Improving Accuracy of RSSI-Based Indoor Localization Using Three-Element Array

Ryota Tazawa[1], Naoki Honma[1], Miura Atsusi[2], and Minamizawa Hiroto[2]
[1]Graduate School of Engineering, Iwate University
4-3-5 Ueda, Morioka, 020-8551, Iwate, Japan
[2] Embedded Resource Integration, Inc.
3-8-44, Kamido, Morioka, 020-0125, Iwate, Japan

Abstract **– The authors have proposed a method of estimating the location of the receiving terminal by a triangulation technique using DOD information from the multiple transmitters, which is calculated only from the Received Signal Strength Indicator (RSSI). In our previous study, DODs are calculated using four beacon signals, but the number of the antennas for each array is limited to two, which offers insufficient DOD accuracy. This paper presents a new method, which improves the accuracy of the localization by extending the number of antenna elements to three. The experiment reveals the presented method improves the accuracy up to 0.7 m, which is 0.2 m better than that of the previously presented method.**

Index Terms **—RSSI, DOD, Localization**

1. Introduction

Currently, the location estimation called GNSS (Global Navigation Satellite System) has been widely used in outdoor environment. However, it does not work in indoor environment since the satellite signal is not available. The indoor localization method using a radio beacon has been well studied to resolve this problem. The Radio beacons must be inexpensive, and low-power consumption, and easy to install, and capable of transmitting a signal to a number of terminals including smartphones. Currently, the commercially available beacons mainly base on Bluetooth-Low-Energy (BLE), however, only the RSSI of the beacon signal is available at the receiver. The authors have studied an indoor localization method using RSSI [1]. In this method, the multiple beacon transmitters are located in the indoor environment, and each of them has two-element antennas connected to the feed network, which forms four different patterns corresponding to four beacon transmitters. This method calculates DOD (Direction-of-Departure) from RSSI at the receiver side, and the receiver estimates its location by using triangulation technique. However, the location accuracy of this method is not sufficient because the number of the antenna elements at the beacon transmitters is limited to two.

In this paper, an improvement method of DOD accuracy using three-element antenna is presented, where the number of the beacon transmitters is four, which is same to the previously presented method [1]. The proposed method improves accuracy without increasing the number of transmitter. Also, the localization accuracy based on the presented method is experimentally evaluated.

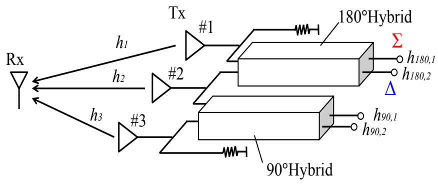

Fig. 1 Proposed system configuration

2. RSSI-Based DOD Estimation Method

Fig. 1 shows proposed system configuration. Four beacon signals are transmitted from the three-element array antenna through the 90-degree and the 180-degree hybrids. The transmission antennas, # 1 and # 2, are connected to the 180 degree hybrid, and the transmission antennas, # 2 and # 3, are connected to the 90 degree hybrids. The antennas are fed through the dividers. The one side of the terminal of dividers at the both ends is terminated. The receiver with one-element antenna observes the signal transmitted from the 3-element array antenna. The DOD can be calculated only at the receiver side, where the correlation matrix is estimated by the proposed method. h_1, h_2, and h_3 in the figure represent propagation channel between the transmitting and receiving antennas. $h_{180,1}$, $h_{180,2}$, $h_{90,1}$, and $h_{90,2}$ in figure represents the observed channel through the feed network including the 180-degree, 90-degree hybrids. The correlation matrix is defined by using the propagation channel as,

$$\boldsymbol{R} = \begin{pmatrix} |h_1|^2 & h_1 {h_2}^* & h_1 {h_3}^* \\ {h_1}^* h_2 & |h_2|^2 & h_2 {h_3}^* \\ {h_1}^* h_3 & {h_2}^* h_3 & |h_3|^2 \end{pmatrix} \approx \begin{pmatrix} |R_{12}| & |R_{12}|e^{j\alpha} & R_{13} \\ |R_{12}|e^{-j\alpha} & |R_{12}| & |R_{23}|e^{j\beta} \\ {R_{13}}^* & |R_{23}|e^{-j\beta} & |R_{12}| \end{pmatrix}, \quad (1)$$

where $\{\cdot\}^*$ represents complex conjugate transpose α and β represent the phase of R_{12} and R_{23}, respectively. A set of the observed RSSIs are represented as,

$$\begin{pmatrix} |h_{90,1}|^2 & |h_{90,2}|^2 \\ |h_{180,1}|^2 & |h_{180,2}|^2 \end{pmatrix} = \frac{1}{4}\begin{pmatrix} A - jh_1{h_2}^* + j{h_1}^*h_2 & A + jh_1{h_2}^* - j{h_1}^*h_2 \\ B + h_2{h_3}^* + {h_2}^*h_3 & B - h_2{h_3}^* - {h_2}^*h_3 \end{pmatrix}, \quad (2)$$

where, $A = |h_1|^2 + |h_2|^2$, and $B = |h_2|^2 + |h_3|^2$. A correlation matrix can be approximated from them by using following procedure. The signals transmitted via the 180-degree hybrid satisfy the relation as,

$$\left|h_{180,1}\right|^2 + \left|h_{180,2}\right|^2 = \frac{1}{2}(|h_2|^2 + |h_3|^2) \geq |h_2 h_3| = |R_{23}| \quad (3)$$

$$\alpha \approx \pm\cos^{-1}\left(\frac{\left|h_{180,1}\right|^2 - \left|h_{180,2}\right|^2}{\left|h_{180,1}\right|^2 + \left|h_{180,2}\right|^2}\right) \quad (4)$$

Similarly, the signals transmitted via the 90-degree hybrid satisfy the relation as,

$$\left|h_{90,1}\right|^2 + \left|h_{90,2}\right|^2 = \frac{1}{2}(|h_1|^2 + |h_2|^2) \geq |h_1 h_2| = |R_{12}| \quad (5)$$

$$\beta \approx \sin^{-1}\left(\frac{\left|h_{90,1}\right|^2 - \left|h_{90,2}\right|^2}{\left|h_{90,1}\right|^2 + \left|h_{90,2}\right|^2}\right), \pi - \sin^{-1}\left(\frac{\left|h_{90,1}\right|^2 - \left|h_{90,2}\right|^2}{\left|h_{90,1}\right|^2 + \left|h_{90,2}\right|^2}\right), \quad (6)$$

Each of deviation angles, i.e. α and β, has two solutions, where one of two is true. By considering the physical fact, α and β should ideally identical if there is no multipath component. Therefore, the true solutions of α and β will agree whereas the false solutions do not. Hence, a selection method is quite simple, and is just choosing a set of α and β with a smallest difference.

Also, the component, R_{13}, physically represents the signal correlation between the Tx antennas, #1 and #3, and can be approximated as,

$$R_{13} \approx |R_{12}||R_{23}|e^{j(\alpha+\beta)}/|R_{12}|. \quad (7)$$

Thus, all components of the correlation matrix have been derived only from the strength information. After that, DOD can be easily calculated by using MUSIC (MUltiple SIgnal Classification) method, and multiple DOD information determines the location of the receiver by using triangulation technique. In this study, an angular probability function is introduced, where the Gaussian function is used and has a maximum at the estimated DOD. By taking the all probabilities into consideration, the location most likely to be true is estimated.

3. Measurement Conditions and Experimental Results

Fig. 2 shows experimental environment. This experiment was carried out in the indoor environment, where the size of the tested area was 14m × 10m, and the operating frequency was 2.47 GHz band. The transmitting arrays were placed at the four corners of the tested area, and directed at the angle of 45 ° with respect to the wall. The channel was measured at 65 locations of the receiving antenna, shown in Fig. 2. A sleeve antenna was used at the receiving side. Each of the transmitting arrays consists of three-element patch antennas, where the inter-element spacing was a half wavelength. The 180-degree and 90-degree hybrids were assumed in the post-processing, where the hybrids are lossless and frequency-independent. Fig. 3 shows CDF (Cumulative-Distribution-Function) of the distance errors in the estimated position. The proposed method was compared to the conventional method, i.e. the localization technique using 2-element array antennas [1], where both of them do not rely on the phase information.

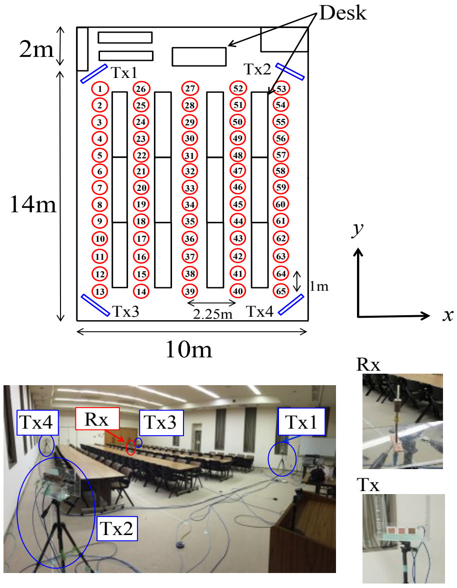

Fig. 2 Experiment environment

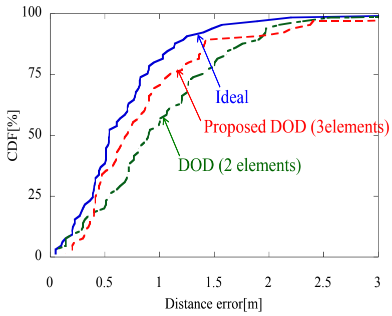

Fig. 3 CDF of the position estimation error

Also, the location is estimated by using the complex channel, where the full phase information is available, and this estimation is defined as 'ideal method'. The 50% values of the error in the ideal, proposed and conventional methods were 0.5 m, 0.7 m, and 0.9 m, respectively. Even though the error in the proposed method was slightly larger than that in the ideal method, it is found that the proposed method improves the position estimation error by 0.2 m compared to that of the conventional method.

4. Conclusion

This paper has proposed an improved indoor localization method using DOD information calculated from RSSI. This method uses the multiple beacons, each of which comprises three antennas connected to beacon transmitters by way of 180-degree and 90-degree hybrids. The experimental result showed that the proposed method improves 0.2 m of the position estimation error compared to that of the conventional method.

References

[1] N. Honma, K. Ishii, Y. Tsunekawa, and, H. Minamizawa, A. Miura, "DOD-based localization technique using RSSI of indoor beacons," 2015 International Symposium on Antennas and Propagation, S4.11, pp.923-924, Nov. 2015.