Proceedings of the 2009 IEEE International Conference on Systems, Man, and Cybernetics
San Antonio, TX, USA - October 2009

Real Time Autonomic Nervous System Display with Air Cushion Sensor while Seated

Kenta Yamamoto, Syoji Kobashi, Yutaka Hata
Graduate School of Engineering
University of Hyogo
Hyogo, Japan
hata@ieee.org

Naoki Tsuchiya, Hiroshi Nakajima
Core Technology Center
OMRON Corporation
Kyoto, Japan

***Abstract*—This paper proposes functional assessment system of autonomic nervous system by the heart rate variability using an air cushion sensor. The air cushion sensor can unconstraintly detect vital information by sitting down on the sensor. We perform functional assessment of autonomic nervous system by heart rate variability obtained by the system. We built the real time display system for visualizing the autonomic nervous system functions. In this system, we employ fuzzy membership functions with dynamic parameter to detect RR intervals. The experimental results show that we detect RR intervals with the correlation coefficient of 0.846 with comparison to that of electrocardiograph. Then, the errors of the HF (index of parasympathetic system) and the LF/HF (index of sympathetic system) are 18.34% and 16.99%, respectively.**

***Keywords*— air cushion sensor, fuzzy membership function, heart rate variability, autonomic nervous system, real time display.**

I. Introduction

Recently, daily health care becomes important according to the increment of aging population and life style-related illness. The measurement of the biological information is indispensable to daily health care while people do a daily living activity. The monitoring technology of the biological information in daily life is also effective in the home and office.

Heartbeat is an example of the index of the health care. The heartbeat can evaluate the autonomic nervous system by using heart rate variability (HRV). The autonomic nervous system is an important index of the health care, because autonomic nervous system is closely related to enhance quality of life. Spectral analysis of HRV based on Fast Fourier Transform (FFT) derives three major spectral components [1], [2], [3], [4]. We are able to perform functional assessment of autonomic nervous system for an index in these frequency components.

In general, HRV is measured by an electrocardiograph. However, this method has to constrain human body. Then it gives physically and psychologically burdens to them. In addition, an electrocardiograph is too costly to use daily health monitoring. For the daily monitoring, the low cost and unconstraint system is required. In the conventional method of using unconstraint sensor for HRV measurement, there is the method using the air pressure sensor developed obtained by mat sensor with the sensor [5]. Ref. [5] described the functional assessment of autonomic nervous system in bed.

Many studies are done on autonomic nervous system in bed [6], [7]. In this paper, we develop a new cushion sensor used in the measurement of sitting position, and apply it to detect heart rare for displaying real time autonomic nervous system changes. In the cushion sensor, an air pressure sensor is connected to rubber tube in an air cushion, and it detects heart rate. The cushion sensor system is small and low cost because the sensor consists of a rubber tube and the low cost air pressure sensor on the market [8]. We employ a detection method of heartbeat point using fuzzy membership functions [9], [10]. We evaluate it by comparing our results with truth values obtained by an electrocardiograph. In the experiment on seven volunteers, we preciously detected RR interval tachogram. We performed functional assessment of autonomic nervous system with the obtained HRV. Consequently, our real time system can demonstrate signal, HRV and autonomic nervous system such as parasympathetic nervous system and sympathetic nervous system.

II. Air Cushion Sensor

Air cushion sensor is shown in Fig. 1. The structure of the air cushion sensor is shown in Fig. 2. The air cushion sensor consists of the sensor part and the cushion part (Tatsuno Cork Kogyo Co. Ltd., Cubeads Cushion). Cushion size is 400mm × 400mm. The structure of sensor part is shown in Fig. 3. The rubber tube set in a spiral pattern. The sensor part includes ultra sensitive pneumatic sensor (Fuji Ceramics Co., FKS-111). This sensor detects a pressure change generated by the vibration of

Figure 1. Air cushion sensor.

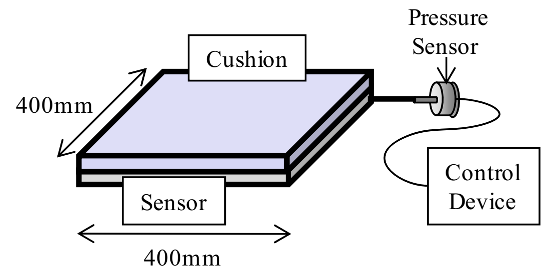


Figure 2. Structure of an air cushion sensor.

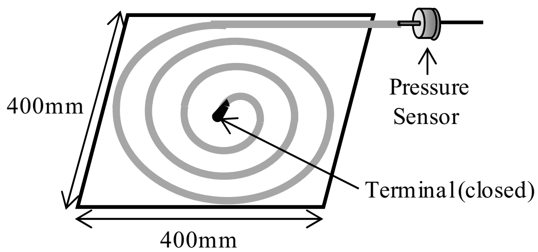


Figure 3. Structure of sensor part

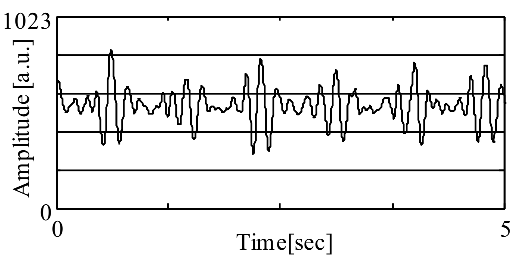
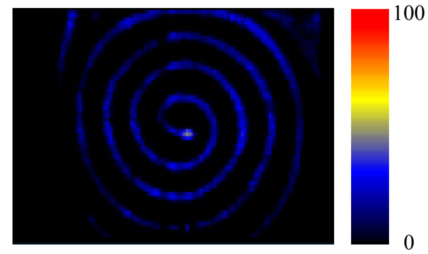


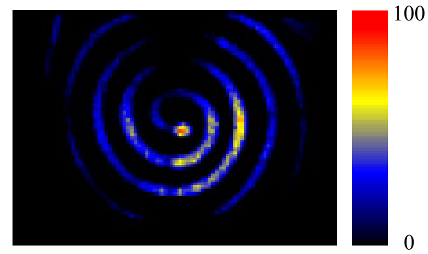
Figure 4. Example of acquisition data

vital activity. The example of acquisition data is shown in Fig. 4. The ultrasensitive pneumatic sensor outputs electronic signal based on 3.0V. This signal is quantized to 1024 levels (10bits) by a personal computer. The sampling intervals of the air pressure sensor are 2.5msec.

The air cushion has the mechanism that its shape is freely changed to the shape of buttocks of the individual. That is many small size articles are inserted in the cushion; they form the shape of buttocks when we release air from the cushion by pushing the air release button (Fig. 1.).We test the mechanism of the cushion sensor by a load distribution sensor. The load distribution sensor outputs the pressure on the sensor by level values of 8bits. The load distribution of air cushion sensor is shown in Fig. 5. Fig.5 shows the distributions with and without cushion of sensor when a person (95kg) sits down. Fig. 5(a) shows that the load is distributed all tubes, and Fig. 5(b) shows that the terminal and several parts have heavy loads. Thus, Fig. 5 shows the cushion effectively disperses the load of the sensor to the tube. Therefore the air cushion sensor can effectively acquire the data.



(a) With cushion part



(b) Without cushion part

Figure 5. The load distribution of the air cushion sensor.

III. Heart Rate Variability Detection and Autonomic Nervous System Evaluation

This section describes a detection method of heartbeat points using fuzzy logic and method of autonomic nervous system evaluation. These methods were mentioned in detail by Ref. [5]. In Section A, we briefly describe heart rate variability detection. In Section B, we briefly describe autonomic nervous system.

A. Heart Rate Variability Detection [5]

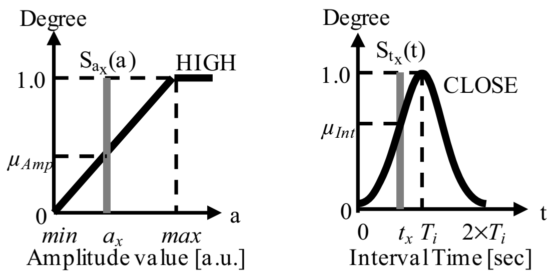
First, we perform full-wave rectification processing as preprocessing. As shown in Section II, the obtained data are provided based on medium value of 10 bit. Therefore, we perform a full-wave rectification processing based on 512 for the obtained data.

Second, we calculate T_i as heartbeat cycle. We extract data between the measurement start point and 60[sec] from calculated data by full-wave rectification. We divide these data into three data section of every 20[sec]. We perform FFT for each part, and we calculate three peak frequencies for each part. We calculate the average f_i of the three peak frequencies, and we calculate the heartbeat cycle T_i (=1/ f_i). We update heartbeat cycle T_i whenever we find ten heartbeat points.

Finally, we detect heartbeat point. We determine first heartbeat point h_1. First heartbeat point is decided the point of the highest peak point from between search start point and T_i. When we detect heartbeat points after h_1, we use the following fuzzy logic based method. We assume that h_i exists in the range between previous heartbeat point h_{i-1} and $2\times T_i$ [sec] later point. To determine h_i, we analyzed the characteristic of heartbeat point. As a result, we obtain knowledge of heartbeat as follows.

Knowledge 1 : The large peak is caused by the heartbeat.

Knowledge 2 : Heartbeat period has no sudden change.



(a) Rule 1 (b) Rule 2

Figure 6. Fuzzy membership functions.

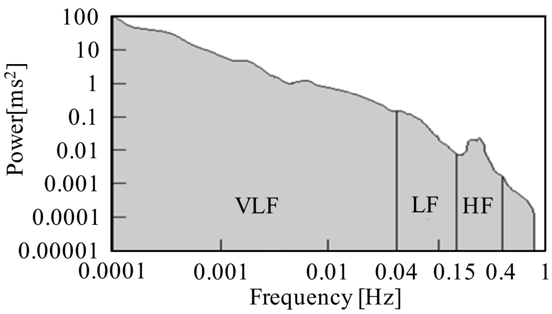


Figure 7. Example of spectrum density.

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

Rule 1 : IF a_x is HIGH, THEN the degree of heartbeat point (μ_{Amp}) is high.

Rule 2 : IF t_x is CLOSE to T_i, THEN the degree of heartbeat point (μ_{Int}) is high.

The "HIGH" membership function [10] for amplitude and "CLOSE" membership function for interval time are defined in Fig. 6. The amplitude a_x and interval time t_x from h_{i-1} are calculated from input value x. In Fig. 6(a), *max* denotes the maximum amplitude and *min* denotes the minimum amplitude among datum x. We define the "CLOSE" membership function by Equation (1).

$$CLOSE(t) = \exp\left(\frac{-(t-T_i)^2}{2\sigma^2}\right), \quad \sigma = \frac{T_i}{3} \tag{1}$$

Fuzzy singleton functions are defined by Equations (2) and (3), respectively.

$$s_{a_x}(x) = \begin{cases} 1 & if \quad x = a_x \\ 0 & otherwise \end{cases} \tag{2}$$

$$s_{t_x}(t) = \begin{cases} 1 & if \quad t = t_x \\ 0 & otherwise \end{cases} \tag{3}$$

The fuzzy degrees $\mu_{Amp}(x)$ and $\mu_{Int}(t)$ are calculated by Equations (4) and (5), respectively.

$$\mu_{Amp}(x) = \min(HIGH, s_{a_x}(x)) \tag{4}$$

$$\mu_{Int}(t) = \min(CLOSE, s_{t_x}(t)) \tag{5}$$

The total degree $\mu_{Target}(x)$ of the heartbeat point is calculated by algebraic product of $\mu_{Amp}(x)$ and $\mu_{Int}(t)$ by Equation (6).

$$\mu_{Target}(x) = \mu_{Amp}(x) \times \mu_{Int}(t) \tag{6}$$

We determine the next heartbeat point h_i as the point with the maximum $\mu_{Target}(x)$.

B. Autonomic Nervous System Evaluation

HRV analysis is performed according to Ref. [1]. We use the method of short-term recordings of 2 to 5 minutes. The spectrum of HRV signal is calculated from the RR interval tachogram. The RR interval is an interval in time of R wave which is the peak of the electrocardiograph. In the other words, the RR interval is an interval of the heartbeat points. The RR interval tachogram is RR intervals vs. number of progressive beats. We employ FFT as the frequency analysis. In the frequency domain, 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 Fig. 7. The frequency range of VLF is less than or equal to 0.04Hz and the frequency range of LF is 0.04 to 0.15Hz, and the frequency range of HF is 0.15 to 0.4Hz. Frequency components of the factor of both the sympathetic system and parasympathetic is 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 Equations (1) and (2), respectively.

$$LF(n.u.) = \frac{LF}{TotalPower - VLF} \times 100 \tag{1}$$

$$HF(n.u.) = \frac{HF}{TotalPower - VLF} \times 100 \tag{2}$$

Total power of Equations (1) and (2) shows a frequency domain less than or equal to 0.4Hz. As mentioned above, LF is not only frequency component of the factor of sympathetic system but also frequency component of the factor of parasympathetic. 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.

IV. REAL TIME DISPLAY SYSTEM

We develop a real time display system for visualizing the heartbeat and functions of autonomic nervous system. As the development environment, we used MATLAB ver.7.0.4. and LABVIEW ver. 8.6. The flow chart of the real time system is shown in Fig. 8. This system consists of two modules. The first module acquires data and saves them. The second module performs the detection of the heartbeat change and does the method mentioned in Section III. The operation of this module runs in MATLAB. The display of the real time system is shown in Fig. 9. This system displays the raw data, RR interval tachogram, number of heartbeat, power spectrum, LF, HF and LF/HF. Raw data is updated every second. RR interval tachogram is displayed after we calculate the heartbeat point. Afterward, this system update RR interval tachogram every detection of a heartbeat point. Power spectrum is the frequency ingredient of RR interval tachogram. We calculate the spectrum at every 256 points of heartbeat detection.

We tested that this system runs for over one hour.

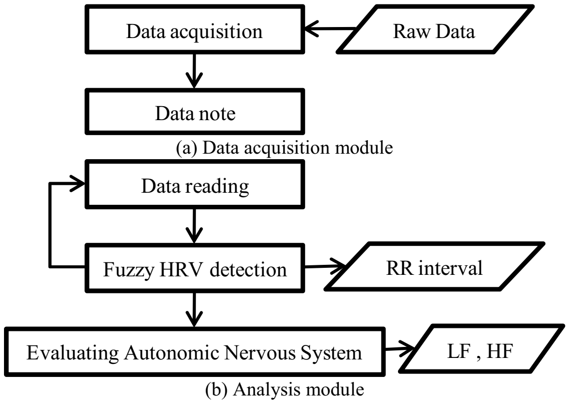


Figure 8. Flowchart of the real time display system.

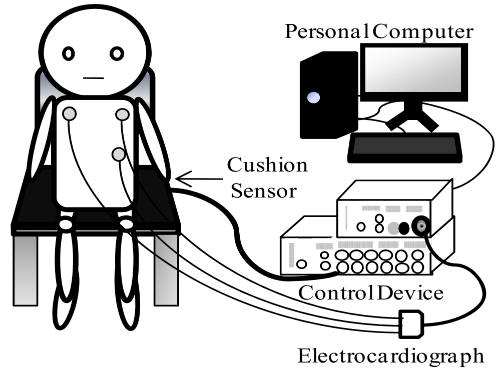


Figure 10. Experimental method.

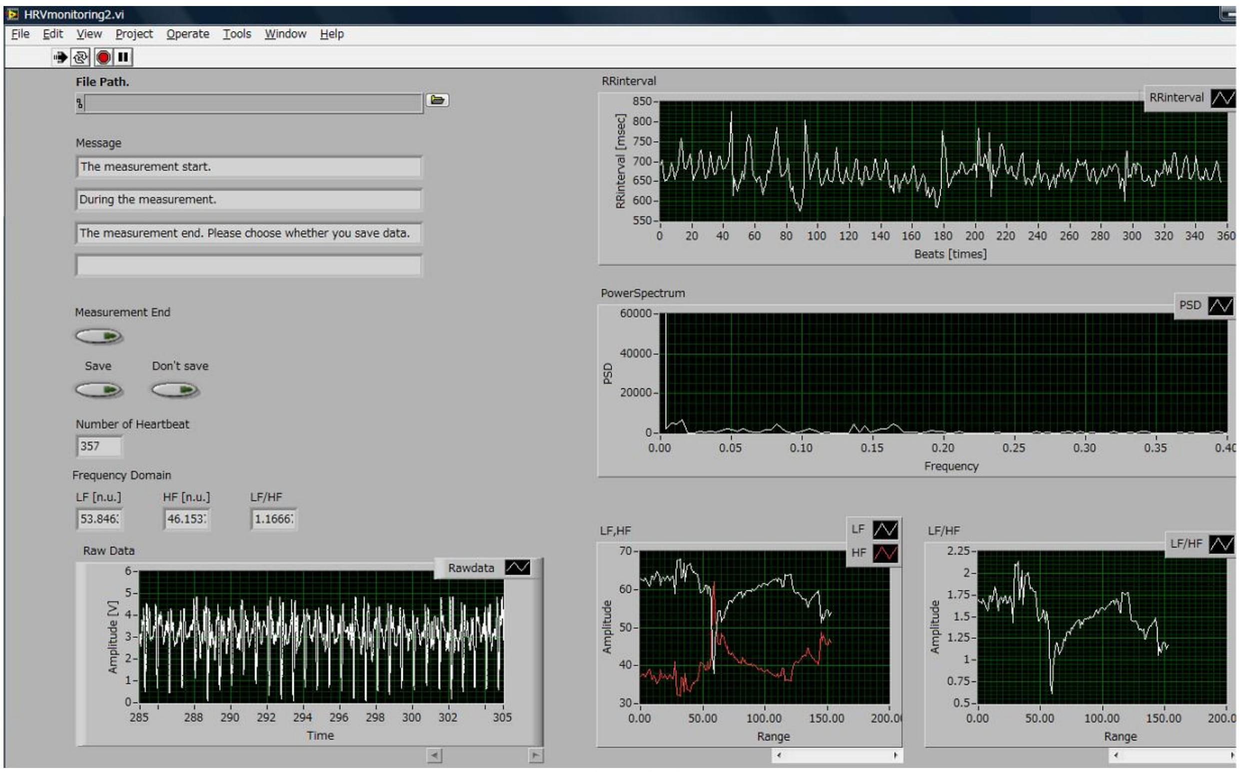


Figure 9. Real time display system

V. Experimental Results

Our experimental system is shown in Fig. 10. We measure the data by electrocardiograph (ADInstruments Pty. Ltd., ML132) at the same time. We employ data of the electrocardiogram as the truth value. The electrocardiograph is attached to the chest of the subject, and the air cushion sensor is placed on a chair. We did the experiment on two cases to examine the utility of our method.

First, we perform an experiment to examine influence on result of the cushion sensor. For this experiment, we employed two volunteers of subjects A and B in Table I. The result of this experiment is shown in Table II and Fig. 11. Table II and Fig. 11 show that the cushion part improves the precision to detect the heartbeat. Thus, the cushion sensor is effectively used for the measurement on the chair from this result.

Second, we evaluate precision of the heartbeat detection and functional assessment of autonomic nervous system. We employed six healthy volunteers as shown in Table I. We obtained data of five minutes for each. After we detect heart rate variability by our method, we perform the HRV analysis. Table III shows the results of correlation coefficients of the HRV. As an example, the result of heart rate variability of subject C is shown in Fig. 12 and the results of frequency domain of subject C is shown in Fig. 13. The average of

TABLE I SUBJECTS 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

TABLE II RESULTS OF COMPARISON OF THE CUSHION

Subject	Correlation Coefficient	
	with cushion part	no cushion part
A	0.759	0.072
B	0.863	0.758

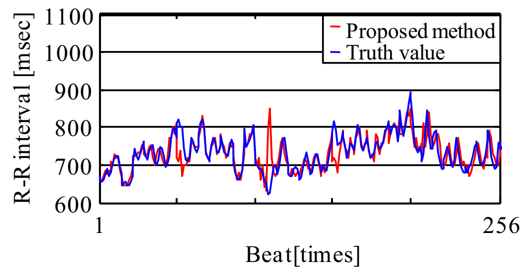
TABLE III RESULTS OF CORRELATION

Subject	Correlation Coefficient
	with cushion part
A	0.759
B	0.885
C	0.932
D	0.782
E	0.884
F	0.836

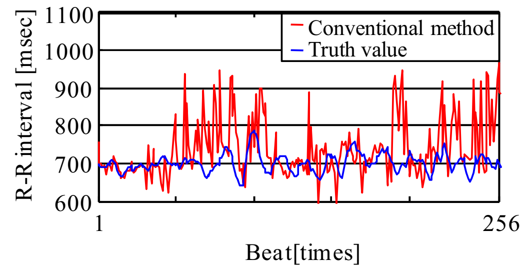
TABLE IV RESULTS OF FREQUENCY DOMAIN

Subject		Our method	Truth Value	Error(%)
A	HF(n.u.)	30.97	30.76	0.68
	LF/HF	2.23	2.25	0.89
B	HF(n.u.)	69.61	67.88	2.55
	LF/HF	0.44	0.47	6.38
C	HF(n.u.)	86.16	87.16	1.15
	LF/HF	0.16	0.15	6.67
D	HF(n.u.)	45.90	24.10	90.46
	LF/HF	1.18	3.14	62.42
E	HF(n.u.)	60.37	59.92	0.75
	LF/HF	0.66	0.67	1.49
F	HF(n.u.)	55.02	48.08	14.43
	LF/HF	0.82	1.08	24.07

correlation coefficients of HRV was 0.846. Table IV shows results of the frequency domain method. The mean error of HF(n.u.) was 18.34%, and the average error of LF/HF was 16.99%.



(a) With cushion part



(b) No cushion part

Figure 11. Example of the result of HRV (subject A).

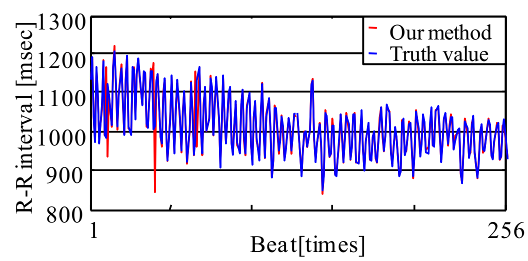


Figure 12. Example of the result of HRV (subject C).

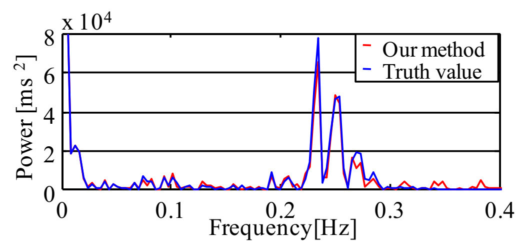


Figure 13. Example of the result of frequency domain (subject C).

VI. CONCLUSIONS

In our study, we have developed the display system to visualize the detected heart rate variability by heartbeat points obtained by the cushion sensor system. The display visualized the functional assessment of autonomic nervous system by the HRV while sitting. Our cushion sensor was applied to the heartbeat detection of the subject (58-95kg). We show that the cushion improves the detection precision. As the result on six healthy volunteers, we detected heart rate variability with correlation coefficient 0.846, and we detected HF(n.u.) (an index of the parasympathetic system) at mean error of 18.34%, LF/HF (an index of the sympathetic system) at mean error of 16.99%. It remains as the future studies to apply our method in practical use in real situation.

References

[1] M. Malik et al., "Heart Rate Variability - Standards of Measurement, Physiological Interpretation, And Clinical Use," European Heart Journal, Vol.17, pp.354-381, 1996.

[2] R. D. Berger, S. Akselrod, D. Gordon and R. J. Cohen, "An efficient algorithm for spectral analysis of heart rate variability," IEEE. Transactions on Biomedical Engineering, Vol. BME-33, No. 9, 1986.

[3] C. V. R. Arts, L Kollee and J Hopman. "Heart rate variability," Ann Intern Med. 118, pp. 436-447, 1993.

[4] H. -L. Chan, M. -A. Lin, P. -K. Chao,C. -H. Lin, "Correlates of the shift in heart rate variability with postures and walking by time-frequency analysis," Computer Methods and Programs in Biomedicine, Vol. 86, No. 2, pp. 124-130, May. 2007.

[5] K. Yamamoto, N. Tsuchiya, H. Nakajima, S. Kobashi and Y. Hata,, "Fuzzy Heart Rate Variability Detection by Air Pressure Sensor for Evaluating Autonomic Nervous System," in Proc. 2008 IEEE International Conference on Systems Man and Cybernetics, pp. 3067-3071, Oct. 2008.

[6] H. -L. Chan, C.-H. Fang, Y. -L. Ko, M. -A. Lin, H. -H. Huang, C. -H. Lin, "Heart rate variability characterization in daily physical activities using wavelt analysis and multilayer fuzzy activity clustering," IEEE. Transations on Biomedical Engineering, Vol. BME-53, pp. 133-139, Jan. 2006.

[7] S. Apeel, A. Kuritzky, I. Zahavi, M. Zigelman, S. Akselrod, "Evidence for Instability of the Autonomic Nervous system in Patients With Migraine Headache," The Journal of Head and Face Pain, Vol. 32, pp.10-17, May. 2005.

[8] Y. Kamozaki, T. Sawayama, K. Taniguchi, S. Kobashi, K. Kondo and Y. Hata, "Fuzzy Extraction System for Heart Pulse by Air Pressure Sensor, " in Proc. of 2006 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS 2006), pp.919-922, Dec. 2006. (CDROM)

[9] K. Nagamune, S. Kobashi, K. Kondo, Y. Hata, K. Taniguchi, and T. Sawayama, "Unconstrained Evaluation System for Heart Rate Using Ultrasonic Vibrograph," Japanese Journal of Applied Physics, vol. 43, No. 5B, pp. 3237-3238, 2004.

[10] Y. Kamozaki, T. Sawayama, K. Taniguchi, S. Kobashi, K. Kondo and Y. Hata, "A New Ultrasonic Oscillosensor and Its Application to Biological Information Measurement System Aided by Fuzzy Theory," IEICE Transactions on Information and Systems, 2007.