Distance Estimation Algorithm Based on Multi-Antenna Signal Attenuation Model

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***Abstract*—Received Signal Strength Indicators (RSSI)-based indoor positioning technology is widely used in the field of Wi-Fi indoor positioning. However, the propagation of RSSI is still affected by indoor multipath, and we cannot obtain signals in some corner areas. This paper analyzes the distance relationship between the RSSI on each antenna of the receiver and the distance between transmitter and proposes a novel ranging algorithm based on multi-antenna RSSI measurements. This novel algorithm uses a Least Squares Method (LSM) on the basis of a signal attenuation model to optimize, eliminate the noise and redundancy of the original data and reduce the positioning error. Experimental results show that the indoor multi-antenna RSSI ranging based on the single Gaussian model has high fitting accuracy and applicability. The proposed approach achieves significant localization accuracy improvement over using the single antenna RSSI-based ranging method. Meanwhile, the algorithm improves the influence of multiple paths in a complex indoor environment on location, and the method can obtain more accurate ranging results.**

***Index Terms*—Received Signal Strength Indicators; Indoor ranging algorithm; Least squares method; Multi-Antenna.**

I. Introduction

Indoor positioning technology [1] includes RSSI, Time of Arrival (TOA), Time Difference of Arrival (TDOA), and Angle of Arrival (AOA), etc. Methods based on RSSI measurement values can be divided into two categories: range-based and range-free [2], [3]. The RSSI ranging method uses a theoretical propagation model to estimate the distance between the transmitter and the receiver, and then performs position estimation.

The ranging technology based on RSSI has become an important research direction for indoor positioning due to its low cost and easy implementation. The ranging algorithm based on RSSI can obtain the distance information between indoor personnel and the transmitter. However, in actual measurement, the path loss of RSSI is easily affected by external environmental factors such as multipath effects, obstacles, and shadow effects. This makes the RSSI values obtained at different times at the same location fluctuate up and down around a certain central value, and there may even be glitches that deviate from the normal range. That is, the distribution of RSSI value is Gaussian model.

A study [4] established a mapping relational database of RSSI and distance range, and then obtained the distance between the transmitter and the receiver by weighting and summing the distance space obtained by querying the mapping database. Literature [5] proposes a novel dynamic three-dimensional weighted centroid location algorithm based on path loss index through the analysis of some commonly used algorithms. Literature [6] proposes a weighted centroid algorithm without height influence by filtering the RSSI signal and considering the impact of the deployment height of the access point (AP) on the positioning accuracy.

However, these methods do not consider the influence of the antennas at the transmitting end and the receiving end on the accuracy of the RSSI measurement. On the other hand, these documents' models or empirical values cannot meet the needs of dynamic changes in the actual environment. To optimize the ranging algorithm and improve the positioning accuracy, this paper analyzes the distance relationship between the RSSI on each antenna of the receiver and the distance between transmitter and proposes a novel ranging algorithm based on multi-antenna RSSI measurements.

The rest of this paper is organized as follows. In section II, we introduce the proposed ranging algorithm based on multi-antenna RSSI. The implementation of the noval algorithm and experimental evaluations are presented in Section III. Finally, conclusions and future research are presented in Section IV.

II. Proposed algorithm

RSSI-based ranging uses a theoretical model of radio wave transmission to convert wireless signal propagation loss into the distance. The empirical model must perform a large number of measurements in a specific space and time to obtain environmental parameters, and cannot adapt to changes in the environment. The relationship [7] between the received signal power and the communication distance is:

$$\frac{P_{\mathrm{R}}\left(d_0\right)}{P_{\mathrm{R}}\left(d_i\right)}=\left(\frac{d_i}{d_0}\right)^\alpha \tag{1}$$

Where d_0 is the distance from the reference node to the signal sending node, generally lm. $P_R(d_0)$ is the received signal power at d_0. $P_R(d_i)$ is the received signal power at d_i. α is called the path loss index and is related to the actual environment. The $P_R(d_0)$ used as a reference for signal reception energy in Formula (1) can be obtained by the following Formula (2) .

$$P_{\mathrm{R}}\left(d_0\right)=\frac{P_{\mathrm{T}} G_{\mathrm{T}} G_{\mathrm{R}} \lambda^2}{(4 \pi)^2 d_0^2 L} \tag{2}$$

Where P_T represents the energy of the transmitted signal. G_T represents the antenna gain of the signal sending node. G_R represents the antenna gain of the signal receiving node. λ represents the radio signal wavelength. L represents the system loss factor. Take the common logarithms on both sides of Formula (1), and substitute Formula (2) to get

$$\left(P_{\mathrm{R}}\right)_{\mathrm{dBm}}=A-10 \alpha \lg \left(d_i / d_0\right) \tag{3}$$

where $(P_{\mathrm{R}})_{\mathrm{dB_m}} = 10\lg \frac{P_{\mathrm{R}}(d_i)}{1\ mW}$ is the received signal power at d_i. $A = 10\lg \frac{P_{\mathrm{T}}}{1\ \mathrm{mW}} + 10\lg \frac{G_{\mathrm{T}} G_{\mathrm{R}} \lambda^2}{(4\pi)^2 d_0^2 L}$ is the received signal power at d_0. Equation (3) is the ideal situation of free environment d_i. The received signal power is expressed in milliwatt decibels. Taking into account the noise factor, Formula (3) can be expressed as

$$\left(\mathrm{RSSI}_{d_i}\right)_{\mathrm{dBm}}=A-10 \alpha \lg \left(d_i / d_0\right)+X_\sigma \tag{4}$$

Equation (4) is also called the logarithmic normal distribution model, where X_σ is a Gaussian distributed random noise variable that obeys $(0, \sigma^2)$. The scope of α, σ is closely related to the specific environment. Literature lists some actual measured values, which can be used as reference values for algorithm simulation or implementation. Reasonably estimate the best $\overline{\mathrm{RSSI}}_{d_i}$, so that the noise x has a minimal impact on the measurement results. Further, the mean value of x_σ is 0, so that $d_0 = 1$, by Formula (4)

$$\overline{\mathrm{RSSI}}_{d_i}=A-10 \alpha \lg \hat{d}_i \tag{5}$$

which is

$$\hat{d}_i=10^{\frac{A-\overline{RSSI}_{d_i}}{10 \alpha}} \tag{6}$$

Therefore, the $\overline{RSSI}_{d_i}$ environmental parameters A and α will affect the estimation accuracy of the distance $\hat{d}_i$in Equation (6).

Since the transmission signal must take different paths when it reaches the three receiving antennas, The phase is also different. When the three-antenna signal is superimposed, the signal will be distorted. The signal will be strengthened in the same phase, and the signal will be weakened when the phase is reversed. Therefore, the phase of the signal arriving at the receiving antenna must be the same to be undistorted. The problem of incomplete equipment makes the measurement data on antenna 3 unusable. We only considered the RSSI measurement data on antenna 1 (a) and 2 (b). We build a model based on the RSSI measurement value of multiple antennas as follows:

$$\overline{\frac{\mathrm{RSSI}_{\mathrm{ant1}}+\mathrm{RSSI}_{\mathrm{ant2}}}{2}}_{d_i}=A-10 \alpha \lg \hat{d}_i \tag{7}$$

The estimated distance obtained based on the enhanced multi-antenna RSSI ranging model is:

$$\hat{d}_i=10^{\frac{A-\overline{\frac{\mathrm{RSSI}_{\mathrm{ant1}}+\mathrm{RSSI}_{\mathrm{ant2}}}{2}}_{d_i}}{10 \alpha}} \tag{8}$$

where $RSSI_{ant1}$ is the Gauss-Kalman RSSI filter value obtained on antenna a. $RSSI_{ant2}$ is the the Gauss-Kalman RSSI filter value obtained on antenna b. $\hat{d}_i$ is the estimated distance value.

III. Experiments and Performance Evaluation

A. Experimental Scenarios

The experiments were carried out in the 3rd-floor corridor of Kyungpook National University (KNU) IT1 Building, as shown in Fig. 1. The equipment required for the ranging solution is: (1) A laptop with an Intel 5300 installed, the operating system is Ubuntu 10.04 LTS, and the kernel and wireless network card drivers are customized; (2) An 802.11n wireless AP device. In experiments, we use ipTIME N3004 as a node and place it at the height of 0.2m on the ground.

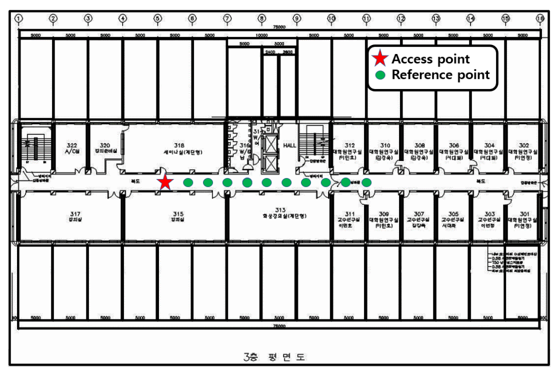

Fig. 1. Representative indoor corridor environment (3rd-floor lobby of KNU IT1 Building).

A notebook computer DELL Inspiron N4010 is used as a mobile node. We obtain the RSSI measurement values on different antennas at fixed positions separated by 1m from the transmitter between 1m and 15m. At each reference point, 400 measurements were taken on the AP.

B. Performance Evaluation

In the RSSI-based ranging algorithm, it is inevitable that the sampled signal will be contaminated by noise due to various random interference noises in the actual external environment. For these reasons, these acquired signals contain a large number of abnormal values, which deviate from their true values to a large extent. Fig. 2 shows the initial values of RSSI on

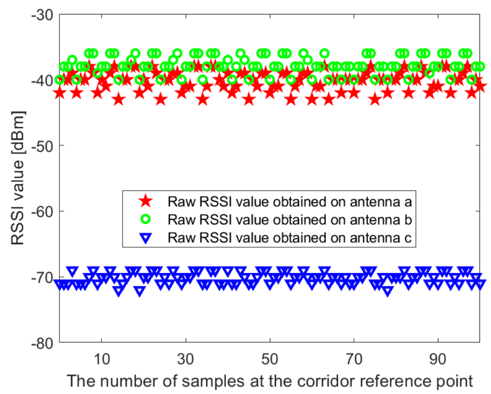

Fig. 2. The original RSSI value obtained at the reference point.

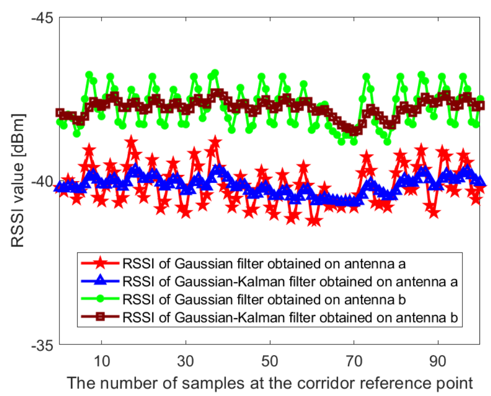

Fig. 3. The RSSI value of Gaussian Kalman filter is obtained at the reference point.

different antennas acquired at a fixed reference point.

For linear systems, Kalman Filter is optimal and highly efficient, so we use Gaussian Kalman filtering to preprocess the RSSI data. The RSSI result of Gaussian Kalman filtering is shown in Fig. 3 . Fig. 3

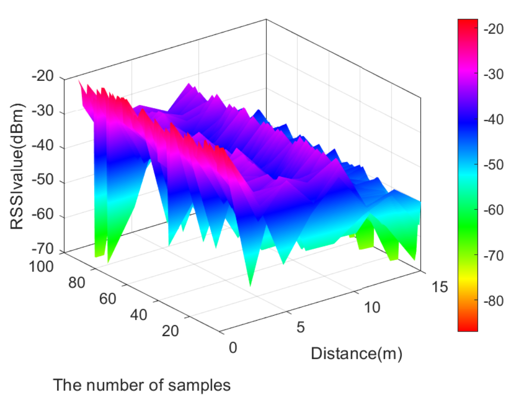

Fig. 4. Three dimensional signal attenuation model based on multi antenna RSSI filter value

shows a three-dimensional multi-antenna-based RSSI signal attenuation model.

TABLE I
COMPARISON OF THE DISTANCE ERROR OF THE EXISTING METHOD AND THE PROPOSED METHOD.

Ranging methods	Average distance error	Standard deviation
RSSI-based method	2.312m	1.296m
The proposed method	1.472m	1.152m

It can be seen from Table 1 that the average positioning accuracy of the proposed multi-antenna RSSI ranging algorithm is higher than the average ranging accuracy based on the single antenna RSSI.

IV. Conclusions and Future Research

In this paper, the amplitude distribution of RSSI is analyzed, and Gaussian Kalman filter is used to remove the abnormal data, which improves the reliability of the data. At the same time, based on the RSSI ranging model algorithm, an algorithm based on multi antenna RSSI is proposed. The experimental results show that the algorithm improves the accuracy of the original ranging algorithm without changing the indoor environment hardware equipment. However, the algorithm does not verify the situation of the algorithm in different indoor environments, which will be further studied.

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