Elderly Health Care System of Systems by Non-Contacted Multiple Sensors

Yutaka HATA[1], Osamu Ishikawa[2], Hiroshi Nakajima[3]

[1]Graduate School of Engineering, University of Hyogo, Himeji, Japan
[1]WPI Immunology Frontier Research Center, Osaka University, Osaka, Japan
[2]Ishikawa Hospital, Himeji, Japan
[3]Omron Corporation, Kizugawa, Kyoto, Japan
[1]hata@ieee.org; [2]ishicri@giga.ocn.ne.jp; [3]nak@ari.ncl.omron.co.jp

***Abstract*- This paper describes a system of systems for elderly heath care. The system consists of three systems: one is the system that detects heart rate, which provides the condition of autonomous nerve system. The second one is the system detecting respiration. Third one is the system detectingthe sound to do suctiontreatment of phlegm. In them we emply non-contacted three senors. An ultrasonic oscillosensor touched to bed frame, an air pressure mat with an air tube in bed and PCM Recorder with microphone are employed. The system of systems can detect heart rate, respiration and sound to dosuctiontreatment of phlegm. This system assesses autonomous nerve system from the heart rate.**

Keywords*- *Health Care; Medical Engineering; Fuzzy Logic; Sensor Network; Heart Rates

I. INTRODUCTION

According to the increment of the population of elderly persons in Japan, the lack of care persons and their heavy duty become a social issue. Especially in home care, these problems caused serious accidents. In next decade, we should develop low cost home health care systems to avoid the accidents as well as to improve their quality of life. Currently, health monitoring systems are mainly used in hospitals. Conventional health monitoring system needs to contact some devices to patient body, that is, electrocardiographs and electroencephalographs constrain patients and stand the sensors to their bodies. In home care for elderly, anon-contacted health monitoring system is needed, especially, for the elderly in home alone because it allows us not to concern ourselves with input device being detached. In addition, the elderly do not accept a touching sensor in daily monitoring. A number of health monitoring sensors for humans in bed have been developed [1-5]. For one of them, we developed systems of human health monitoring in bed [6-14]. References [6-8] described a system using an ultrasonic oscillosensor. The ultrasonic oscillosensor system has a cylindrical tank of 26 mm (diameter) × 20 mm (height) filled with water and an ultrasonic probe. It detects the vibration of a patient by obtaining echo signals reflected from the water surface. This sensor can noninvasively detect vibration of the person by placing it under the frame of a bed. The detectable vibrations are ranged at 10 Hz or less in the direction of all three axes. The system recognized the conditions either an empty bed or sleeping or active in bed. References [9-12] described a monitoring of heart rate by an air mat with an air tube in bed. The heart rate accesses an automatic nervous system activity, and its rate is an important parameter to influence a blood pressure change, an aspiration system, and a temperature control and so on. Inside pressure sensor detects the air pressure change of vital information of patients. These described the system for detecting the heartbeat. In the experiment, the air pressure sensor system detected them with high accuracy and provided the state of autonomous nerve system. Reference [12] described a monitoring of respiration by the air mat in bed. In it, we detected respiration with high accuracy.

This paper mainly describes a system of systems approach for detecting heart rate, respiration, the sound to do suction treatment of phlegm. We show only the experimental results for heart rate and respiration detection since the detailed methods are already shown in References [16]. The sound of cough with phlegm to do suction treatment is an important sign for the elderly, because the elderly passed away if we did not catch the worst signal. Therefore, we should care it for all night; it means heavy duty to the care person. To solve this problem, we developed a detection system by using PCM recorder with microphone aided by fuzzy signal processing [13]. In the experimental results, we successfully detect the sound to do suction treatment of phlegm on six elderly subjects.

II. SYSTEM OF SYSTEMS

Figure 1 shows a system of systems for human health monitoring. The health monitoring system is composed of an air pressure sensor system (Figure 2) [9-12] and an ultrasonic oscillosensor sensor system (Figure 3) [6, 7, 10]. The air pressure sensor system consists of the air tube in cushion of 175 mm × 780 mm and an ultrasensitive pneumatic sensor (Fujisera, FKS-111). This sensor detects a pressure change generated by the power provided to the tubes. It outputs electronic signal based on 1.35 Volt. This signal is quantized to 1024 levels by the A/D converter with the control device. The obtained data is provided to the personal computer.

DOI:10.5963/PHF0203007

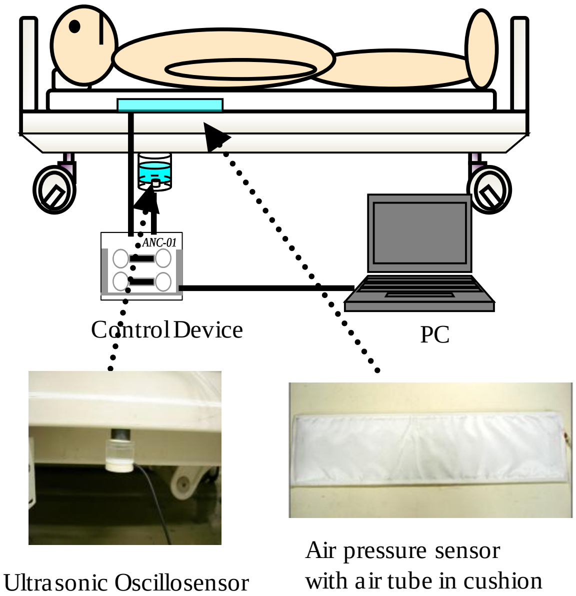


Fig. 1 System of systems for human health monitoring

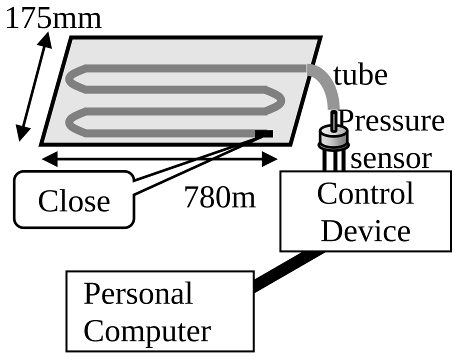


Fig. 2 Air pressure sensor system

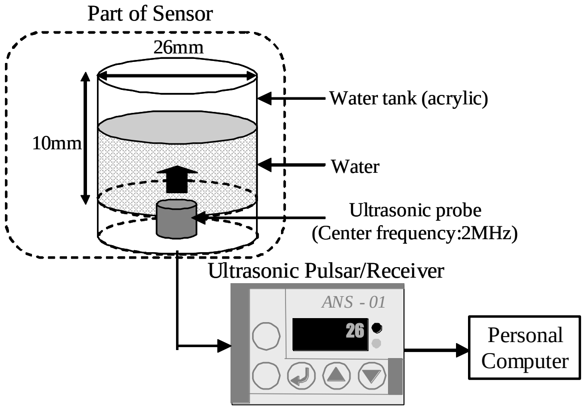


Fig. 3 Ultrasonic Oscillosensor system

The ultrasonic oscillosensor system (Figure 3) consists of a part of sensor and a control device, which includes an ultrasonic pulsar/receiver and an A/D converter. The part of sensor consists of a cylindrical tank of 26mm (diameter) × 10mm (height) filled with water and an ultrasonic probe (central frequency: 2MHz) set to the bottom of tank. The ultrasonic pulsar/receiver transmits and receives the ultrasonic wave via the ultrasonic probe. The maximum amplitude of the reflected wave onvibrated condition is higher than that of non-vibrated condition because the flat water surface causes the maximum amplitude of the reflected waves. Thus, the vibration of a target object is detected by analyzing the temporal change of the maximum amplitude of the reflected wave. The reflected waves are acquired at intervals of 20 micro second, and the detected maximum amplitude value is quantized to 1024 levels (10 bits) by an A/D converter. We obtain these quantized data as time-series data of vibration of a target object. The received ultrasonic wave is provided to the personal computer through the A/D converter. Figure1 also shows the mounted places of the both sensors. The ultrasonic oscillosensor is set under the center of the

DOI:10.5963/PHF0203007

bed (Paramount Bed Co. Ltd., A5141) using a magnet and the air pressure sensor is set under of the bottom of a mattress. Then the vibration of the bed frame is detected by ultrasonic sensor system and the vibration of the body of the patient is directly detected by the air pressure system.

Table 1 shows the detected signals by the systems. Heartbeat is detected by a system of systems by both sensors [13]. Respiration is detectable by the air pressure sensor system. Activity of human in bed is detected by an ultrasonic oscillosensor system [7]. The behavior of getting out of bed is detected by the system of systems of ultrasonic oscillosensor and air pressure sensor [14]. The remaining important issue is to detect the sound to do suction treatment of phlegm. In this paper, we describe the system for detecting the sound to do suction treatment of phlegm in detail.

TABLE 1 SYSTEM OF SYSTEMS PROPOSED HERE

No.	signal	System
1	Heartbeat (Autonomous nerve system)	System of systems of ultrasonic oscillosensor and air pressure sensor
2	Respiration	Air pressure sensor system
3	Activity of human in bed	Ultrasonic oscillosensor system
4	Behavior of getting out of bed	System of systems of ultrasonic oscillosensor and air pressure sensor
5	Aspiration of sputum	Sound detection system

III. HEARTBEAT AND RESPIRATION MONITORING

Using 5 healthy volunteers (22-23 years old, male), we perform experiments on them four times for each. The detailed algorithm to detect heartbeat is shown in References [16]. In Case 1, subjects lie on one’s back. In Case 2, subjects lie on one’s side. In Case 3, subjects sit on the bed. In Case 4, subjects lie on one’s back for higher heart rate (after exercise).

We measured heart pulse and the error ratio detected by each method. These error ratios are calculated by comparing each result with the true value. The true value was obtained by a sphygmograph. First, we count the heart pulse number. The results of the error ratio (5 minutes) are tabulated in Table 2. In Table 3, the mean absolute error ratio was 22.73% in the ultrasonic system for the all cases. In the air mat system, the mean error ratio is 1.28% for the all. Thus, air mat system detected the heartbeat number with higher accuracy than the other. Hereafter, we describe Heart Rate Variability (HRV) analysis and respiration detection using the air mat.

HRV analysis is performed according to Ref. [17]. We use the method of short-term recordings of 2 to 5 minutes. The spectrum of heart rate variability signal is calculated from tachogram of an interval of the heartbeat points. The interval of heartbeat points are defined as the RR intervals. The RR interval is an interval in time of R wave which is the peak of the electrocardiograph. The RR interval tachogram is the RR intervals vs. the number of progressive beats, as shown in Figure 4. We employ FFT as the frequency analysis of the RR interval tachogram. In the frequency domain of the RR interval tachogram, three main spectral components of very low frequency (VLF), low frequency (LF), and high frequency (HF) are distinguished in a spectrum calculated from short-term recordings, as shown in Figure 5. The frequency range of VLF is less than or equal to 0.04 Hz and the frequency range of LF is 0.04 to 0.15 Hz, and the frequency range of HF is 0.15 to 0.4 Hz. In the control of the heartbeat change by the autonomic nervous system, the sympathetic system affects a change of low frequency, and the parasympathetic system affects a change of both frequency, but affects mainly a change of high frequency. Therefore frequency components of the factor of both the sympathetic system and parasympathetic are shown in LF, and frequency component of the factor of the parasympathetic is shown in HF. LF and HF are calculated in normalized units (n. u.) by Eqs. (1) and (2), respectively.

$$LF(n.u.) = \frac{LF}{TotalPower - VLF} \times 100$$

$$HF(n.u.) = \frac{HF}{TotalPower - VLF} \times 100$$

TABLE 2 MEAN ERROR RESULTS OF THE NUMBER OF HEART PULSE

Subject#	Case Number	Ultrasonic system (%)	Air pressure system (%)
1	1	1.02	2.38
	2	23.61	0.69
	3	58.57	2.18
	4	1.96	0.65
2	1	8.58	1.65
	2	25.77	1.53
	3	12.06	2.54
	4	68.42	0

DOI:10.5963/PHF0203007

3	1	3.92	1.81
	2	7.81	1.25
	3	46.93	0.56
	4	20.29	0.88
4	1	40.28	3.47
	2	31.8	0.35
	3	32.87	0
	4	4.95	1.98
5	1	4.82	0.3
	2	40.29	1.76
	3	16.33	0.29
	4	4.42	1.4
Average		22.735	1.284

TABLE 3 SUBJECT DATA

Subject	Age	Height(cm)	Weight(kg)
A	23	180	95
B	22	165	58
C	22	175	61
D	22	167	64
E	21	179	67
F	22	166	67
G	23	172	57
H	21	173	65
I	22	160	40
J	21	172	76

Total Power in Eqs. (1) and (2) shows a frequency domain less than or equal to 0.4 Hz. As mentioned above, LF is not only frequency component of the factor of the sympathetic system but also the frequency component of the factor of the parasympathetic system. Therefore, we regard LF/HF as an index of the sympathetic system, and we regard HF (n. u.) as an index of the parasympathetic system. Using 10 healthy male volunteers as shown in Table 3, we measure the heart waves by electrocardiograph (AD Instruments Pty. Ltd., ML132) at the same time. We employ data of the electrocardiogram as the truth value. First, we show an experimental result in bed shown in Figure 1(a). We obtained data of five minutes for every subject. After we detect heart rate variability, we perform autonomic nervous system assessment by the HRV analysis. Table 4 shows the result of correlation coefficients of the HRV by our method. The average of correlation coefficients of HRV was 0.894. Table 5 shows results of the autonomic nervous system evaluation. The average error of HF (n. u.) was 13.32%, and the average error of LF/HF was 19.16%. Consequently, they are enough to assess their autonomic nervous system.

Second, we show an experimental result on respiration detection. Using 4 subjects (22-23 years old, male), the results are shown in Table 6. Consequently, they are enough to employ a respiration detection system in bed.

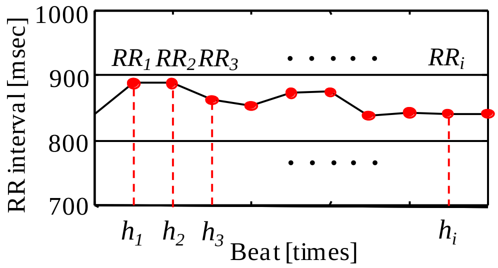


Fig. 4 RR interval tachogram.

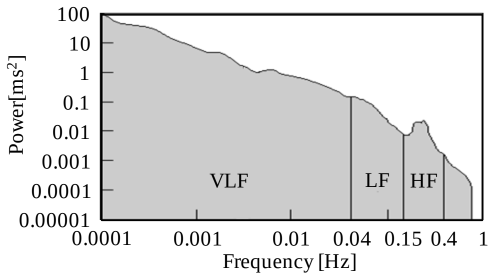


Fig. 5 Example of spectrum density.

TABLE 4 RESULTS OF CORRELATION OF HRV

Subject	Correlation Coefficient
A	0.941
B	0.916
C	0.994
D	0.890
E	0.748
F	0.833
G	0.975
H	0.990
I	0.829
J	0.828

DOI:10.5963/PHF0203007

TABLE 5 RESULTS OF ANS ASSESSMENT IN BED

Subject		Our method	Truth Value	Error(%)
A	HF(n.u.)	48.29	43.51	10.99
	LF/HF	1.07	1.29	17.05
B	HF(n.u.)	45.88	42.07	9.06
	LF/HF	1.18	1.37	13.87
C	HF(n.u.)	80.71	81.70	1.21
	LF/HF	0.24	0.22	6.70
D	HF(n.u.)	32.48	21.96	47.91
	LF/HF	2.08	3.54	41.24
E	HF(n.u.)	56.57	50.87	11.21
	LF/HF	0.77	0.97	20.41
F	HF(n.u.)	69.72	69.87	0.21
	LF/HF	0.43	0.44	1.63
G	HF(n.u.)	45.87	51.01	10.08
	LF/HF	1.18	0.97	21.65
H	HF(n.u.)	47.07	46.21	1.86
	LF/HF	1.12	1.16	3.45
I	HF(n.u.)	65.90	49.68	32.65
	LF/HF	0.52	1.01	48.81
J	HF(n.u.)	60.44	55.97	7.99
	LF/HF	0.65	0.79	16.79

TABLE 6 RESULTS OF RESPIRATORY RATE (40 sec. measurement)

Subject	Experimental Number	Count		
		Proposed Method	***True Value***	***Error Ratio(%)***
P	1	35	36	2.8
	2	37	37	0.0
Q	1	41	41	0.0
	2	40	41	2.4
R	1	39	40	2.5
	2	39	40	2.5
S	1	43	43	0.0
	2	32	32	0.0

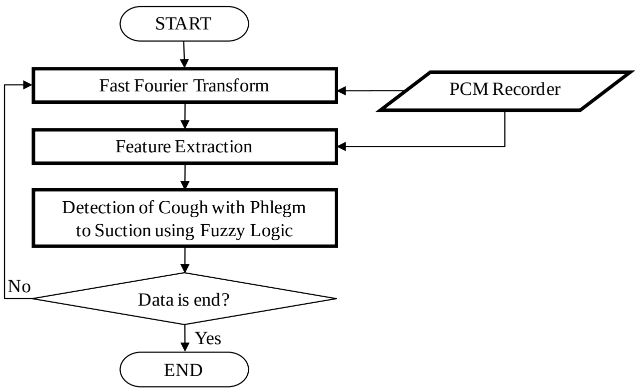


Fig. 6 Procedure of the method

IV. A SYSTEM FOR DETECTING SOUND TO DO SUCTION TREATMENT OF PHLEGM

A. Method

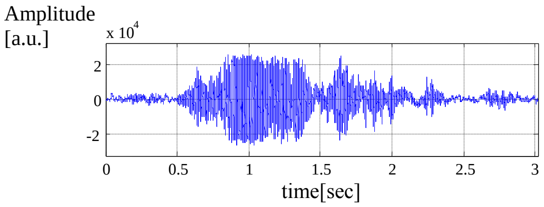
The procedure ofsystem is shown in Figure 6. First, the system performs Fast Fourier Transform to the data obtained by a PCM recorder with a microphone. Second, the system extracts four features of sound to do suction treatment of phlegm in the obtained data. Finally, the system detects sound to do suction treatment of phlegm aided by fuzzy logic technique [18].

B. Features Extraction

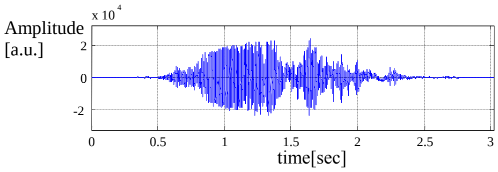
The system performs Fast Fourier Transform (FFT) to the data obtained by the PCM recorder. Figure 7 shows the data of sound to do suction treatment of phlegm. Figure 7(a) shows the raw data. The system employs the hamming window function

DOI:10.5963/PHF0203007

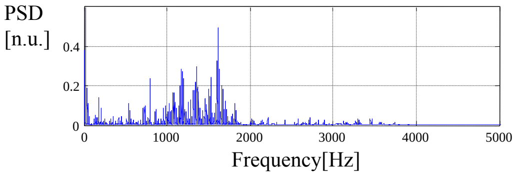
and does FFT to the obtained data. In it, the number of samplings, N, is 131072. Figures 7(b) and (c) show the data obtained by hamming window function and FFT, respectively.



(a) Raw data



(b) Data obtained by hamming window function



(c) Spectrum obtained by fast Fourier transform

Fig. 7 Data of sound to do suction treatment of phlegm

The system extracts four features of sound to do suction treatment of phlegm from the obtained data and spectrum. As shown in Figure 7(a), the data of sound to do suction treatment of phlegm has high amplitude. As shown in Figure 7(c), the spectrum of cough with phlegm has the highest peak of Power Spectrum Density (PSD) between 900 Hz and 3000 Hz. This peak has wide bandwidth.

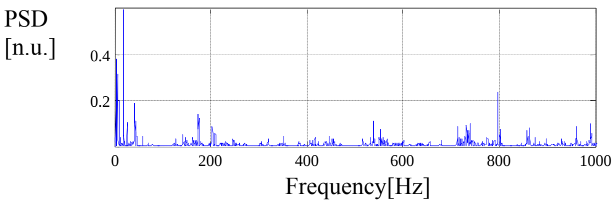
Figure 8 shows 0-200 Hz spectrum of Figure 7(c). As shown in Figure 8(a), the spectrum has no remarkable peaks of PSD between 200 Hz and 700 Hz, which seems to include the sound of human voice. As shown in Figure 8(b), the spectrum has the peak of PSD between 10 Hz and 50 Hz. Considering the characteristics of the experimental knowledge; we defined the four features as follows.

1. a_x: The sound volume, obtained by raw data.

2. p_{x1}: *PSD ratio*, obtained by the integral PSD in the frequency between 900 Hz and 3000Hz divided by that between 200Hz and 700 Hz.

3. p_{x2}: *PSD ratio*, obtained by the integral PSD in the frequency between 10 Hz and 50 Hz divided by that between 200 Hz and 700 Hz.

4. p_{x3}: *PSD ratio*, obtained by the integral PSD in the frequency between 900 Hz and 3000 Hz divided by that between 10 Hz and 50 Hz.



(a) 0-1000Hz

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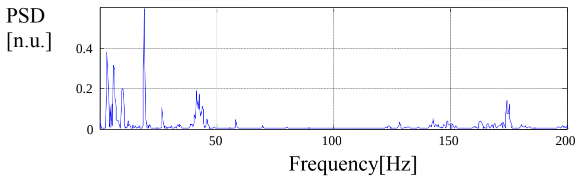


(b) 0-200Hz

Fig. 8 Spectrum obtained by fast Fourier transform

On p_{x1}, p_{x2}, and p_{x3}, their integral calculations indicate wide bandwidth to describe the characteristic of spectrum. On p_{x2}, the calculated p_{x2} of human voice is small because almost human voice has a large PSD in the frequency ranges from 200 Hz to 700 Hz, In addition, the noises such as the sounds of footsteps and door have no large PSD in the frequency ranges from 200 Hz to 700 Hz. These noises have large PSD in the frequency range from 10 Hz to 50 Hz. Thus, the calculated p_{x2} of the noise is large. Besides, the calculated p_{x2} of sound to do suction treatment of phlegm is approximately constant, which is larger than that of the human voice, and it is smaller than that of the above noises.

By using the extracted features, the system detects sound to do suction treatment of phlegm using fuzzy inference. The following knowledge of sound to do suction treatment of phlegm is derived.

Knowledge 1: The sound of sound to do suction treatment of phlegm has high volume, a_x.

Knowledge 2: The spectrum of sound to do suction treatment of phlegm has high *PSD ratio*, p_{x1}.

Knowledge 3: The spectrum of sound to do suction treatment of phlegm has approximately constant *PSD ratio*, p_{x2},

Knowledge 4: The spectrum of sound to do suction treatment of phlegm has high *PSD ratio*, p_{x3}.

These knowledge are converted into the following *fuzzy* IF-THEN rules,

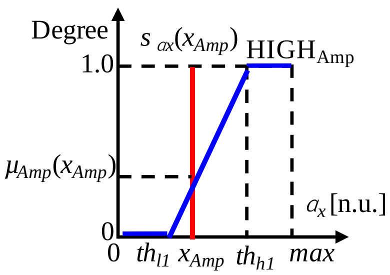
Rule 1: IF a_x is high, THEN the degree sound to do suction treatment of phlegm, μ_{Amp} is high.

Rule 2: IF p_{x1} is high, THEN the degree of sound to do suction treatment of phlegm, μ_{PSD1} is high.

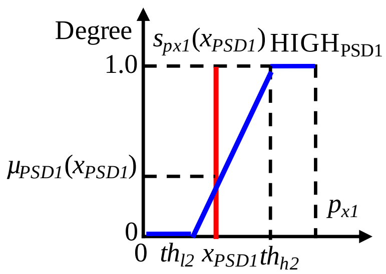
Rule 3: IF p_{x2} is close to th_{m3}, THEN the degree of sound to do suction treatment of phlegm, μ_{PSD2} is high.

Rule 4: IF p_{x3} is high, THEN the degree of sound to do suction treatment of phlegm, $\mu_{PSD3}$is high.

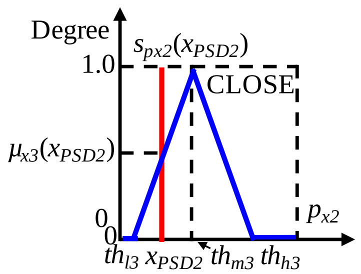
The notations μ_{Amp}, μ_{PSD1}, μ_{PSD2} and μ_{PSD3} denote the degrees of sound to do suction treatment of phlegm for input data. The "*HIGH*$_{Amp}$" membership function for amplitude value and "*HIGH*$_{PSD1}$", "*CLOSE*", "*HIGH*$_{PSD3}$" membership functions for the *PSD ratio* are defined by Figure 9. For a given x, the amplitude a_x, μ_{PSD1}, μ_{PSD2} and μ_{PSD3} are calculated. In Figure 9(a), *max*, $th_{l1}$and th_{h1}denote the maximum amplitude of datum x and two parameters for a_x, respectively. In Figure 9(b), th_{l2} and th_{h2} denote the parameters for p_{x1}. In Figure 9(c), th_{l3} and th_{h3} denote the parameters for p_{x2}. In Figure 9(d), th_{l4} and th_{h4} denote the parameters for p_{x3}. These parameters are determined experimentally.



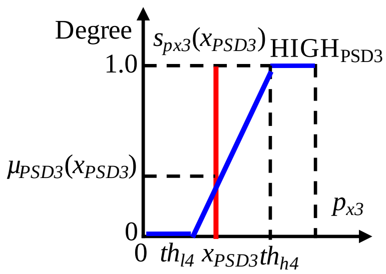
(a) a_x



(b) p_{x1}



(c) p_{x2}



(d) p_{x3}

Fig. 9 Fuzzy membership functions.

DOI:10.5963/PHF0203007

Fuzzy singleton functions are defined by the following equation.

$$S_p(x)=\begin{cases}1 & \text{if } x=p\\ 0 & \text{otherwise}\end{cases}$$

The fuzzy degrees $\mu_{Amp}(x)$, $\mu_{px1}(x)$, $\mu_{px2}(x)$ and $\mu_{px3}(x)$ are calculated by the followings:

$$\mu_{amp}(x) = \min(HIGH_{amp}, S_{ax}(x))$$

$$\mu_{px1}(\mathrm{x}) = \min(HIGH_{PSD1}, S_{px1}(x))$$

$$\mu_{px2}(x) = \min\left(\mathrm{CLOSE}, S_{px2}(x)\right)$$

$$\mu_{px3}(x) = \min(\mathrm{HIGH}_{\mathrm{PSD3}}, S_{px3}(x))$$

A total degree $\mu_{phlegm}(x)$ of the sound to do suction treatment of phlegm is calculated by arithmetic product of $\mu_{Amp}(x)$, $\mu_{px1}(x)$, $\mu_{px2}(x)$ and $\mu_{px3}(x)$ by

$$\mu_{phlegm}(x) = \mu_{amp}(x) \times \mu_{px1}(x) \times \mu_{px2}(x) \times \mu_{px3}(x).$$

If $\mu_{phlegm}(x)$ is larger than a threshold, input data x is determined as sound to do suction treatment of phlegm. Here, we determined the threshold as 0.4, experimentally. All processes repeat for continuous input data at intervals of 65536 samples.

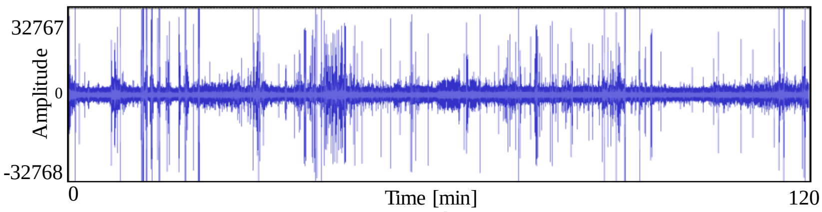
C. Experimental Results

In the experiment, we applied this system to six elderly patients with dementia (age: 87.6±2.3) in Ishikawa hospital. They are shown in Table 7. We obtained data of 11 hours (17:00-4:00) and one day for each subject. In our study, each truth value is decided, qualitatively.

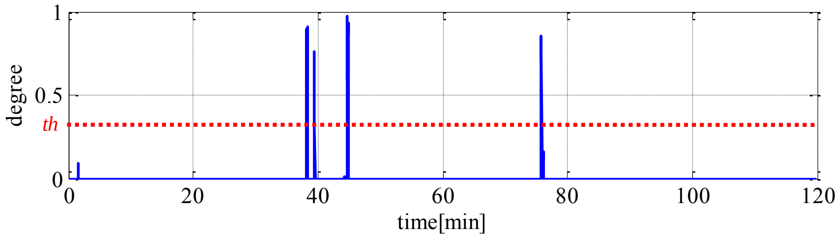
TABLE 7 VOLUNTEERS DATA

Subject	Age	Gender	Characteristics
A	84	Male	Undergone a tracheotomy
B	78	Female	Undergone a tracheotomy
C	89	Female	congestive heart failure
D	88	Female	Nothing particular
E	85	Female	Acute pneumonia
F	89	Male	Pneumonia

Figures 10 and 11 show the examples of the detected sound to do suction treatment of phlegm for 2 hours (17:00-19:00). In these figures, dashed lines and X mark denote threshold for detection and false detected point, respectively. In Figure 10, the false detected point was caused by a child voice. The system assumes that the human voice has the frequency from 200 Hz to 700 Hz. However, this child voice has the higher frequency.



(a) Raw data.



(b) Detected cough with phlegm to suction.

Fig. 10 Result (Subject A, from 17:00 to 19:00)

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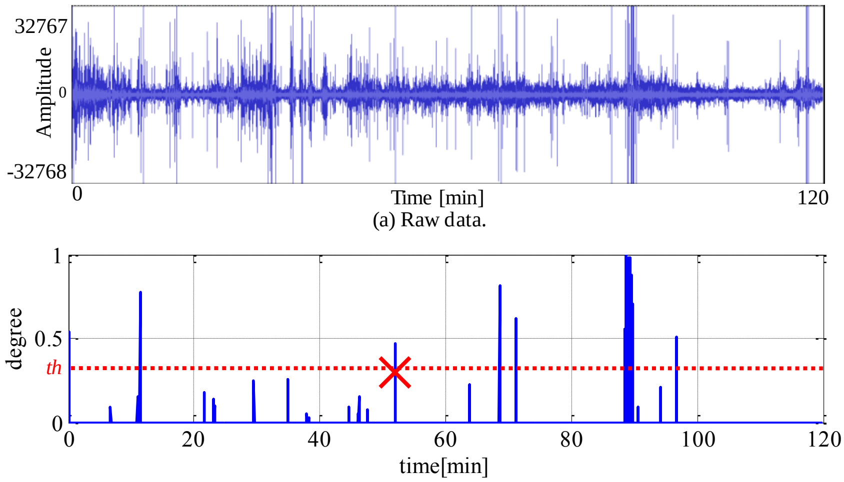

(a) Raw data.

(b) Detected cough with phlegm to suction.

Fig. 11 Result (Subject B, from 17:00 to 19:00)

Table 8 shows all results of the number of detected and the error ratio. As shown in this table, the mean of error ratio in the system was 4.5%, which is 4.5% of false positive (FP) detection and 0.0% of false negative (FN) detection. Therefore, the system using fuzzy inference successfully detected the sound to do suction treatment of phlegm for subjects without false negative detection. Consequently, the system can be available to the clinical usage.

TABLE 8 EXPERIMENTAL RESULTS

Subject	True values	Detected	FP	FN	Error ratio [%]
A	15	15	0	0	0.0
B	11	14	3	0	27.0
C	2	2	0	0	0.0
D	2	2	0	0	0.0
E	0	0	0	0	0.0
F	1	1	0	0	0.0

V. CONCLUSIONS

This paper has described a system of systems approach to elderly care system for detecting heartbeat, respiration, and sound to do suction treatment of phlegm, which consists of multiple sensors of the ultrasonic sensor, air mat, and PCM recorder. The constructed system of systems successfully detected fundamental bio signals of the heart and respiration, as well as autonomous nerve system and body moving in bed and the sound to do suction treatment of phlegm. The sound to do suction treatment of phlegm is rather clinical than the others. The extraction is strongly requires in daily home care. The system of systems is illustrated in Figure 12. The system was developed with low cost sensors and thereby is available to home usage.

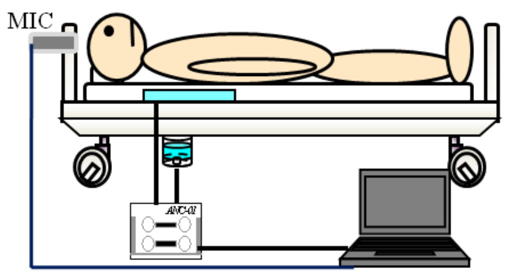

Fig. 12 System of systems proposed in this paper

It remains as future studies to examine the system of systems to clinical practice.

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YUTAKA HATA received the B.E. degree (Electronics) in 1984, the M.E. degree (Electrical Engineering and Electronics) in 1986 and the Ph.D (Doctor of Engineering) in 1989 all from Himeji Institute of Technology, Japan. He is currently a Professor in the Graduate School of Engineering, University of Hyogo, Japan. He spent one year in BISC Group, University of California at Berkeley from 1995 to 1996 as a visiting scholar. His research interests are in medical system, health monitoring system, fuzzy system and Immune system. He received 13 international awards such as the Franklin V. Taylor Best Paper Award (IEEE SMC 2009), Biomedical Wellness Award (SPIE Defence, Security, and Sensing 2010) etc. He is an Editor-in-chief: International Journal of Intelligent Computing in Medical Sciences and Image Processing, USA and 5 Journal editors including IEEE Systems Journal. He is the Founder and Director of Himeji Initiative in Computational Medical and Health Technology, University of Hyogo, Japan. He is an IEEE Fellow and an IEEE SMCS BoG member.

OSAMU ISHIKAWA received the MD Ph.D from Okayama University, Japan. He is a Vice-President of Ishikawa Hospital, Japan. He is also the President of A Geriatric Health Services Facility, SEIYOU. His research interests are in medical imaging, surgery systems, and care systems for elderly persons.

HIROSHI NAKAJIMA received the B.Eng. degree in systems engineering from Kobe University, Hyogo, Japan, in 1985 and the D.E. degree from Kumamoto University, Kumamoto, Japan, in 2004.He is a Senior Advisory Technology Researcher at the Sensing and Control Laboratory of OMRON Corporation, Kyoto, Japan. His interests include human-machine collaborative systems with optimal integration of human and machine intelligence based on fuzzy logic and soft computing. He is also interested in health management technologies for humans, machines, and nature. Dr. Nakajima received the Best Paper Award from Interaction'99, the Best Author Award from the Information Processing Society of Japan in 2000, and the Industrial Outstanding Application Award from the International Fuzzy Systems Association in 2007.

DOI:10.5963/PHF0203007