Breath Detection Method Using Time-Variant MIMO Channel

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1. Introduction

Recently, the technology using biological information has become common in various fields such as medical, welfare, and security. The biological information is personal physical information like the heart beat, breathe, fingerprint pattern, and walking pattern. However, such as the biometrics and ECG (EelectroCardioGraph), most of currently prevailing technologies have the problem that those have physical heavy burden and big mental resistance because the devices or probes must be contacted directly to the body when they detect the biological information. Now the studies of non-contacting detection technologies using the microwave are made progress to solve such the problem. Noncontact biological information detection technologies using the microwave can be categorized in two types. One is the reflective type which illuminates a biological body with the microwave and observes the changes in the reflected wave as shown in Fig. 1. Another one is the transmission type which transmits the microwave through a body between transmitter and receiver and detects the biological information from change of the channel as shown in Fig. 2. The former can detect even the phase fluctuation accurately, but there is the problem which the system becomes expensive and complicate because it must transmit and receive the signal simultaneously. The latter is simple system, but there is a problem that detection performance is not accurate due to the frequency offset between the separated transmitter and receiver. Therefore, it is difficult to measure the accurate phase transition caused by the biological body.
In this paper, the noncontact breath detection method using MIMO sensor [1] is proposed. In this scheme, the biological information is observed by using time variant MIMO channel. MIMO transmission scheme has the defect that communication quality degraded by the change of the propagation environment. In contract, the proposed method exploits this defect for detecting biological information. The proposed method using the MIMO sensor can be achieved with a simple system and detect the phase fluctuation accurately without the influence of the phase rotation in the MIMO channel.
In 2, the proposed noncontact breath detection method using time variant MIMO channel is expressed. In 3, MIMO channel measurement condition in the experiment is described. In 4, the experimental results using the proposed detection method are discussed.

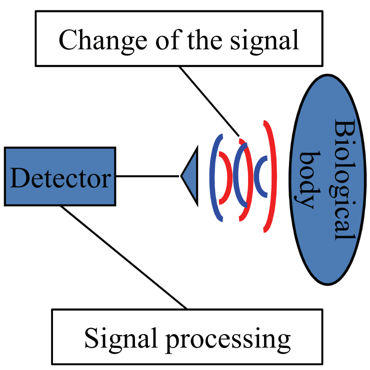


Fig. 1 Reflective type.

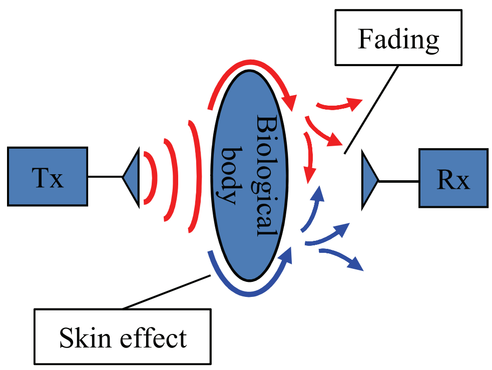


Fig. 2 Transmission type.

2. Proposed breath detection method

The detection system measures the channel in the environment where biological body exists between transmitter and receiver. The biological information is detected from the change in the channel. Because the microwave propagates along the surface of the biological body, the amplitude and phase of received signal change according to the surface movement. Therefore, biological activity like the breath can be detected by monitoring the change of the measured channel. But, there is a frequency synchronization error between real transmitter and receiver, so that phase of measured channel continues to be rotated. The measured SISO channel with the phase error can be expressed as,

$$\boldsymbol{H}' = h_{11} e^{j(\omega_t - \omega_r)t} \tag{1}$$

where, ω_t and ω_r are the frequency of transmitter and receiver. Because the change of channel phase due to biological activity is very slower than ω_t-ω_r, it cannot be detected and detection accuracy becomes degraded.

The proposed method measures the channel by using MIMO antennas and detects the breath from correlation matrix of MIMO channel as shown Fig. 3. 2x2 MIMO channel with the phase error is expressed as,

$$\boldsymbol{H}' = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} e^{j(\omega_t - \omega_r)t} . \tag{2}$$

The correlation matrix is expressed as,

$$\boldsymbol{R}_r = \boldsymbol{H}'\boldsymbol{H}'^H = \begin{pmatrix} |h_{11}|^2 + |h_{12}|^2 & h_{11}h_{21}^* + h_{12}h_{22}^* \\ h_{21}h_{11}^* + h_{22}h_{21}^* & |h_{21}|^2 + |h_{22}|^2 \end{pmatrix} \tag{3}$$

where, $\{\cdot\}^H$ and * express Hermitian transpose and complex conjugate operations, respectively. Because the phase error is cancelled in all of the components, proposed method can detect the biological activity more accurately than the method using SISO channel.

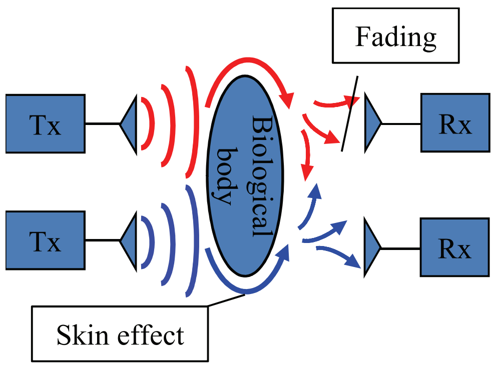


Fig. 3 Proposed method.

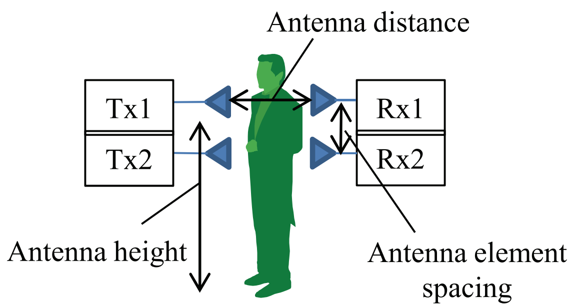


Fig. 4 Experimental configuration.

3. Channel measurement conditions

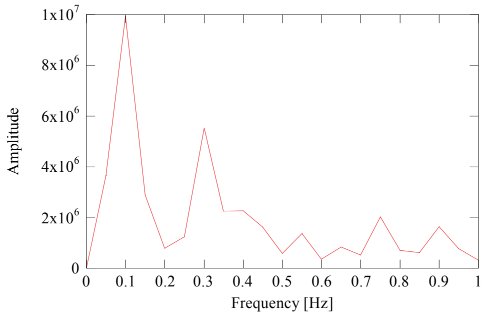
Figure 4 and Table 1 show experimental configuration and measurement conditions. Both transmitter and receiver have two patch antennas and the frequency is 2.55 GHz. Two types the antenna element spacing, i.e., 0.5 λ and 2.0 λ, are used and verified. Three types of the antenna height, i.e., 1.46 m, 1.14 m and 0.82 m are evaluated. The distance between two facing array antennas is set to, 0.4 m, 1.0 m or 2.5 m. In total, 18 channel measurements are carried out, and the channel is observed over 20 seconds for each measurement.

Table 1 Measurement conditions.

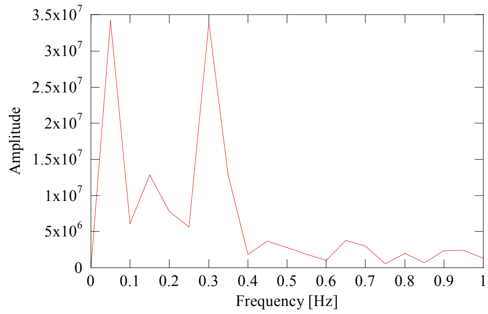
Antenna	Patch Antenna		
Measuring Time	20 sec		
Frequency	2.55 GHz		
Transmit antennas	2		
Receiver antennas	2		
Antenna element spacing	0.5 λ	2.0λ	
Antenna height	1.46 m	1.14 m	0.82 m
Antenna distance	0.4 m	1.0 m	2.5 m

4. Detection results

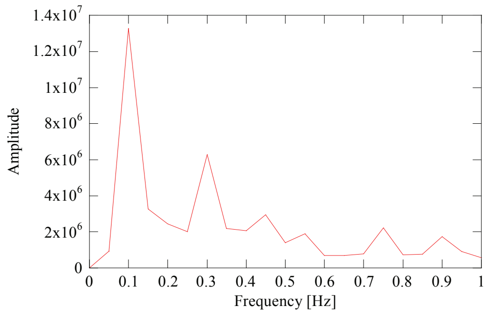
Figure 5 shows the frequency response for ***H***'(1,1), $\boldsymbol{R}_r(1,1)$, $\boldsymbol{R}_r(1,2)$ and phase angle of $\boldsymbol{R}_r(1,2)$ which are obtained from the measured channel. All of these results indicate large amplitude at 0.3 Hz. Because breathing rate of human is 16 ~ 20 per minutes, it can be recognized that the amplitude at 0.3 Hz mean the breath of human body.



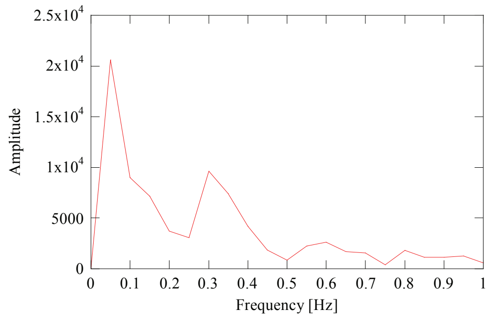
(a)$\boldsymbol{R}_r(1,1)$



(b)$\boldsymbol{R}_r(1,2)$



(c)***H***'(1,1)



(d)$\angle \boldsymbol{R}_r(1,2)$

Fig. 5 Frequency response.

The detection sensitivity is defined as (measured amplitude of 0.3 Hz component)/(noise). Figure 6 compares the detection sensitivity of the various detection methods for comparison the methods using the components of the correlation matrix and SISO channel are shown in order to confirm the advantage of MIMO over SISO. From this result, it is clear that the case using $\boldsymbol{R}_r(1,2)$ indicates the highest detection sensitivity. Because $\boldsymbol{R}_r(1,2)$ is complex number and has the amplitude component and phase component, it is estimated to have more information than others.

Next, the detection sensitivity with various measurement conditions is verified to find the measurement set up suitable for the breath detection. Figure 7 compares the detection sensitivity with the various antenna heights. The distance between two arrays is set to 0.4 m, and the antenna element spacing is set to 2.0 λ. This comparison result indicates that the highest detection sensitivity is observed when antenna height is 1.14 m. It is because 1.14 m is as tall as the chest of the human body and it corresponds to the position the lung.

Figure 8 compares the detection sensitivity with the various antenna distances. The antenna height is set to 1.14 m, and the antenna element spacing is set to 2.0 λ. The comparison result indicates that the highest detection sensitivity is observed when antenna distance is 0.4 m. It is because the closer array distance yields less direct path component in the channel, the influences of fading by the breath become conspicuous.

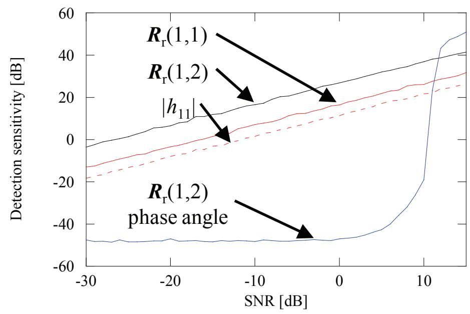


Fig. 6 Comparison of detection methods.

Figure 9 compares the detection sensitivity with two different antenna elements spacing. The distance between two arrays is set to 0.4 m, and the antenna height is set to 1.14 m. This result indicates that detection sensitivity with 0.5 λ is higher than that with 2.0 λ. it is interesting that the narrower antenna spacing yields higher sensitivity, but this may need further investigation.

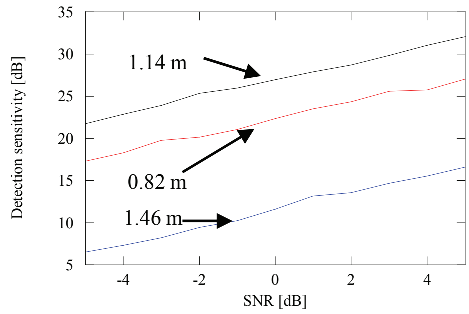


Fig. 7 Comparison of antenna height.

5. Conclusion

This paper has proposed a noncontact breath detection method using the time variant MIMO channel. The Frequency response of the measured correlation matrix indicates large amplitude at 0.3Hz corresponding to the breath rate and it is confirmed that can detect the breath of biological body by using the MIMO channel. The comparison result of the methods using correlation matrix components and SISO channel indicates that the method using non-diagonal component of the correlation matrix shows the highest detection sensitivity and it is confirmed that the proposed method outperforms the method using SISO channel. The comparison result of measurement condition indicates that detection sensitivity is high when antenna height is 1.14 m that corresponds to the position of the chest of the biological body. It is found that two arrays should be placed closely enough for suppressing the direct path in order to obtain further high sensitivity. These results support the effectiveness of the MIMO sensor in the breath detection of the biological body.

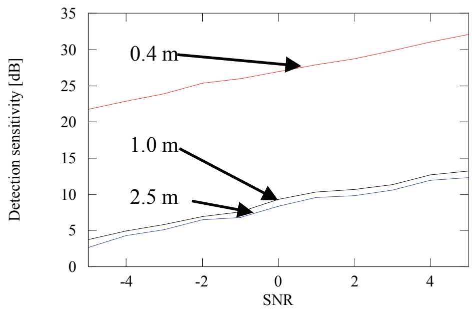


Fig. 8 Comparison of antenna distance.

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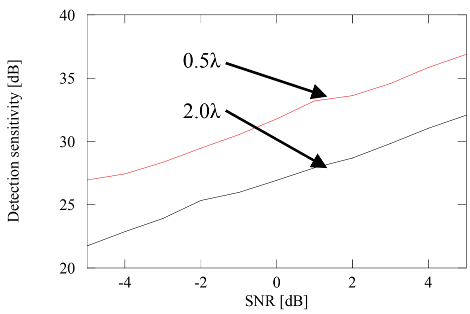

Fig. 9 Comparison of element spacing.

References

[1]Naoki Honma, Takashi Sugiura, Kentaro Nishimori, Hiroaki Sato and Yoshitaka Tsunekawa,"MIMO Sensor ~Experimental Channel Characterization in Indoor Environment~," In Proc. 2010 International Symposium on Antennas and Propagation (ISAP 2010) Nov. 2010.