

Indoor Localization System Based on Passive RFID Tags

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Abstract — In this paper, we present a low-cost localization system using UHF RFID passive tags in indoor environment. This system can be applied to locate objects or people in an unfamiliar building. Landmark reference tag grid is used in our system. The tag RSSI (Received Signal Strength Indication) is the main input value for our improved K nearest neighbor algorithm. Path Loss models for an indoor environment are also analyzed. The error map and the accuracy of the reference positions are constructed through the Path Loss model for helping to choose corresponding K reference positions.

Keywords-Passive tag; indoor localization; propagation model; K nearest neighbor algorithm; received Signal Strength Indication; UHF RFID

I. INTRODUCTION

Currently, indoor localization is paid more attention for locating items in a warehouse or helping to navigate elderly people and customers who may be located away from visual supervision in an unfamiliar building [1]. Accuracy and reliability as well as estimation speed are the key issues for an indoor localization system. The well-known technique of outdoor localization is the Global Positioning System (GPS). The primary drawback of GPS is GPS signals blocked completely or too weak to be received in indoor environments [2]. To overcome these limitations, various technologies have been proposed and evaluated such as ultrasonic, infrared, computer vision and radio frequency (RF) - based technologies including RFID (Radio Frequency Identification), wireless LANs. Recently, RFID technology is a solution with advantages of resolution of position estimation and cost of system installation [4-8]. The UHF band is normally used in RFID localization system [2], [5-6]. It causes that our system is focused on UHF band.

Typically, a RFID system consists of a reader, tags and a computer that holds and processes the tags information. In general, RFID tags can be classified into active, passive and semi-passive tags. Active tags embed an internal battery which continuously powers themselves and their RF communication circuitry. Readers can thus transmit very low-level signals, and the tag can reply with high-level signals. Tags without battery are called passive tags. Generally, it backscatters the received carrier signal from a reader. Passive tags have a smaller size and are cheaper than active tags, but have very limited functionalities. The third type is semi - passive tags. These tags communicate with the readers in the same way as passive tags but they embed an internal battery that constantly powers their internal circuitry.

Low cost systems usually use passive tags instead of active tags [9].

In complex environments, there are factors as severe multipath, low probability for availability of line-of-sight (LOS) path, and specific parameters such as floor layout, wall, moving objects, and numerous reflecting surfaces, hence, it is not easy to simulate the radio propagation in an indoor environment. The important target is to build higher quality database, which is presented in more detail and compared in the result part. This paper is organized as follows. After discussing related work, we present path loss models for indoor environments. Then we describe how to determine the location of target tags using the improved K - Nearest Neighbor algorithm. Finally, the experimental part presents data collection methods, data processing steps and localization results.

II. RELATED WORK

Depending on the application and the context, there are several configurations for the RFID localization system setup. It can be classified into two configurations: objects are mounted and moved (1) with reader, noted by RTm; or (2) with target tags, noted by TTm. Our work is focused on the second configuration with one fixed reader antenna and passive reference and target tags. Some previous researches using (2) configuration are resumed in the Table I.

TABLE I. PREVIOUS RESEARCHES

Reference /Time	Hardware	Method	Tag type/ $r(cm)$	Error
[7]/2003	9 tags/ 2 antennas	+Landmark	Passive/30	60cm
[8]/2008	374tags/4 antennas	snapshots + "fingerprinting+ filter	Passive/20	20 - 26cm
[9]/2009	198tags/1 antenna	Landmark	Passive/34	<10cm
[10]/2011	>36 tags/4 antennas	Landmark	Passive	<10%
[11]/2011	100 tags/4 antennas	Trilateration+filter+fuzzy logic	Passive/ 30	14cm.
[12]/2011	1 object/2 antennas	Landmark	Passive/<10	<10cm
[13]/2011	30/1 antenna	Hybrid = WCL + Pratical	Passive/ 27	<10cm
[14]/2011	9 antennas	PassTrack model	Passive/60	30cm

r : distance between two nearest reference tags

Results in [9 - 10], [12 - 13] obtained a localization error of around 10cm, but these systems are arranged with large number of antenna and reference tag. The system in [7] used only 9 passive tags and two antennas ($r = 30cm$), but the obtained localization error is 60cm. Our work is focused on a low-cost system using smaller number of passive tags and only one antenna reader with a good localization error. This system will be presented for more details.

III. LOCALIZATION ANALYSIS

The localization system includes passive reference tags and one fixed reader, locating object is mounted a mobile tag. Information of tags is stored in a profile including number, ID, collection time and Received Signal Strength Indication (RSSI) value of collected tags. Based on these data, the Path Loss is used to construct an error map for all reference positions. Then, this error map and calibrated RSSI values are applied in an improved KNN method to locate object coordinates. In this part, there are two basic concepts applied: Path Loss (PL) models and K nearest neighbor (KNN) algorithm.

A. Path Loss Models

The major model is free space Radio Wave Propagation (RWP) model released following the Friis propagation equation [15]:

$$P_r = \frac{P_t g_t^2 \lambda^2 \sigma}{(4\pi)^3 d^4} \quad 2.1$$

Where, P_t is the transmitting power value from a reader; P_r -the receiving power value from a tag; g_t -transmitting antenna gain; λ -the wave length at UHF frequency; d -the distance between transmitting and receiving antennas; σ - radar cross section of a tag (RCS) depending on characteristics of tag [16]. The RCS tag must be calculated exactly before estimating the power backscattered from this tag.

According to the practical experiments of previous researchers, the RWP model has changed into an approximately linear Log–Distance form [17 - 18]:

$$PL = PL_0 + 20n \log d \quad 2.2$$

In formula (2.2), PL_0 is the losses calculated in the building for a reference distance (usually 1m); PL - the losses calculated for a distance d ; n - a PL exponent. A popular technique for determining coefficients PL_0 and n is named Ordinary Least Squares (OLS). Values of PL_0 and n are chosen to minimize the sum of squared residuals. PL equation is constructed to obtain features: the regression

standard error - $\hat{\sigma}$ and the “good of fit” - R^2 . There are two equations for calculating these values:

$$\hat{\sigma} = \sqrt{\frac{SSR}{n-2}}, \quad R^2 = 1 - \frac{SSR}{SST} \quad 2.3$$

Where, SSR is the Sum of Squared Residuals, SST is the Total Variation – Total Sum of Squares.

Regression Standard Error $\hat{\sigma}$ shows the data change level. R^2 is a more standardized statistic, which also gives a measure of the “good of fit” of the estimated equation with value ranging $0 \leq R^2 \leq 1$. The value $R^2 = 1$ is a “perfect score” that is obtained only if data points lying exactly along a straight line.

B. K - Nearest Neighbor Algorithm

The second concept is KNN algorithm that is a non-parametric method for classifying objects based on K nearest training samples [19]. Reliability and accuracy of this algorithm are dependent on Weighting Centroids of each reference point K_i . In this study, two weighting factors are proposed, named w_{PL_i} and w_{D_i} . The factor w_{PL_i} indicates the discrepancy of path loss values, which is inversely proportional to the discrepancy [20].

$$w_{PL_i} = \frac{\sum_{j=1}^K |PL(T) - PL(R_j)|}{|PL(T) - PL(R_i)|} \quad 2.4$$

Where $PL(T)$ and $PL(R_i)$ are the path loss values of target position and reference position i (with value i from 1 to K).

The weighting factor w_{D_i} is a function related to the reliability of the chosen reference position i , which is also inversely proportional to the estimated distance error ΔD_i . From the PL equation, ΔD_i error level of each reference position i is calculated by expression $|d_{estimated_i} - d_{actual_i}|$. Thus, w_{D_i} is given by the following formula:

$$w_{D_i} = \frac{\sum_{j=1}^K \Delta D_j}{\Delta D_i} = \frac{\sum_{j=1}^K |d_{estimated_j} - d_{actual_j}|}{|d_{estimated_i} - d_{actual_i}|} \quad 2.5$$

In above formula, $d_{estimated_i}$ is an estimated distance of reference position i ; d_{actual_i} is an actual distance of reference position i .

Then, an assorted weighting centroid is suggested with expression $W_i = w_{PL_i} * w_{D_i}$; finally, this coefficient is transformed into below form:

$$\bar{W}_i = \frac{W_i}{\sum_{j=1}^K W_j} \quad 2.6$$

Therefore, the target position with coordinates $(x_{\text{target_position}}; y_{\text{target_position}})$ is given by [20 – 21]:

$$x_{\text{target_position}} = \sum_{i=1}^K \bar{W}_i * x_i; y_{\text{target_position}} = \sum_{i=1}^K \bar{W}_i * y_i \quad 2.7$$

There is an important problem appeared in considering the number of these appropriate reference positions (value K). According to practical experiments, a small value K causes many noises influencing on results; while, a large value K increases computation time and volume. Therefore, finding relevant value K is quite important and difficult. A simple and conventional approach to select K is setting $K = \sqrt{m}$ (m is a reference tag number on the experimental table) [22].

IV. EXPERIMENTS AND RESULTS

As we mentioned above, the UHF (860-960 MHz) band is recommended for an indoor localization system. At this band frequency, passive tags AD – 222 of Avery Dennison and RFID Thingmagic 6e reader are used to reduce the system-cost [24]. In addition, the Reader can read any EPC Class 1 Generation 2 tag and communicates information to a host computer through a USB port. An antenna 865 – 956 MHz MT – 242025/TRH/A with a gain of 7dBi at 868MHz [23] is used for the RFID reader. The performance of these kinds of tag, reader and antenna is described in [23-24]. These experiments have been conducted after implementing some other experiments in [25].

A. Localization System Setup

1) Reference tag grid

Passive tags AD222 with size of 10cmx1cm are attached to a wood bar which is stood on the table. The system setup is based on the Landmark model with modified features to fit actual conditions [20]. The grid size is 30cmx30cm (larger than $\lambda/2$) to reduce signal interference caused by tags on the experimental table [20], [24]. The table has a size of 180cmx90cm; therefore, it is divided into small 28 regions. Each region has one reference position. Thus, the tag grid includes 28 reference positions. Target positions are distributed randomly in this tag grid. The experimental setup is shown in the Fig 1.

2) Antenna and reader positions

Experiments are implemented in a room with a lot of electrical equipment around. Tags are faced directly to the face of reader antenna. The reader antenna with size of 19cmx19cm is fixed at distance of 1m from the table (Fig. 1).

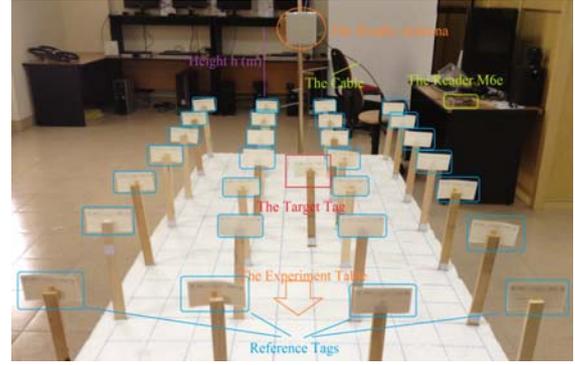


Figure 1. Experimental Setup

B. Measurement and localization Results

1) RSSI collection

In each database, RSSI value of tags is collected at a fixed antenna position. An acceptable orientation of antenna is the position of reader antenna that can detect more than 20 tags. A database collecting process has the following measurement steps:

The first step is to collect the data of all reference tags. Each measurement time runs for 30 seconds and is repeated 10 times. A failed reference node has read time below than six times.

The second step is to collect the data of target positions. At this time, the table has 29 tags (28 reference and one target tags). Each target position is measured 10 times like reference positions. This process total is done systematically from the first target position to the last target position.

Next measurement processes with remaining reader antenna positions corresponding to remaining databases are gone again.

2) Measurement Results

As above presented parts, the interference between tags on the experimental table affects too much the stability level of collected data, especially in the case having 28 reference tags on the experimental table. It means the greater the tags number is, the worse the stability of direct collected databases is.

There are 5 databases collected with following features:

TABLE II. COEFFICIENTS OF DATABASES IN EXPERIMENTS

Number	α (°)	h (cm)	R^2	δ (dBm)
1	20	133	0.28	3.72
2	20	143	0.43	3.33
3	20	129	0.31	3.84
4	20	141	0.45	3.24
5	15	138.5	0.42	3.45

h : height of reader antenna ; α : angle of reader antenna;
 δ : standard error; R : coefficient "good of fit"

All databases have small value coefficient “good of fit” R^2 and large value standard error $\hat{\sigma}$ indicating large data change level.

In our previous study on [25], to reduce interference effects, we use only one tag moving through all positions on the experimental table; hence, the challenge at that case is to find a good orientation of the reader antenna. However, in this case, when installing all reference tags on the experimental table, finding the good orientation is difficult and consumes a lot of time. Therefore, we must calibrate all data before positioning objects. The below part is going to describe how to calibrate collected all data.

3) Data processing for reference positions

After receiving all data, the collected data from all reference tags is calibrated according to the Bilinear Interpolation method [26]. For example, a reference tag is located in center of four nearest reference positions as following figure:

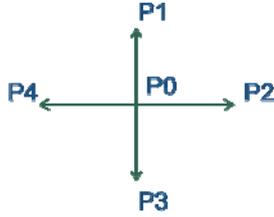


Figure 2. Bilinear Interpolation Model for Position P_0

In this case, calibrated RSSI value of center reference position is the average value of these nearest reference positions. It means:

$$RSSI_{P_0} = \frac{RSSI_{P_1} + RSSI_{P_2} + RSSI_{P_3} + RSSI_{P_4}}{4} \quad 3.1$$

After calibrating data for all reference positions, new databases are built. The different stability between the direct collected databases and calibrated databases is shown in the table III. The “good of fit” – R^2 and the standard error having acceptable values, calibrated databases are much better in quality than direct databases. Besides, any calibrated database can be used to locate objects; hence, time and energy to search the best orientation for the reader antenna are saved.

TABLE III. COEFFICIENTS OF DIRECT AND CALIBRATED DATABASES

Number	α ($^\circ$)	h (cm)	Using direct data		Using calibrated data	
			R^2	$\hat{\sigma}$ (dBm)	R^2	$\hat{\sigma}$ (dBm)
1	20	133	0.28	3.72	0.74	1.05
2	20	143	0.43	3.33	0.81	1.03
3	20	129	0.31	3.84	0.74	1.16
4	20	141	0.45	3.24	0.81	1.05
5	15	138.5	0.42	3.45	0.69	1.70

h : height of reader antenna ; α : angle of reader antenna;
 $\hat{\sigma}$: standard error; R : coefficient “good of fit”

4) Data processing for target positions

In the one hand, all data for reference positions is calibrated as presented above. In the other hand, the data of target positions is also calibrated. This calibrated path loss amount is shown in the expression below:

$$\Delta PL_i = PL_{i_direct_data} - PL_{i_calibrated_data} = f_i(d) \quad 3.2$$

The estimated distance d from direct PL equation is inserted into Equation (3.2) to calculate ΔPL_i amount, with:

$$\text{Log}(d) = \frac{PL_{direct_data} - PL_{o_direct_data}}{20 * n} \quad 3.3$$

After all calibration steps are completely performed, we have new and stable values of data for positions.

C. Localization steps

The last process is to locate target positions. For example, the target position P_i is estimated following steps [7]:

- Estimating K value is used in KNN method. $K = \sqrt{m} = \sqrt{28} = 5.6$; however, in this case, the value $K=5$ is fixed
- Choosing K reference positions from calibrated database having nearest RSSI values
- Calculating the first weighting factor W_{PL_i} for above K reference positions using equation (2.4)
- Estimating the second weighting factor W_{Di} for above K reference positions using equation (2.5)
- Estimating coordinates of the target position P_i using equations (2.7) and (2.8)

V. GOALS AND PERSPECTIVES

After calibrating all data and establishing localization steps, target positions in five databases are estimated coordinates. Locating results of 68 target positions are shown in the figure below:

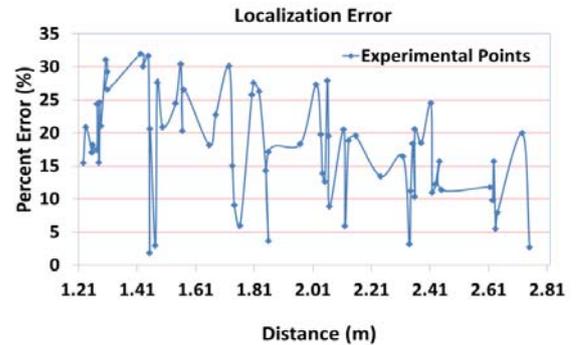


Figure 3. Localization Results for Target Positions

With the above-achieved experimental results, data calibrating method and improved KNN algorithm are applied

to locate target positions with an acceptable average localization error of 32.3cm (corresponding to 17.92%). This result is compared with results in our previous article in a national journal [25] having average locating error is 34.25cm (corresponding to 23%). Besides, this result is compared with previous good quality researches in [7] and [8] having average error by the length of tag grid size (in this case, $r = 30\text{cm}$). Another point, the system in [8] used many reference tags (about 374 tags for 4 antennas) and complex algorithms (snapshots, fingerprinting and filters) increasing computing time and volume) while the system in [7] had little reference positions (9 reference tags for 2 antennas) reducing the reliability of collected data. An additional advantage, our system uses only one reader antenna and passive tags. This structure makes the experiment setup cheaper.

Results suggest that it is possible to localize objects with good accuracy based on calibrated data and improved KNN methods. In the next work, larger area such as localization objects in a room, locating people in a building will be developed and experimented using this results. The passive tags which could be installed on the floor or on the wall or on human body will also be designed for this system.

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