Indoor Localisation for Complex Building Designs using Passive RFID Technology

***Farhan Manzoor*[1] *and Karsten Menzel*[2]**

[1]Room 2.12, Western Gateway Building, Department of Civil and Environmental Engineering (CEE), University College Cork (UCC), Ireland, f.manzoor@studentucc.ie
[2]k.menzel@ucc.ie

Abstract

Amongst various application usages of Radio Frequency Identification (RFID) Technology, Indoor localization or positioning has gained much importance and value over the past few years. Different algorithms and hardware have been developed with active research still in place. Research towards localization of objects and personnel specifically using passive RFID technology has immensely reduced the overall solution cost, while effectively increasing positioning accuracy. In this paper, we present a passive RFID-based indoor localization algorithm for the Buildings and Constructions Industry. In complex building designs, such as multi-storey car parks or high-rise hospitals, it is often required to locate a particular car or medical personnel at least at a room level accuracy in case of emergencies.

In the methodology presented, passive RFID tags with unknown locations are tracked and identified using a number of similar tags with known positions. This approach offers the advantage to have less number of expensive RFID readers to locate unknown tags. Instead, low cost passive RFID tags collaborate together to find the unknown tags' locations. The distance and positions of the known tags along with mathematical techniques and computations form the basis of our algorithm to compute the final position of unknown tags. The experimental results are acquired by considering a simulated implementation in a 10mx10m room using two UHF RFID readers. A number of simulation results show an average linear error in positioning of 1.32m from reader 1 and that of 3.14m from reader 2.

1. Introduction

Radio Frequency Identification (RFID) is a technology that uses radio waves to send and receive information between an RFID reader and its corresponding tags. An RFID system can be either active or passive [1] depending upon the source of energy and radio communication [2] between a reader and tag. The main advantages of passive RFID systems over active are the lower costs, smaller sizes, and longer life-spans. This comes along an issue of firstly issues with energy collection via the process of backscattering [3]. A tag has to be in the reader's read range for enough time to allow energy collection and induce enough current for the tag IC to 'wake up'. This *waking up* is associated with the tag chip being active to transmit the unique ID number stored to a reader antenna. The second issue with regards to passive RFID is that a tag's antenna has to be at parallel orientations and not perpendicular to the reader antenna for a read.

Advantages of RFID have made interest in the research and industrial communities to develop applications in almost all fields. One such potential usage has been for localization or positioning of objects and personnel for indoor environments [4, 5]. Many techniques, methodologies, and algorithms [6] have been proposed and implemented using active RFID systems. Position estimating methods using a probabilistic approach have been proposed in [7-9] using the Bayesian estimation. These and traditional positioning approaches use a constant transmission power of RFID readers. In this paper we propose to use the multi-sensing-range [10] ability of an RFID reader to locate an unknown tag.

Passive RFID systems in particular have been deployed and used through typical positioning techniques [11]. These include trilateration or triangulation, scene analysis, Received Signal Strength (RSS), and Time-of-Arrival (TOA) [11], etc. Angle-of-Arrival (AOA) technique is used to estimate angles of unknown tags that determine their unique location on a reader's read circle in our approach. In this paper the localization algorithm for positioning of passive UHF Generation 2 RFID tags is presented. The localization methodology proposed in this paper is targeted towards applications in complex designed buildings where localization accuracy to a few meters is acceptable.

2. Proposed Algorithm

The working of the algorithm [12] is such that, as a first step, it takes into account the deployment scenario. The number of reference and tracking tags are found out from the RFID readers' read range. The tags with known and

978-1-4244-6051-9/11/$26.00 ©2011 IEEE

predefined IDs and location points are considered as the so called *reference tags*. The remaining tags with unknown IDs (Default code by vendor) are considered as the tracking tags.

The idea for deployment is to have a number of passive UHF RFID tags as the reference tags that are laid out to form a 2-Dimensional grid (Fig. 1). The empty space between these reference tags (1m apart) is to place tracking tags or RFID readers, depending upon the design of a particular deployment. Because each deployment can be in a different size of area with a unique environment that can vary the number of tracking tags, certain reference tags can be neighbours to a particular tracking tag. Neighbours would be the tags considered to lay close enough to a certain tracking tag. More neighbours of a tracking tag can offer greater positioning accuracy, as their information would contribute to the tracking tag's final position calculation.

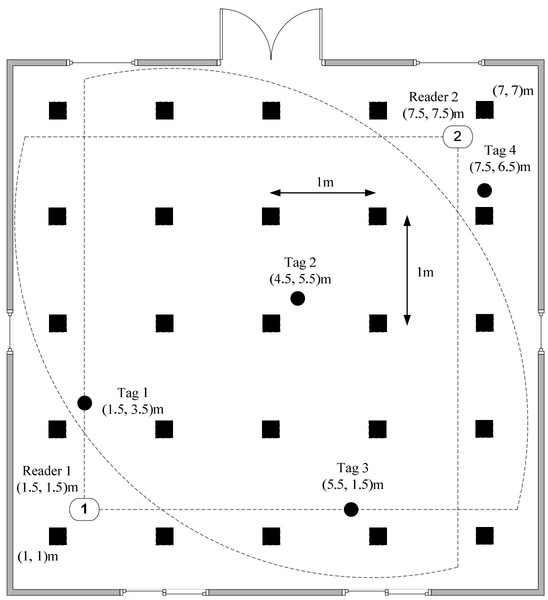

Figure 1: Indoor localisation setup environment for a reference tag grid

2.1 Calculating Distances and Angles

Figure 2 shows a possible arrangement of a tracking tag (T) with four other reference tags (R_1, R_2, etc.) and an RFID reader (R). Two of the four reference tags, i.e., R_1 and R_2 are shown to make angles with the tag, T. Firstly, the distances D_{R1} and D_{R2} and angles, θ_{R1} and θ_{R2} between each reference tag placed at (x_{R1}, y_{R1}) and (x_{R2}, y_{R2}) to the reader at (x_r, y_r) are calculated, respectively.

$$D_{R1} = \sqrt{(x_{R1} - x_r)^2 + (y_{R1} - y_R)^2} \text{ (1) and } \theta_{R1} = \tan^{-1}\left(\frac{y_{R1} - y_R}{x_{R1} - x_R}\right) \text{(2)}$$

For simplicity, equations (1) and (2) give the distance and angle values for reference tag R_1, respectively. Similar, equations and discussions hold valid for all other reference tags. These are the reference tags that would lie in the read range vicinity of readers upon interrogation and would be considered one after another by the respective reader. From figure 2, R_1 and R_2 form two triangles, T_1 (R_1-T-R-R_1) and T_2 (R_2-T-R-R_2) with respect to the tracking tag, T and the RFID reader, R which will be discussed later.

As a second step, calculations for angles A_{R1} and A_{R2} are done using the concept of Angle-of-Arrival (AOA) and spherical coordinates [13]. This is done assuming a 0^o reference vector pointing north. *AOA is defined as the angle between the propagation direction of an incident wave and some reference direction known as orientation* [14]. Orientation is the fixed direction against which the AOAs are measured. It is represented in degrees in a clockwise direction from the North [14]. If the orientation is 0^o (North), the AOA is absolute, otherwise, relative. We calculated angles A_{R1} and A_{R2} for reference tags, R_1 and R_2, respectively using orientation (incident projection from the reader).

This is based upon considering which semicircle (assuming a perfect circle) of the reader's read range a tag lies in. If a tag lies in the upper semicircle (i.e., 0 to π), the angles, A_{R1} and A_{R2} calculations are made in anticlockwise directions; contrary to this, if a tag lies in the lower semicircle (i.e., π to 2π), the calculations are made in a clockwise direction. Besides the dependency of semicircle and north facing reference vectors to calculate A_{R1} (and A_{R2}), the sign of calculated θ_R is also important such that. A thing to notice here is that the algorithmic calculations are all made in radians (π), only the north pointing reference vector is considered to be in degrees for explanation purposes.

If θ_{R1} is positive, then $A_{R1} = \theta_{R1} - \pi$, (3), else, if θ_{R1} is negative, then $A_{R1} = \theta_{R1} + \pi$, (4)

Because the tracking tag's position is unknown, the distance between each tag and a reader is calculated initially estimating its possible position. This is done using the multi-sensing-range of RFID readers through which different reading levels can be achieved. This essentially means adjusting the readers RF transmission power at different watts to get different reading power. If a reader detects a tracking tag (from vendor-based format of the tag ID) to be inside the read range, it will decrease its read range one step (typically by a 100 mW step) by reducing the RF emission power. After a step decrease, the reader will again try to detect the tracking tag, if detected so, the read range is decreased a step further. This continues until the tracking tag is not detected anymore. At this point, the RF power is now increased a step until the tag is detected again; this value of the RF power is noted and is considered as the initial estimated position of tag T. The radius of the read range circle (ideally) at this RF power level is the distance, D_T between the tracking tag at (x_T, y_T) and the RFID reader at (x_r, y_r).

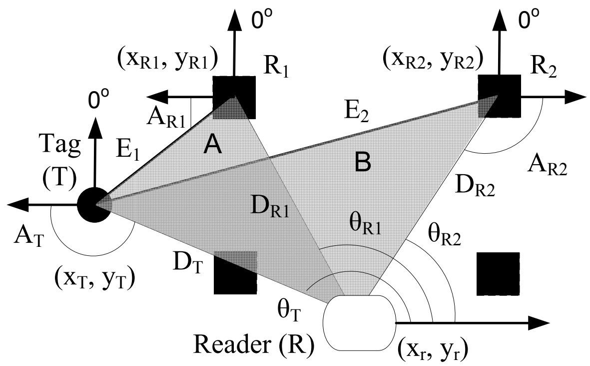

Figure 2: Logical and mathematical parameters of calculation

Angle, A_T for the tracking tag is possible to be calculated similarly to that of A_{R1} and A_{R2} using spherical coordinates with a 0^o north reference vector. Once A_T is known, the projection angle, θ_T between reader projection and the normal plane (figure 2) can be found using similar rules as those with θ_R, such that;

If A_T is positive, then $\theta_T = A_T - \pi$, (5), else if, A_T is negative, then $\theta_T = A_T + \pi$ (6)

The estimated position for tag, T is based on assuming a perfect circle of the reader's read range; it is thought to be constant throughout. Surely, practically this will not be the case and would be a distorted shape depending upon antenna gain, attenuation, and other environmental and physical factors. Knowing the estimated circle boundary on which a tracking tag, T may lie is not enough to compute its final position. Angle, A_T is useful to be known as each angle value corresponds to a unique position on the circle circumference at a specific read range. After θ_T and θ_R, the difference between the two, namely φ (phi), the modular difference of the two angles can be found as;

$$\varphi_1 = absolute(\theta_{R1} - \theta_T) = |\theta_{R1} - \theta_T| \quad (7)$$

2.2 Law of Cosines

As mentioned earlier, from the arrangement of R_1, R_2, T, and reader R in figure 2, two triangles T_1 and T_2 are formed. Considering one tracking tag at a time, each would form similar triangles with all the detected reference tags one by one with one reader at a time. Triangle, T_1 for instance has the sides, D_{R1}, D_T, and E_1. D_{R1} and D_T are the linear distances from R_1 and T to reader, R, respectively. E_1 is the linear distance between tags R_1 and T. In calculating the final position of the tracking tag, *E* distance values are important as they give a measure of how close a reference tag lies to a particular tracking tag. The closer a reference tag, the more weight value (discussed later) it will be assigned with towards computations for final position of a tracking tag. These E values are computed using a trigonometric postulate of geometry called the law of Cosines which states that; "*In a triangle, if two sides and the angle opposite to the unknown side are known, then the unknown side can be found out*" [15].

$$\text{i.e., } c = \sqrt{a^2 + b^2 - 2ab\cos(\gamma)} \text{ (8)}, \ E_1 = \sqrt{D_{R1}{}^2 + D_T{}^2 - 2D_{R1}D_T\cos(\varphi_1)} \text{ (9)}$$

Equation (8) holds for any triangle a-b-c-a with a known angle, γ. Mapping this to the situation in figure 2 say for E1, equation (9) would hold true. If there is a total of *n* number of reference tags, *n* such triangles (T_1, T_2, …, T_n) would be formed with *each* of the tracking tags, corresponding to a total of E_n values. Therefore, each out of a total of *m* tracking tags would have a set of *n* values of E, as; $E_{T1}=\{E_1, E_2, …, E_n\}$, $E_{T2}=\{E_1, E_2, …, E_n\}$, …, $E_{Tm}=\{E_1, E_2, …, E_n\}$. Each value of E in sets of $\{E_1, E_2, …, E_n\}$ are different when computed for each of *m* tracking tags (E_{Tm}). After knowing all the above parameters, the final position for a tracking tag, T can be computed using equation (10). In (10), *w* is the weight assigned to each of the reference tags and j=1, 2, 3, …, *m* is the total number of tracking tags to be tracked. Weight, *w* depends upon how close a reference tag lies to a particular tracking tag. It can be calculated through different methods [6]. We use the formula in Eq. (11) which takes into account all reference tags detected to calculate *w* for a single reference tag repeatedly for every tag.

$$(x, y)_{Tj} = \sum_{i=1}^{n} w_i(x_i, y_i) \text{ (10)}, \ w_i = \frac{1/E_i^{\,2}}{\sum_{i=1}^{n} 1/E_i^{\,2}} \text{ (11)}$$

3. Simulation Positioning Results

As mentioned earlier, it is important how many reference tags are close to a tracking tag as its neighbours. More the neighbours to a tracking tag, better the accuracy in positioning as the assigned weight, *w* to each contributes in calculations. Also from figure 1, it is apparent that the distance between reference tags is also important for accuracy of results. For results, we carried out test simulations at different placements of reference tags ranging from 1m to 7m (2m spacing shown in figure 1). This inter-spacing between reference tags is the so called as *spacing*, S. Spacing at 1m is expected to have the greatest accuracy as the reference tags are closest (considering no placements at 0.5 of a meter). Calculated positioning coordinates and respective error by readers are given in table 1.

Table 1. Actual vs. Calculated positions with errors

Actual Position	Calculated Reader 1	Error1	Calculated Reader 2	Error2
(1.5, 3.5)	(2.69, 3.57)	1.1996	(2.45, 4.05)	1.1010
(4.5, 5.5)	(4.48, 5.22)	0.2783	(4.52, 5.39)	0.1089
(5.5, 1.5)	(5.25, 2.15)	0.6925	(5.32, 2.21)	0.7328
(7.5, 6.5)	-	-	(6.99, 6.59)	0.5138

5. Conclusion and Future Work

A potential usage of the technique is in complex multi-storey car parks to locate and identify cars that have been parked but location has been forgotten. In hospitals, to locate doctors, nurses, or important medical equipment in case of emergencies is another potential use case scenario.

The approach presented is supported by simulations at different inter-reference tag spacing, S of 1-7m. Average mean error in positioning is seen to decrease from 3.41m to 0.61m due to a decrease of distance, S between reference tags. However, essential advantage of the proposed algorithm can be seen and demonstrated in a practical deployment. This would involve considering physical environmental factors such as signal degradation, interference, multi-path fading, and the dynamic deployment environment.

6. References

1. Student Handbook, CompTIA RFID+ Certification Training, RFID4U
2. S. Shepard, "RFID (Radio Frequency Identification)," New York: McGraw-Hill, pp. 40-45, 2005.
3. D. Dobkin, "The RF in RFID, Passive UHF RFID in Practice," Newnes, Elsevier, 2008.