Experimental evaluation on MIMO sensor employing eigenvector diversity

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Abstract: An intruder detection method by using time variant Multiple Input Multiple Output (MIMO) channels has been proposed (MIMO sensor). In this letter, the detection performance using eigenvectors, which are obtained by singular value decomposition for MIMO channel matrix, is evaluated in actual indoor propagation environment. Moreover, a new diversity method using multiple eigenvectors is proposed to enhance the performance of the intruder detection using eigenvectors. Scenarios that are effective for 1st and 2nd eigenvectors is verified and the effectiveness using multiple eigenvectors is shown compared to the MIMO sensor using the channel matrix.

References

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1   Introduction

Reliable security systems have been recently attracted much attention. Radiowave sensors using existing signals, such as the radio using Frequency Modulation (FM), Television (TV) broadcast signals and so on, have been studied [1]. The method is relatively simple but there is a issue for the detection accuracy [2]. Moreover, since VHF-FM and UHF-TV signals are used in [1], the variation of the propagation channel from the outdoor to indoor might be occurred due to the change in outdoor propagation environment. In order to solve these problems, an intruder detection using array signal processing is proposed [2].

In this method, Single Input Multiple Output (SIMO) channel is assumed and the variation of 1st eigenvector, which is obtained by the correlation matrix of the received signal, is utilized as a cost function of intruder detection. We proposed an intruder detection method which utilizes channel matrix in Multiple Input Multiple Output (MIMO) channels [3], in order to enhance detection performance in [2]. We call this method *MIMO Sensor* [3]. Since not only receiving but also transmitting diversity effects are obtained by using MIMO transmission, it was shown that higher reliability for the intruder detection is obtained by using the MIMO Sensor compared to the SIMO sensor in an actual indoor environment [3].

The time correlation using the channel matrix has been compared with that using eignevectors, when 2×2 MIMO system is considered [4]. It is shown that the detection performance by using the channel matrix is almost same with that by the eigenvectors [4]. Moreover, only results using a ray-tracing simulation have been shown in [4]. In this letter, the diversity scheme, which selects multiple eigenvectors according the propagation characteristics, is proposed : we utilize that the propagation characteristics of 1st and 2nd eigenvectors in the MIMO channel are different with each other [5]. The effectiveness of the proposed method is clarified by the indoor measurement when considering a person inside the room.

2   Proposed method

Fig. 1 shows a concept of MIMO sensor using eigenvectors. Fig. 1 (a) and (b) compare the variation of eigenvectors in the MIMO channel due to a person. M and N are the numbers of transmitting and receiving antennas in Fig. 1. $\boldsymbol{V} \in \mathbb{C}^{M \times M}$, $\boldsymbol{U} \in \mathbb{C}^{N \times N}$ are transmitting and receiving eigenvector matrixes, respectively. As can be seen in Fig. 1, the eigenvectors, $\boldsymbol{V}$ and $\boldsymbol{U}$ are changed to $\boldsymbol{V}'$ and $\boldsymbol{U}'$ due to the intrusion by the person. We realize the intrusion detection by checking the variation of the channel matrix, $\boldsymbol{V}$ and $\boldsymbol{U}$.

For simplification, let us assume that receiving eigenvectors are considered and $u_{no,ij}$ ($i = 1 \sim N, j = 1 \sim L$) is a component at the eigenvector without people in the room. $L = \min(N, M)$. When $u_{ij}(t)$ is a component of the
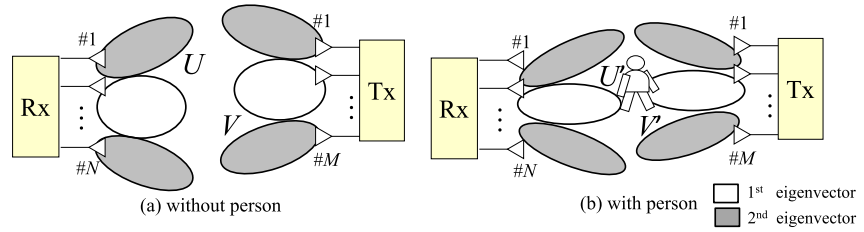
Fig. 1. Concept of MIMO sensor using eigenvectors.

eigenvector at time t, the time correlation, $\rho_U(t)$ is represented by

$$\rho_U(t) = \frac{\left| \sum_{i=1}^{N} \sum_{j=1}^{L} u_{no,ij}^* u_{ij}(t) \right|}{\sqrt{\sum_{i=1}^{N} \sum_{j=1}^{L} |u_{no,ij}|^2} \sqrt{\sum_{i=1}^{N} \sum_{j=1}^{L} |u_{ij}(t)|^2}}. \tag{1}$$

We have to judge whether the intrusion is employed or not by using the value which is obtained in Eq. (1). There are two reasons why Eq. (1) becomes small.

(a) Variation on channel matrix due to the intrusion or surrounding environment

(b) Variation on channel matrix due to thermal noise

We evaluate influence on the time correlation by the thermal noise, because the influence by only reason (a) must be detected. The correlation considering the thermal noise, $\rho_{U,w/n} \in \mathbb{C}^{N \times L}$ is represented as

$$\boldsymbol{U}_{w/n} = \boldsymbol{U}_{w/o,n} + \frac{1}{\mathrm{SNR}} \boldsymbol{U}_n \tag{2}$$

$$\rho_{U,w/n} = \frac{\left| \sum_{i=1}^{N} \sum_{j=1}^{L} u_{wo/n,ij}^* u_{w/n,ij} \right|}{\sqrt{\sum_{i=1}^{N} \sum_{j=1}^{L} |u_{w/o,n,ij}|^2} \sqrt{\sum_{i=1}^{N} \sum_{j=1}^{L} |u_{w/n,ij}|^2}} \tag{3}$$

where $\boldsymbol{U}_{w/n}$ and $\boldsymbol{U}_{w/o,n}$ are the receiving eigenvector matrixes with/without the thermal noise, respectively. $\boldsymbol{U}_{w/o,n}$ is ideally assumed to be estimated receiving eigenvector matrix.

We obtain $\boldsymbol{U}_{w/o,n}$ with high SNR in the measurement. Since the range of SNR on the measurement in Sect.4 is 30 to 35 dB, we assume that estimated channel matrix $\boldsymbol{H}$ is ideal channel without the noise. Moreover, $\boldsymbol{U}_{w/o,n}$ is obtained by $\boldsymbol{H}$. Hence, $\boldsymbol{U}_{w/o,n}$ is regarded as the ideal channel without noise.

After the estimation of $\boldsymbol{U}_{w/o,n}$, we artificially add the thermal noise in order to evaluate the performance by the MIMO sensor using the eigenvectors versus the SNR. $\boldsymbol{U}_n$ is the matrix by the thermal noise, which is obtained by computer simulation after the measurement.

$u_{w/n,ij}$ and $u_{w/o\ n,ij}$ are components on the channel matrix. In this letter, we used as the threshold value $\rho_{U,w/n}$. Detailed calculation method to obtain the threshold value is the same when considering the channel matrix [3].

Next, a diversity scheme, which selects multiple eigenvectors according the propagation characteristics, is proposed. It is well known that 1st eigenvector is generated for the direct wave or wave with the maximum power [5]. On the other hand, eigenvectors except 1st eigenvector are generated for the multipath waves [5]. Hence, the diversity effect, which means the detection using *different* waves, is expected when using multiple eigenvectors.

Let us consider kth eigenvector, $\boldsymbol{u}_k \in \mathbb{C}^{N \times 1}$ $(k = 1 \sim L)$. Let us assume that $u_{k,no,i}$ $(i = 1 \sim N)$ is a component at the k eigenvector without people in the room. When $u_{k,i}(t)$ is a component of the k eigenvector at time t, the time correlation at k eigenvector, $\rho_{U,k}(t)$ is represented by

$$\rho_{U,k}(t) = \frac{\left| \sum_{i=1}^{N} u_{k,no,i}^* u_{k,i}(t) \right|}{\sqrt{\sum_{i=1}^{N} |u_{k,no,i}|^2} \sqrt{\sum_{i=1}^{N} |u_{k,i}(t)|^2}}. \tag{4}$$

In the proposed method, the diversity effect can be expected by using the following scheme:

- The intruder is judged when at least one of $\rho_{U,k}(t)$ $(k = 1 \sim L)$ is less than threshold value.

- The intruder is not judged when all the $\rho_{U,k}(t)$ $(k = 1 \sim L)$ are greater than threshold value.

Note that the threshold value must be calculated for each eigenvector, because the SNRs among all the eigenvalues are different with each other. Although we explained the receiving eigenvector, the transmitting eigenvectors can be incorporated into the proposed method in the same way.

3 Measurement environment

In order to clarify the effectiveness of proposed method, we conducted the measurement in an actual indoor environment. The measurement environment is shown in Fig. 2. The number of transmitting and receiving antennas are two and four, respectively. Therefore, two eigenvectors (1st and 2nd) are obtained. The sleeve antenna, which is known as omni-directional antenna in the horizontal plane, is used for the transmit and receive antennas. In this measurement, the frequency is 2.55 GHz. MIMO-OFDM signals based on IEEE802.11n standard are used and detail signal format and configuration of MIMO OFDM testbed are described in [3]. The array width d_{Tx} and d_{Rx} at the transmitter and receiver sites are set to be $1.5\,\lambda$ (λ : one wavelength). The positions of transmit antennas were moved 10 times with the interval of $0.5\,\lambda$ by using a position controller so as to keep $d = 1.5\,\lambda$. The antenna height at Tx and Rx sites are set to be 1.0 m. As shown in Fig. 2, the MIMO
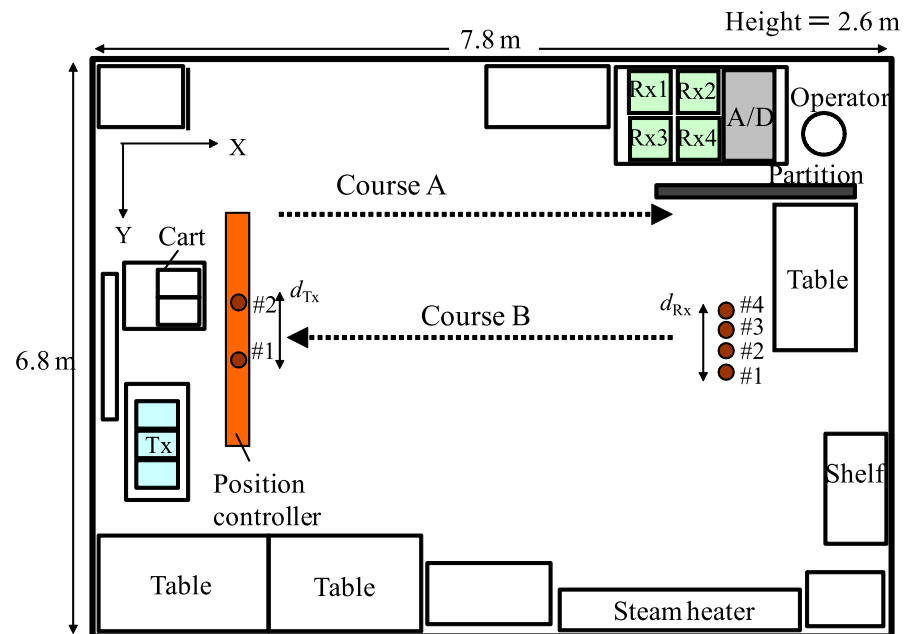
Fig. 2. Measurement environment.

channels are measured when a person moves on Courses A and B. Since the range of SNR on the measurement in Sect. 4 is sufficiently high (30 to 35 dB), the noise was added in the computer simulation after the estimation of H, to change the value on SNR.
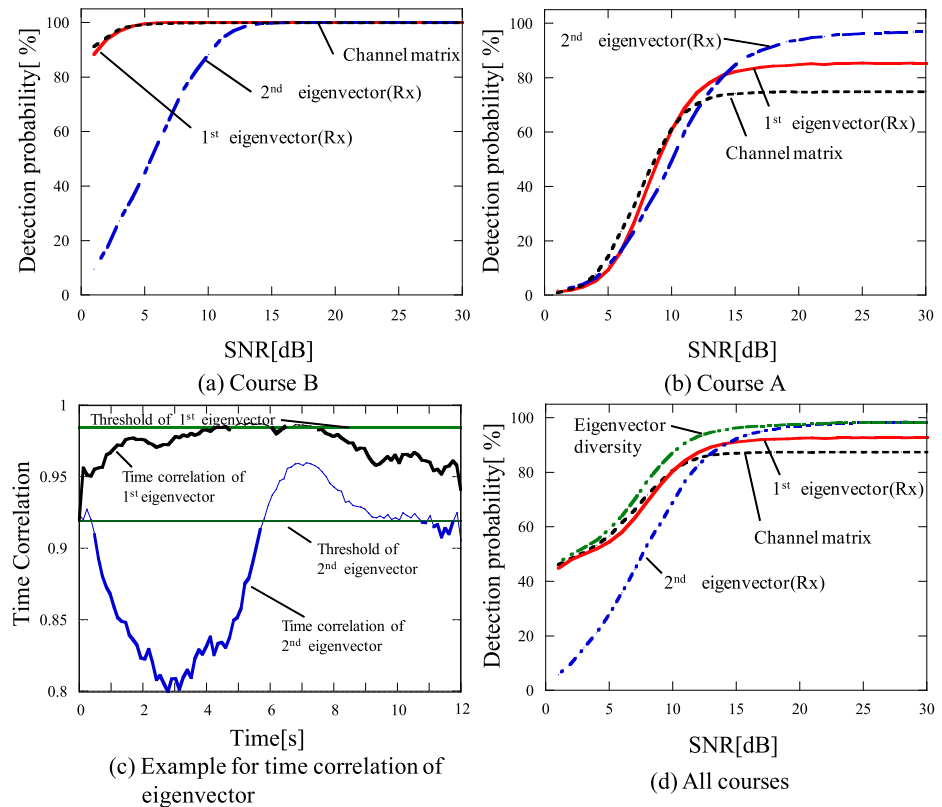
4 Person detection performance by eigenvector diversity

First, the detection performance is considered by Courses A and B, in order to clarify the feature using 1st and 2nd eigenvectors. Fig. 3 (a) shows the detection probability versus SNR at course B. As can be seen in Fig. 3 (a), the detection performance by 1st eigenvector and channel matrix is higher than that by 2nd eigenvector. It is observed that the time correlation by 1st eigenvector is small when the person moves in front of antennas, because 1st eigenvector detects the directed wave.

Fig. 3 (b) plots the detection probability versus SNR at Course A. As can be seen in Fig. 3(b), the detection performance by 2nd eigenvector is higher than that by 1st eigenvector and channel matrix. Since 2nd eigenvector is changed by the variation of propagation channel which arises by 1st reflected wave, it is confirmed that detection rate by 2nd eigenvector is relatively higher than that by 1st eigenvector, when the person is away from the antennas.

The diversity effect can be expected by the results in Fig. 3 (a) and (b). Fig. 3 (c) shows an example of the time correlation of eigenvectors at Course A. The person is judged when each correlation value by 1st and 2nd eigenvectors is smaller than the corresponding threshold values in Fig. 3 (c). As can be seen in Fig. 3 (c), the location where the correlation value is smaller than the threshold value by 1st eigenvector is different from that by 2nd eigenvector.

The detection probability when employing eigenvector diversity is plotted

Fig. 3. Detection performance with eigenvectors and effect on eigenvector diversity method.

in Fig. 3 (d). The results on all the Courses A and B are considered in this figure. As can be seen in Fig. 3 (d), the detection probability by the eigenvector diversity is higher than that by channel matrix [3]. When the SNR is 15 dB, the detection probability using the eigenvector diversity is 96.3%. On the other hand, the detection probability using channel matrix is only 87.0% with the same SNR. Therefore, it is shown that the eigenvector diversity is effective for improving the detection rate in the MIMO sensor.

5   Conclusion

In this letter, we evaluated the detection performance on the person by the MIMO sensor using multiple eigenvectors, when considering the person in the room. From the measurement results, the time correlation by 1st eigenvector and channel matrix is small when the person moves in front of antennas, because 1st eigenvector detects the directed wave. On the other hand, it is verified that 2nd eigenvector can detect the reflected wave because the detection rate by 2nd eigenvector is higher than that by 1st eigenvector in such a scenario. Moreover, we proposed the diversity scheme which selects multiple eigenvectors by using the different feature between 1st and 2nd eigenvectors. Finally, it is shown that the eigenvector diversity is effective for improving the intruder detection performance in the MIMO sensor.

Acknowledgments