Recognizing Aspiration Presence using Model Parameter Classification from Microwave Doppler Signals

Shuhei Inui, Kosuke Okusa, Kurato Maeno, and Toshinari Kanakura

Abstract—A study on the healthcare application is very important for the solitary death in aging society. Many previous works had been proposed a detection method of aspiration using the non-contact radar. But the works are only in subjects with sitting in a chair. We consider that user falls down in the state when he happen abnormal situation as daily life.

In this study, we focus on the detection of "aspiration" or "apnea" for the lying position, because the final decision of the life or death is aspiration. As initial stage of the system, we propose the recognition method for the presence of aspiration with lying position under the low-disturbance environment from microwave Doppler signals by using support vector machine (SVM).

Index Terms—microwave doppler radar, monitoring system, aspiration, SVM.

I. INTRODUCTION

RECENTLY, a study on the healthcare application is very important for the solitary death in aging society. The non-contact radars are attracted an attention because the system requires that daily life of user doesn’t interfere. Many of these radars (e.g. infrared radar, sound radar, Doppler radar) has in the system, especially the microwave Doppler radar has the advantage against the noise, light and temperature than another radars. Therefore, this feature is considered to be suitable for application to the system. However, the radar receives all environment movements in this area. Therefore, the radar is not robust under the disturbance environment. Most studies have not focused on the radar.

As perspective of monitoring for the elderly, we focus on the detection of "aspiration" or "apnea" for the lying position, because we think the final decision of the life or death is aspiration. As initial stage of the system, this study proposes the recognition method for the presence of aspiration with lying position under the low-disturbance environment from microwave Doppler signals by using support vector machine (SVM). If the presence of aspiration can be recognize, it is expected to apply to the detection of apnea syndrome and solitary death.

We describe the microwave Doppler radar system in section 2, we review other studies in section 3. We define the proposed method in section 4, we explain our experimental condition of proposed method in section 5 and we discuss result of analysis. Finally, we discuss to the conclusion in section 7.

II. MICROWAVE DOPPLER RADAR

We describe the microwave Doppler radar system. The radar irradiates the microwave to the target and let $F_0$ be the frequency of transmitted wave. The wave hits the target, and let $F_1$ be the frequency of reflected wave toward the radar. The frequency of Doppler subtract $F_0$ from $F_1$. The radar output the electric signal according to it.

In this study, the radar use the IPS-154 manufactured by Innocent Co., Ltd, and the A/D converter use the USB2.0 compatible analog output terminal manufactured by Contec Co., Ltd. The radar is shown above (see Figure 1).

![Microwave Doppler Radar (IPS-154)](image)

The radar is classified into two types (dual type and single type) which differ to the output wave. It derives two outputs $V_I$ and $V_Q$, which have a quadrature phase relationship, that is to say their phases are 90 degrees different from each other. If we do not consider the noise, both $V_I$ and $V_Q$ are shown below.

\[
V_I = A_1 \sin \left( \frac{4\pi R_1}{\lambda} \right) \tag{1}
\]

\[
V_Q = A_2 \cos \left( \frac{4\pi R_2}{\lambda} + \phi \right) \tag{2}
\]

where $A_1$ and $A_2$ are amplitudes, $\lambda$ is the wave length, $R$ is the distance between the radar and target and $\phi$ is the initial phase.

It follows from Eq.(1) and (2) that the phase change $\Delta \phi$ is proportional to the range change between the target and the radar $\Delta R$.

\[
\Delta \phi = \frac{4\pi \Delta R}{\lambda} \tag{3}
\]
Instantaneous amplitude $A$ and phase difference $\phi_t$ are shown below.

\begin{align*}
    A &= \sqrt{V_i^2 + V_Q^2} \\
    \phi_t &= \tan^{-1} \frac{V_Q}{V_i}
\end{align*}

\(4\)

\(5\)

III. RELATED WORK

We review the related works of this study.

Naoi et al. (2005) proposed the heartbeat detection method based on the microwave Doppler sensor using time-difference approach. Aoki et al. (2005) focused on the behavior patterns of solitude senior using pyroelectric sensor, then they proposed the detection method of irregular states.

Zhou et al. (2006) proposed the heartbeat wave model under the multi Doppler sensor environment. However, their method is difficult to set the initial value. Zhou et al. (2006) focused on distinguishing aspiration from heartbeat, then they verified method of RACMA and ICA.

Tanigawa et al. (2008) proposed a human chewing detection method based on the microwave Doppler sensor using wavelet transform and auto-correlation coefficient. Sekine et al. (2009) proposed a human activity (e.g. shaking hands, walking, etc...) recognition algorithm based on the microwave Doppler sensor using Support Vector Machine (SVM).

Lien et al. (2009) proposed the respiration and heartbeat detection method based on the millimeter-wave Doppler radar system using root-MUSIC method. Kubo et al. (2010) proposed a human activity recognition method based on the Doppler sensor using three binary classifiers (least squares, SVM and AdaBoost) approach. They detected the move (the target is changing his/her position or pose), resp (the target sits still and is aspirating) and hold (the target sits still and holds his/her aspiration) movement.

Kubo et al. (2011) proposed the respiration wave estimation method using the microwave Doppler sensor. They introduced a criterion in evaluating the phase estimation. Then, they proposed five methods (offset estimation, mean, least squares method, estimation based on raster images, estimation based on Monte Carlo method) to estimate the signal phase and compared their performances by computer simulation and experiment.

IV. PROPOSED METHOD

We define the proposed method. In this study, we discuss recognizing the presence of aspiration with lying position.

Firstly, the proposed method remove high frequency component. Generally, the aspiration component is distributed in 0.3Hz area, and the heartbeat component is distributed in 1 ~ 1.2Hz area. Human activity is distributed in low frequency. We filter the received signal with a low-pass filter (see Figure 2), so a pass band set up 0 ~ 2Hz. Figure 2's x-axis means time index, and y-axis means Voltage(V) of microwave Doppler signals. Above figure of Figure 2 is observed data, and below figure of Figure 2 is low-pass filtered data. Many of low-pass filter method had been reported. In this study, we apply the Fast Fourier Transform (FFT) based on the method.

Secondly, Eq. (4) produce instantaneous amplitude of I-Q signal from low-pass filtered data.

Thirdly, we calculate feature quantities for the SVM. We are focusing mean, variance, maximum value, minimum value, skewness and kurtosis of instantaneous amplitude of I-Q signal, then these value consider feature quantities for the SVM. Window size is set to 1000 samples, and window shift size is set to 1 sample when we calculate feature quantities for the SVM.

Fourthly, Eq. (7) estimates amplitude, frequency, phase of instantaneous amplitude of I-Q signal. Estimation result of each parameter considers feature quantities for the SVM. Estimation model is shown below.

\begin{equation}
y(x_i) = A \sin \left(2\pi \omega x_i \frac{1}{f} + \phi_1 \right) + A \cos \left(2\pi \omega x_i \frac{1}{f} + \phi_2 \right) + \epsilon_i \tag{6}\end{equation}

where $A$ is amplitude, $\omega$ is angular frequency, $f$ is sampling frequency and $\phi_1, \phi_2$ are phases. Let $x_i$ be data index runs from $i = 1, ..., n$.

We minimize the Eq. (7), and estimate each parameter. We use the R (http://www.r-project.org/) for estimation of each parameter.

\begin{equation}
S(A, \omega, \phi_1, \phi_2) = \sum_{i=1}^{n} \left\{ y_i - \left( A \sin \left(2\pi \omega x_i \frac{1}{f} + \phi_1 \right) + A \cos \left(2\pi \omega x_i \frac{1}{f} + \phi_2 \right) \right) \right\}^2 \tag{7}\end{equation}

The initial values are set as follow: $A$ is half value of the range of instantaneous amplitude of I-Q signal, $\omega$ is 0.3 (aspiration frequency) and $\phi_1, \phi_2$ are 0 (We assume that these phases does not exist). Window size is set to 1000 samples, and window shift size is set to 1 sample when we estimate each parameters. Result of estimation is shown Figure 3. Figure 3's x-axis means time index, and y-axis means Voltage (V) of microwave Doppler signals.

Finally, we detect the 2 situation of "aspiration" and "apnea" using 2-class SVM (Gaussian Kernel). We use 10 feature quantities for the SVM like; mean, variance, maximum, minimum, skewness, kurtosis, $A$, $f$, $\phi_1$ and $\phi_2$. 
A. Feature quantity for the SVM

Method of calculating the feature quantity for the SVM is shown below. \(x_1, x_2, \ldots, x_N\) stand for N pieces of data, then \(x_1 \leq x_2 \leq \ldots \leq x_N\) stand for N pieces of data arranged in ascending order.

Mean (\(\mu\))

\[
\mu = \frac{1}{N} \sum_{i=1}^{N} x_i
\]

Variance (\(\sigma^2\))

\[
\sigma^2 = \frac{1}{N} \sum_{i=1}^{N} (x_i - \mu)^2
\]

Max. value

Maximum value = \(x_N\)

Min. value

Minimum value = \(x_1\)

Skewness (\(\gamma_1\))

\[
\gamma_1 = \frac{1}{N\sigma^3} \sum_{i=1}^{N} (x_i - \mu)^3
\]

Kurtosis (\(\gamma_2\))

\[
\gamma_2 = \frac{1}{N\sigma^4} \sum_{i=1}^{N} (x_i - \mu)^4 - 3
\]

B. SVM

We assume patterns on the two-dimensional vector space. The pattern on the space of two-dimensional vector distinguishes the linearness (see Figure 4), then circle and triangle belongs to another class.

Generally, the problem of pattern recognition purpose that boundary determine the inclusion in pattern either class. The boundary refers to identification plane.

Identification plane determine a straight line, so pattern recognition is the space of two-dimensional. The line through the center of the known pattern of belonging to each class which mean maximum of margin. Calculation of SVM purpose that the line draw a maximum of margin. We use twelve parameters in this study, so vector space is twelve-dimensional.

V. OUTLINE OF THE EXPERIMENT

We explain our experimental condition of proposed method. In this study, we focus on the lying position subject’s aspiration.

Our experimental condition assumed a eight-mat room. Space of square (3.6 by 3.6 meters) reserved, then angle of the square made a paul (see Figure 5). The radar was seated at the place where height was 2.3 meters and 40 degree angle to the ground. Subject lain position at center of square, then the state was the turning your head to the direction radar (see Figure 5) and turn around by 90 degree (see Figure 6). We acquired data which is supination and prone in the state.

We set the number of subjects was 4, the radar frequency was 1,000Hz, and we measured 80 seconds. As measurement, subject held his aspiration for 20 seconds, then He took in a aspiration for 20 seconds. We made twice the flow of the above as a dataset.

VI. RESULT

We discuss result of analysis. We used the data which cut out 15 seconds of data each 20 seconds of apena and aspiration data. When we calculate SVM, so training data is three portions (72,012 samples) and test data is one portion (26,004 samples). We are shown result of analysis below. The state of dataset is the lying on subject back, and turning your head to the direction radar.
1) Training data are subjects (A, B, C), test data is subject (D).

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>RESULT OF RECOGNITION RATE (%) -1-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>apnea</td>
</tr>
<tr>
<td>apnea</td>
<td>81</td>
</tr>
<tr>
<td>aspiration</td>
<td>19</td>
</tr>
</tbody>
</table>

2) Training data are subjects (A, B, D), test data is subject (C).

<table>
<thead>
<tr>
<th>TABLE II</th>
<th>RESULT OF RECOGNITION RATE (%) -2-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>apnea</td>
</tr>
<tr>
<td>apnea</td>
<td>99</td>
</tr>
<tr>
<td>aspiration</td>
<td>1</td>
</tr>
</tbody>
</table>

3) Training data are subjects (A, B, C), test data is subject (B).

<table>
<thead>
<tr>
<th>TABLE III</th>
<th>RESULT OF RECOGNITION RATE (%) -3-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>apnea</td>
</tr>
<tr>
<td>apnea</td>
<td>79</td>
</tr>
<tr>
<td>aspiration</td>
<td>21</td>
</tr>
</tbody>
</table>

4) Training data are subjects (B, C, D), test data is subject (A).

<table>
<thead>
<tr>
<th>TABLE IV</th>
<th>RESULT OF RECOGNITION RATE (%) -4-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>apnea</td>
</tr>
<tr>
<td>apnea</td>
<td>81</td>
</tr>
<tr>
<td>aspiration</td>
<td>19</td>
</tr>
</tbody>
</table>

5) Result of average recognition rate is shown below.

<table>
<thead>
<tr>
<th>TABLE V</th>
<th>RESULT OF AVERAGE RECOGNITION RATE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>apnea</td>
</tr>
<tr>
<td>apnea</td>
<td>85</td>
</tr>
<tr>
<td>aspiration</td>
<td>15</td>
</tr>
</tbody>
</table>

VII. CONCLUSION AND FUTURE WORK

According to results of analysis, it becomes evident that result of analysis differs depending on the test data. It is likely that the cause is habit of aspiration. We will cope with the feature of habit of aspiration, then accuracy of recognition improves.

This study gets the data which observed center of square to assume the eight-mat. Healthcare application needs high and robust recognition rate of subject’s state. We are accumulating the acquisition of data.

REFERENCES