:26</td>
<td>44</td>
<td>-62</td>
<td>1.6</td>
</tr>
<tr>
<td>RMI68FYDITHJ83VN0G1</td>
<td>10/1/2014 17:25</td>
<td>33</td>
<td>-52</td>
<td>0.25</td>
</tr>
<tr>
<td>ZNI68FYDITHJ83VN0G1</td>
<td>10/1/2014 17:26</td>
<td>57</td>
<td>-56</td>
<td>1.65</td>
</tr>
<tr>
<td>WQI68FYDITHJ83VN0G1</td>
<td>10/1/2014 17:23</td>
<td>24</td>
<td>-51</td>
<td>1</td>
</tr>
<tr>
<td>ZGI68FYDITHJ83VN0G1</td>
<td>10/1/2014 17:24</td>
<td>19</td>
<td>-57</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Based on the outcomes of the initial read range testing, we found that all initial read distances were not very long. To fly the drone safely and increase the possibility of detecting these tags, the three tags with the longest read range were chosen for further testing with the UAV. These tags were an Omni-ID Max tag (ZNI68FYDITHJ83VN0G1), a Confidex tag (AJI68FYDITHJ83VN0G1), and a Thingmagic tag (YBM58FYDITHJ83VN0G1).

**RFID Mounted on UAV Testing**

The initial testing of the RFID unit mounted on the UAV consisted of
1. Flight stability given the additional payload,
2. Flight time with additional weight,
3. Control of the aircraft given the frequency range of the RFID.

The tests were conducted in a large indoor environment, and communications were maintained with the UAV throughout the testing, with no interferences or interruptions in either the UAV or the RFID operation. The average
flight time was approximately 6 minutes and although the UAV was able to fly and maneuver with the heavier payload of the RFID reader, the flight time was significantly lower than the flight time with no payload.

After initial testing was complete, the three RFID tags were attached to the floor of the building as shown in Figure 4. Each tag was approximately 5 meters away from the other and all three were in a straight line. The UAV was operated in manual flight to allow it to maneuver within 1 meter of the tags. Results of the test are shown in Table 2. During the first test, one tag was identified. During the second and third tests, two tags were identified. In no test were all three tags identified. Since the UAV was flown in manual mode, the flight patterns had variable flight patterns and speeds for each test.

Table 2

<table>
<thead>
<tr>
<th>Tag ID</th>
<th>TimeStamp</th>
<th>Position</th>
<th>ReadCount</th>
<th>RSSI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test 1</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>10/8/2014 15:49</td>
<td>40.427852 -86.916011</td>
<td>14</td>
<td>-66</td>
</tr>
<tr>
<td>AJI68FYDITHJ83VN0G1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Test 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZNI68FYDITHJ83VN0G1</td>
<td>10/8/2014 16:00</td>
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<td>19</td>
<td>-74</td>
</tr>
<tr>
<td>AJI68FYDITHJ83VN0G1</td>
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<td></td>
<td>-69</td>
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<tr>
<td><strong>Test 3</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZNI68FYDITHJ83VN0G1</td>
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<td>-70</td>
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<td>AJI68FYDITHJ83VN0G1</td>
<td></td>
<td></td>
<td></td>
<td>-68</td>
</tr>
</tbody>
</table>

Discussion

This test evaluated the potential for a UAV/RFID combination to read a variety of passive RFID tags. Limitations included the reading range of the RFID unit and the flight time, which was significantly reduced due to the excessive payload. The speed and height of the flying drone were not accurately controlled in this test. The researchers had tried to keep the drone 1 meter above vertically. However, due to manual control of the drone, both speed and height were difficult to maintain. In future tests, a simulated construction site will be set up to allow a prescribed flight plan using the automated flying system. Speed and height control should not be an issue in autopilot mode flying. Other RFID equipment is also being evaluated to which may provide a longer reading distance and a reduced weight to improve tag identification and flight time.

The database of tag information derived from the proposed RFID system mounted on a UAV can be used for many applications. The data attained can be used in conjunction with BIM models to provide a three dimensional
representation of the component with the RFID tag. The visual representation could assist workers in identifying the material on the job site and provide additional information on installation location and installation instructions through information in the BIM model. Additionally, there have been studies on integrating RFID technologies in the construction supply chain management systems to facilitate project control and management. Wang, Y. Lin and P. Lin (2007) proposed a formal supply chain system in a construction project with the help of RFID technology and hand held computer systems.

The use of UAVs in the U.S. is currently an important issue that is being reviewed by the Federal Aviation Administration (FAA). UAVs are now readily available and many commercial applications have been proposed for UAVs. New government legislation will determine to what extent UAVs may be used on the construction site. An important part of this study was the proper training for safe UAV flight. The project was done in conjunction with a new graduate course to train in the operation and use of UAVs. This course is part of the Purdue Aviation Technology program which has a professional pilots training program and also supports research/training in UAV technology. The use of replacing drones on a construction site with tasks that may have typically been completed by other means will hinge on future legislation and the efficiency of UAVs to complete the task.

Conclusions and Recommendations

The preliminary testing and analysis provided a successful proof of concept for the combination of UAV and RFID technologies. When fully implemented, the integrated technologies would improve construction project management by providing immediate material information on the job site. The successful combination of UAV and RFID technologies can provide additional information that can be used in conjunction with other construction systems including BIM models and project supply chain management software.

As the test demonstrated, an off-the-shelf UAV was able to manage the payload of RFID reader and operate with the radio-emitting device without frequency interference. Selection of equipment proves to be crucial to the success of implementation. Two areas that need to be addressed for improved tag identification and system implementation in the field are the RFID reading range and the UAV battery life. Our next research step will be to further develop this technology integration and implement it into supply chain management process for construction projects.

References


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