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DYNAMIC MEASUREMENT OF PHYSICAL STRENGTH IN EXERCISE

Kosuke Sentoku, Yuki Matsuda, and Shigeru Takayama

Department of Electrical & Electronic Engineering, Science & Engineering
Ritsumeikan University, BKC, Shiga, JAPAN, re005076@ed.ritsumei.ac.jp

Abstract: Facilities for travel are developing conveniently in recent years. A lot of people do not exercise sufficiently in daily life. As a result, the life-style related diseases like high blood pressure and obesity increase. A moderate exercise is very important to keep a healthy body for them but it is too difficult to know how to exercise moderately. Then, this paper shows the audio advising system and method to keep a moderate exercise with heart rate (HR). Additionally, a user is able to choose the exercise level from light exercise to heavy exercise.

Keywords: Sensing system, Physical strength, Dynamic measurement

1. INTRODUCTION

1-1. Background

In recent years, life became rich by the development of transportation and the electrification of home life. But, accordingly, the exercise in one's daily life decreased. Therefore, exercising ability decreased. Decline in exercising ability leads various problems. For example, high blood pressure, obesity, adult disease. Especially for older people, it leads to bed-ridden. It is a serious social problem.

1-2. Purpose

It is too difficult to know how to exercise moderately but it is important to set a moderate exercise level. If the exercise level is too low, it is impossible to increase the health. If the exercise level is too high, the responsibilities of the heart increase. Especially for older people, it is very dangerous. This advising system is able to set the exercise level and manage the HR of a user. Then, a user keeps a moderate exercise level safety.

2. SYSTEM CONFIGURATION

All of the system is called the Body Area Network (BAN) System that manages the health of human beings. Figure 1 shows the concept of BAN.

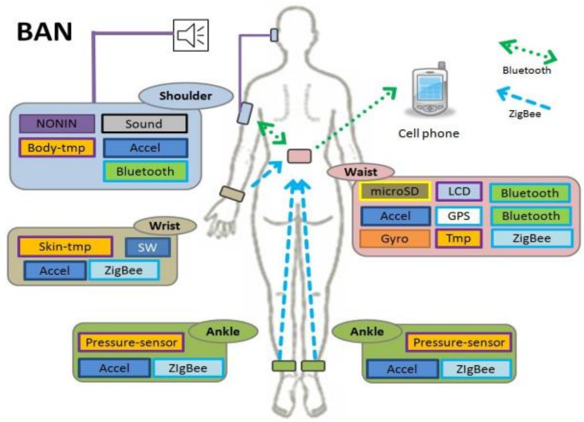

Fig.1 The concept of BAN.

BAN has 5 modules; shoulder, wrist, waist and both ankles. Each module measures several parameters and send data to the main module by wireless network. The Waist module collects data and sends some pieces of advice to users. If users have some health problems, the system send the attention to others (for example, a doctor and a family). Then, they are able to know it through a cell phone in real time automatically. This advising system will be integrated into BAN as a shoulder module but the present module is not integrated. Therefore, this paper shows waist module that send advice to keep physical strength in motion. This advice system has CPU-board (AP-SH3D-1A), micro SD card UART access module (MSC-MOD10), HR_SpO2 sensor and earphones. AP-SH3D-1A determines moving or not from data of Accelerometer, it is obtained HR data and SpO2 data from X-pod is wired serial. Then, it records the obtained data onto micro SD card by MSC-MOD10. Figure 2 shows the advice system configuration.

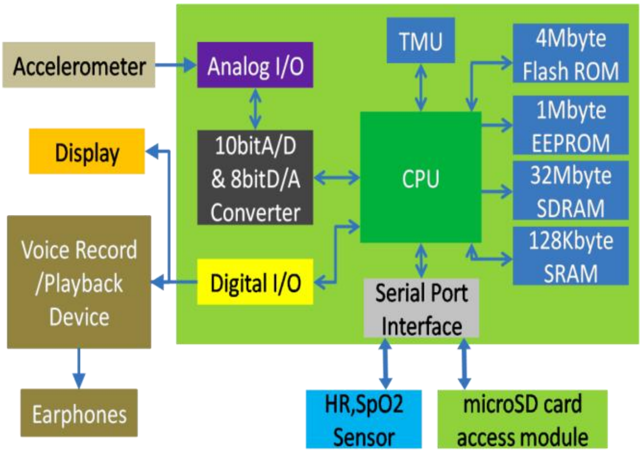

Fig.2 Advice System Configuration.

2-1. CPU-board

The advice system uses CPU-board (AP-SH3D-1A make an Alpha Project) for data processing and analysis. AP-SH3D-1A has 32 bit RISC CPU H7729R made RENESAS technology. CPU clock frequency is 192 MHz (when using crystal oscillator 16 MHz). AP-SH3D-1A has 8 channel 10 bit AD converters, digital I/O ports, and 3 channel serial interfaces. Size is 120 (W) x 90 (D) x 11 (H) millimeter. Figure 3 shows AP-SH3D-1A.


Fig.3 AP-SH3DE-1A.

2-2. Accelerometer

The advice system use accelerometer (KXM52-1050 module made of Kionix Inc.) for determining moving. This accelerometer has 3 axes. Measuring range is ± 19.6 m/s². Sensitivity is 660 mV per m/s² and 0 m/s² offset is 1.65 V when it used 3.3 V. Bandwidth is 10Hz to 1500 Hz. Size is 10 (W) x 10 (D) x 5 (H) millimeter. Figure 4 shows KXM52-1050 module.


Fig.4 KXM52-1050 module. (Kionix Inc.).

2-3. HR-SpO2 Sensor

The advice system uses HR-SpO2 sensor (OEM-III made of NONIN Medical Inc.). It can measure heart rate (HR) and percutaneous oxygen saturation (SpO2). It is photoelectric pulse monitor and serial output. Serial communication format is 9600, n, 8, 1 binary data output. Sensor unit is the shape of the ear clip. Sampling rate is 333.33 [ms]. Size is 34 (W) x 23 (D) x 8 (H) millimeter. Figure 5 shows OEM-III.


Fig.5 OEM-III. (NONIN Medical Inc.)

2-4. Mount the system

CPU-board, micro SD card access UART module and accelerometer are mounted at the waist fixed by the belt. It is mounted at the center of waist. X-pod and earphones are mounted at the ear. The sensor part of X-pod is glued on earphones, for advice by voice, hanger part. The ear clip sensor is connected by cable from the waist. Figure 6 and 7 shows state of the mounting.

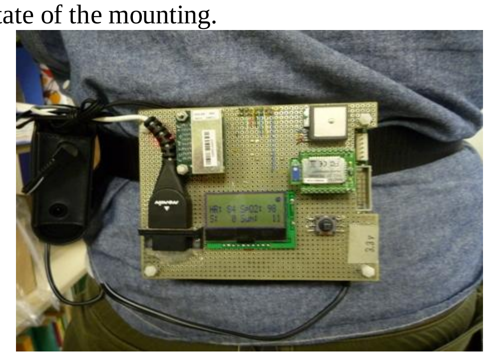
Fig.6 State of the mounting the system, Waist.

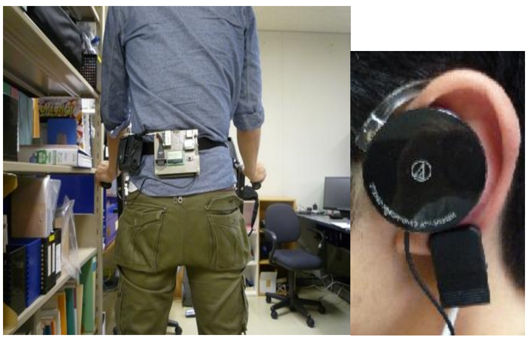
Fig.7 State of the mounting the system, (Left Figure) Attached module , (Right Figure) Ear.

3. MEASURING METHOD

As an application of the system, we have tried to realize constant strength by monitoring heart rate (HR). Fig.8 shows the time transition of heart rate (red line) in a motion sequence of walking, running and walking (Lab. a student;

male, age:22). By using it, dynamic situation of heart rate is observed on line like this.

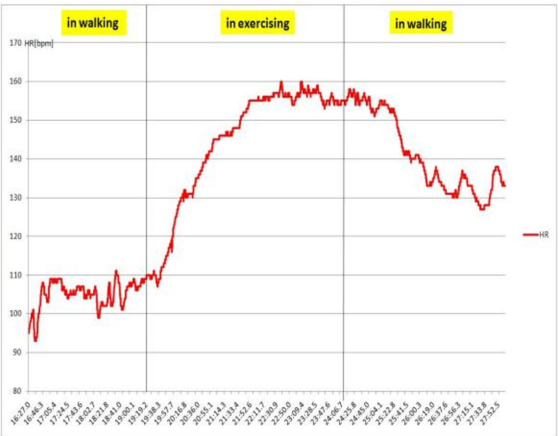

Fig.8 Time transition of heart rate in a motion sequence.

It has been confirmed that the heart rate responses according to human motions. In walking, the heart rate increased gradually. In running, his heart rate increased quickly. He felt so tired at finish to run. This means that his physical condition became hard. In the second walking, the heart rate decreased gradually. It means physical strength can suppose from HR of users.

3-1. The choice of exercise levels

Users are able to choose the exercise level from light exercise to heavy exercise. EI (Exercise Intensity) is well known as a unit to express strength of physical exercise. By using the heart rate, EI is calculated as follows,

$$EI[\%] = (HR\text{-}HRmin)/(HRmax\text{-}HRmin) \times 100 \quad \text{[Karvonen Formula]} \qquad (1)$$

HRmin : heart rate in quiet,
HRmax : heart rate in the most heavy exercise

The EI is defined according with the strength of physical exercise roughly (Table I).

Table 1 Relation of EI and strength of exercise

40-50[%]	light exercise (walking)
50-60[%]	medium exercise (slow running)
60-85[%]	stressed exercise
85-100[%]	heavy exercise (professional level)

3-2. Some pieces of advice

To keep a constant strength of physical exercise, the system supplies several advice to current exercise under conditions that are value and trend of HR. Table 2 and Table 3 show the selection of advices by these conditions

Table 2 List of six advices

	Advice
Advice 1	Pace up slowly
Advice 2	Keep pace
Advice 3	Pace down slowly
Advice 4	Pace down
Advice 5	Pace down quickly
Advice 6	Stop exercise now, have a short rest

Table 3 Selection of advice to keep a constant strength of physical exercise

<table>
<tr><th>Trend of HR / Value of HR</th><th>Even or Slow down</th><th>Rising up gradually</th><th>Rising up</th></tr>
<tr><td>$HR < HR_{by\_min\ EI}$</td><td colspan="2">Advice_1</td><td rowspan="3">Advice_3</td></tr>
<tr><td>$HR_{by\_min.EI} < HR < HR_{Thr1}$</td><td>Advice_1</td><td>Advice_2</td></tr>
<tr><td>$HR_{Thr1} < HR < HR_{Thr2}$</td><td colspan="2">Advice_2</td></tr>
<tr><td>$HR_{Thr2} < HR < HR_{by\_max.EI}$</td><td>Advice_2</td><td>Advice_4</td><td>Advice_5</td></tr>
<tr><td>$HR_{by\_max.EI} < HR$</td><td colspan="3">Advice_6</td></tr>
</table>

$HR_{by\_min\ EI}$: Heart rate at minimum EI ,
$HR_{by\_max.EI}$: Heart rate at maximum EI ,
HR_{Thr1} : 1/5 ($HR_{by\_max.EI}$ - $HR_{by\_min\ EI}$) + $HR_{by\_min\ EI}$,
HR_{Thr2} : 4/5 ($HR_{by\_max.EI}$ - $HR_{by\_min\ EI}$) + $HR_{by\_min\ EI}$.

When users set EI, the appropriate HR of the exercise are calculated. Then pieces of advice are sent to users when they exercise.

4. MEASUREMENT RESULTS AND MANAGEMENT OF PHYSICAL STRENGTH

4-1. Purpose

The purpose of this experiment is to check the system can send accurate advice. Advice are sent according to the value of HR and the trend of HR

4-2. Experimental condition

These are the condition of subjects. Table 4 shows details of subjects.

Table 4 Details of subjects

	Height	Weight	Age
Subject A	170cm	65kg	23
Subject B	171cm	52kg	24
Subject C	175cm	75kg	22
Subject D	168cm	52kg	24

4-2. Experiment description

(4-2-1)When the EI is set from 35 to 60, subject A exercises. (in walking)

a) Firstly, he walks 2 minutes
b) Secondly, he exercises 5 minutes with advice.
c) Finally, he walks 5 minutes.

(4-2-2)When the EI is set from 35 to 60, subject B exercises. (in walking)

a) Firstly, he walks 2 minutes
b) Secondly, he exercises 5 minutes with advice.
c) Finally, he walks 5 minutes.

(4-2-3)When the EI is set from 50 to 75, subject C exercises.(in running)

a) Firstly, he walks 2 minutes

b) Secondly, he exercises 5 minutes with advice.

c) Finally, he walks 3 minutes.

(4-2-4)When the EI is set from 40 to 60, subject B exercises. This experiment ignores advice to make sure advice is appropriate

a) Firstly, he walks 3 minutes

b) Secondly, he exercises 3 minutes without advice.

c) Finally, he walks 3 minutes.

At this point, HR of the user is measured by the module. Then appropriate advice is sent to the user

4-3. Results

(4-3-1) About experiment 4-2-1 (in walking)
In fig 11,

$HR_{by\_min\ EI}$:109, $HR_{by\_max.EI}$:139,
HR_{Thr1}:115, HR_{Thr2}:133.

The appropriate HR of this exercise is 115 [bpm] to 133 [bpm]. When the subject walks, HR is under the target. So advice is “pace up slowly”. In running, when HR is over than 133 [bpm], it says “pace down”. If HR is appropriate, it says “keep this pace”. Therefore, the subject could exercise moderately. Figure 9 shows time transition of heart rate and advices about experiment 4-2-1.

Fig 9. Time transition of heart rate and advice (4-2-1).

(4-3-2) About experiment 4-2-2 (in walking)
In fig 12,

$HR_{by\_min\ EI}$:115, $HR_{by\_max.EI}$:145,
HR_{Thr1}:121, HR_{Thr2}:139.

The appropriate HR of this exercise is 121 [bpm] to 139 [bpm]. When the subject walks, HR is under the target. So advice is “pace up slowly”. In running, when HR is over than 139 [bpm], it says “pace down”. If HR is appropriate, it says “keep this pace”. Therefore, the subject could exercise moderately. Figure 10 shows time transition of heart rate and advices about experiment 4-2-2.

Fig 10. Time transition of heart rate and advice (4-2-2).

(4-3-3) About experiment 4-2-3 (in running)
In fig 13,

$HR_{by\_min\ EI}$:129, $HR_{by\_max.EI}$:159,
HR_{Thr1}:135, HR_{Thr2}:153.

The appropriate HR of this exercise is 135 [bpm] to 153 [bpm]. When the subject walks, HR is under the target. So advice is “pace up slowly”. In running, when HR is over than 153 [bpm], it says “pace down”. If HR is appropriate, it says “keep this pace”. Therefore, the subject could run. When he was running, his HR kept appropriate zone through some pieces of advice. Figure 11 shows time transition of heart rate and advices about experiment 4-2-3.

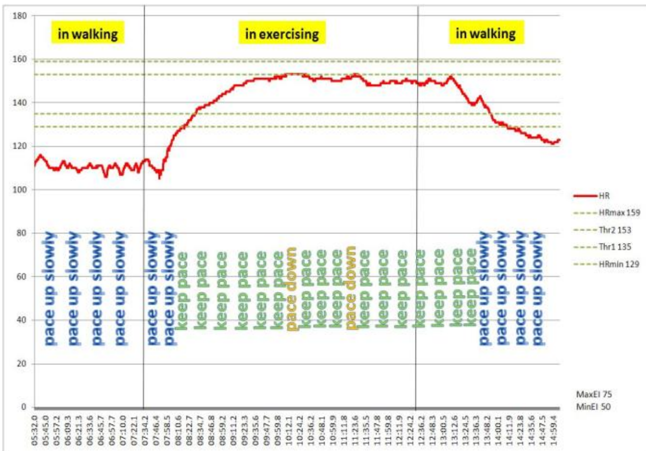

Fig 11. Time transition of heart rate and advice (4-2-3).

(4-3-4) About experiment 4-2-3 (in running)
In fig 14,

$HR_{by\_min\ EI}$:128, $HR_{by\_max.EI}$:153,
HR_{Thr1}:133, HR_{Thr2}:148,

The appropriate HR of this exercise is 133[bpm] to 148[bpm]. When the subject walks, HR is under the target. So advice is “pace up slowly”. In running without advice, when HR is over than 153[bpm], it says “stop exercise now, have a short rest”. It means the advising system is able to send appropriate advice if HR of users changes a lot. Figure 12 shows time transition of heart rate and advice about experiment 4-2-4.

Fig 12. Time transition of heart rate and advice (4-2-4).

4-4. Consideration

We could confirm that the system could measure the transition of heart rate. Besides, it could send appropriate advice for a user. In the case of experiment 4-2-1, 4-2-2 and 4-2-3, subjects could exercise according to set EI by advice. In the case of experiment 4-2-4, HR changed suddenly. Then, the system sent appropriate advice. In addition, the advising system could measure the data of accelerometer. It was found as a new light when HR of the user increases, the value of accelerometer increases too. This advising system has accelerometer. X-axis is the vertical direction named AccX. Y-axis is the horizontal direction named AccY. The value of AccX means bobbing in exercising. The value of AccY means body swing in exercise. It is supposed when bobbing in exercise increases; HR is in proportion to AccX. In addition, it is supposed when users feel physical fatigue, body swing in exercise increases. Figure 13 and 14 show time transition of heart rate and the value of accelerometer. These data are same to experiment 4-2-1, experiment 4-2-2 and experiment 4-2-4. Red dotted lines are HR. Blue dotted lines are AccX. Green dotted lines are AccY. The value of AccX and AccY is a standard deviation. All of solid lines are the approximate polynomial.

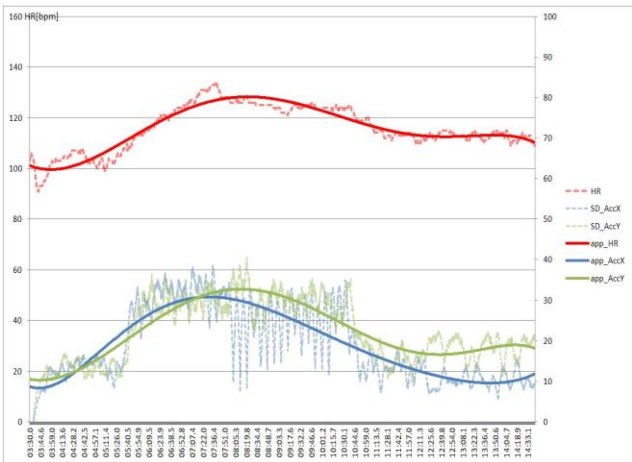

Fig 13. Time transition of heart rate and the value of accelerometer about experiment (4-2-1).

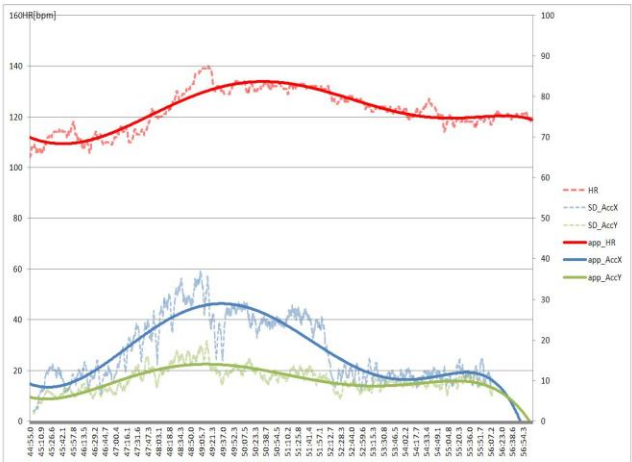

Fig 14. Time transition of heart rate and the value of accelerometer about experiment (4-2-2).

Firstly, Red solid lines and Acc data are similar shapes. When AccX (blue line) increased, HR increased too. It means bobbing exercise affect HR. In addition, it is supposed AccY (green lines) is affected by physical fatigue. It means when a human feel tired in exercise, body swing increases. Fig 13 and 14 are transition of heart rate and the value of accelerometer in walking. Fig 15 and 17 are scatter grams that show the relationship between HR and AccX. Fig 16 and 18 are scatter grams that show the relationship between HR and AccY. Blue mark is a standard deviation of AccX. Green mark is a standard deviation of AccY. Red line is linearization. By using these graphs, it was confirmed HR and SD_AccX were related. In the case of AccY, the slope of linearization does not resemble in linearization of AccX if users do not feel tired like Fig 18. As a result HR increases by changes of AccX that means bobbing in exercise.

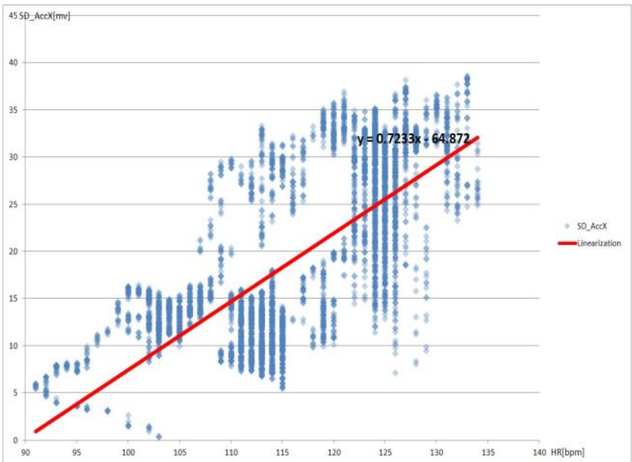

Fig 15. Scatter gram(AccX) and linearization about experiment (4-2-1)

Fig 16. Scatter gram(AccY) and linearization about experiment (4-2-1)

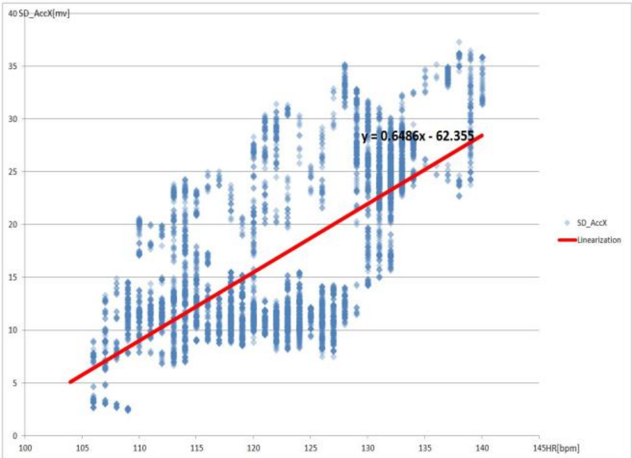

Fig 17. Scatter gram(AccX) and linearization about experiment (4-2-2).

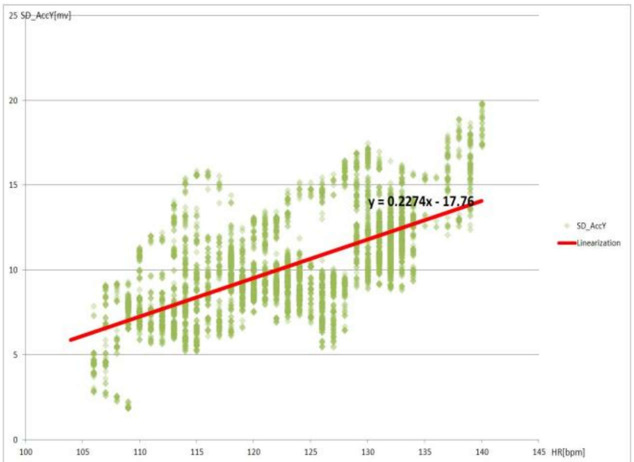

Fig 18. Scatter gram(AccY) and linearization about experiment (4-2-2)

It has been confirmed HR is related to the value of accelerometer by the graphs but these things should be considered more because data are few to determine. Then, the system is able to control physical strength effectively by using accelerometer as a new parameter.

5. CONCLUSION

It was confirmed to keep suitable physical strength in exercise by the interaction between the system and a user. One flow of the interaction is the monitoring of dynamic physical parameters of user. Other flow of that is the advising of exercise level to user. In addition, there are some relevancy between HR and the value of accelerometer. As future work, the physical strength of various kinds of people (athletes, aged persons and so on) in exercises will be managed. In addition, we will compose the Body Area Network (BAN) System that manages the health of human beings. This advising system will be integrated into BAN as a shoulder module by reconstructing it as a small and light system. Consequently, all the system can collect a lot of parameters and supposes another problem about the health (for example, body distortion, stepping strength). By using various parameters, BAN system is able to manage the health effectively. In addition, if users have some health problems, the system sends the attention to others (for example, a doctor and a family) by using cell phone. Then, the application fields will spread more and more.

6. REFERENCES

[1] Mienkovic M., Jovanov E., Chapman J., Raskovic D. and Price J., "An Accelerometer-Based Physical Rehabilitation System", ECE Dept., University of Huntsvile, Alabama Department of Electrical Engineering & Comp. Eng. University of Alabama in Huntsvile, Huntsvile, AL 35899 USA. IEEE, pp.57 – 60, 2002.

[2] Gafurov D., Helkala K. and Sǿndrol T., "Gait Recognition Using Acceleration from MEMS", *First International Conference on Availability, Reliability and Security* (ARES '06). IEEE, 2006

[3] Lee J. A., Cho S. H., Lee J. W., Lee K. H. and Yang H. K., "Wearable Accelerometer System for Measuring the Temporal Parameters of Gait", *Proceedings of the 29th Annual International Conference of the IEEE EMBS. France*. pp.483 – 486, August, 2007.

[4] Han J., Jeon H. S., Jeon B. S. and Park K. S., "Gait detection from three dimensional acceleration signals of ankles for the patients with Parkinson's disease", June 28, 2006.

[5] Wertsch J. J., Webster J. G. and Tompkins W. J., "A portable insole plantar pressure measurement system", *Journal of Rehabilitation Research and Development*, Vol.29, No. 1, pp. 13-18, 1992.

[6] Slyper R. and Hodgins J. K., "Action Capture with Accelerometers", *Eurographics/ACM SIGGRAPH Symposium on Computer Animation*, 2008.

[7] Westerterp K. R., "Physical activity assessment with accelerometers", *International Journal of Obesity*, Vol.23, pp. S45 – S49, 1999.

[8] Mathie M. J., Coster A. C. F., Lovel N. H. and Celler B. G., "Accelerometry: providing an integrated, practical method for long-term, ambulatory monitoring of human movement", *PHYSIOLOGICAL MEASUREMNT, Institute of physics publishing,* Vol.25, pp. R1 – R20, 2004.

[9] Kim D. J., Pradhan G. and Prabhakaran B., "Analyzing Coordination of Upper and Lower Extremities in Human Gait", *BodyNets'09*, April 1-3, 2004.