MIMO Sensor
~ Experimental Channel Characterization in Indoor Environment~

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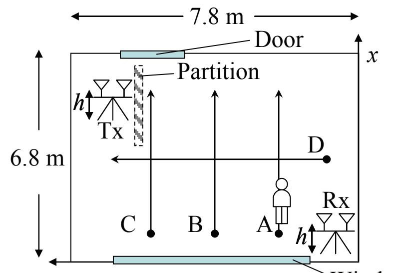
1. Introduction

Several kinds of the sensor systems for home safety and security systems have been developed, and most of them employ the optical devices, such as infrared sensor and video camera. However, these optical sensors cannot detect the target behind the obstacles since they depend on the visibility. The microwave sensor can be a strong candidate for the robust detection system for such application. The microwave sensor using existing signals, such as wireless LAN, TV broadcast signals and so on, have been studied, and they have proved that the microwave sensor can be effective in break-in detection [1]-[2].

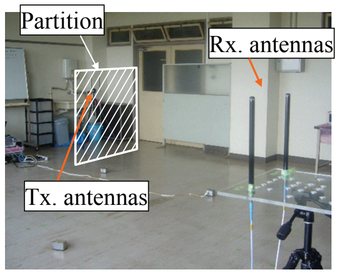
MIMO (Multiple-Input Multiple-Output) communication systems are widely used recently since they can greatly enhance the data rate without expanding the frequency band width [3]. MIMO system uses several antennas and the spatial multiplexing is one of the key features for enhancing communication quality. However, the time-variant channel greatly affects its performance if the spatial resources are fully exploited [4]. This means, an event detection scheme using MIMO channel variation has a great potential to achieve high performance sensor systems.

In this paper, a MIMO sensor using microwave band is proposed and evaluated based on the MIMO channel measurement in indoor environment. This MIMO sensor uses all components of the MIMO channel matrix, and detects the events based on the channel variation [5].

In 2, the key idea of MIMO sensor is described and the measurement setup for verifying MIMO channel is indicated. In 3, the channel characteristics are experimentally verified and the phenomena of the channel variation are considered. In 4, the MIMO sensor performance based on fundamental scheme is clarified.



(a) Layout and routes



(b) Photo of the environment

Fig. 1 Measurement environment

2. Measurement Setup

The key idea of our MIMO sensor is just observe the channel variation from the regular situations, and does not have to know the direction or distance of the target. To detect the unusual event correctly, the MIMO sensor must know the regular channel characteristics. Therefore, the channel characterization based on an actual environment is important.

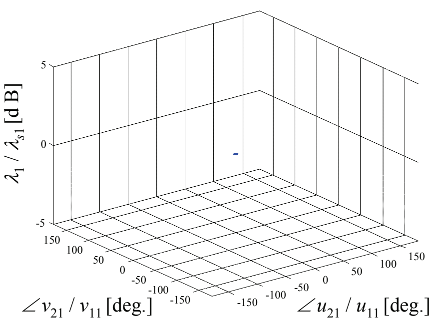


Fig. 2 Trajectory of static environment

In this study, the indoor environment is used for the channel measurement. Figure 1 shows the environment of this channel measurement campaign. The size of the room is 7.8 m x 6.8 m x 2.6 m. Two sides of the wall are concrete, and other sides have door or window. Both the transmitter and receiver have two antennas, and they are located at the corners of the room. The sleeve antennas are used and their inter-element spacing is 1.5 λ_0 (λ_0: wavelength in a vacuum). The height of the antenna is h [m]. The transmitted signal is OFDM with 56 subcarriers and the bandwidth is 10 MHz. While the signal is observed at the receiver side, the person walks along the courses A~D.

3. Characterization of Time-Variant MIMO Channel

By using SVD (Singular Value Decomposition), the $N \times N$ MIMO channel can be expressed as,

$$\mathbf{H} = \mathbf{U}\,\mathbf{\Lambda}\,\mathbf{V}^H \quad (1)$$

where, $\mathbf{U}$, $\mathbf{\Lambda}$, $\mathbf{V}$ represent left singular vectors, $\mathbf{U} = [\mathbf{u}_1, ..., \mathbf{u}_N]$, singular values, $\mathbf{\Lambda} = \mathrm{diag}(\sqrt{\lambda_1}, ...\sqrt{\lambda_N})$, and right singular vectors, $\mathbf{V} = [\mathbf{v}_1, ..., \mathbf{v}_N]$, respectively. In this study, the channel is characterized by using these values. Since the major path components are contained by the first mode, corresponding to, $\mathbf{u}_1, \lambda_1, \mathbf{v}_1$, we observed their behaviour during a person is walking. When the object is moving in the environment, AoD (Angle-of-departure) and AoA (angle-of-arrival) can be changed since the direction of the scattered signal at the object is changed. Also, the arriving signal level can be changed by the shadowing or scattering at the object. Therefore, the three components are jointly treated by, $(\angle u_{21}/u_{11}, \lambda_1, \angle v_{21}/v_{11})$, where $\mathbf{u}_1 = [u_{11}, u_{21}]^T$, $\mathbf{v}_1 = [v_{11}, v_{21}]^T$, and $N = 2$.

Figure 2 indicates the observed three components for static environment without any persons. Here, the eigenvalue is normalized by the static environment averaged eigenvalue, λ_{s1}. It can be seen that the trajectory is always at the center of the region shown in the plot. This means that this environment is not disturbed by the unexpected components.

Figure 3 indicates the trajectories with various courses when h = 1.2m and no partition is used. (A)~(C) are the courses where a person walks toward $+x$ direction. It can be clearly seen that trajectories caused by moving person appear. Very similar curves are observed in these three plots. The plot (D) corresponds to the course along y-direction, and there is less variance in eigenvalue, λ_1. Similarly to (B), since the person does not approach to the antenna closely, the power of the major path has little effect from the person.

Figure 4 shows the trajectories when height of the antenna is varied. It is clearly seen that placing antenna at low position, the sensitivity of the sensor can be greatly enhanced. On the other hand, the antenna with h = 2.3 m suffers from too small variation in the trajectory. This is because the path between the antennas located higher than person cannot be affected.

To verify the performance of the MIMO sensor under the NLOS (Non-Line-Of-Sight) situation, the conductor partition is placed in front of the antennas. Figure 5 indicates the trajectories with two NLOS scenarios, where one is a partition in front of Tx and another is a partition in front of Rx. It can be seen that the trajectories can be clearly observed even with NLOS environment. Especially, the plot with the partition at Tx shows the fluctuation in the eigenvalue is caused while the small variance is observed in the angles in the eigenvectors.

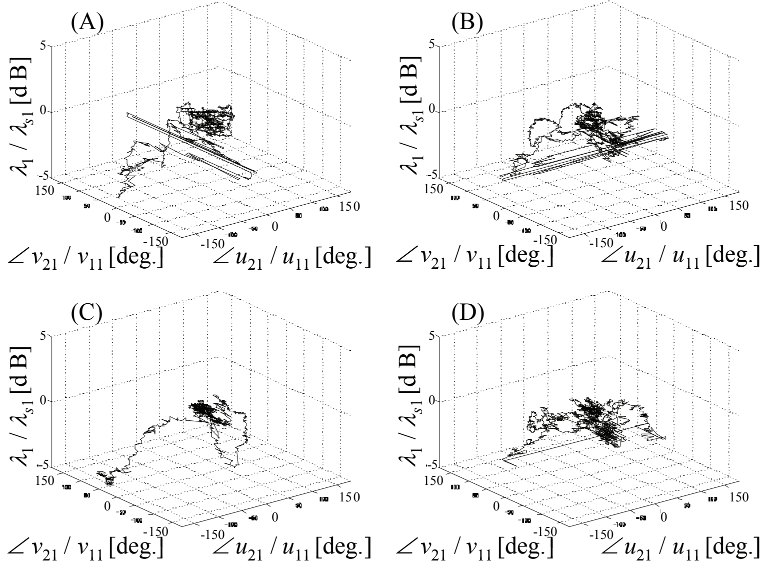


Fig. 3 Trajectory of course A~D

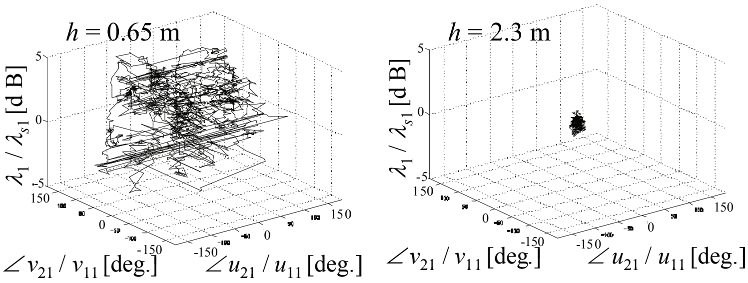


Fig. 4 Trajectory with different antenna height

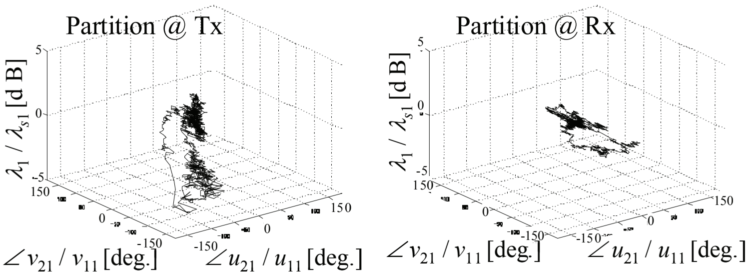


Fig. 5 Trajectory with NLOS situation

Since the major path does not exist and the most of the paths arrives from various directions in the NLOS situation, less variations in eigenvalues and eigenvectors is observed compared with the LOS situation.

4. Break-in Detection Performance

The break-in detection performance is demonstrated based on the measured channel. To evaluate the channel variation with simple procedure, the time correlation of the channel is employed in this consideration. When the channel components of the static and moving environment is defined as, h_{ij} and h'_{ij}, respectively, the time correlation of the channel can be described as,

$$\rho = \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}\frac{h_{ij}{h'_{ij}}^*}{|h_{ij}||h'_{ij}|} \tag{2}$$

where $\{\}^*$ means the conjugate of the complex number. It must be also considered the apparent fluctuation in time correlation caused by the noise, and we define it as, ρ_n. The detection is performed when $\rho < \min(\rho_n)$. Therefore, the detection probability versus SNR is verified.

The time transitions of ρ and ρ_n are shown in Fig. 6. Here, two channel measurements are performed for obtaining the channels with both no person existing and a person walking along the course A. It can be seen that the correlation, ρ, varies depending on the time when a person is walking. It can be also found that the ρ_n is decreased by lowering SNR. Since the detection can be valid when $\rho < \min(\rho_n)$, the high SNR is needed for achieving high detection probability.

Figure 7 shows the detection probabilities when the antenna height is varied. Here, these results are obtained from the all courses, A~D, and the channel responses are measured for two different persons to verify inter-subject variance. It is shown that required SNR for 90 % detection at h = 0.65 m is 11 dB lower than that at h = 1.2 m. On the other hand, the SNR higher than 25 dB is required to achieve 90 % detection rate when $h \geq 1.7$ m. It is shown

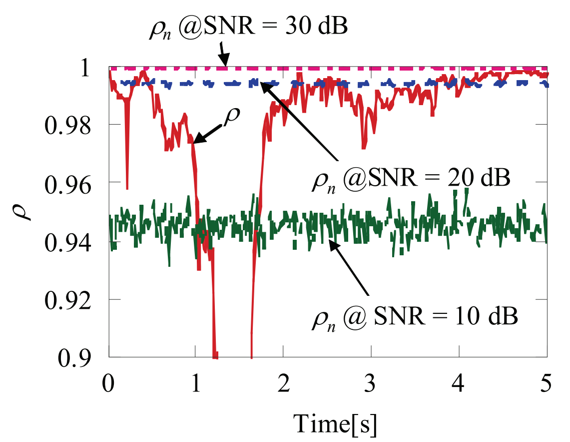


Fig. 6 Correlation, ρ, versus observing time

that the placing antenna at lower position is effective in enhancing detection probability without increasing the transmitting power. It is found that the plots (i) and (ii) agrees very well, and quite similar channel can be reproduced even with different subjects.

The detection performance difference between LOS and NLOS environment is verified in Fig. 8. Here, the height of the antenna is set to 1.2 m, and the course D is used. It is found that the difference in the required SNR between LOS and NLOS situation is around 6dB for the 90 % detection probability. This result indicates that the IMO sensor has a high performance for detecting invisible object.

5. Conclusion

This paper has proposed a MIMO sensor using microwave band and showed evaluation results based on the MIMO channel measurement. The channel characteristics are experimentally verified and found that eigenvectors and eigenvalue can be useful in expressing time-varying channel. It is also found that placing antenna at low height enhances the detection performance without increasing transmitting power. It is also shown that MIMO sensor is effective for detecting invisible target since the difference in the required SNR between LOS and NLOS situation is around 6dB. These results shown in this paper proves that MIMO sensor has high potentials for break-in detection systems.

Acknowledgement

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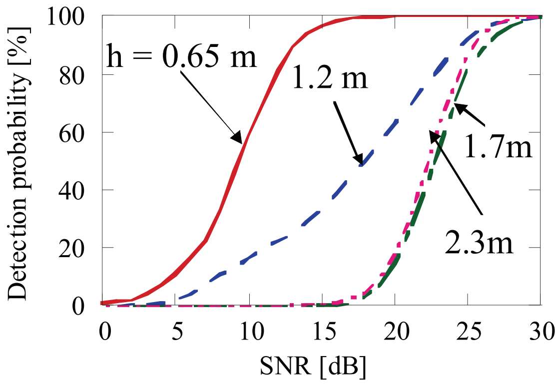
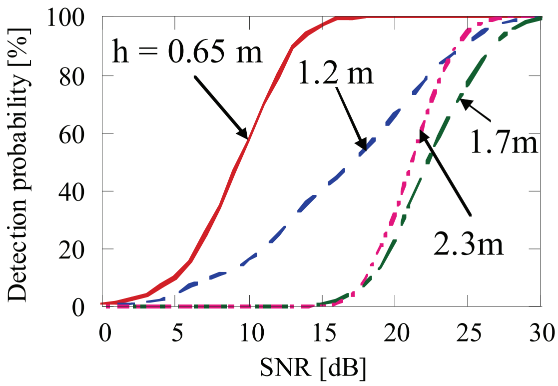


(i) Subject 1



(ii) Subject 2

Fig. 7 Detection probability versus SNR

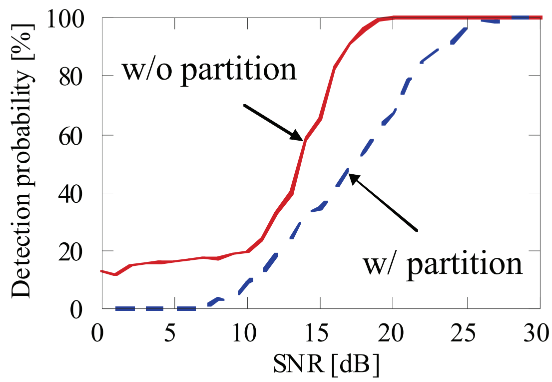


Fig. 8 Detection probability w/ and w/o partition.

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