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Compact Antenna Arrangement for MIMO Sensor in Indoor Environment

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1. Intruduction

Intrusion sensors using microwave for security application have been studied in these days [1]∼ [3]. These microwave sensors can detect the intrusion even when the intruder is at the NLOS (Non Line-Of-Sight) locations, and this is the most attractive feature compared to the other sensors [2].

The authors have studied MIMO (Multiple-Input Multiple-Output) sensor that uses the MIMO channel variation to detect the intruders for indoor environment [2]∼ [3]. The MIMO sensor detects the intrusion by comparing the varying channel with the person to the static one. In these studies, the transmitting and receiving arrays are placed separately at the ends of the rooms. It was found that the arrays with wide antenna spacings are desirable for the high detection performance. However, this antenna arrangement requires wide space at two distant locations, but it is not suitable for actual environment such as an office.

In this paper, we propose the antenna arrangement for the MIMO sensor where the transmitting and receiving antennas are placed together. The arrangement requires the space half of the conventional one. The path distribution and the detection probabilities are evaluated based on the raytracing simulation. It is shown that the proposed antenna arrangement can achieve the fair detection performance.

2. Concept of MIMO sensor and detection method

Figure 1 is the conceptual sketch of MIMO sensor. This system has M_t transmitting and M_r receiving antennas. At first, the MIMO channel without a person is measured in advance.

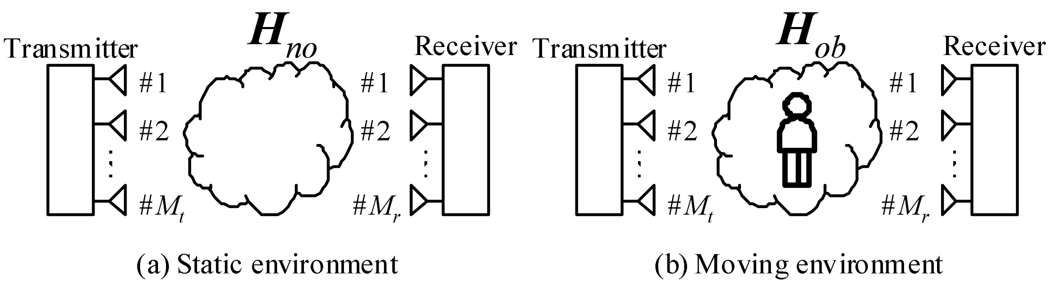

Figure 1: MIMO sensor concept

This channel is static and defined as,

$$\boldsymbol{H}_{no} = \begin{pmatrix} h_{no,11} & \cdots & h_{no,1M_t} \\ \vdots & \ddots & \vdots \\ h_{no,M_r1} & \cdots & h_{no,M_rM_t} \end{pmatrix}, \tag{1}$$

where, the static channel is assumed to be obtained accurately by many trainings. On the other hand, the channel with a person is defined as

$$\boldsymbol{H}_{ob} = \begin{pmatrix} h_{ob,11} & \cdots & h_{ob,1M_t} \\ \vdots & \ddots & \vdots \\ h_{ob,M_r1} & \cdots & h_{ob,M_rM_t} \end{pmatrix}. \tag{2}$$

The channels, $\boldsymbol{H}_{no}$ and $\boldsymbol{H}_{ob}$, are compared by the evaluation function,

$$\rho = \frac{\left| \sum_{i=1}^{Mr} \sum_{j=1}^{Mt} h_{no,ij}^{*} h_{ob,ij} \right|}{\sqrt{\sum_{i=1}^{Mr}\sum_{j=1}^{Mt} |h_{no,ij}|^2} \sqrt{\sum_{i=1}^{Mr}\sum_{j=1}^{Mt} |h_{ob,ij}|^2}}. \tag{3}$$

The ρ shown in (3) is defined as a channel correlation [3]. ρ is lowered when the intrusion takes place. We define a threshold value, ρ_t, and the intrusion is detected when $\rho < \rho_t$. However, the estimated channel contains the error caused by the noise, and apparently fluctuates even without a person in the environment. When the estimated channel contains a strong estimation error, the channel correlation is lowered and this yields the false detection. Therefore, ρ_t needs to be sufficiently small so as to reduce the false detection. In this study, the ρ_t is determined so that the false detection probability becomes 1 % in the static environment.

3. Proposed antenna arrangement and numerical analysis model

3.1 Antenna arrangement

The MIMO sensor dealt with in this discussion comprises 2×2 vertical dipoles. Figure 2 (a) indicates the proposed antenna arrangement. The transmitting and receiving antennas are arranged vertically each other, and this yields small mutual coupling between two dipoles. Two sets of such antennas are arranged horizontally with the spacing, d. The advantage of this arrangement is that the configuration of the sensor system becomes very compact since all of the antennas are placed closely.

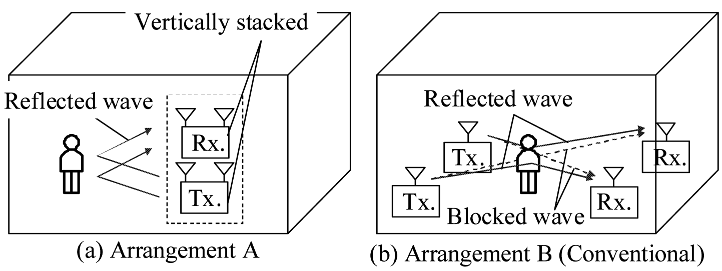

Figure 2: Antenna arrangement: (a) Arrangement A (Proposed), (b) Arrangement B (Conventional).

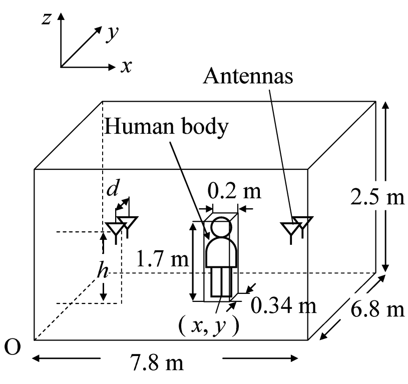

Figure 3: Analysis model

Figure 2(b) shows the antenna arrangement B, which is the conventional one. The transmitting and receiving arrays are located at both ends of the room. This arrangement is normally used in MIMO systems, and this has been well studied in our previous works [2]∼ [3].

3.2 Numerical analysis model

In this study, the detection performance is evaluated using the raytracing simulation based on the imaging method. Figure 3 shows the numerical analysis model for indoor environment. The dimension of the room is $7.8 \times 6.8 \times 2.5$ m^3 and wall material is assumed to be concrete (the relative permittivity: 6.0). The human body is approximated as the rectangular dielectrics whose dimension is $0.2 \times 0.34 \times 1.7$ m^3 (the relative permittivity: 37.5), and it is placed at the position (x, y). The height of the antenna is $h = 1.0$ m, and the antenna spacing and positions are mentioned in the following section. In the raytracing simulation, the number of the maximum reflection times is set to 5. The number of the human body is 1, and the human body is moved with 0.5 m step in xy directions, i.e., 180 positions are evaluated. The frequency is 2.4 GHz, and the bandwidth is 10 MHz. The dipole radiation pattern is used, but the mutual coupling is neglected for simplicity.

4. Results

Figure 4(a) shows the detection rate versus the antenna spacing, d. Here, all of the antennas are located in the plane, $X = 3.9$ m, and d corresponds to the spacing between two sets of the transmitting and receiving antennas. The antenna location in y-axis is $Y = 3.6$ m. The transmitting power is 1 W, and the noise power is set to ${\sigma_n}^2 = -78, -68$, or -58 dBm. From this result, it is found that the detection rate improves by increasing d. The detection rate cannot be improved even with large d when the noise power is high (${\sigma_n}^2 = -58$ dBm). This is because of the failure in the channel estimation. On the other hand, more than 90 % detection ratio is obtained even with small d when the noise power is sufficiently small. This indicates the proposed arrangement is effective in downsizing the antenna system.

Figure 4(b) shows the channel correlation distribution for arrangement A. Here, $d = 0.5\lambda_0$ (λ_0: wavelength in vacuum), $X = 3.9$ m, $\sigma_n^2 = -78$ dBm. The antenna location in y-axis is $Y = 3.6$ m. The axes indicates the position of the human body in the room, and the intensity of ρ is shown in gray scale. The bright color means the place where the correlation is lowered by the human, and the intrusion can be easily detected at this place. The undetectable places are indicated by the mark, '□'. It can be found that the correlation at the location around the antenna is lowered compared to that at others.

Figure 5 represents the results of the arrangement B, i.e., the conventional one. In this case, the transmitting and receiving antennas are placed on the planes at $X = 0.6, 7.6$ m, respectively. Here, the spacing between the transmitting antennas and that between receiving antennas are set to identical, and they are represented by d. D represents the distance between two arrays, and it is set to 7 m. Figure 5(a) shows the detection rate versus the antenna spacing, d. The other parameter excluding the antenna arrangement is set to identical to the simulation in Fig. 4. From this result, it can be seen that small d yields low detection rate. When $d = 0.5\lambda_0$ and ${\sigma_n}^2 = -78$ dBm, the detection rate was 92 %.

Figure 5(b) shows the distribution of the correlation coefficient of the arrangement B when $d = 0.5\lambda_0$ and $\sigma_n^2 = -78$ dBm. It is found that the bright spots appear on the direct and one-time reflected paths. However, the undetected spots appear at the both sides of the room. This is because not so many paths distribute at the corner of the room and these areas become the dead zone.

5. Conclusion

In this paper, the antenna arrangement for the MIMO sensor has been proposed. In this arrangement, the transmitting and receiving antennas are placed together. The numerical analysis

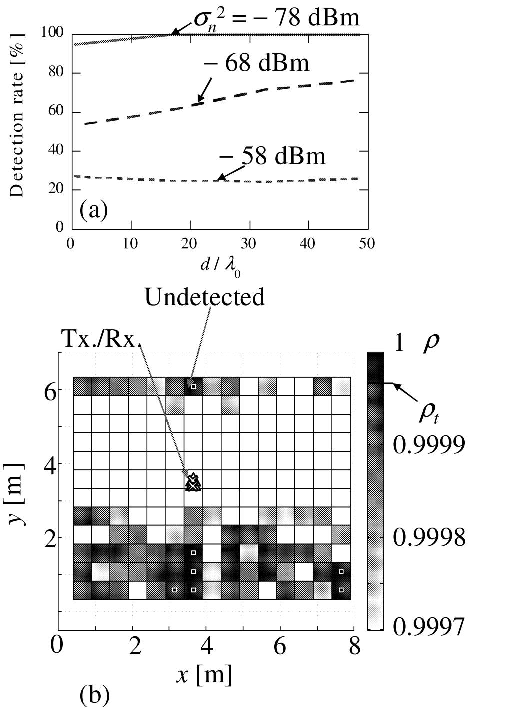

Figure 4: Detection characteristics (arrangement A): (a) Detection rate versus d, (b) Distribution of channel correlation.

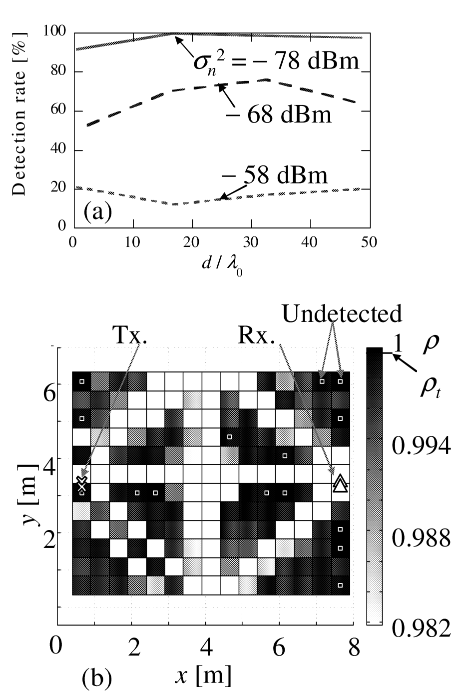

Figure 5: Detection characteristics (arrangement B): (a) Detection rate versus d, (b) Distribution of channel correlation.

of the indoor propagation based on the raytracing method is carried out. The intrusion detection performance with the various antenna arrangements are evaluated for the human positions all over the room. The numerical analysis results showed that the proposed antenna arrangement method can achieve more than 90 % of the detection rate, that is comparable to that of the conventional arrangement even though the proposed arrangement requires the space half of the conventional one.

Acknowledgments

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