Map-Based Localization Indoor Environment for Object Tracking using RF Trackers

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Abstract. This paper proposed a RF-based mapping-based indoor localization technique to locate their packages and items. The Received Signal Strength Indicator (RSSI) is commonly used in trilateration to allocate the packages or items location. However, several problems need to overcome to increase the accuracy of the RSSI signal propagation for the localization. The problems include the complexity of the indoor environment will affect the radio waves experienced multipath effect such as the signal may be reflected, refracted, absorbed or blocked by other matter. The paper is designed to study the propagation of radio waves in indoor conditions, identify the type of antenna used and determine the accuracy of the localization model. The RSSI is recorded for every 1m until reached the maximum read range of 20m to study the behaviour of radio waves propagation and the relationships between RSSI and distance. The RSSI mapping experiment was carried out to determine the type of antenna used to carry out the experiment. The localization is performed with mapping-based technique to predict the random coordinates in the testbed. The predicted coordinates and actual coordinates were compared to determine the accuracy of the localization model. The error between the actual coordinates and predicted coordinates can achieve an average of 0.95 meter. The RF mapping-based indoor localization technique results shown that the effectiveness of the techniques to be implemented in a company to improve the efficiency in the production line.

1. Introduction

Indoor localization has become one of the main focus in research due to the low accuracy of the GPS localization in indoor environments. The GPS propagates weak signal which is unable to penetrate the building blocks and results in high error location estimation in the indoor environment [1,2]. Many researchers have reported works on solutions for indoor localization by proposing multiple devices such as WiFi, RFID, ZigBee and other devices to be used for indoor localization [3]. The indoor localization positioning approaches can be divided into Time of Arrival (TOA), Angle of Arrival (AOA), Time Difference of Arrival (TDOA) and Received Signal Strength Indicator (RSSI) based system. Among all of the indoor localization positioning approaches, the RSSI has a major advantage over other methods.
because it does not require extra hardware to support the infrastructure of the algorithm [4]. The most common RSSI technique usage is the RSSI fingerprinting localization. However, the RSSI based indoor localization is prone to fluctuations due to signal strength being non-linear against distance and is affected by the presence of obstacles [5,6]. In this work, map-based RF indoor localization technique is proposed with the RSSI mapping in the experimental testbed. The RSSI mapping is being used in the algorithm to predict the unknown location with the predefined RSSI mapping.

2. Literature Review

RSSI is now widely used for location sensing in many location tracking systems based on the RF signal. The most common classes of RSSI positioning technique are the radio propagation model distance prediction and fingerprinting techniques [7]. The typical radio propagation model distance prediction uses the relationship between distance and RSSI as shown in Equation 1;

\[
RSSI = -(10n \log d + A)
\]  

(1)

where \(A\) is defined as the absolute energy measured at 1m away from the transmitter, \(n\) is the signal transmission constant and \(d\) is the distance between the transmitter and the receiver. However, RSSI is a measure of signal strength and it is subjected to the non-linear and non-Gaussian relationship with distance. Therefore, Equation 1 may not satisfy all the unique conditions indoor environment.

On the other hand, the fingerprinting technique consists of two phases: offline training phase and online phases [8]. During the offline phase, a database is built by collecting all of the RSSI for every reference points (RP) in the experimental testbed. Then, in the online phase, the position can be estimated by comparing the real-time RSSI value with the RSSI database built. However, this is a time-consuming process to collect all the RSSI value in every RPs manually and it is subjected to environmental changes [8].

The trilateration technique uses signal strength from at least three different access points to predict the location of the mobile terminal [9]. The trilateration forms circles at the centre of each access points and the radius of the circle can be determined by measuring the signal strength (RSSI) of the mobile terminal. The intersection points between at least three different access points give the estimated location for the mobile terminal [10]. The trilateration technique illustration is shown in Figure 1. Another work stated that the trilateration technique would be prone to errors due to the signal strength can be affected by obstacles or error while converting the RSSI values to distance [11].

![Figure 1. Illustration of trilateration technique](image)

Although many efforts being proposed by researchers to reduce the error in the trilateration method, there are still errors presented in the trilateration technique due to the complexity of the indoor
environment. Another work presents a new error correction algorithm for trilateration technique as an alternative for the standard trilateration algorithm calculations that will reduce the offset error by more than 50% [12].

In this paper, a combination of RSSI mapping method is proposed. The localization is based on the measured distance between the RSSI mapping and the overlapping area for every antenna in the testbed.

3. Methodology

First, the reader’s performance is evaluated by performing distance and RSSI measurements throughout the testbed. This is to ensure the reader’s placement is able to fully cover all the testbed area. Based on the reader’s performance evaluation, the relationship between the RSSI and distance is obtained by curve fitting the RSSI against distance graph with a logarithmic curve.

The experiment is divided into two stages and is summarized in Table 1. At the first stage, the 14m-by-8m testbed is divided into 2m by 2m grid. There are three identical readers placed at locations (0, 0), (0, 8) and (14, 8) respectively. The RSSI values for signal transmission at every grid point is collected based on three readers. The experiment continues until all the RSSI for every point are collected. All of the collected data is plotted in multiple contour map graphs to observe the RF signal propagation in each of the readers. Then, in the second stage, a transmitter is placed at random coordinates. Based on the RSSI value collected from three different location readers, the location of the transmitter can be based on the combined contour graph and pattern matching with the current unknown RSSI location. The error of the location prediction is quantified based on the Euclidean distance between the actual position and the predicted position.

| Stage | Experiment Steps |
|-------|------------------|
| Step 1: | Experimental testbed was divided into 2m by 2m grid and marked. |
| Step 2: | Antenna 1, antenna 2 and antenna 3 was placed at locations (0, 0), (0, 8) and (14, 8) respectively. |
| Step 3: | RSSI values of the transmitter were collected for each antenna at each grid point coordinates. |
| Step 4: | Contour map of the RSSI value for each of the antennas was plotted. |
| Step 5: | Transmitter is placed at random coordinates. |
| Step 6: | Transmitter RSSI values at random coordinates were recorded when it was detected by each of the antennas. |
| Step 7: | Resemblance of transmitter RSSI values at random coordinates were identified based on the intersection between antennas from the previous plotted contour map. |
| Step 9: | The predicted coordinates and actual coordinates were compared to determine the accuracy of the proposed method. |

4. Results and Discussions

4.1. Relationship between RSSI and distance

Due to the complexity of the indoor environment, the RSSI exhibited fluctuations throughout the experiment. It is difficult to model a distance equation model based on only RSSI because the model may not be suitable for all the different indoor environmental conditions. Therefore, the RSSI value for every 1m distance is collected until the transmitter is not detected by the receiver. Due to the fluctuations of the collected RSSI value, the logarithmic curve fitting method was chosen to obtain the relationship equation between RSSI and distance as shown in Figure 2.
Based on Figure 2, the logarithmic curve fitting is done with the MATLAB curve fitting tools and obtained the model equation as shown in Equation 2. The R^2 of the curve fitting model is 0.8342. It is approximately 83.42% of the observed variation can be explained by the model’s inputs.

\[
RSSI = 0.06086x^2 - 2.145x - 72.68
\]  

(2)

Where \( x \) is the distance between the transmitter and the receiver in meter.

4.2. **RSSI Mapping**

This experiment is designed to determine the antenna range used in the following experiments. The antenna is placed at the centre of the testbed as shown in Figure 3. Based on Figure 3, the omnidirectional antenna is able to cover 14 meters x 8 meters area of the testbed. As the transmitter moves further from the antenna, the RSSI value became more negative and this indicates the signal strength decrease with increasing distance. It is difficult to model a distance model equation due to the non-linear RSSI changes as shown in Figure 3.

![Figure 2. Relationship between RSSI and distance based on logarithmic curve fitting](image_url)
4.3. RSSI-based Localization

Based on the transmitter’s RSSI values at random coordinates, the location can be predicted based on previously recorded RSSI contour map. The centre of the intersection location of three different contour map graphs is the predicted location. The proposed algorithm location prediction is shown in Figure 3. Based on Figure 3, the actual location and the predicted location are different due to the error present in the proposed algorithm. The error between the actual location and the predicted location is calculated by using the Euclidean distance equation as shown in Equation 3.

\[ Error = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \]  (3)

Based on Equation 3 and Figure 3., the actual coordinate of the transmitter is (2, 2) and the predicted coordinate by the algorithm is (2, 3.5). By using Equation 3, the error of the algorithm is 1.5 meters. The
experiment is repeated at another random coordinate to observe the reliability of the algorithm. The proposed algorithm’s predicted location and the actual location is tabulated in Table 2.

| Position | Actual Location (x,y) | Predicted Location (x,y) | Error (m) |
|----------|-----------------------|--------------------------|-----------|
| 1        | (2,2)                 | (2,3.5)                  | 1.5       |
| 2        | (8,6)                 | (8,5.6)                  | 0.4       |

The results represent a promising start for this approach to RSSI map-based localization in an indoor environment. Rather than relying on building a perfect model for RF propagation to execute trilateration algorithm, the mapping-based algorithm is able to produce comparable accuracy compared to previous works reported on RF based location with simple approaches.

5. Conclusion
The proposed method with RSSI measurement metric has an average error of 0.95m. The localization error in the method is expected mostly due to the multipath propagation of the RF signal causing fluctuations and uncertainties in the RSSI. In this explorative work, the RF signal behavior in an indoor environment was studied and a method to localize objects and items based on RSSI maps was proposed. The relationship between the RSSI and distance is proposed with the logarithmic curve fitting method. The accuracy of the algorithm can be improved by increasing the number of antennas in the testbed but this will increase the infrastructure cost. The trade-off between the cost and the accuracy is required to be considered while planning the research. The current method can be further improved with the integration of machine learning algorithm or integration of probabilistic methods in future works. If there is a high amount of data supplied to the machine learning algorithm, the accuracy of the localization is envisaged be improved.

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