Statistical Disturbance Rejection of the Background Noise by Microwave Doppler Radar - Modelization of an Electric Fan Noise

Tomoo Tsujimura, Kosuke Okusa, Kurato Maeno, Toshinari Kamakura

***Abstract*—Recently, the study with microwave Doppler radar is paid attention to. Microwave Doppler radar is one of the non-contact sensor, and detects the action of objects. The study focused on indoor human behavior has been developed. However, disturbance environment that pet and electronic device are moving in the room is considered in real daily life. We considered that an oscillating electric fan is most difficult disturbance environment to discriminate from human breathing, because the frequency range of which each signature appears is similar. In this paper, we propose a method to simulate the moving of an oscillating electric fan based on the data obtained from microwave Doppler radar. Finally, we evaluate the modelization of the moving of an oscillating electric fan. We compare computer simulation with metering experiment by residual sum of squares. As a result, our model shows good performance.**

***Index Terms*—Microwave Doppler radar, Statistical disturbance rejection, Disturbance modeling**

I. Introduction

THE aging of the population is rapidly progressing in Japan, and the solitary death of the elderly that becomes sparse with society contact has been a social problem. It is predicted that the proportion of elderly people over the 65 years old increases more. Therefore, it is apprehended that the solitary death of the elderly increases more in the future.

From this background, the introduction of health care and daily life support, safety confirmation system with network, and the technical development has been strongly predicted. Recently, the study with microwave Doppler radar is paid attention to. Microwave Doppler radar is one of the non-contact sensor, and detects the action of objects.

Naoi et al. proposed a method extract heartbeat component from moving of human body surface with several microwave Doppler radar[1]. Sekine et al. and Kim et al. proposed a method distinguishes several actions of objects from output signal of microwave Doppler radar[2][3]. Tanigawa et al. proposed a method to detect chewing by periodicity of jaw motion based on a microwave Doppler radar[4].

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The study focused on human behavior such as classification of life pattern and detection of outliner, estimation of heart beat and breathing has been developed. However, disturbance environment that pet and electronic device are moving in the room is considered in real daily life. Previous works do not consider the such disturbance noise. In the electronic device, one is temporal moving like a microwave oven, another is contiguous moving like an electric fan. The identification of an electric fan and human breathing is difficult because the frequency range which each signature appears is similar.

We considered that an oscillating electric fan is one of the most influential disturbance environment in room, and focused on the moving of an oscillating electric fan to discriminate from human breathing in disturbance environment.

A goal of this study is to simulate the moving of an oscillating electric fan. Generally, the measurement that took advantage of Doppler effect computes the speed from the sensor to the target. However, in the case of that measures the variation of distance between the sensor and the target like a oscillating electric fan with Doppler signal, we need estimate the phase difference of signal[5].

In this paper, we evaluate the modelization of the moving of an oscillating electric fan by the computer simulation and the metering experiment.

II. Signal model of a microwave Doppler radar

In this study, we used the microwave Doppler radar of dual type. This sensor provides two outputs V_1 and V_2 which the phase is different from each other, and the difference is 90 degrees. V_1, V_2 are said to I-Q component. The two outputs show Eq.(1) and Eq.(2).

$$V_1 = A_1 \sin\left(\frac{4\pi R}{\lambda} + \phi\right) + O_1 + \omega_1 \tag{1}$$

$$V_2 = A_2 \cos\left(\frac{4\pi R}{\lambda} + \phi\right) + O_2 + \omega_2 \tag{2}$$

Where, A is the amplitude of the signal, λ is the microwave length, R is the distance between the sensor and the target, ϕ is the initial phase, O is the DC(direct current) offset and ω is the noise. From Eq.(1) and Eq.(2), the phase change is proportional to the range change between the target and the sensor.

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

When we plot two outputs in two dimensional plane, the phase change of signal is described by turn around the offset of outputs(Fig.1). The signal output point moves on the dotted line circle, clockwise if the target is going away from

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the sensor, counterclockwise if the target is coming close to the sensor.

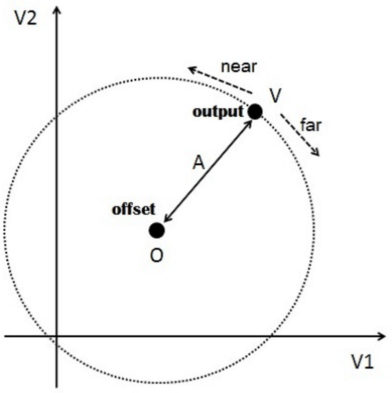

Fig. 1. The phase change of the signal

In this study, we use the microwave Doppler radar. The Doppler frequency f_d Hz can express in Eq.(4),

$$f_d = \frac{2f_0 \times v}{c} \tag{4}$$

where f_0 is sensor's center frequency, v is a object's speed m/s, c is a light speed 3.0×10^8 m/s.

III. A PROPOSED METHOD TO SIMULATE THE MOVING OF AN OSCILLATING ELECTRIC FAN

A. *Oscillating electric fan's angle modeling*

Oscillating electric fan's moving is not constant. For example, a rotation of a fan temporarily stops at both ends, the fan's rotating speed slows little by little before the fan stops. Therefore, we need an oscillating electric fan's moving model. We show θ(the variation of the fan's rotating angle in one period) at fig.2. X-axis is time, Y-axis is angle.

$$\theta = \frac{-\cos(x) + 1}{2}\theta_{max} \tag{5}$$

This function is generated under the variation of a fan's rotating speed and rest time at both ends. The fan's rotating angle is 60 deg and rest time at both ends is 0.5 s. θ_{max} is 60 deg.

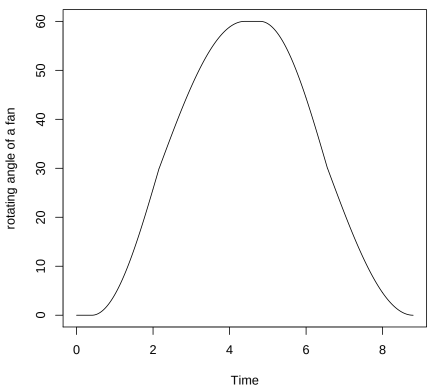

Fig. 2. The variation of fan's rotating angle

We need to compute the variation of a fan's surface area in seeing the fan from the front of the sensor, and the variation of distance between the sensor and the fan that detects objects moving based on the the variation of fan's rotating angle.

B. *The variation of surface area*

An amplitude of the received signal obtained from microwave Doppler radar depends on irradiation area of the objects. Therefore, we must consider the variation of surface area which saw the fan from the front of the sensor. If the surface of a fan is circle, we assume that the surface area of a fan change like the part surrounded with a frame at Fig.3 in the case of settig fan and sensor in same height.

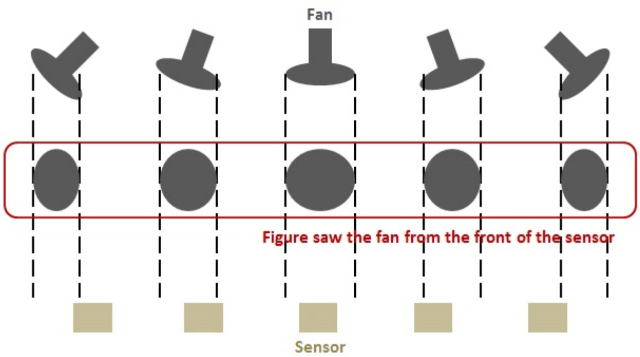

Fig. 3. The variation of fan's surface area which saw the fan from the front of the sensor

In this case, we can express S(the surface area) based on the variation of rotating angle in Eq(5). R is a radius of the fan's surface. θ is a fan's rotating angle.

$$S = R^2\pi\cos(\theta) \tag{6}$$

C. *The variation of the distance*

We need to calculate the variation of distance between a sensor and a surface of the fan, because the phase change is proportional to the range change between the target and the sensor.

$$l = \sqrt{(E\sin(\theta) - R\cos(\theta))^2 + (l_0 - (E\cos(\theta) + R\sin(\theta)))^2} \tag{7}$$

Where R is a radius of the fan's surface, E is a distance from the fan's surface to rotation axis. l varies according to a fan's rotating angle(θ). Our proposed method doesn't consider the fan's elevation.

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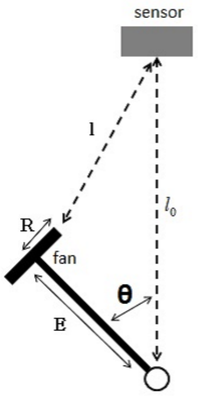

Fig. 4. The variation of distance from the sensor to the fan

Then, we expressed the phase difference $\Delta\phi$ in subtraction of transmitter pulse phase ϕ_r from receipt pulse phase ϕ_s. ϕ_0 is the initial phase, $Tr(t)$ is round trip time. Round trip time is a time from outgoing to feed back of a signal, and expresses in $T_r(t) = 2l/c$.

$$\phi_r = 2\pi f_0(t - Tr(t)) + \phi_0 \tag{8}$$

$$\phi_s = 2\pi f t \tag{9}$$

$$\Delta\phi = \phi_r - \phi_s \tag{10}$$

We can simulate the Doppler sensor signal of the oscillating electric fan by substituting $\Delta\phi$ and S from Eq.(6), Eq.(10) to Eq.(1), Eq.(2).

IV. Experiment

In this experiment, we use IPS-154(24 GHz continuous-wave) manufactured by Innosent Co.,Ltd as a micro-wave Doppler radar, and EF-D945W manufactured by Twinbird Co.,Ltd as a fan.

We set the sensor's sampling frequency is 500 Hz, and we cut the high-frequency noise by low pass filter from 0 Hz to 1.0 Hz. The observation time is 60 s in this experiment.

We set the distance from the senor to the fan is 1.4 m, the height of the sensor and the fan is 0.76 m. A rotating angle of the fan we used is 60 deg. The fan stops 0.5 s at the rotating angle in the point of 0 deg and 60 deg. The onset point of all datasets is at the left point of fan's rotating angle. The rotating time from the left to the center of the rotating angle is 1.8 s , and the rotating time from the center to the right of the rotating angle is 2.4 s.

We considered 3 patterns as the fan's setting angle against the sensor(Fig.5). The fan faces the sensor in each pattern, and rotates from -60 deg to 0deg against the sensor at (A), rotates from -30 deg to 30 deg against the sensor at (B), rotates from 0 deg to 60 deg against the sensor at (C).

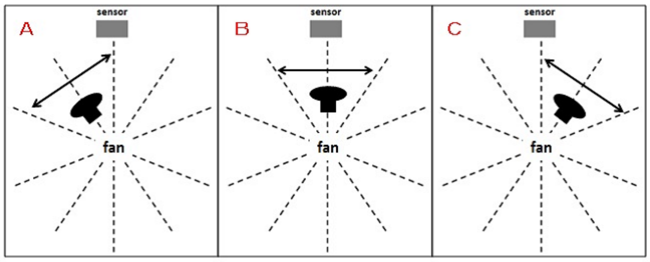

Fig. 5. 3 patterns of the fan's setting position against the sensor

We show two outputs V_1 and V_2 obtained from microwave Doppler radar at Fig.6. Solid line is V_1, dot line is V_2.

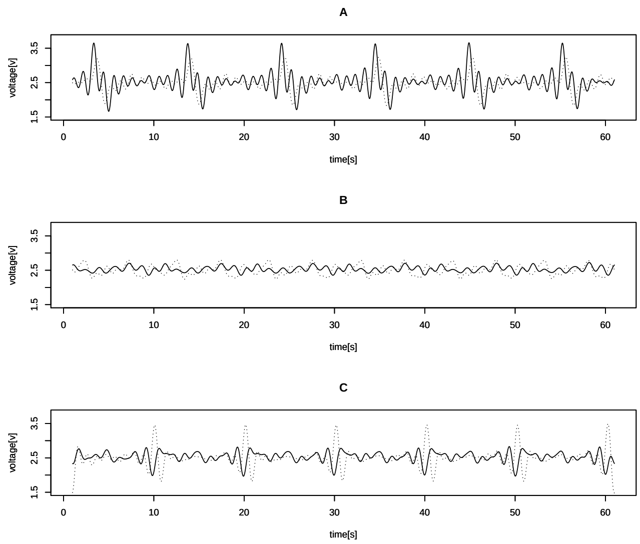

Fig. 6. Time series data of two outputs obtained from microwave Doppler radar

V. Simulation

A. About parameters

We simulate signal output of microwave Doppler radar by the oscillating fan model(Sec.2, Sec.3). The advantage of simulation by computer is that we can freely change the parameter, and tackle various condition.

In this section, we simulate fan's rotating angle by adjusting the parameter under the same condition with experiment data. We show initial value of each parameters at Table.1. H is sampling frequency(500 Hz). f_0 is the sensor's center frequency(2.4×10^{10} Hz). c is light speed(3.8×10^{8} m/s). v_0 is the migration speed of a fan(0 m/s). ϕ_0 is the initial phase(2). l_0 is the initial distance between the fan and the sensor. As the feature of an electric fan used in this experiment, R is the radius of fan's surface, E is the distance from the fan's surface to the rotation axis. And, we considered T_i is the rotating time of a fan from left side to right side, I is the temporal difference of rotating time and W is the rest time in both ends. F is the fan's rotating angle, D is the initial

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angle of a fan. And, we cut the high-frequency noise by low pass filter from 0 Hz to 1.0 Hz.

TABLE I
EACH PARAMETERS

T_i	I	W	l_0	R	E
4.2 s	0.6 s	0.5 s	1.4 m	0.175 m	0.15 m
F	D				
60 deg	-60, -30, 0 deg				

B. Result of the simulation

To evaluate the modelization of the moving of an oscillating electric fan by the computer simulation and the metering experiment, we paid attention to Phase-plane. Phase plane is a method that let us get a different viewpoint about the phenomena can be found in nonlinear system. X-axis is velocity(1st derivation of one-dimensional time-series behavior), and Y-axis is acceleration(2nd derivation of one-dimensional time-series behavior)[6]. By computing trajectory distance D of the output V1 and V2,

$$D = \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} \quad (i = 2, ..., n), \quad (11)$$

we can compress the data to one-dimension. n is the data length.

We show phase-plane of experimental data and our proposed model at Fig.7. The center of fan's rotating angle is (A)-30 deg, (B)0 deg, (C)30 deg. Above figure is the result of experiment, below figure is the result of simulation.

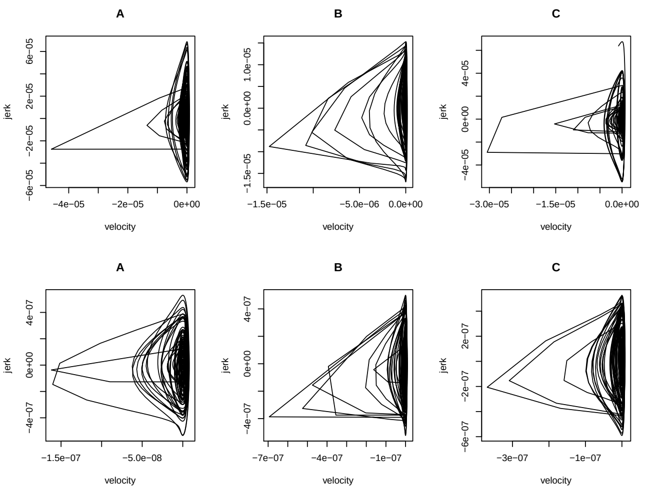

Fig. 7. The result of experiment and simulation

We calculate power spectrum of the ovserved and simulated signals using FFT(Fast Fourier Transform), and standardize at max value of the results. We calculate residual sum of squares to evaluate the modelization of rotating angle of a oscillating fan by the computer simulation and the metering experiment at Table.2.

TABLE II
RESIDUAL SUM OF SQUARES

(A)	(B)	(C)
2.488	3.409	1.444

VI. CONCLUSION

In this paper, we proposed a method to simulate the moving of an oscillating electric fan based on the data obtained from microwave Doppler radar. And, we evaluated the modelization of it by the computer simulation and the metering experiment with each residual sum of squares. Our proposed method is very sensitive, and the result changes by slightly changing the initial angle of a fan. For example, when we change the initial angle of a fan in steps of -2 deg each other, each residual sum of squares is $(A)2.489$, $(B)3.145$, $(C)1.396$.

Because we set the sensor and the fan in the same height each other in this study, we expressed the distance from the sensor to the fan in flatland. But these height is not necessarily the same height in service deployment of safety confirmation system. Therefore, we want to study three dimensional space model as a distance calculation method in the future.

REFERENCES

[1] Naoi,T., Maeda,N. and Iwama,S., *Non-contact Cardiac-beat Detection using Time-difference of Microwave Doppler Signal.*, IEICE Technical Report, MBE2005-86(2005-11), 2005.
[2] Sekine,M., Maeno,K.,and Nozaki,M., *Activity and State Recognition without Body-Attached Sensor Using Microwave Doppler sensor.*, IPSJ SIG Technical Report, Vol.2009-HCI-130 No.10, 2009.
[3] Kim,Y., and Ling,H. *Human Activity Classification Based on Micro-Doppler Signatures Using a Support Vector Machine*, IEEE Transactions on Geoscience and Remote Sensing, Vol.47, No.5, 2009.
[4] Kubo,H., Mori,T., and Sato,T., *Respration measurement with microwave Doppler sensor.*, 16th Robotics Symposia, 2011.
[5] Tanigawa,S., Nishihara,H., and Kaneda,S., *The Detection of the Chewing with Microwave Doppler sensor.*, 60th IPS, 2008.
[6] Ramsay,J.O., and Silverman,B.W., *Applied Functional Data Analysis -Methods and Case Studies*, Springer Series in Statistics, pp.44–56,
[7] Kubo,H., Mori,T., and Sato,T., *Detection of Human Motion and Repiretion with Microwave Doppler sensor*, The 2010 IEEE/RSJ International Conference on Intelligent Robots and System, 2010.

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