RFID Reader Localization Using Passive RFID Tags

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Abstract: **This paper describes an indoor wireless localization method of an RFID reader using passive tags placed at known locations. The reader location is estimated using the received signal strength indication (RSSI) and trilateration. However, in an indoor wireless environment, the RSSI undergoes fading due the presence of unavoidable scatterers. Hence, trilateration under such fading environments would cause errors in localization. In this paper, we examine techniques to reduce the error of the estimated reader positions.**

Index Terms — **RFID reader, passive tags, localization, received signal strength indication RSSI, shadow fading.**

I. INTRODUCTION

Currently indoor geolocation is attracting considerable attention not only for the localization of specific tagged items and containers in a warehouse but also to help to track, locate and navigate elderly and people with special needs who may be located away from visual supervision. The well known method of localization using the Global Positioning System (GPS) suffers from great signal attenuation when operating in indoor environments making this technology not practical for indoor environments [1, 2]. An alternative solution to overcome such limitation is therefore necessary. Various techniques have been proposed to compliment the GPS problem and some of the proposed solutions work independently even without GPS [1-4]. The other types of localization methods in use are ultrasonic, infrared, visible light cameras etc in addition to wireless LANs. Recently use of RFID as an aid for localization is gaining momentum [3]. It must be remembered that depending on the nature of the application, each technique offers certain advantages as compared to the others, and therefore no one technique has all the desired features.

One of the key reasons that localisation and navigation using RFID is becoming attractive is due to its lower cost of deployment and its suitability for indoor and built-up environments. RFID performance can also degrade due to interference which has similarities with other wireless communication systems. Hence, various approaches that have been developed and used in wireless communication systems can be tailored and employed for RFID [2, 5]. In addition, the developments in computer and VLSI technologies are making implementation of new algorithms feasible and practical for emerging RFID systems.

In RFID localization, the object to be tracked can be a tag or a reader, and the objects can be either static or moving. A number of works are available in the literature that consider localisation with RFIDs, however, most of them considered localization of static objects with tags placed on them for identification[1, 6]. Development of techniques of localisation or navigation of moving objects is very important. Most of the existing research on this type of application using RFID considers localising or tracking moving tags. In certain applications that require self localisation of people with special needs, it would be helpful to localise an RFID reader as carried by the person. This paper examines some simple methods with an aim for a low cost dynamic self localization using a single reader in an indoor environment where passive tags are placed everywhere. In our work a reader is the object to be localized and passive tags are placed at known locations which are stored in the reader's computer.

Proper selection of RFID systems is essential to ensure the proposed system is practical and affordable. Typical RFID system consists of a reader, tags and a computer that holds a database of tag information. In general, RFID tags can be classified into active and passive tags. Tags equipped with battery are active tags and tags without battery are called passive tags. Systems targeting low cost solution would use passive tags instead of active tags.

Another important factor in choosing RFID is its interrogation range. The range of an RFID interrogation is determined by the power transmitted and the carrier frequency used. Carrier frequencies for RFID are grouped into low, intermediate, high and ultrahigh frequency bands. Having wider interrogation coverage would not only reduce complexity of tag placement but also reduces the number of tags required per unit area for localization. The most practical frequency bands for long range are UHF 850-950 MHz and 2.4-5.8 GHz. For indoor environments, the UHF band is normally used. Hence, RFID with UHF band is considered for this study.

A. RFID Localization

RFID localization can be categorized in three groups; distance approximation, scene analysis and proximity. In this system we use distance approximation derived from RSSI to predict reader position.

Rough estimation of RFID reader location can be easily determined by acquiring IDs of nearby tags and retrieving their positions from the stored database. RFID database is used to store additional information such as tags positions,

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thus allows fast interrogation between reader and tags. This small fraction interrogation time makes dynamic RFID tracking possible.

More accurate reader position can be obtained by extracting additional information from reader-tag interrogation signal. The necessary localization parameters such as reader-tag separations can be obtained by exploiting this signal. Methods such as angles of arrival (AOA), received signal strength indication (RSSI), carrier signal phase arrival (POA) and time of arrival (TOA) are among the possible techniques that can be used to obtain reader-tag separation[1, 3]. In this study, we consider the simplest method with least computational burden using RSSI. Although the RSSI method suffers when operating in a cluttered environment, it is however relatively reliable and practical for localization application where the line of sight between reader and nearby tags is always available. This is realized by placing tags with 3-5 meters separation and the reader antenna is positioned at a higher elevation on the moving object. This simple arrangement gives better correlation between RSSI and propagation distance offering low computational complexity making it feasible for low cost application.

In this paper, RSSI method is used with trilateration to localize a single reader in indoor environments with the purpose of navigating object from one location to another location. Errors due to fading and shadowing effects are minimized using averaging technique and the reader position is approximated using simplified trilateration. The effectiveness of the proposed approached is examined using computer simulations. The remainder of this paper is organized as follows. In Section II, components of reader localization algorithm are discussed. It then followed by Section III, describing simulations and results. Finally conclusions are given in Section IV.

II. READER LOCALIZATION

The aim here is to localize the reader and navigate it by using RFID. The RFID reader is assumed to be carried by an object that can move, and passive tags are arranged in such a way that the area to be covered is within the interrogation range of RFID reader-tag as shown in Figure1. The proposed localization process consists of finding euclidean distance from RSSI, estimating the current position using signal from near by tags, determining reader orientation, and finding a close point to the desired path leading to the destination. The algorithm combining all the above localization components is shown in Figure2. These are discussed in the following subsections.

A. Distance approximation

Euclidean distance 'D_i' between reader and tag can either be approximated using RSSI measured at RFID tag or at the reader itself. RSSI obtained from the first approach involves only downlink hence Friis transmission equation can be directly used to approximate the distance 'D_i'. This approach however requires additional features at the tag to allow RSSI to be measured and retransmitted to the reader. The latter method on the other hand is fairly simple where it does not require any tag modification. It however requires uplink and downlink channels to be included in approximating the distance 'D_i'. Here, we use the second method to approximate 'D_i', the propagation model for this case is shown in (1) [1, 4].

$$P_i = \alpha - 10\beta \log(D_i) - X_\sigma (dB) \qquad (1)$$

P_i is power at distance D_i, β is path loss exponent varies for different propagation environments. The term X_σ follows lognormal distribution representing fading and shadowing effects with variance 'σ^2_{dB}'. The term α can be calculated as;

$$\alpha = 10\log\left(P_t G_t G_r \left(\frac{\lambda}{4\pi D_0}\right)^4 (g_t \Gamma g_r)\right) \qquad (2)$$

P_t is the reader transmitted power, G_t and G_r is transmitter and receiver antenna gain respectively, $(g_t\Gamma g_r)$ is defined as the function of radar cross section 'κ'with wavelength 'λ' that is $(g_t\Gamma g_r) = 4\pi\kappa/\lambda^2$ [4]. In this study the reference distance D_0 is taken at 1m, and β *is* chosen for indoor with soft partition environments [5]. The Euclidean distance D_i is obtained by using (1) and (2), the relation of this distance to the RSSI is shown in (3):

$$D_i = 10^{\left(\frac{\alpha - \overline{RSSI}}{10\beta}\right)} \qquad (3)$$

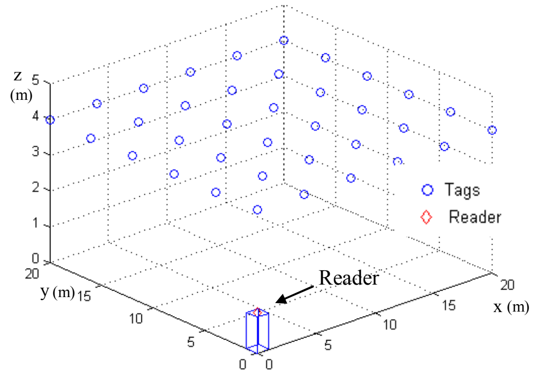


Figure1: Tags arrangement

B. Position Estimation

With a set of given distances and known tag locations, reader position can be predicted using trilateration. A new coordinate reference is introduced so the referred tags fall on a common plane z'. With this arrangement a simple trilateration equation as shown in (4) can be used.

$$(x'_Q, y'_Q, z'_Q) = \left(\frac{r_1^2 - r_2^2 + d^2}{2d}, \frac{R_1^2 - R_2^2 + f^2}{2f}, \sqrt{R_1^2 - \left(\frac{R_1^2 - R_2^2 + f^2}{2f}\right)^2}\right) \qquad (4)$$

Where;

$$R1 = \sqrt{r_1^2 - \left(\frac{r_1^2 - r_2^2 + d^2}{2d}\right)^2} \qquad R2 = \sqrt{r_3^2 - \left(\frac{r_1^2 - r_2^2 + d^2}{2d} - e\right)^2}$$

'r_i' represents euclidean distances between reader and the tags, the parameter 'd', 'e', and 'f' are displacements between tags as seen on the z' plane. The trilateration result obtained from the above equations is then transformed back to original reference by typical translation and rotation operations.

C. Error Minimization

Under ideal conditions, the trilateration given in section *(B)* gives explicit positions of the tracking object. Unfortunately in practice this is not always the case, since fading and shadowing interfere with RSSI and cause the expected position to vary from the actual location. This error can be minimized in several ways namely using probabilistic approach, Kalman filtering, and multi-sensor fusion etc [1-3]. However these methods can be quite complex requiring high processing power.

In this study a simple method based on changing power level is employed [7]. Here we employ radiation of two power levels to improve RSSI estimation, but with additional modification to cater for both uplink and downlink channels. This method uses the fact that at any instant RF signal propagates through the same channel therefore the signal possess similar path loss characteristic for both high and low power signal levels. This characteristic is used to discriminate the RSSI as given by

$$P_{rH} - P_{rL} \equiv P_{tH} - P_{tL} \equiv C_{HL} \qquad (5)$$

Where 'P' represents power, the subscripts '$_r$' and '$_t$' represents transmitting and receiving components, '$_H$' and '$_L$' indicates high and low power level respectively. The term 'C_{HL}' is a constant obtained from the measurement.

To further improve the RSSI estimation, a time averaging filter is employed. This error reduction technique involves simple computations thus deemed suitable for a system that is targeting a low cost solution.

III. SIMULATION

Tags are arranged with a separation of four meters as shown in Figure1. This separation distance is within UHF RFID communication range where the reader is still able to communicate at least with three tags. The reader antenna is positioned at an elevation side of the object in such a way there exists line of sight to the nearby tags. The reader is localized quasi dynamically where in every short time interval the reader acquires tags' IDs and records the associated RSSI, 25 samples of RSSI is taken for every tag.

The interference due to fading and shadowing is included as explained in section *(A)*. A typical value of 3dB standard variance is used in these simulations, this value is also been used in other literature [6]. Parameters in the transmission equation are calibrated prior to reader localization. For the calibration all the RFID tags are assumed to be placed at known positions. A known path with a known step size is used during this calibration process.

Reader position is estimated using (4). Trilateration parameters such as euclidean distances and its references are obtained from (3) and the database respectively. In this study we do not consider collision effects. We assume that the reader moves with a constant speed and follows a predefined path. At every time interval the reader position is estimated and the new direction is computed. The object carrying the reader is assumed to move at an average speed of 1.5m/s. A series of simulations were conducted to evaluate the proposed algorithm, and the results are explained in the next section.

A. Results

Root mean square error (RMSE) was used to quantitatively evaluate the proposed system performance. The simulation results are depicted in Figure3. By just using simple trilateration the resulting RMSE was 40cm, this error is reduced by 50% to 20cm when the time averaging filter is applied. This value is comparable to the others reported works, which ranges from 13 to 150cm RMSE [1, 3, 6]. The two power levels method was found to provide stable RSSI resulting better localization estimation.

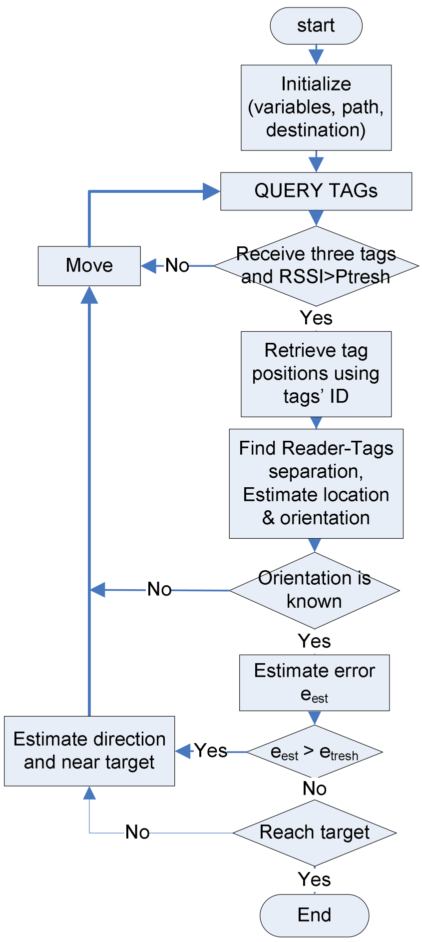
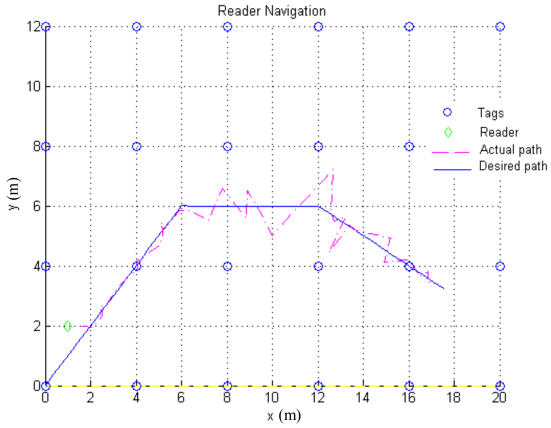
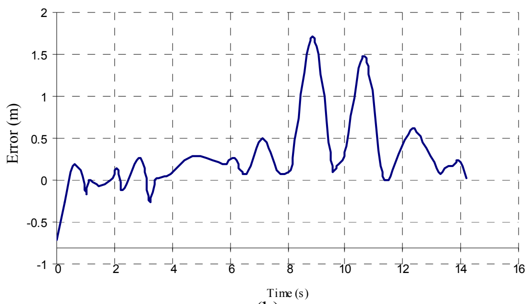


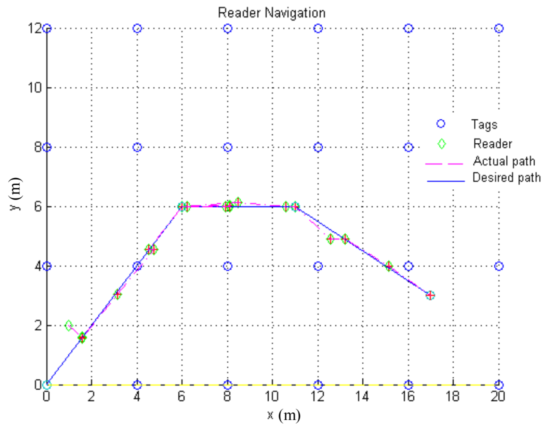
Figure2: Localization Algorithm



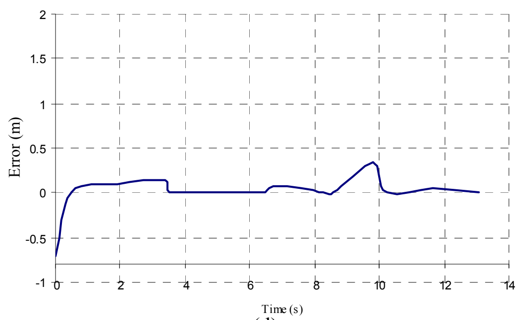
(a)



(b)



(c)



(d)

Figure3: Navigation comparison (a) By just using trilateration, (b) Its tracking error, (c) By applying simple error reduction, and (d) Its tracking error.

VI. CONCLUSION

A low cost indoor localization using single reader with passive tags for indoor environments is presented. The proposed system uses backscattered signal from passive tags to estimate reader position. The proposed algorithm involves the simplified trilateration with the time averaging filter that requires less computational power. The proposed approach is cost effective and could be used as an alternative solution for the conventional localization.

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