RSSI-Based Estimation Method of Living-Body Direction Using Parasitic Antennas

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Abstract - **In this paper, we propose estimation method of living body direction using parasitic antennas, where only an RSSI (Received Signal Strength Indicator) is used. The measurements were carried out in an indoor environment, and the experimental results showed that the angular error is less than 9.5° even if the phase information of the received signal is not available.**

Index Terms **— DOA estimation, parasitic antenna, RSSI.**

1.   Introduction

Recently, a variety of living-body sensing technologies have been attracting attention. The estimation of the human-body direction and localization using microwave has an advantage that it hardly violates the privacy. The estimation methods of living body direction using SIMO / MIMO sensors have been proposed [1]. This algorithm uses a time variant complex channel, but it requires a number of receivers that can observe the phase information.

In this paper, we proposed estimation method of living body direction using the parasitic antenna, where only an RSSI without phase information is used. This method allows the simplification of the RF-frontend since the number of the receivers can be reduced. Moreover, it does not need phase information of the signal, which allows the use of the commercially available receivers, such as Wi-Fi and Bluetooth hardware. In this paper, the algorithm of the estimation method of living body direction is briefly described, and some experimental results are shown to demonstrate the performance of the estimation accuracy.

2.   Algorithm of Proposed Method

In this study, we describe an RSSI-based method of estimating the arrival direction of the signal reflected from the living body, where the multiple parasitic (Px) antennas and single receiving (Rx) antennas are used. Fig. 1 shows antenna system model in the proposed method. T, R，and P mean the transmitting (Tx), Rx, and Px ports, respectively. This system is composed of one-element Tx antenna and Rx antenna, and M-element Px antennas terminated by the load impedance. Where, h_{RT} represents channel response between Tx/Rx antennas, and h_{PT} represents channel response between Tx/Px antennas. And h_{RP} are S-parameters that represent cross coupling between Rx/Px antennas. S-parameters of Tx, Rx, and Px antennas are S_{TT}, S_{RR} and S_{PP}, respectively. Among the mentioned elements, h_{RT} and h_{PT} corresponds channel
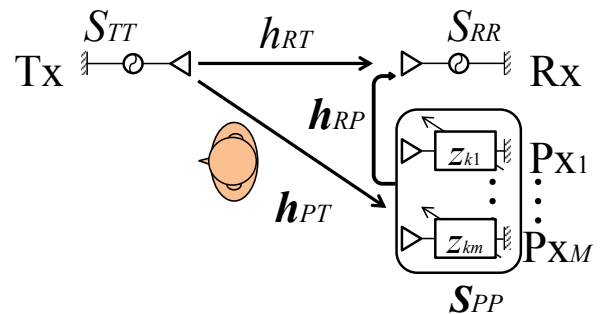

Fig. 1. antenna system model

and the unknown value that change by the antenna arrangement and the environment. On the other hand, S_{TT}, S_{RR}, S_{PP} and h_{RP} represents the characteristics of the antenna, and they are the known value that is constant after producing antenna. The load impedance at the Px antenna is defined as

$$Z = \begin{bmatrix} z_1 \\ \vdots \\ z_K \end{bmatrix} = \begin{bmatrix} z_{11} & \cdots & z_{1M} \\ \vdots & & \vdots \\ z_{K1} & \cdots & z_{KM} \end{bmatrix}, \qquad (1)$$

where, K represents the number of patterns of variable impedance for terminating each Px antenna. In the proposed method, the signals in response to the termination condition are observed by changing the termination conditions, where K patterns of the conditions are given within the sufficiently short period that must be shorter than the cycle of the vital sign.

The cycle of K times observation described above is repeated by L times to observe the temporal variation of the channel due to the vital sign. Here, the measurement period of L time cycle needs to be sufficiently long, which can be comparable to the cycle of the vital sign. In the measurement of the l-th $(1 \le l \le L)$ snapshot, the received signal strength in the k-th $(1 \le k \le K)$ termination pattern is defined as $\left| y_k^{(l)} \right|$. In the multi-path environment, there are unnecessary waves such as direct wave between the Tx/Rx antennas and reflected wave from the wall. They need to be eliminated to estimate the living body direction correctly. Therefore, the mean signal strength over the certain period is subtracted from the observed signal strength because the mean value corresponds to the constant component in channel, which may not contain the vital sign. At the l-th measurement, the signal strength through the living body that excluded the fixed component is expressed as

$$\left|{y'_k}^{(l)}\right| = \left|y_{\boldsymbol{k}}^{(l)}\right| - \frac{1}{L}\sum_{l=1}^{L}\left|y_{\boldsymbol{k}}^{(l)}\right|. \qquad (2)$$

Now, the channel estimation method from the signal strength information obtained by (2) is discussed. In the first step, the arbitrary channel is assumed as,

$$\boldsymbol{h}'_{test}{}^{(l)} = \begin{pmatrix} h'_{test,R} \\ h'_{test,P1} \\ \vdots \\ h'_{test,PM} \end{pmatrix}, \qquad (3)$$

where, $h'_{test,R}$ represents channel between Tx/Rx antennas, and $h'_{test,Pm}$ represents channel between Tx and Px antennas in the m-th $(1 \le m \le M)$ element. After that, the assumed channel is iteratively optimized so as to make the signal responses estimated from it fit to the observed responses. The signal strength terminated by termination condition $\boldsymbol{\Gamma}_k$ in the k-th termination pattern is

$$|y'_{test,k}| = \left| h'_{test,R} + \boldsymbol{h}_{RP}(\boldsymbol{\Gamma}_k^{-1} - \boldsymbol{S}_{PP})^{-1} \cdot \begin{pmatrix} h'_{test,P1} \\ \vdots \\ h'_{test,PM} \end{pmatrix} \right| |s|, \qquad (4)$$

where, s represents the signal transmitted from Tx antenna, and $\boldsymbol{h}_{RP}$, $\boldsymbol{S}_{PP}$ are the known value because they represent the characteristics of the antenna at the reception side. . The termination condition at the k-th termination pattern is

$$\boldsymbol{\Gamma}_k = \mathrm{diag}(\gamma_{k1}, \cdots, \gamma_{kM}), \qquad (5)$$

where, γ_{km} shows the reflection coefficient of the terminating load of Px antenna in the m-th element. When z_{km} is connected to the m-th element of the Px antenna, γ_{km} is calculated as

$$\gamma_{km} = (z_{km} - z_0)/(z_{km} + z_0). \qquad (6)$$

The above equations show the receiving signal strength changes by changing the termination condition. Also, the channel response of the assumed channel can be calculated and is compared to the actual response by using evaluation function as,

$$e^{(l)} = \sum_{k=1}^{K}\left\{\left|{y'_k}^{(l)}\right| - \left|{y'_{test,k}}^{(l)}\right|\right\}. \qquad (7)$$

The channel is optimized to minimize the error, $e^{(l)}$, by the steepest descent method for example. In this study, the target direction is calculated from the estimated channel by using the MUSIC (MUltiple SIgnal Classification) method.

3. Measurement Conditions and Experimental Results

Fig. 2 shows the measurement setup. The antenna in this experiment was 3×1 SIMO configuration using one element square patch at Tx side, and one active and two parasitic square patches at Rx and Px sides, respectively, where Rx and Px antennas are arranged horizontally. The antenna was constructed on a PTFE substrate (relative dielectric constant: 2.2). The operation frequency band was 2.4 GHz, the distance of the array antennas was 0.4 λ, the antenna height H was 1.05 m, and the distance between
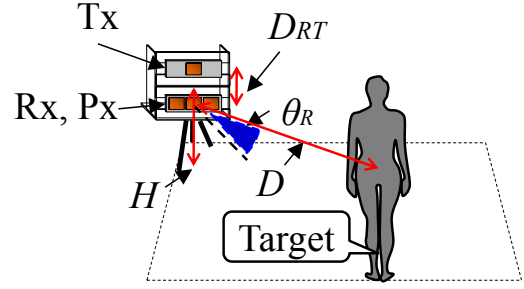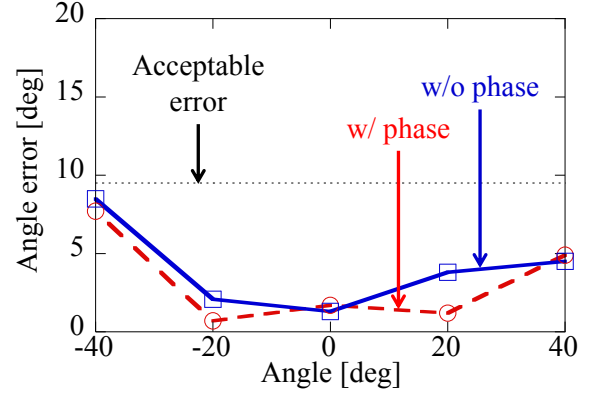

Fig. 2 Measurement setup

Fig. 3 Median value of angle error

antennas and target was 1.5 m. Also, the channel snapshot frequency was 10 Hz, and measurement time is 25.6 s. The target stood straight at the position of $\theta_R = -40, -20, 0, 20, 40°$ with respect to the broadside direction of the array, and measurement was carried out 100 times in each direction. For comparison, the estimation using the complex channel with phase information was carried out, too.

Fig. 3 shows the median value of the angular error in each direction, where the error is defined as the angular difference between the actual and estimated directions. From this figure, the error in the proposed method is by up to 6.8° higher than that in the ideal method, where 'ideal' represents the full phase information is available. Also, the angular error in the proposed method is less than 9.5° that is acceptable error. Here, the acceptable error is the half angular width of the target's body.

4. Conclusion

This paper has proposed the estimation method of living body direction using RSSI and parasitic antennas. The experimental results showed that the angular error is less than 9.5° even though the phase information is not available.

References

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