INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 4, Issue 1)
Available online at www.ijariit.com.

BContri- An Algorithm for Monitoring Construction Site using RFID, GPS and GSM

Afiya V. N
Department of Civil Engineering
Mahatma Gandhi University, Athirampuzha, Kerala
afiyavn@gmail.com

Abstract: ***Construction is recognized internationally as one of the information-intensive industry and subject to harsh conditions (e.g., rain and dust) and is often criticized for delivering projects late and over budget. Collection of detailed, accurate and a sufficient volume of information and timely delivery of them are vital to operating a well-managed and cost- efficient construction project. This paper investigates the fully automated data collection using integrated applications of Radio Frequency Identification (RFID), Global Positioning System (GPS) and Global System for Mobile Communication (GSM) technologies in the construction industry which focused on the real-time exchange of information between the construction site and off-site office, how this technology could change current practice. Therefore, the main objective of this study is to propose a system to improve efficiency and cost effectiveness, practical communication and control among participants, and increase flexibility in terms of information delivery and response time on and off construction sites. Most of the used technologies in this research are commercially available and are inexpensive (RFID, GPS, GSM). Some application of advanced tracking and data storage technologies used in construction information management are discussed briefly.***

Keywords: Construction, RFID, GPS, GSM, BARCODE.

INTRODUCTION

Construction projects generally take place in uncontrolled and unprepared environments where accurate and timely information is vital to operating a well-managed and cost-efficient construction project. Due to the complex, unprepared, information-intensive, and uncontrolled nature of the construction site, not only using of automated advanced tracking and data storage technologies for efficient information management is needed but also construction industry has greatly benefited from technology in rising the speed of information flow, enhancing the efficiency and effectiveness of information communication, and reducing the cost of information transfer.

Construction materials may account for 50-60% of the total project cost in construction projects. Tracking of project related entities, such as materials, equipment, and personnel, has been a significant topic of research for the last decade. Different tracking technologies, such as barcodes and RFID tags, Ultra-Wide Band (UWB) and 3D range imaging cameras, global and local positioning systems and computer vision techniques, have been applied at construction sites, pre-cast plants, and factories to provide tracking data. Combinations of GPS and RFID technologies have been recently explored. The advantage of this combination is that GPS sensors need only accompany the tag readers and not the materials. Every time a tag is located, the 3D coordinates (as reported by the GPS) can be recorded as the location of each piece of material at that given time. However, the near-sightedness of RFID still limits the applicability of such solutions for real-time component tracking. More research is needed to overcome this limitation.

This paper presents a unique algorithm termed BConTri that combines a "boundary condition method" and trilateration to estimate tag locations in three dimensional (3D) real world coordinates from four or more mobile readers equipped with GPS. It was observed that the newly developed algorithm provides a high accuracy.

OBJECTIVES

The specific objectives of this paper are to develop a 3dimensional (3D) location sensing algorithm using RFID and GPS technologies (BConTri algorithm), to compare the method with other project tracking methods such as barcodes, Ultra-Wide Band (UWB) ,3D range imaging cameras, Global and local positioning systems, Vision-based tracking and to identify the limitations and advantages of the BConTri method.

GENERAL REQUIREMENTS OF A MATERIAL TRACKING SYSTEM

Evaluating the design option for any automated materials management system requires sufficient information about the project characteristics. The general requirements that any automated materials management system must fulfill are classified as follows:

- *Safety:* Technology must work at any location and time and may not harm people.
- *Cost:* It must have reasonable set-up cost.
- *Accuracy: It* should result in more accurate locations than from manual localisation practices.
- *Network: It* should be the most suitable for small device communication, capable of scaling.
- *Flexibility and scalability:* This system must be flexible, have minimum infrastructure requirements and must be portable so that the functionality can be transferred to new projects.
- *Ease of use:* It should be easy to mobilize, be simple and user friendly and reduce errors.
- *Ambient environment: It* must work well when natural illumination is low, obstructions are present, and the likelihood of signal multipath is high.
- *Ruggedness: S*ystem must be rugged enough to withstand harsh construction environments.
- *Time:* It should take minimal time for initial set up.

PROJECT TRACKING TECHNOLOGY

Project Tracking refers to the management of projects. Project Tracking can refer to Project Management software, which automates the tracking of tasks, assignments, events, and activities related to the project. Project management is the process of overseeing planning, organizing, scheduling, leading, communicating and controlling of activities to achieve the pre-defined outcome on time and within budget.

BARCODE TECHNOLOGY

RFID and barcodes systems are relatively similar, where both are proposed to present the capability of quick and reliable technologies in item identification and tracking. However, the two technologies have different methods for reading and writing data. With RFID systems, the reader interrogates or scans the tag using Radio Frequency (RF) signals, and does not need a direct line of sight between the reader and the tag. On the other hand, in the Barcode technology, a laser beam is used by the reader to scan a printed label and requires a direct line of sight between the optical scanner and the barcode labels. Barcodes use Universal Product Codes (UPC), whereas RFID uses Electronic Product Codes (EPC). In summary, there are some principal advantages that RFID has over barcodes. These are:

- Having a unique code, RFID tags are able to identify every item individually.
- RFID systems are capable of reading multiple tags simultaneously and instantaneously and can cope with harsh and dirty environments.
- RFID tags can hold greater amounts of data, and data on tags can be read or updated without line of sight.
- Tagged items can be automatically tracked without worker input, eliminating human error.
- RFID tags are reusable, more durable and suitable for a construction site environment, and they are not damaged as easily as barcodes.

The combination of all the below mentioned advantages will provide quick access to a wealth of information, eliminate human error, and reduce labour, which leads to reduced project activity time and a saving in project costs.

Table 1: Advantages and Disadvantages of Barcode Systems

ADVANTAGES	DISADVANTAGES
▪ Affordable ▪ Easy to use ▪ Mature and proven technology ▪ Established quality standards ▪ Reliable and accurate	▪ Optical line-of-sight scanning ▪ Limited visibility ▪ Restricted traceability ▪ Incapable of item level tracking ▪ Labour- intensive ▪ Susceptible to environmental damage ▪ Prone to human error ▪ Limited memory

Fig 1: Barcode Technology used in a Warehouse

ULTRA WIDE BAND (UWB)

UWB is another type of radio technology that can be applied to short-range communications. UWB transmits short and low power pulses using the radio frequency ranging a very wide bandwidth. UWB is able to detect time-of-flight of the radio transmissions at various frequencies, which enables it to perform effectively in providing 2-D and 3-D precision localization even in the presence of severe multipath. It was used for a real-time material location tracking system with primary applications to active zone work safety. Its ability to provide accurate 3D locations in real-time is a definite benefit to tracking in construction sites. However, a total station should be employed in order to convey adequate positioning data to the system prior to the UWB system implementation. Same as GPS and RFID, it also requires the installation of sensors on every entity to be tracked. Considering the number of entities in large-scale construction sites, this increases the amount of equipment (tags) required for each particular job and the time and cost associated with its installation. UWB systems were mainly developed as radar systems for military applications. Advantages of the UWB systems are:

- High Data Rates
- Low Equipment.
- Multipath Immunity
- Multipath Effect
- High Penetration Capability
- Low Power Consumption

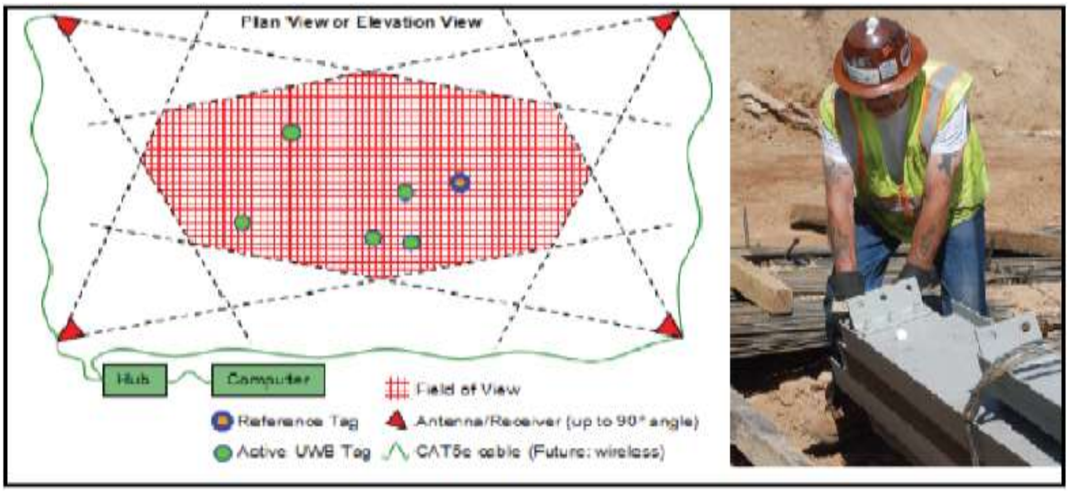

Fig 2: Ultra-Wide Band Receiver and Hub Configuration, UWB tags on iron worker and material

3D RANGING CAMERA

A 3D range imaging camera, which is also called a Flash LADAR, provides not only the intensity but also the estimated range of the corresponding image area. Illumination units emit lights to the scene and image sensors detect the reflected lights. Using the time-of-flight principle and the calibration information which is usually given by manufacturers, it measures the distance of each pixel area in the scene. The 3D range imaging camera can obtain data at the frame rate up to 30 frames per second which are high enough for tracking. Also, when compared to 3D laser scanners which have been used in construction, the device is portable and inexpensive. Recent research efforts presented the application of 3D range cameras to construction. Testing various kinds of data filtering, transformation, and clustering algorithms, 3D range cameras are used for spatial modeling and demonstrated the tracking with 3D range cameras and the potential of its use for site safety enhancement. However, the low resolutions and short range make it difficult to be applied to large scale construction sites.

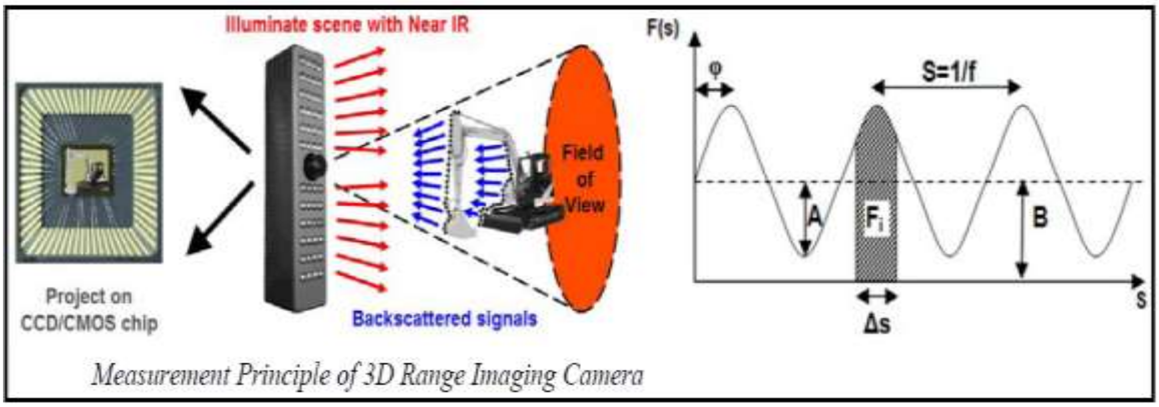

Fig 3: Measurement Principle of 3D Range Imaging Camera

Few tests have been executed in outdoor construction sites where the environments are more cluttered and less controlled. Also, it is reported that the reflectance of a surface varies extremely even in indoor environments. Moreover, when multiple cameras are used, they can interfere with each other.

Especially in the application for detecting, tracking, and modelling moving objects, this technology is preferred to non-real-time range sensing. The biggest benefits from 3D Range Imaging Cameras are:

- Ability to collect dense point cloud range data in real-time of a larger field-of-view.
- Deliver range, amplitude, and intensity maps in one frame and at the same time
- Safe and very short data acquisition time with high frame update rate for immediate range feedback
- Wide field-of-view
- Capturing static and dynamic scenes and thus not conceivable to laser scanners
- Ease of use at day and during night
- Insensitivity to background light
- Handhelds like small sized and compact devices
- Competitive prices

The applicability of optical 3D sensing techniques restricts its use to areas where line-of-sight is the preferred alternative. Light as a carrier wave to collect range data is sensitive to ambient environments.

The main limitations of 3D Range Imaging Cameras are currently:

- Missing standardized calibration technique for laser range imaging systems and data processing algorithms
- Ambient environment influencing measurements requiring post data filtering
- Optics or physical camera effects causing inaccuracies in distance measurement performance
- Non-optimal manufacturing of camera device and parts
- Line of sight produces shadow effects (2½D image only)
- Diverted, extended, or (non-)reflected light beams (due to object colour, edges)
- Ambient environment (background light and jitter noise)

A three-dimensional imaging system such as 3D Range Imaging Cameras can rapidly measure the range, amplitude and intensity image including thousands of points to objects or scenes at high update rates. Once these dense "point clouds" are accurate enough they can be processed to generate e.g. 3D models.

GLOBAL AND LOCAL POSITIONING SYSTEMS

GPS is an outdoor satellite-based worldwide radio-navigation system formed by a constellation of satellites and ground control stations. The 3D position of the user is determined by the GPS receiver using triangulation from these satellites. GPS applications have been applied to construction practices, such as positioning of equipment and surveying. However, when using only GPS, there is limited potential in other applications such as improving the management of materials on construction job sites, due to the limitations of this technology; it can only operate outdoors, and it needs to be attached to each entity that is being tracked. Since the number of materials involved in a project is usually significantly large, it is in most cases infeasible to attach a GPS receiver to each piece of the material. In the case that very accurate positioning data is needed, higher installation and maintenance costs are involved. Therefore, GPS could be a cost-effective option for tracking the position of larger resources such as heavy equipment fleets. Construction activities take place in outdoor and indoor environments, while GPS is the ideal solution for tracking outdoor activities; it is not applicable for indoor application due to the lack of line-of-sight to satellites signals. Therefore, GPS-less means of tracking is required in indoor environments.

Table 2: Advantages and Disadvantages of GPS

ADVANTAGES	DISADVANTAGES
• Fairly inexpensive, easy-to-use	• Multi-path error
• High accuracy	• Insufficient accuracy in urban areas
• Elimination of intermediate data entry	• Not available in many remote areas and widespread implementation is expensive
• Worldwide availability	• More complex post-processing
	• Requires more time in field data collection
	• More training for complex units

Fig 4: a) GPS Data Logger Mounted on a Loader b) Two Units Mounted Inside an Excavator Cabin

VISION-BASED TRACKING

Vision camera is a cost-effective technology which covers a large field of view of job sites remotely; however, it requires line of sight. A source of illumination is also required when working at night. Since the video or images from the camera need to be processed, it is not well suited to automated tracking of materials in complex environments of construction job sites. Vision-based tracking does not require tagging sensors on the entities. The vast size of the area that camera views can cover is also one of the advantages of this technology. Vision-based tracking can track

a number of objects as long as they appear in the camera view. Therefore, it can derive maximum possible benefits under the congested large-scale conditions where such a large number of objects appear that installation of sensors become impractical.

PROPOSED METHOD OF RFID AND GPS

An RIFD system consists of tags (transponder) with an antenna, a reader (transceiver) with an antenna, and a host terminal. The RFID reader acts as a transmitter and receiver and transmits an electromagnetic field that ‘‘wakes-up’’ the tag and provides the power required for the tag to operate. The whole RFID system requires the tags and the reader including an antenna to be operated. The RFID tags or transponder are normally located on the object Reader Antenna Transponder (“TAG”) Reader broadcasts a signal through antenna Computer System Transponder receives signal and returns an identifying response (and maybe other data) Reader sends data to a computer system for processing or people to be identified. The RFID reader or interrogator provides, read and write/read facilities through a fixed or mobile reader to communicate data to and from the tags.

RFID Tags

An RFID tag is a portable memory device located on a chip that is encapsulated in a protective shell and can be embedded in any object which stores dynamic information about the object. Tags consist of a small integrated circuit chip, coupled with an antenna, to enable them to receive and respond to radio frequency queries from a reader. RFID tags can be classified into active tags and passive tags.

Table 3: Comparison between Active and Passive Tags

ACTIVE TAGS	PASSIVE TAGS
• Longer reading ranges; 60-300 feet(20-100m)	• Shorter read ranges- upto 30feet
• much larger and heavier, and more expensive	• Comparatively smaller
• Better noise protection	• Low noise protection
• Have larger memories and are rewritable	
• ability to store additional information and are used on large assets	
• Own internal power supply	• Powered by the magnetic field emanated from the reader
• They have a shorter battery life of 10 years.	• Unlimited lifetime

Reading and writing ranges depend on operation frequency (low, high, ultra-high, and microwave). Tags operating at Ultra High Frequency (UHF), typically, have longer reading ranges than tags operating at other frequencies. Communication distance between RFID tags and readers may decrease significantly due to interferences by steel objects and moisture in the vicinity, which is commonplace at a construction site. The passive RFID tags consist of a microchip attached to an antenna and can be packaged in a different way such as mounted on a substrate to create a tag, sandwiched between an adhesive layer and a paper label to create a printable RFID label (or smart label), embedded in a plastic card, a key fob, the wall of a plastic container, and special packaging (to resist heat, cold or harsh cleaning chemicals).

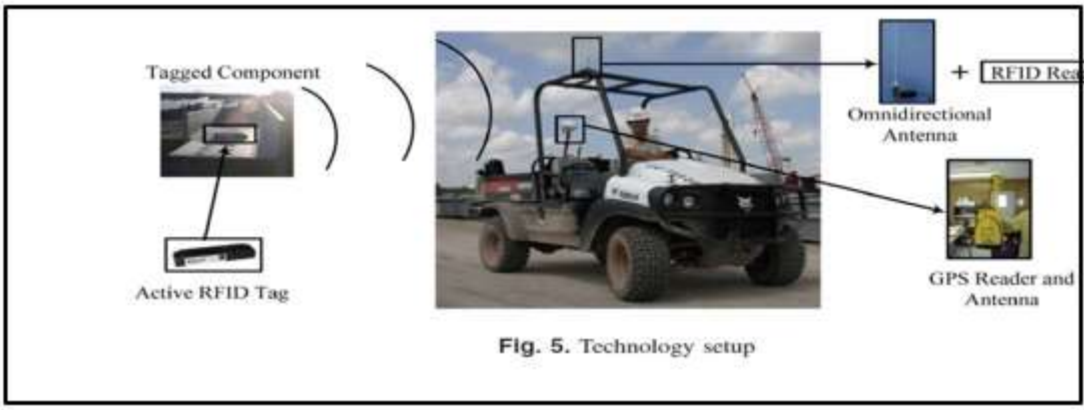

Fig 5: Tracking a Truck with RFID tag

Fig 6: Safety Helmet with Attached Tag

RFID Readers

The reader, combined with an external antenna, reads and writes data from, or to, a tag, via radio frequency, and transfers data to a host computer. RFID readers or the interrogator typically contains a radio frequency module (transmitter and receiver), a control unit and a coupling element to the transponder. The RFID readers may be fixed or mobile and capable of communicating data to and from the tags to share data with the larger information system they support. The data is exchanged between tags and readers using radio waves. The RFID readers included an antenna for sending and receiving signals to give instructions and information to the reader through the scanner. The information provided in the scanner is converted into a digital format by the reader, which the computer can then use for data analysis, recording, and reporting.

Fig 7: RFID Readers

RFID Antenna

An RFID antenna is a conductive element that enables the tag to send and receive data. The antenna attached to reader functions to transmit an electromagnetic field that activates a passive and active tag when it is within reading range.

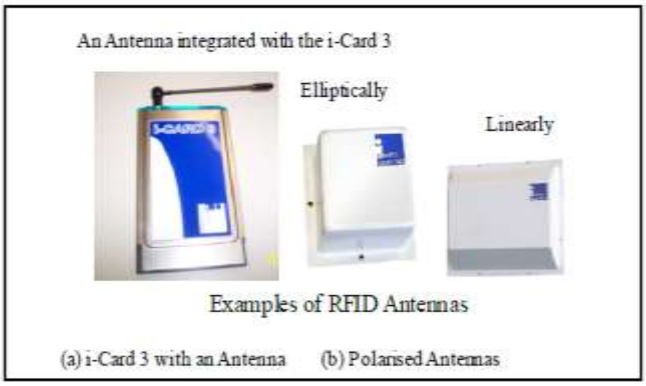

Fig 8: RFID Antennas

Table 3: Advantages and Disadvantages of RFID

ADVANTAGES	DISADVANTAGES
• Non-line-of-sight scanning	• Cost of tags and new infrastructure
• Simultaneous automatic reading	• Lack of training and limited knowledge
• Labour reduction	• Concern of return on investment
• Enhanced visibility and forecasting	• Lack of ratified standards
• Item level tracking	• Immature technology
• Traceable warrantees	• Cost of tags and new infrastructure
• Reliable and accurate	
• Information rich	
• Enhance security	
• Robust and durable	
• Reusable	

LOCATING 3D OBJECTS USING TRILATERATION AND BOUNDARY CONDTION

Distance estimation, proximity techniques, and scene analysis are the main techniques utilized to locate objects in location sensing techniques. For the purpose of construction applications, scene analysis has not been conducted as much research is not available. In order to overcome the challenge associated with uncertain detection range in RFID, a boundary condition-based algorithm, called BContri, is proposed to estimate the 3D location of objects. This algorithm is based on the concept of trilateration.

Distance Estimation

Triangulation and trilateration are the two techniques that fall under distance estimation algorithm. Trilateration uses received signal strength (RSS) which depends largely on the signal propagation nature of the particular environment or time of flight (TOF) to determine the distances between three or more reference points and target tag to estimate its position.

Trilateration

Considering four reference reader locations in figure 9 with known coordinates (x_k,y_k,z_k)and the distance between targeted tag with coordinates (x,y,z) can be estimated to be r_k, k= 1,2,3,…,n. The equations are formed as below. The targeted tag coordinates (could be calculated by using the RSS correlation with distances. But when the distances are unknown due to RSS not being considered in the case of this study, there would be four equations with seven unknowns (x, y, z, r_1,r_{12},r_{13}, r_4) making it impossible to solve.

$$r_1 = (x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2$$
$$r_2 = (x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2$$
$$r_n = (x - x_n)^2 + (y - y_n)^2 + (z - z_n)^2$$

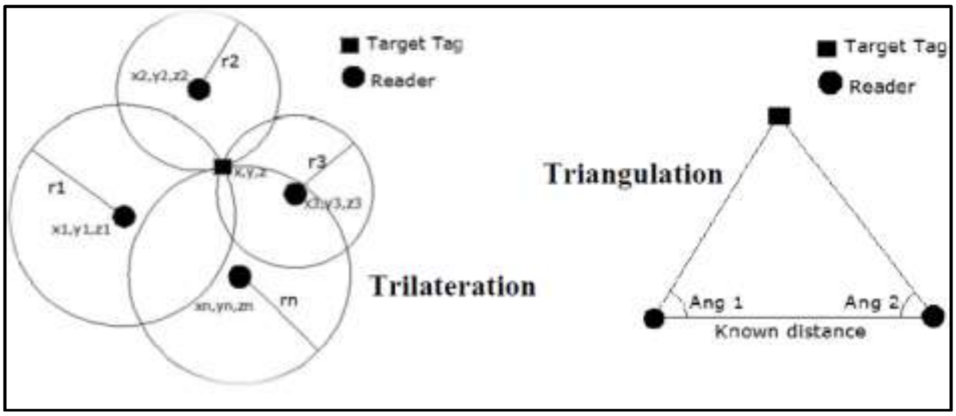

Fig 9: Trilateration and Triangulation

Proximity Technique

This technique relies on the dense deployment of readers to determine how near a target tag is, to one or more reader locations when the target enters the communication range of these readers. Comparisons of the signals are made and the target assumed to collocate with the reader that has the strongest signal. The accuracy, however, depends on the size of the cell. In 2010 static RFID readers were used with reference tags to calculate the location of passive target tags in 3D for indoor tracking based on RSSI values and gradient descent method. The algorithm developed adopted the concept of trilateration by using four static readers and reference tags to generate a correlation that will be used with RSSI values to estimate the targeted tag position in 3D. In 2005 mobile RFID reader with GPS were used to estimate the location of RFID tags for material tracking on construction site in 2D. The concept of proximity techniques algorithm uses the approximate RF communication area to detect the presence of a tag within the region was considered based on a job site grid system. However, these techniques either consider 3D tracking based on RSS or 2D tracking.

BOUNDARY CONDITION ALGORITHM

An algorithm termed BConTri that combines a “boundary condition method” and lateration to estimate tag locations in three-dimensional (3D) real world coordinates from four or more mobile readers equipped with GPS is considered in this study. The boundary condition refers to the situation that a tag is at the boundary of the detection range of a reader. Such a condition can be determined by checking the RF communication between a reader and a tag to identify a “disappearing” or “appearing” event. A “disappearing” event indicates that the reader is moving away from the tag and an “appearing” event indicates that the reader is moving towards the tag. Under both events, the tag is located at the detection boundary of the corresponding reader.

The BConTri algorithm flow chart shown in Figure 11 works in such a way that given the detection of a single tag under the boundary condition by four or more spatially distributed readers, spheres of the same radius centered at reader locations are generated as shown in Figure 10. The assumption made in choosing the radius is based on the read range of a particular RFID system in use. The initial radius serves as a starting or threshold radius for each set of four reader locations. These spheres are then expanded or shrunk simultaneously maintaining the same radius until a common intersecting volume in (Figure 10b) plan view and (Figure 10c) isometric view is reached. If no common volume is reached, the threshold radius is increased interactively until a common volume is reached, and then a determination is made based on how large or small is the common volume. A condition of having at least 10 points or less is assumed to be the threshold of how small a common intersecting volume should be. This is based on the minimal increment or decrement of the radius.

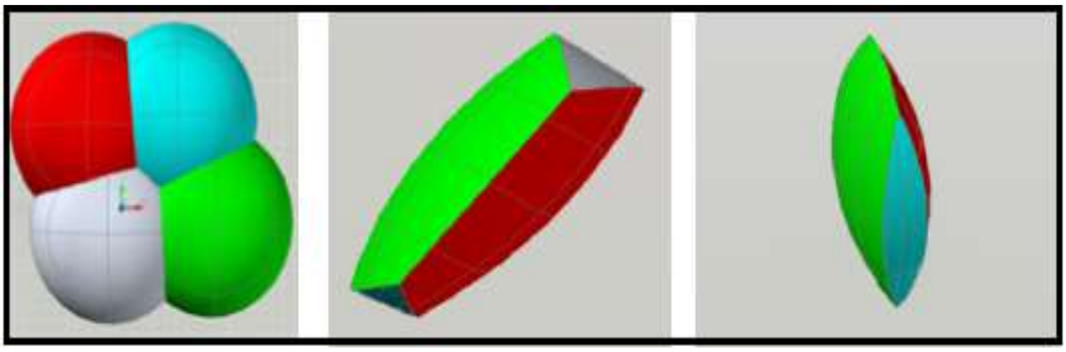

Fig 10: (a) Sphere Volume Intersection (b) Common Volume (Plan View) (c) Common (Isometric View)

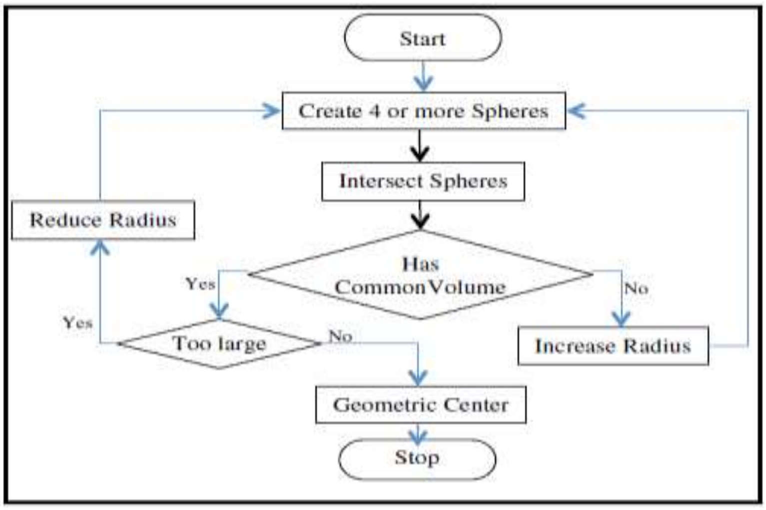

Fig 11: The Flow Chart of the Proposed BConTri algorithm

To achieve this solution. If the volume is in this condition, then it is considered large and therefore iteratively calculates the optimal radius for a common volume to be formed. The geometric center of the intersecting common volume becomes the estimated most probable location of the tag. This is achieved by finding the centroid of the points generated from the common volume formed.

CHALLENGES AND LIMITATIONS OF THE SYSTEM

- One of the expected challenges is social. Wide Implementation of such systems would bring resistance from companies, as these companies have been using traditional methods with which they are comfortable.
- Applications of any technology in construction should be accompanied by its inspection and monitoring guidelines during the implementation phase. Thus, extra effort and training are needed.
- Though the cost of RFID tags has been reduced and is comparable with barcode labels in using chip-less RFID tags, RFID technology is still relatively expensive and the cost of RFID tags in active technology should be taken into account. It should be noted that RFID tags are reusable, which may alleviate this challenge.
- Power can be identified as another challenge. For active RFID systems, the reader can be set to be triggered to wake-up by motion, activity, or on a set time interval if desired. For low power RFID systems, the tag goes to sleep in between transmissions, so, the reader needs to be on at all times, listening for tags, to wake up and transmit.
- Although in the ISO and EPC global world, the standards for some frequencies are already approved, the lack of a complete and international standard for RFID technology, and a lack of multi-protocol tags and readers are two important challenges. There for mentioned standards should deal with the technology in different countries in which RFID operational frequencies are different.

COST-BENEFIT ANALYSIS METHODOLOGY

Implementing the new methodology and using a technology based approach to automate construction management tasks requires a cost-benefit analysis, by carrying out a cost comparison between manual and RFID based systems. There are two categories of system costs, investment, and operation and maintenance. The fixed cost of this system depends on the amount of hardware installed, which is governed by the phases (e.g. production, shipping, and jobsite) to be covered. The variable costs of this system consist of the cost of RFID tags and labour costs for inspection. The benefits from the usage of a technology-based materials management system can be direct, such as a reduction in man hours, or indirect, such as an increase in productivity. Using such a system will automate labour-intensive tasks in material management, such as paperwork for recording, updating and reporting the material status through daily checking and check-up activities. In addition to the reduction in labour cost, cost saving on document handling and storage space, by reducing the volume of historical archives, should be taken into account. It is important to note that the fixed costs for technology based material management system remain the same at the level of first time implementation, even if the project duration increases.

CONCLUSION

This study presented a new approach for integrating the latest innovations in automated detecting technologies, which address a clear path to automate the tracking and monitoring of construction resources (e.g. materials and components), using minimal or no human effort. Collected information can then be shared among all of the construction including upstream parties (e.g. material suppliers) and downstream parties (e.g. contractors). The use of automated advanced tracking and data storage technologies can provide comprehensive benefits in communication and labour utilization, and it can also facilitate extremely low-cost, infrastructure-free solutions to form the backbone of a construction resource management system (e.g. materials management system).

The BConTri algorithm could estimate the 3D of real world coordinates location of tagged objects on construction site. It clearly identified that these are important for effectively managing materials management in the construction project in order to provide better handling of construction materials to provide an overall performance of construction projects in term of time, budget (cost) and quality. The employment of RFID to support current practices of materials management in the construction site is considered improving for effective managing construction materials on site.

REFERENCES

1. Abdul Rahman Andoh , Xing Su, Hubo Cai , " *A Boundary Condition –Based Algorithm For Locating Construction Site Objects using RFID And GPS"*, Construction Research Congress 2012, ASCE 2012.
2. Elhami Nasr, Tariq Shehab, Ana Vlad, *"Tracking Systems in Construction: Applications and Comparisons"*, 49th ASC Annual International Conference Proceedings, 2013, Associated Schools of Construction
3. Ioannis Brilakis, Man-Woo Parkb, Gauri Jog, "*Automated vision tracking of project related entities"*, Advanced Engineering Informatics 25 (2011) 713–724.
4. Javad Majrouhi Sardroud, "*Influence of RFID Technology on Automated Management of Construction Materials and Components*", Scientia Iranica, Transactions A: Civil Engineering 19 2012, PP 381-392.
5. J. Majrouhi Sardroud, M.C. Limbachiya, "*Effective Information Delivery at Construction Phase with Integrated Application of RFID, GPS, and GSM Technology",* Proceedings of the World Congress on Engineering 2010 Vol I WCE 2010, June 30 - July 2, 2010, London, U.K.
6. Mandeep Kaur, Manjeet Sandhu, Neeraj Mohan and Parvinder S. Sandhu, "*RFID Technology Principles, Advantages, Limitations & Its Applications" ,* International Journal of Computer and Electrical Engineering, Vol.3, No.1, February 2011, 1793-8163
7. Narimah Kasim, Aryani Ahmad Latiffi, Mohamad Syazli Fathi, "*RFID Technology for Materials Management in Construction Projects – A Review",* International Journal of Construction Engineering and Management 2013, 2(4A): 7-12.
8. Xing Su, Shuai Li, Chenxi Yuan, Hubo Cai, and Vineet R. Kamat, *"Enhanced Boundary Condition–Based Approach For Construction Location Sensing Using RFID and RTK GPS",* Journal Of Construction Engineering Management, ASCE 2014.140.