

Tracking Systems in Construction: Applications and Comparisons

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Locating resources on construction sites has been a challenging task. Due to this challenge, the worldwide construction industry has claimed $2.7 trillion of untapped resources (e.g. tools). To overcome this problem and in an effort to efficiently utilize all available resources, the use of tracking technologies is suggested. This paper presents three affordable technologies that have proven their effectiveness in many construction applications. These technologies are Ultra-Wide Bands (UWB), Radio Frequency Identification Cards (RFID) and Global Positioning Systems (GPS). It describes the principle of operations and applications of the presented technologies. Furthermore, it compares between presented technologies in terms of performance and cost.

Key Words: Automation, RFID, GPS, UWB, Asset Tracking

Introduction

Wireless communication tools play important roles in the construction industry. Although IPhones have demonstrated very good performance in many construction applications such as, creating and tracking bid processes; navigating 3D Building Information Models (BIM) and their associated data; creating and saving CAD drawings and performing many electrical/mechanical/carpentry/drywall/concrete/excavation calculations, they might not be very suitable tools for tracking of resources, specially tools (Rodriguez 2013).

Locating resources on construction sites has been a challenging task for many project managers. Untapped resources (e.g. tools) was claimed to be largely contributing to wastes in the construction industry (Holness 2008). The cost of wasted/lost materials and tools could be equivalent to $0.75 trillion and $2.7 trillion in the US and worldwide, respectively (Holness 2008). Another major problem in the construction industry is safety. The rate of injuries and fatal accidents is considered higher in construction compared to many other industries (Occupational Safety and Health Administration 2009).

In the attempt to solve these problems without substantial investment costs and by using easily applicable and affordable technologies, researchers have focused on developing efficient location tracking systems to be utilized for asset tracking and safety assurance.

This paper presents a comprehensive literature review of the current research efforts in use and development of automated tracking systems that improve operations and maximize safety on construction sites. It focuses on three affordable technologies that have proved their effectiveness in many construction applications. These technologies are Ultra-Wide Bands (UWB), Radio Frequency Identification Cards (RFID) and Global Positioning Systems (GPS). The paper explores the most applicable tracking technologies for specific construction applications, considering performance and cost as major criteria. This exploration effort was conducted based on a series of recent case studies, technical articles and data collected from manufacturers. Cost information was acquired either from published articles or by contacting system manufacturers and/or suppliers.

Understanding Tracking Systems

The GPS was developed by the United States Department of Defense as a reliable means of navigation for military applications, but in 1983, the government made this technology available for civilian uses. The system is based on a set of satellites that orbits the earth at high altitudes and is designed to operate 24 hours a day.

Satellites rotate around earth in very precise orbits and send orbital information to earth. GPS receivers gather this information and use triangulation to determine their own locations. The position of GPS receivers is determined by comparing the time satellites transmit signals and time the signals are received. With this time delay factor, the distance between satellites and GPS receivers can be calculated. This process is repeated, using multiple satellites, until the exact position of the GPS receiver is determined. Civilian GPS systems utilize two low power signals of L1 frequency 1.6 GHz and L2 frequency of 1.2 GHz in the UHF band to transmit signals. At present, the GPS receivers are highly accurate, thanks to the multi-channel design. The parallel multi-channel receivers are incredibly quick to lock on to satellites and maintain these locks. This reduces the errors caused by dense flora or tall buildings although certain atmospheric factors and other sources of error can affect the accuracy of GPS receivers.

Radio-frequency identification (RFID) technology is used to wirelessly identify objects from a distance. This technology consists of a RFID tag that senses electromagnetic radiations within its range. The tag can store up to 2 kilobytes of identification data. To read the information stored in the tag, a reader is required. A typical reader is a device with one or more radio antenna that emits radio waves and can receive signals from RFID tags. When the tag picks up the signal from the reader, it sends back a unique identification number, thus helping to remotely locate the object. The main advantage of RFID is the ability to read the tags from several meters away from objects that are not in the line of sight. The range of RFID tags vary from anywhere between couple of inches to hundreds of feet. It is a widely used technology and has many commercial and industrial applications. RFID may operate in the low-frequency range (124 – 134 kHz), high frequency range (13.56MHz) and also in the ultra-high frequency range (868 – 928MHz) depending on its application.

RFID tags are of two types: 1) active and 2) passive. Active RFID tags have batteries to power the tag and the internal radio frequency communication circuitry. Since Active RFID tags have its own power source, this enables them to receive low power signals from the receiver and generate a high power signal response. Due to this reason, they can transmit signals over a larger distance and consequently increase the reading distance. Passive RFID tags do not have a power source, and relies on the signal power received from the receiver to power the tag. The Passive RFID tags reflect the energy received from the reader to generate a response signal. They have short read distance due to the low power signal response by the limited energy.

The Ultra-Wide Band (UWB) technology is a radio transmission technology that utilizes low power levels for short range high-bandwidth communications. This is achieved by using a wide portion of radio spectrum. It offers many advantages, especially in terms of precision. Due to the extremely low transmission energy and very high bandwidth in short range, it is ideal for the use in radar and geo-location applications. The operating costs are low compared to other technologies because of the nearly all-digital architecture.

To compare the economic feasibility of these tracking systems, many criteria could be used. Among the most commonly used ones are the Return on Investment (ROI) and payback period. Although initial investment and interest rates cause wide variations in the outcomes of these economic criteria, many researchers reported an average payback periods of 18 and 36 months for RFID and GPS technologies, respectively (Pisello 2006, European Commission 2008, Telogis 2013 and GPS Insight 2013). The average ROI values associated with the RFID and GPS technology applications may be up to 10% (Pisello 2006, European Commission 2008, Telogis 2013 and GPS Insight 2013). Table 1 presents additional information regarding initial and running costs of adapting GPS and RFID technologies in trucking and warehouse applications (Read and Baird 2009 and GPS Direct 2013). It should be noted that while many sources documented economic performance criteria (e.g. Initial cost, operating expenses and payback period) of RFID and GPS technologies, not too many presented similar information regarding the UWB technology (Cheng et al. 2011 and Bohn and Teizer 2009). This might be partially attributed to its recent introduction to the construction industry.

Table 1
Average Initial and Operating Cost

	GPS	**RFID**
Number of tracked items	25 cars	2000 items
Number of labors	25	1
Employee wage	$30/h	$12.5/h
Payroll Saving	$4,500/fleet/month	$712/labor/month
Fuel Savings	$806/fleet/month	N/A
Benefits gained from better service delivery	N/A	$1,852/month
Total savings and benefits/month	**$5,306/month**	**$2,564/month**
Hardware Cost (equipment and installation)	$14,000/fleet	$21,000
Tag Cost	N/A	$1200
Software cost	N/A	$15,000
Professional services	N/A	$10,000
Total initial cost	**$24,485**	**$55,000**
Monitoring cost	$10,485/year	N/A
Software maintenance cost	N/A	$3,000/year
Hardware maintenance cost	N/A	$2,000/year
Running cost	**$10,485/year**	**$5,000/year**

Applications of Tracking Systems in Construction

Table 2 and the following sections present the use of RFID, GPS and UWB technologies in construction. They demonstrate their applications in areas such as asset and people tracking, safety and productivity management.

Table 2
Tracking Applications in the Construction Industry

	RFID	**GPS**	**UWB**
Materials	•		•
Tools	•		•
Labors	•		•
Equipment location		•	•
Equipment management	•		
As-built drawings	•		•
Productivity rate (residential and commercial projects)	•		•
Productivity rate (heavy-civil projects)		•	
Safety	•		•

Tracking Assets

Material wastes are one of the reasons for which material management is of vital concern throughout the project management process. Although tracking the location of materials and equipment used to be economically challenging, it has become more viable due to the recently developed advanced automated data collection technologies (Song et al. 2006).

Implementing proper resource management systems should start from the supply chain, with manufacturers ready to implement such technologies on their products. For many years logistics and supply chain management were made easier with the help of GPS devices attached to delivery trucks. This system is often preferred for its worldwide availability and cost effectiveness, especially for locating large items. This cost increases with the need to precisely position a large number of resources within an enclosed space (Teizer et al. 2008).

An alternative to GPS is applying RFID technology. Tags can be attached to materials during the manufacturing phase; materials will then be delivered to the construction site, where a reader is in place either at the entrance of the lay down yard. With this method, every material that enters or is taken out of the construction site can be tracked and introduced in the inventory database (Lu et al. 2011).

As a more affordable option, RFID technology is suggested. RFID tags could be attached to permanent materials used in construction, i.e. structural steel beams, concrete piles, pipes or instruments to determine their locations. Tags placed on steel beams, during erection of a building, would provide an accurate count of material used, thus allowing project managers to monitor production easily; furthermore, tags placed on the bottom of concrete piles would provide information regarding real depth of piles.

Following the original plans during the construction process could become a challenging task due to variable site conditions. Although the current practice requires preparation of as-built drawings, these drawings may not be too accurate due to added undocumented future modifications. RFID technology could be used to solve this problem. In so doing, RFID tags could be attached to dislocated items (i.e. inside building walls or underground pipe fittings). With information about their precise locations recorded on attached RFID tags, their existence and precise locations could be determined easily using RFID readers.

State-of-the-art tracking systems such as Ultra-Wide Band are currently available for real time location of assets. An experiment for monitoring of equipment and materials proved the high accuracy of UWB systems (Venugopal et al. 2010). This system can be integrated with other project management and scheduling software packages to provide prompt updates on changing field conditions.

Tracking People

One of the construction industry's main concerns is to avoid life-threatening situations and offer a safe work environment for all project participants. Falling from elevation is one of the most common incidents. Others are related to equipment operations such as being struck by collapsing equipment (e.g. crane boom), caught in between heavy equipment (e.g. worker trapped between the apron and the cutting edge of a scraper bowl) or caught in the range of heavy equipment (e.g. worker caught in the range of a horizontal boring machine). To limit potential causes of similar accidents, the Occupational Safety and Health Administration Agency (OSHA) has developed several regulations to be adopted on construction sites. As a result, the 2009 Bureau of Labor Statistics (BLS) for Workplace Injuries and Illnesses showed a 22 percent decline in cases compared with the previous year (Bureau of Labor Statistics 2009). Although this is considered a major achievement, the rate of accidents could be further reduced by the employment of different tracking technologies on construction sites.

In an effort to improve the safety environment on construction sites, especially in relation to equipment manipulation related accidents, and to enhance the detection range of equipment operators, a study that addressed fully automated blind spot detection systems using RFID systems was conducted (Teizer et al. 2010). RFID tags were placed on equipment and personnel protection units and antennas were installed on sites to activate visual, acoustic and vibratory alerts for both approaching personnel and equipment operators. Field tests were performed on many heavy equipment such as, loader, excavators, dozers, scrapers and moving labors. These tests proved the high capabilities of active RFID technology in improving safety on construction sites. Further tests were performed to demonstrate the high effectiveness of active RFID in prevention of collision accidents of heavy equipment such as, hydraulic excavators and mobile cranes (Chae and Yoshida 2010).

As an early effort to utilize the UWB technology in improving the safety environment on construction sites, it was combined with Bluetooth devices (Castro-Lacouture et al. 2007). In so doing, workers attach UWB tags to their vests. This allows the developed system to pinpoint workers' location and display them on a CAD drawing. At monitoring stations safety officers manually detect dangerous zones and alert individuals through Bluetooth devices. To improve this system, Carbonari et al. (2011) Implemented a real-time safety system to prevent work accidents of personnel being struck by suspended objects. Their system used UWB technology to prevent workers from being exposed to hazardous environments such as zones in which high risks of falling objects exists. Tests were conducted in which UWB tags were attached to workers' hard hats. Positions of workers were recorded in short time intervals, which made it possible to determine their real time accurate positions. Thus, in cases in which are workers approaching risky areas, they are notified as well as all safety officers. More studies proved the effectiveness of real-time monitoring of workers' positions on construction sites using UWB technology (Elghamrawy and Boukamp 2010). Many researchers suggested other uses of this technology related to safety on construction sites such as, workforce tag-in and tag-out recording in excavation and other infrastructure projects.

Quality and Productivity Management

Correlating RFID technology with the quality management process has been documented by many researchers (Wang 2008). Wang (2008) proposed the usage of RFID systems with PDAs for inspectors to capture and immediately store data. Introducing such a method would lead to time savings since the system can schedule inspection operations and assign tasks to appropriate staff members. A similar combination of RFID tags and PDA's is applicable to machinery maintenance. Tags attached to equipment (i.e. cranes, forklifts, excavators) can be read by a hand-held RFID devices (e.g. PDA); thus, providing information regarding time of last inspection, personnel who performed last inspection, conditions of machinery or date of last repair. Using the same system, information about additional modifications made to the machinery can be stored and read later on (Lu 2011).

Elghamrawy's (2010) introduced a new approach to quality management by augmenting RFID technology with construction documents database systems. This augmentation process made it possible to archive and retrieve information about construction items associated with RFID tags. Such an application can be augmented with more advanced tools such as, Building Information Modeling systems to deliver a wide range of applications.

Monitoring productivity rate is critical in assuring a proper project management. This can become an easy task by incorporating tags in several key points throughout the construction process and evaluating the received information. A recent field study showed how concrete pouring activities could be monitored using RFID technology (Moon and Yang 2010). Five reading points (antennas) were chosen for this study. While two were used at the batch plant, three were used on a construction site. Tags were attached to mixer trucks. During the operation, data regarding concrete pour amounts, delivery time and time spent by mixer trucks on the road were generated and made available on a Web application.

A combined application of RFID and four-dimensional computer-aided design (4D CAD) technology was used for erection of structural steel members (Chin et al. 2008). This combined approach delivered better logistics and progress management results. In this application, RFID tags were attached by the manufacturer at the end of steel members and covered with luminous paint for easier visual recognition on site. It should be noted that tags were removed, before erection, by the erection crew and sent back to the manufacturer for reuse. With a 4D model that uses different colors according to steel member status, an accurate monitoring system was produced for non-produced, produced, received-at-site and erected members. It should be noted that this system reported 17% more time efficiency and less material loss compared to conventional practices.

A technology fusion comes with the employment of combined GPS and RFID for tagging materials in order to track them on lay down yards and on construction sites without adding resources to regular site operations (Song et al. 2006). This system does not require a fixed communication network or modification to RFID hardware, no line of sight is necessary and it could be used with inexpensive passive RFID tags. It should be noted that the overall accuracy of the system was reported to be about 11 ft.

Performance of Systems in Open and Closed Environment

Tracking systems on construction sites are meant to be used in both indoor and outdoor environments. But these technologies encounter performance limitations based on site conditions (e.g. weak signal and poor line of sight). Several studies were performed to evaluate the effectiveness of current tracking technologies in open and closed construction site situations. Saidi, et al. (2011), focused on evaluation the performance of commercially available UWB technology using outdoor experiments. Their experiments simulated two open-space construction sites: 1) 2000 ft^2 and 2) 1,000,000 ft^2. This study concluded that while the accuracy of results revealed by the 2D positioning system was within the manufacturer's specifications, the 3D error is dominated by the measured tag's height. This error was found to be decreasing as the tag heights increased. It should be noted that although this study considered outdoors construction environments only, the researchers acknowledged the suitability of the UWB technology for indoor applications.

To compare the performance of GPS and UWB systems for indoor applications, such as material storage buildings, Khoury and Kamat (2009) considered moving objects. While the outcome of their experiment showed low errors of GPS applications (i.e. 0.5-1.0 in.), the UWB systems had up to 20 in. error. Despite the high accuracy of the GPS systems, they require clear line of sight and several calibration points. Furthermore, their implementation cost could be three times more expensive than the UWB systems.

Chao et. al. (2010) provided additional information regarding UWB performance in construction indoor asset tracking applications. Three tests were performed in static environments and on different sites (i.e. open space, wood framed building site and steel frame building site). Results showed no particular difference in accuracy depending of building materials, however line of site proved to be a determinant factor. Elevated UWB tags performed better than on floor ones. Moreover, it was determined that human body interacts with UWB tags and decreased its accuracy. The researchers performed another study in which a dynamic environment and fully furnished office area was used. The results of this study showed that elevated tags were more precise than on floor ones. Furthermore, larger errors were detected due to interference by high frequency cordless phones, human body, metal furniture and other computer facilities. In conclusion, the UWB technology was found to be a good tracking indoor tool with an average accuracy that ranges from 20 in. to 26 in. in static and highly congested closed space, respectively.

Commercially Available Technologies and their Associated Cost

Currently, the GPS systems have become one of the most commonly used worldwide tracking devices. In addition to the military usage, its applications in many civilian sectors are numerous. These applications include, but are not limited to: aviation industry, marine industry, highway transportation, survey and mapping. Its market availability and user-friendly features make it a desirable product for individuals and corporations.

In construction, GPS is suitable for asset tracking because of its high working range. For example, GPS can be used by an equipment and machinery rental company to locate their assets across the country or by suppliers to monitor delivery trucks. It should be noted that GPS systems could be fully purchased and /or leased for limited period of time, depending on usage period and value of assets. The biggest disadvantage of GPS systems is their acquisition cost. Often, construction practitioners, suppliers and contractors could be reluctant to implement this technology due to what may appear to be a high initial investment cost.

The RFID technology is making its way to the tracking market. Every year manufacturers introduce improvements and updates, creating more complex and improved systems, which deliver higher accuracy and larger operation range. Several other industries, such as healthcare, transportation logistics and automobile, employ RFID in their activities. Unfortunately, the construction business may not be very open to implement this technology. Many professionals consider there is no current need to implement position tracking systems on construction sites. This may be partially attributed to its initial cost and lack of knowledge regarding their long-term advantages. Lack of support from material suppliers may also be another obstacle to implement this technology on construction sites. Active technology may even be less likely to be used in construction, despite its precision in both indoor and outdoor environments. While the purchase price of RFID passive tags could be few dollars, active RFID tags could be up to $50. It should be noted that GPS systems may cost up to $50,000.

Conclusion

Using location tracking systems in the construction industry could significantly improve daily performance and project management activities. Although the UWB technology is newer technology compared to RFID and GPS systems, it is a good candidate for usage in the construction industry. It is applicable for real-time tracking of materials, machinery and working personnel. It is also considered to be a great tool for improving site safety and document management operations with a high accuracy and higher distance range in indoor and outdoor applications. Implementation cost plays an important role in choosing the more applicable technology. More research efforts are required to evaluate the operating expenses and payback period of UWB technology. UWB and active RFID proved to be more expensive than passive RFID systems, but less costly than GPS. Hopefully, cost will go down over time. Despite the high degree of precision and promising results of active RFID and UWB technologies, they may be less appealing compared to passive RFID systems due to their initial investment cost and lack of understanding of their long-term benefits. Additional cost analyses should be performed to encourage the implementation of tracking technologies in the construction industry.

References

Bohn, J. and Teizer, J. (2009). “Performance Benefits and Barriers of Construction Project Monitoring Using High-Resolution Automated Cameras”, Construction Engineering and Management, 136(6), 632-640.

Read, R. and Baird, R. (2009). “American Apparel Case Study”, RFID Journal, 8, 4-19.

Bureau of Labor Statistics (BLS) (2009). “Workplace Injuries and Illnesses – 2009”, accessed via http//.www.bls.gov.

Carbonari ,A., Giretti, A. Naticchia, B. (2011). “A proactive system for real-time safety management in construction sites”. Automation in Construction, 20, 686-698.

Castro-Lacouture, D., Irizarry, J., Arboleda, C. (2007). “UWB positioning System and method for safety improvement in Building Construction Sites”. Construction Research Congress.

Chae, S., Yoshida, T. (2010). “Application of RFID technology to prevention of collision accident with heavy equipment.” Automation in Construction 19 (2010), 368-374.

Cheng, T., Venugopal, M., Teizer, J. and Vela, P. (2011). “Performance Evaluation of Ultra Wideband Technology for Construction Resource Location Tracking in Harsh Environments”, Automation in Construction, 20 (2011), 1173-1184.

Chin, S., Yoon, S., Choi, C. and Cho, C. (2008).” RFID+4D CAD for progress management of structural steel works in high-rise buildings.” Journal of Computing In Civil Engineering, 22(2), 74-89.

Cho, Y., Youn, J., Martinez, D. (2010). “Error modeling for an untethered ultra-wideband system for construction indoor asset tracking.” Automation in Construction 19, 43-54.

Elghamrawy ,T., Boukamp, F. (2010), “Managing construction information using RFID-based semantic contexts”. Automation inc Construction 19(2010), 1056-1066.

European Commission (2008). “RFID Adoption and Implications”, Impact Study No. 07/2008, accessed via http//.www.ec.europa.eu.

GPS Direct (2013). “ Return on Investment Calculators”, accessed via http//.www.gpsdirect.com.

GPS Insight (2013). “Investing in Fleet Tracking Yields Substantial ROI”, accessed via http//.www.gpsinsight.com.

Holness, G. (2008). “BIM building information modeling: Gaining momentum.” ASHRAE Journal; 50(6), 28-40.

Khoury, H., . Kamat, V. (2009). “Evaluation of position tracking technologies for user localization in indoor construction environments”. Automation in Construction 18, 444-457.

Lu, W., Huang, G., Heng, L. (2011), “Scenarios for applying RFID technology in construction project management” Automation in Construction, 20 (2011), 101-106.

Moon, S. and Yang, B. (2010). “Effective Monitoring of the Concrete Pouring Operation in an RFID-Based Environment.” Journal Of Computing In Civil Engineering, 24(1), 108-116.

Occupational Safety and Health Administration (OSHA) (2009), Census of Fatal Occupational Injuries Summary”, accessed via http//www.osha.gov.

Pisello, T. (2006). “Shrinking the Supply Chain Expands the Return: The ROI of RFID in the Supply Chain”, Alinean: the Business Value Selling Experts, accessed via http//.www.Motorola.com.

Rodriguez, J. (2013).“Some of The Best IPhone/IPad Apps for the Construction Professional”, Construction.about.com, accessed via http//.www.construction.about.com.

Saidi, K., Teizer, J., Fanaszek, M., Lytle, A. (2011). “Static and dynamic performance evaluation of a commercially available UWB tracking system. “Automation in Construction, 20(5), 519-530.

Song, J., Haas, C. and Caldas, C.. (2006). “Tracking the Location of Materials on Construction Job Sites.” Journal Of Construction Engineering And Management, 132(9), 911-918.

Teizer, J., Allread, B., Fullerton, C. and Hinze, J. (2010). “Autonomous pro-active real-time construction worker and equipment operator proximity safety alert system.” Automation in Construction, 19(5), 630–640.

Teizer, J., Venugopal, M. and Walia, A. (2008) , “Ultrawideband for automated real-time three-dimensional location sensing for workforce, equipment, and material positioning and tracking.” Transportation Research Record: Journal of the Transportation Research Board, 56–64.

Telogis (2013). “ GPS Fleet Management ROI”, accessed via http//.www.telogis.com.

Venugopal, M., Cheng, T. and Teizer, J. (2010). “Real-time Spatial Location Tracking of Construction Resources in Lay Down Yards.” Construction Research Congress, 112-121.

Wang, L. “Enhancing construction quality inspection and management using RFID technology”, Automation in Construction, 17 (2008), 467-479.

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