Performance Improvement of Obstacle Detection of Short Range MIMO Sensor Using Signal Subspace

Yuya Aoki, Hisamichi Mori, Nobuyoshi Kikuma, Hiroshi Hirayama, Kunio Sakakibara
Department of Computer Science and Engineering, Nagoya Institute of Technology,
Gokiso-cho, Showa-ku, Nagoya, 466-8555, Japan

Abstract – **For the short-range MIMO sensor to detect the obstacle intrusion, this paper proposes the new method (ESF-MIMO) which improves the conventional method (SF-MIMO). The computer simulation shows that ESF-MIMO can provide improved detection performance over the SF-MIMO.**

Index Terms — **MIMO Sensor, Short Range, Obstacle Detection, Signal Subspace.**

I. Introduction

In wireless high-power charging systems such as electric vehicles, we may have a problem of a fire from the obstacle which gets into the charging system. Therefore, sensing of the obstacle intrusion is essential for the practical application of wireless charging of electric vehicles. MIMO (Multiple-Input Multiple-Output) is often used for sensing of the obstacle intrusion [1]. In this paper, we apply the short-range (near-field) MIMO sensor to detect the obstacle intrusion in a limited space such as the wireless charging system [2],[3]. So far, we have compared two detecting methods which use the MIMO channel matrix and the SIMO (Single-Input Multiple-Output) signal-subspace eigenvectors, respectively [1],[3]. By using the latter method, we can configure a simpler system. However, this method is degraded in detection performance compared with the method using the MIMO channel matrix [3]. Consequently, we try to improve the method using the SIMO signal subspace.

II. MIMO Sensor Arrangement

MIMO is a radio system that uses multiple antennas both for transmitting and receiving signals. When the number of transmitting antennas is M and the number of receiving antennas is N, array received signal $\boldsymbol{y}_m(t)$ obtained from the m-th transmitting antenna at time instant of t is expressed as follows:

$$\boldsymbol{y}_m(t) = \boldsymbol{h}_m(t)x_m(t) + \boldsymbol{n}_m(t) \tag{1}$$

Here, $x_m(t)$ is the transmitted signal from the m-th transmitting antenna, $\boldsymbol{h}_m(t)$ is the propagation channel vector for the signal $x_m(t)$, and $\boldsymbol{n}_m(t)$ is the internal noise vector.

III. Detection Method using MIMO Channel Matrix

We express $M \times N$ channel matrices $\boldsymbol{H}$ for the environments with no obstacle (denoted by "NO") and with an obstacle (denoted by "OB") at time instant of t as follows:

$$\boldsymbol{H}_{\rm NO} = [\boldsymbol{h}_{\rm NO,1}, \cdots, \boldsymbol{h}_{{\rm NO},M}] \tag{2}$$

$$\boldsymbol{H}_{\rm OB}(t) = [\boldsymbol{h}_{\rm OB,1}(t), \cdots, \boldsymbol{h}_{{\rm OB},M}(t)] \tag{3}$$

where $\boldsymbol{h}_{{\rm NO},m}$ and $\boldsymbol{h}_{{\rm OB},m}(t)$ are channel vectors from the m-th transmitting antenna.

The obstacle detection is carried out by using the following equation.

$$G_{H_{\rm D}} = \|\boldsymbol{H}_{\rm NO} - \boldsymbol{H}_{\rm OB}(t)\|_F \tag{4}$$

Equation (4) uses as the intrusion evaluation the Frobenius norm of the difference of two channel matrices, which is referred to as CF-MIMO [3].

IV. Detection Method using Signal Subspace and Improved Method

This method uses the first eigenvector corresponding to the maximum eigenvalue of the correlation matrix of SIMO-based array received data. The correlation matrix $\boldsymbol{R}^{(m)}$ of the array received data $\boldsymbol{y}_m(t)$ obtained from the m-th transmitting antenna is expressed as follows:

$$\boldsymbol{R}^{(m)} = E[\boldsymbol{y}_m(t)\boldsymbol{y}_m(t)^H] = \sum_{i=1}^{N} \lambda_i^{(m)} \boldsymbol{e}_i^{(m)} \boldsymbol{e}_i^{(m)H} \tag{5}$$

Here, $\boldsymbol{e}_i^{(m)}$ is the eigenvector, $\lambda_i^{(m)}$ is the eigenvalue corresponding to $\boldsymbol{e}_i^{(m)}$. Then, in the same manner as (2) and (3), it is possible to construct the matrices by using first eigenvectors with no obstacle and with an obstacle at time instant of t as follows:

$$\boldsymbol{V}_{\rm NO} = [\boldsymbol{e}_{\rm NO,1}^{(1)}, \cdots, \boldsymbol{e}_{\rm NO,1}^{(M)}] \tag{6}$$

$$\boldsymbol{V}_{\rm OB}(t) = [\alpha_1 \boldsymbol{e}_{\rm OB,1}^{(1)}(t), \cdots, \alpha_M \boldsymbol{e}_{\rm OB,1}^{(M)}(t)] \tag{7}$$

where α_m is the phase adjustment factor. The obstacle detection is evaluated by using $\boldsymbol{V}$ in place of $\boldsymbol{H}$ in (4). This method is referred to as SF-MIMO [3].

In the improved method, we use the maximum eigenvalue $\lambda_1^{(m)}$ for weighting of eigenvectors as shown in the following equations.

$$\boldsymbol{W}_{\rm NO} = [\lambda_{\rm NO,1}^{(1)} \boldsymbol{e}_{\rm NO,1}^{(1)}, \cdots, \lambda_{\rm NO,1}^{(M)} \boldsymbol{e}_{\rm NO,1}^{(M)}] \tag{8}$$

$$\boldsymbol{W}_{\rm OB}(t) = [\lambda_{\rm OB,1}^{(1)} \alpha_1 \boldsymbol{e}_{\rm OB,1}^{(1)}(t), \cdots, \lambda_{\rm OB,1}^{(M)} \alpha_M \boldsymbol{e}_{\rm OB,1}^{(M)}(t)] \tag{9}$$

Because the eigenvalues represent capacities of the individual eigenvector channels, it can be expected to improve the detection performance by increasing the detection sensitivity. The obstacle detection is evaluated by using $\boldsymbol{W}$ in place of $\boldsymbol{H}$ in (4), which is referred to as ESF-MIMO in this paper.

V. Computer Simulation

Figs. 1 and 2 show the antenna arrangement for MIMO sensor for two cases with different Tx element spacing of $\lambda/2$ and $5\lambda/2$ (λ: wavelength). Table I shows the simulation conditions. Since the electromagnetic field is dominated by the near field, we use the MoM (Method of Moments) for calculating the propagation channel vector $\boldsymbol{h}_m(t)$. As for the detection rate, it is judged to be detectable if the evaluation value at time instant t with the obstacle is out of the range of the average $\pm 3\sigma$ (σ: standard deviation) of that in the case of no obstacle. Figs. 3 and 4 are results of evaluation showing the detection rate versus SNR (calculated from the 2000 trials). Figs. 3 and 4 correspond to the cases of Tx element spacing of $\lambda/2$ and $5\lambda/2$, respectively. The three methods described above are compared. As found from Fig. 3, at SNR = 5dB, conventional SF-MIMO shows the large degradation of about 80% in the detection rate compared with CF-MIMO. We suppose that this is because the channel matrix of CF-MIMO is obtained from MIMO, whereas that of SF-MIMO is obtained from superposition of SIMO. On the other hand, it is confirmed that ESF-MIMO can provide improved detection rate of about 70% over the SF-MIMO. However, as found from Fig. 4, CF-MIMO has almost the same detection rate as SF-MIMO, and the detection rate of ESF-MIMO slightly deteriorates although ESF-MIMO achieves 100% detection at SNR = 0dB or more. Therefore, we can say that the improved method is effective when the Tx element spacing is narrow. Further, from Figs. 3 and 4, it can also be seen that we can enhance the detection rate of the SF-MIMO by increasing the element spacing of transmitting antennas.

VI. Conclusion

In order to improve the detection performance of the conventional SF-MIMO, we have proposed ESF-MIMO which uses eigenvalues as weighting of eigenvectors in SF-MIMO. As a result of computer simulation, when the element spacing of transmitting antennas is narrow, it is shown that ESF-MIMO exhibits a significant effect on detection performance. It is also found that the detection rate of the SF-MIMO can be improved by increasing the element spacing of transmitting antennas.

As future works, it is necessary to improve further the ESF-MIMO and consider the antenna placement for effective obstacle detection in the limited space.

References

[1] K. Ogawa et. al., "Performance Evaluation of Environment Change Detection Method Using MIMO Sensor", IEICE Tech. Rep., AP2011-43 (July 2011).

[2] K. Nishimori et. al., "Study on Transmission Method in Short Range MIMO Communication", IEICE Tech. Rep., AP2009-83 (Sept. 2009).

[3] Y. Aoki et. al., "A Consideration of Obstacle Detection Method Using Short Range MIMO Sensor in Limited Space", AWAP2014, pp.202, (May 2014).

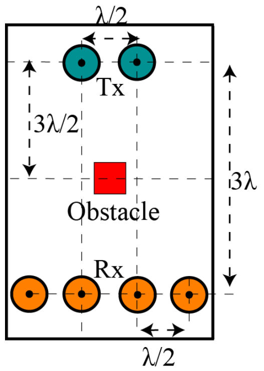

Fig. 1: MIMO sensor and obstacle(Tx spacing = $\lambda/2$)

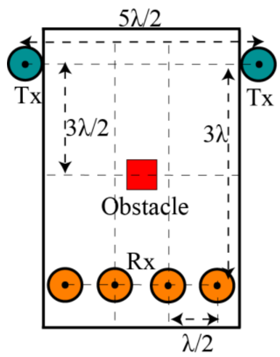

Fig. 2: MIMO sensor and obstacle(Tx spacing = $5\lambda/2$)

TABLE I: Simulation Conditions

Frequency[GHz]	2.45
Transmitted power[W]	1
Antenna	$\lambda/4$ Mono-pole
SNR[dB]	-10 to 20
Number of trials	2000
Size of cube obstacle[cm]	2.5
Material of obstacle	Copper

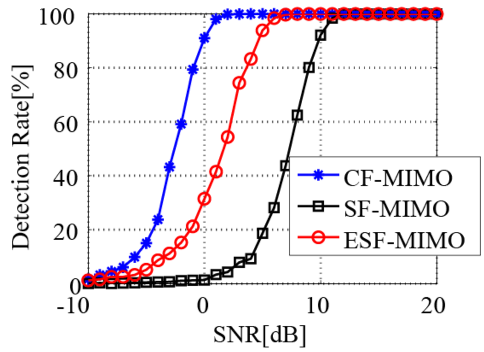

Fig. 3 : SNR vs detection rate (Tx spacing = $\lambda/2$)

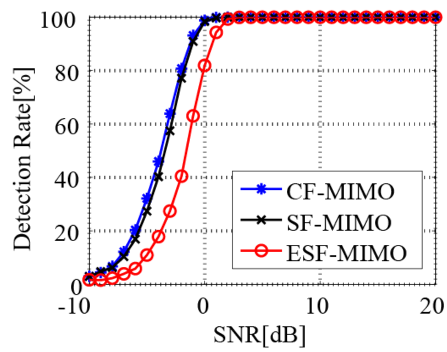

Fig. 4 : SNR vs detection rate (Tx spacing = $5\lambda/2$)