RFID Indoor Location Identification for Construction Projects

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Purpose The purpose of this paper is to present an indoor location identification methodology using low cost passive Radio Frequency Identification (RFID) for construction projects. **Method** Location-aware information at construction sites is an emerging area, concerned with automating the delivery of spatial information on the location of materials, workforce, and equipment. This spatial information can provide knowledge on construction project status. Most RFID localization literature focuses on deploying active RFID tags, which are expensive and aimed at indoor localization. It has been experimented with in operating buildings but not on construction jobsites and with a different time span. For this paper low cost passive RFID-tags were used. Using this methodology, a number of passive RFID tags are distributed onsite where work is progressing and the user, such as the field superintendent, carries a mobile RFID-reader. The indoor construction work-active area is divided into exclusive zones for tracking. Each passive RFID-tag is used as a reference point with known location (LANDMARK) within a predefined zone. The reference tag's known location is used to estimate the location of the user. The methodology uses Received Signal Strength Indicator (RSSI) as the main attribute for signal measurement to process the reader captured data. Two localization algorithms (Trilateration and Proximity) were used to identify the user location. After identifying the user's location, the user can take snapshots with a camera and write comments about onsite activities. The collected data will be then attached to the as-planned project schedule and related CAD drawings automatically at the identified location. This data is used to represent actual progress, which is then compared to as-planned baseline progress using earned value analysis. **Results & Discussion** An actual construction jobsite was used to build 5 test beds at different locations and different construction time spans. Experiments were conducted on the test beds to compare the results obtained from Trilateration and Proximity algorithms. The results shows mean error equals to 1m for Trilateration method with standard deviation of 0.4m and for Proximity method mean error equals to 1.76m with standard deviation of 0.5m. Indoor location identification could be utilized for tracking the project status.

***Keywords**: RFID, indoor location identification, RSSI, trilateration, proximity*

INTRODUCTION

Location awareness provides support for decision-making, timely tracking of the project status, proactive safety monitoring, and, subsequently, operation and maintenance of constructed facilities. Recent advances in sensing technologies have enabled the deployment of a range of technologies for identification, location sensing, and tracking[1-5]. The purpose of object localization is to estimate the absolute or relative location information of that object along with given observations and spatial relation between that object and known references by the localization system[6-7]. Global Positioning Systems (GPS) has well met the need for outdoor location sensing and has great value in determining the position of the mobile reader, referred to later as user, with centimeters accuracy[8,9]. However, when it comes to indoor areas, GPS is not reliable due to poor reception of satellite signals. In addition, GPS is still expensive for deployment to automate tracking of individual material items[10,11].

A wide range of technologies were used for indoor location sensing such as ultrasound solutions[12], Infrared-based solutions[13], and ultra wide band (UWB)[14]. Localization technologies depend mainly on calculating the location based on signal measurements. Signal measurements used for that purpose are Received Signal Strength Indicator (RSSI), Angle Of Arrival (AOA) and Time Of Arrival (TOA)[15,16]. The signal strength has close relationship with distance between the sender and receiver.

RFID Technology is also used in this respect[5,17,18]. Li and Becerik-Gerber[19] conducted a comparative study for the different indoor location sensing technologies taking into consideration the following factors: accuracy, affordability, line of sight, wireless communication, context independence, on-board data storage, power supply, and wide application in the building industry. Based on that study they concluded that RFID technology considered as the most suitable indoor location sensing technology. Choi[8] arrived at the same conclusion; stating that passive Ultra High Frequency (UHF) RFID based localization overcomes the drawback of conventional indoor localization systems such as high cost of installation and maintenance because of the relatively low cost, the absence of a power source, and lightweight of the passive RFID tag. This would justify the applicability of the technology for construction industry, which has a dynamic work environment. Most RFID localization literature focuses on deploying active RFID tags for indoor and outdoor environments. However, active tags are expensive and have limited life time (5-10) years.

Localization based on signal strength measurement has two main advantages; lower cost and simple implementation[4]. Three major methods have been developed to locate a target using that technology; Triangulation, Proximity and Scene Analysis[20-22]. Triangulation is a technique of determining the location of an object, based on geometric properties and mathematical formulation. Triangulation determines the position of an object by measuring its distance from multiple reference positions. When the localization algorithm knows at least a set of three distances from different receiver, the algorithm can draw three circles, the radius of a circle is the measured distance, and the center is the known position of the signal receiver. The intersection of three circles determines the expected signal source's location[23,24]. The Proximity method requires the measurement of the nearness of a set of neighboring points, which have fixed and known location, and are close to the target. The measured nearness, along with the corresponding known locations, are used to estimate the location of the target. Thus, the proximity technique guarantees the most simple and easy implementation for object localization[25].

This paper presents an indoor location identification methodology using low cost UHF passive Radio Frequency Identification (RFID) for construction projects. Two RSSI based localization methods are used (Triangulation and Proximity). A recently constructed project is considered to compare the results obtained from Triangulation and Proximity on construction job sites. Unlike the methods presented in the literature, which were focused on built facilities and not construction jobsites, the proposed methodology enables useful applications during construction and subsequently upon completion of construction to support facility management activities.

PROPOSED METHODOLOGY

In the present study, UHF passive RFID technology is utilized for capturing spatial data of indoor operations. The purpose of indoor location identification using RFID is to estimate the relative location information of the mobile site personal (the user) along with given observations of input and spatial relation between the user and a set of known references by the localization system. "Super-distributed" tag infrastructure approach is proposed. In this approach, a number of low cost passive RFID tags are distributed on the jobsite, and the mobile user carries the RFID reader. Each passive RFID tag is used as a reference point with known location (LANDMARK) within a predefined zone. In this study reinforced concrete columns, shear walls and wall edges were used as landmarks. The known locations of reference tags are used to estimate the location of the user, based on RSSI received from these tags. The indoor construction work-active area is divided into exclusive zones for tracking.

Figure 1 illustrates the process of deploying RFID reference tags, which start with assigning RFID reference tags to each zone's landmark. Afterwards, for each reference tag the user should identify its coordinates (xi,yi) and store all this data in RFID database. This step is performed one time per floor and is used as input for location identification. Locations of reference tags are identified with subscript (i) and the location of the user is identified with subscript (j). Reference tags are used identify the user stationary location as shown in Figure 2. The user at a given location operates the RFID reader at time t_o and captures the signals received from the tags in that location. This process is then repeated at a set of time intervals, referred to here as Δt. In the field experiments, Δt ranged from 15 to 30 seconds. To ensure the use of signals from related reference tags only, a relational database was developed to filter these tags based on their respective IDs. Due to space limitation, the database will not be described here. Processing of the data captured is, using either the proximity method or the Triangulation method, is depicted in Figure 3.

Triangulation method requires a path loss model to convert RSSI to distance (D). The model was developed using 6704 data sets of laboratory experiments. Each data set consists of a number of signals captured at a specific distance. Linear regression was carried out using the average of the capture signals' strength and the associated distance. Distance (D) was varied at an interval of 10cm. The developed relation is represented by Equation (1). (Figure 4).

$$RSSI = -6.182\ D - 32.68 \qquad \text{Equation 1}$$

The distances generated using Equation (1) were used to determine the location based on the Triangulation method described earlier. In case the intersection is not at a point, the center of gravity (C.G.) of the intersection area is used instead. The Proximity method was also applied. As stated earlier, the Proximity method uses Received Signal Strength Indicator (RSSI) as a weighting method to express how near the reader to the reference tags. RSSI is a measurement of the power present in a received radio signal. Therefore, the higher the RSSI number (or less negative in some devices), the stronger the signal is, which means that the user is more near to that tag. The readings collected for each reference tag were averaged and converted into related weight (Wi), which represents how much closer the reader is to that tag. Using Equation (2), the coordinates of the user (Xj,Yj) are calculated. For example, Figure 6-a shows that the user stands in zone one and is surrounded by three reference tags having coordinates (x1,y1), (x2,y2) and (x3,y3) and corresponding averages of (RSSI)1, (RSSI)2 and (RSSI)3, respectively. Using Equation 1, the system automatically calculates the user location (X1,Y1). The developed database will not be described in this paper due to space limitations.

$$Xj = \frac{\sum_{i=1}^{n} xi*Wi}{\sum_{i=1}^{n} Wi} \quad \& \quad Yj = \frac{\sum_{i=1}^{n} yi*Wi}{\sum_{i=1}^{n} Wi} \quad \text{Equation 2}$$

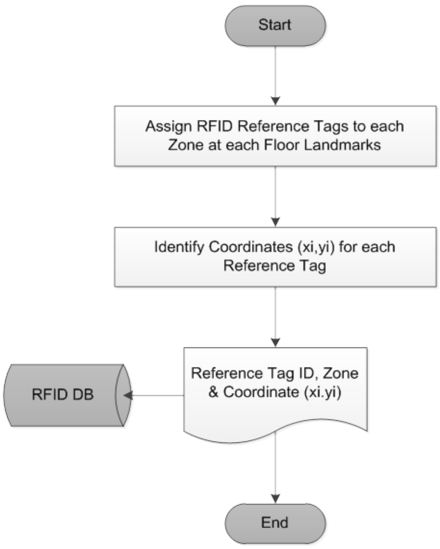


Fig. 1. The process of deploying RFID reference tags

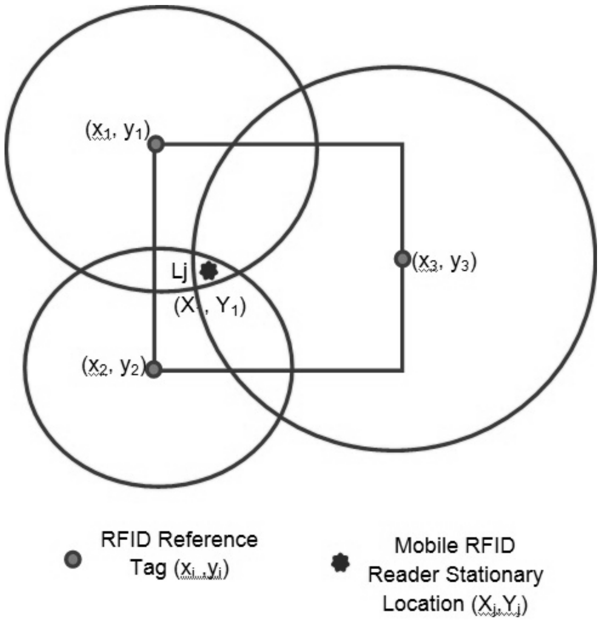


Fig. 2. Diagrammatic Sketch for location identification

Field Experiments

To validate the proposed method and for demonstrating the feasibility of employing the components, methods, and technologies, field experiments conducted on case study was applied on construction jobsite of the Center for Structural and Functional Genomics at Concordia University (Figure 5).

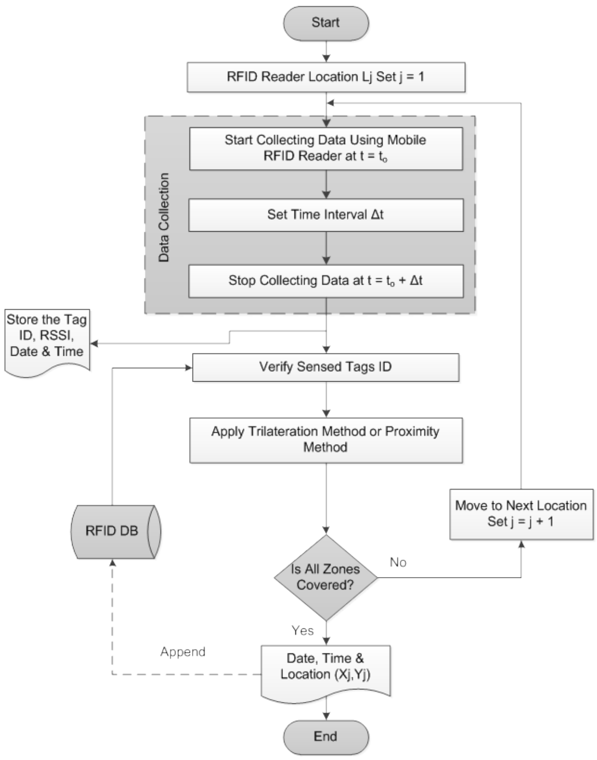


Fig. 3. Flowchart for location identification

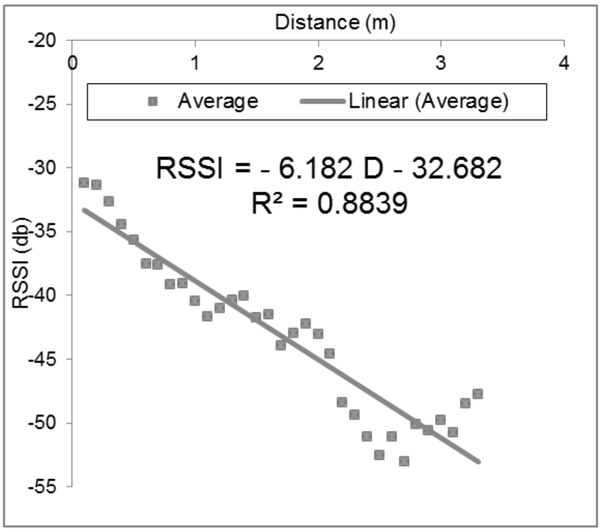


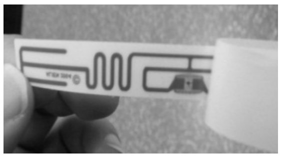
Fig. 4. Path loss regression model

The main RFID hardware components used in the case study (Figure 6) are RFID mobile reader, RFID encapsulated tags, RFID label tags and RFID labels tag printer. RFID hardware could collect data in dirty, harsh, hazardous conditions. For example, the encapsulated RFID tag used, could work in temperatures ranging from -40° C to 66° C cost up to $5 per tag. Regarding its memory size it has a capacity of 512-bit-on-chip. In addition, RFID mobile readers could work under similar harsh conditions such as could work in temperatures ranging from -15° C to 50° C, protected from dirt, dust, oil, other non-corrosive material, and splashing water. The passive RFID tags used in these experiments were printed RFID labels, which cost a couple of cents each, RFID labels tags. The read range for encapsulated tags are 5m for and 3m for label tags (Intermec, 2012).

Fig. 5. Case study (construction jobsite of the Center for Structural and Functional Genomics at Concordia University)

a)RFID mobile reader

b)RFID encapsulated tag



c)RFID label tag

Fig. 6. RFID hardware used

Five test beds were setup at different locations and different construction time span (Table 1). Experiments were conducted on the test beds to compare the results obtained from Triangulation and Proximity algorithms as shown in Figure 7. The figure shows the setup of the test bed, location of RFID reference tags, the user actual location and the estimated location using Triangulation method and Proximity method. Table 2 and figures (8, 9 & 10) show the statistical analysis for the results and the accuracy in meter for the all experiments and the performance for each algorithm for each test bed. Utilizing this methodology offers 1 m mean accuracy for triangulation and 1.65 m mean accuracy. Nevertheless, the experiments yielded 100% accuracy for identifying the correct zone in all test beds, which proves the feasibility of this procedure to be applied in construction jobsites.

Table 1. Characteristics of test beds

Test Bed #	Test Bed 1	Test Bed 2	Test Bed 3	Test Bed 4	Test Bed 5
No. of Samples	418	494	451	729	438
Location	(3rd Floor)	(2nd Floor)	(3rd Floor)	(2nd Floor)	(3rd Floor)
Covered Area (m2)	75.24	75.24	75.24	108	120
No. of Deployed Tags	24	24	24	25	33

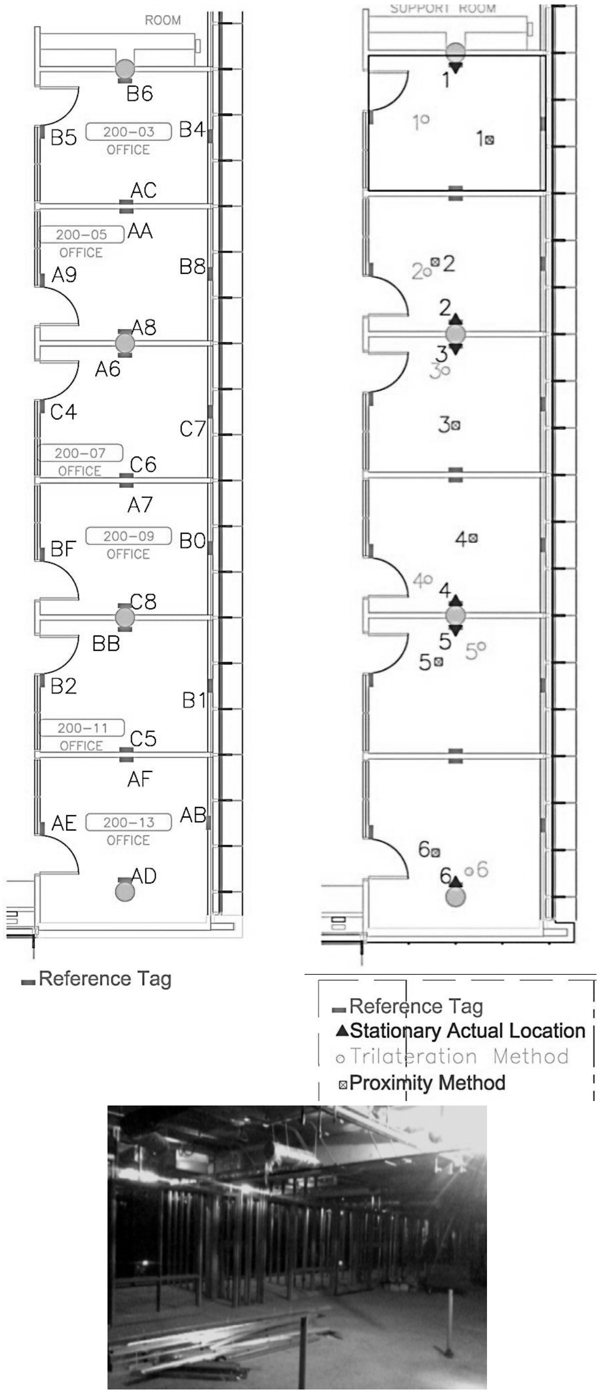


Fig. 7. Test Bed #3 setup, results and pictures

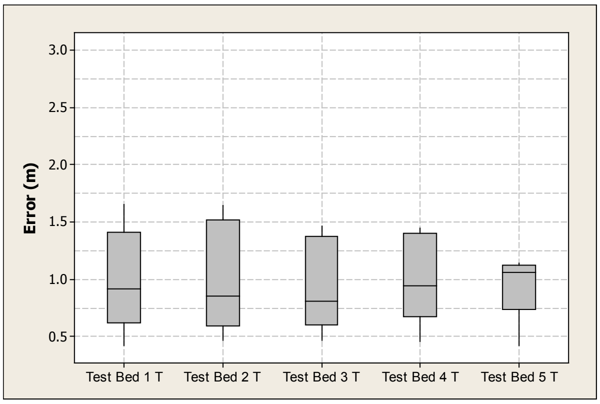


Fig. 8. Box plot for each test beds results using Triangulation algorithm

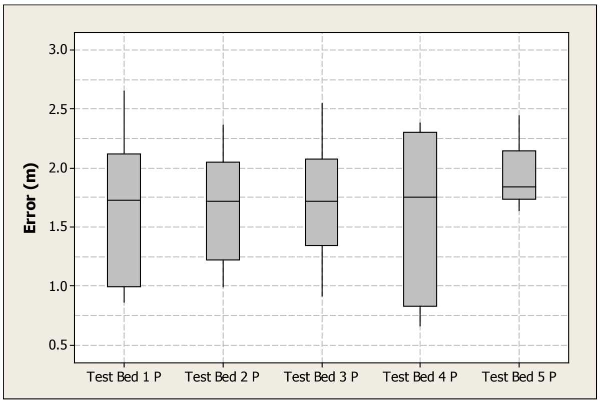


Fig. 9. Box plot for each test beds results using Proximity method

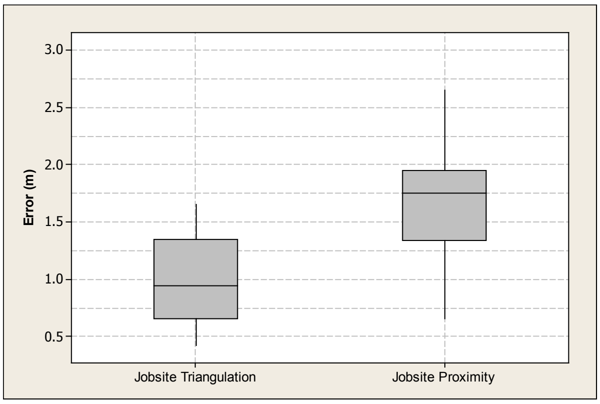


Fig. 10. Box plot comparing the results of each algorithm for all test beds

Table 2. Statistical analysis results for location identification for Triangulation and Proximity methods

Method	Triangulation	Proximity
Mean of Error (m)	0.976128571	1.654275
Median of Error (m)	0.9444	1.74895
St Deviation of Error (m)	0.381141239	0.52751345
Detect Zone Correct	100%	100%

CONCLUSION

This paper presented a low cost location estimation method for indoor construction environment. The proposed method utilizes passive RFID technology for capturing spatial data of indoor construction operations where Global Navigation Satellite System (GNSS) cannot work. In this study, the work-active area is divided into exclusive zones and each zone is spatially covered by a number of passive RFID tags. Two different algorithms (Triangulation and Proximity) which utilize RSSI signal measurements are used to estimate locations of interest onsite. The developed methodology was applied to a recently constructed laboratory facility in Montreal, Canada. The results are presented and compared for different 5 test beds at different construction time intervals. The field experimental results show mean error of 1m for the Triangulation method with a standard deviation of 0.4m and a mean error of 1.76m for the Proximity method with a standard deviation of 0.5m. The accuracy was 100% in zone detection, which is higher than that achieved in an author's earlier study using KNN algorithm (e.g. 90%)[19]. In view of the findings of this study, the developed method can be used efficiently to capture and process sensed data to support near-real-time decision-making, timely tracking of the project status, proactive safety monitoring, and, subsequently, operation and maintenance of constructed facilities.

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