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Recognizing Aspiration Presence using Model Parameter Classification from Microwave Doppler Signals

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***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 used 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 with lying position 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.

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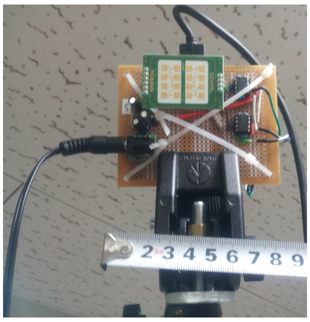

Fig. 1. Microwave Doppler Radar (IPS-154)

II. Microwave Doppler Radar

We describe the microwave Doppler radar system. The radar irradiates the microwave to the target and let F_a be the frequency of transmitted wave. The wave hits the target, and let F_b be the frequency of reflected wave toward the radar. The frequency of Doppler subtract F_a from F_b. 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).

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, λ is the wave length, R is the distance between the radar and target and ϕ 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 ΔR.

$$\Delta_\phi = \frac{4\pi\Delta R}{\lambda} \tag{3}$$

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Instantaneous amplitude A and phase difference ϕ_t are shown below.

$$A = \sqrt{V_I^2 + V_Q^2} \tag{4}$$

$$\phi_t = \tan^{-1}\frac{V_Q}{V_I} \tag{5}$$

III. Related work

We review the related works of this study.

Naoi *et al.* (2005) proposed the heart beat 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 $1 \sim 1.2$Hz 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 $0 \sim 2$Hz. 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-pas 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.

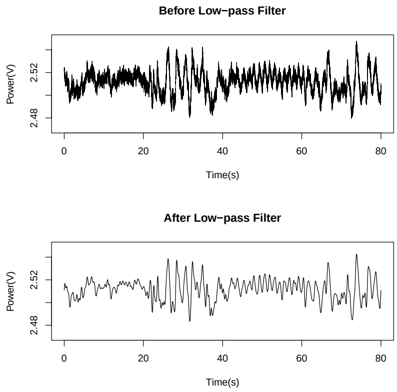

Fig. 2. Comparision between before and after the low-pass filter

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 sift 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.

$$y(x_i) = A\sin\Big(2\pi\omega x_i\frac{1}{f} + \phi_1\Big) + A\cos\Big(2\pi\omega x_i\frac{1}{f} + \phi_2\Big) + \epsilon_i \tag{6}$$

where A is amplitude, ω is angular frequency, f is sampling frequency and ϕ_1, ϕ_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.

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

The initial values are set as follow: A is half value of the range of instantaneous amplitude of I-Q signal, ω is 0.3 (aspiration frequency) and ϕ_1, ϕ_2 are 0 (We assume that these phases does not exist). Window size is set to 1000 samples, and window sift 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, ϕ_1 and ϕ_2.

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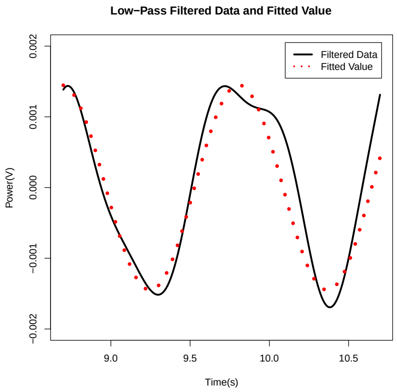

Fig. 3. Low-pass filtered data and fitted value

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(μ)

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

Variance(σ^2)

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

Maximum value

$$\text{Maximum value} = x_N$$

Minimum value

$$\text{Minimum value} = x_1$$

Skewness(γ_1)

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

kurtosis(γ_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 is good. The closest distance between the known pattern and the line refer to margin. The line through the center of the known pattern of belonging 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.

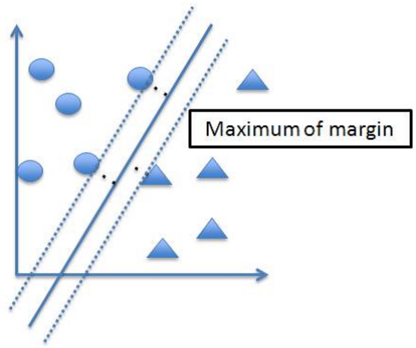

Fig. 4. Margin in the SVM

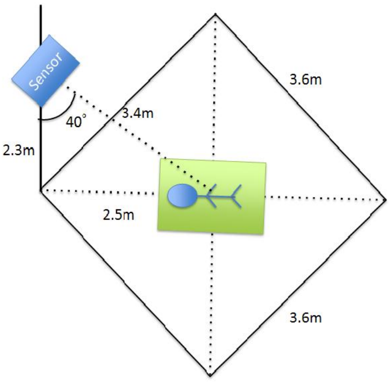

Fig. 5. Experimental condition -1-

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.

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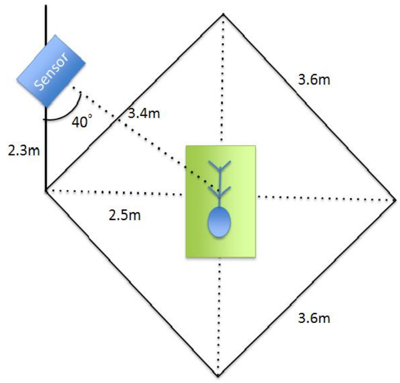

Fig. 6. Experimental condition -2-

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

TABLE I
RESULT OF RECOGNITION RATE (%) -1-

	apnea	aspiration
apnea	81	1
aspiration	19	99

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

TABLE II
RESULT OF RECOGNITION RATE (%) -2-

	apnea	aspiration
apnea	99	49
aspiration	1	51

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

TABLE III
RESULT OF RECOGNITION RATE (%) -3-

	apnea	aspiration
apnea	79	15
aspiration	21	85

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

TABLE IV
RESULT OF RECOGNITION RATE (%) -4-

	apnea	aspiration
apnea	81	2
aspiration	19	98

5) Result of average recognition rate is shown below.

TABLE V
RESULT OF AVERAGE RECOGNITION RATE (%)

	apnea	aspiration
apnea	85	17
aspiration	15	83

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.

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