A Novel Method for Unobtrusive Measurement of Indoor Activities using Sensor-based Monitoring System

°Bo Sun Hwang, °Jong Min Choi, *Kwang Suk Park
°Interdisciplinary program in Medical and Biological Engineering Major
*Dept. of Biomedical Engineering , College of medicine, Seoul National University

Abstract — **We have developed a monitoring system which is focused on the activities of an individual daily living in a home. We installed several types of environmental sensors (Infra-red(IR) sensors were installed dominantly) which can communicate through the wireless communication protocol (Bluetooth). The proposed system could detect the movements of a subject and then his/her activity pattern and position in a home were analyzed by the tracking algorithm. It was also monitored by carers thorough the Internet. In addition, we took experiments to compare actigraph with our system. There have been many researches related to actigraph which has been used to get quantitative data on activities.[5][6][7] And we also used a gas analyzer as a calorimeter to make the regression equation which can calculate the energy expenditure from sensor data. We verified the results using correlation analysis and regression analysis. Finally we were able to obtain the quantitative activities comparable to actigraph, gas analyzer from the sensor data. As a result of this research, we could get the quantitative activities from the proposed monitoring system.**

I. Introduction

These days we are facing to the problems that the population of the elderly and the cost of healthcare are increasing dramatically. Therefore the home healthcare has been becoming an alternative. Especially daily activities are important factors which inform an individual health condition.[5][8] There have been many researches about home healthcare.[1][8][9][10] They have also installed several types of environmental sensors in a smart home. But they just showed the possibilities about future home healthcare, didn't suggest proper applications. Hence we installed some environmental sensors (IR sensors were installed dominantly), and then we decided to focus on activities in a home as our research.

At first, we focused on daily movement monitoring in a home.[8] So we decided to track subject's position in a home. For this position tracking, we made position tracking algorithm using state diagram. After making this system, we were interested in quantitative activities in a home. Many studies have been until nowadays, but they could just show the qualitative activities in a home using sensor-based activity monitoring system. So we concluded to use IR sensor counts as a parameter of activities. As comparing equipments, we chose a gas analyzer (K4b2, Cosmed Italy) which has been used a standard equipment and actigraph (Sleep Watch, AMI USA) which has been used to measure ambulatory activities indirectly.

B. Hwang Author, B08, Department of Biomedical Engineering, College of Medicine, Seoul national University, 28, Yeogeon-dong, Jongno-gu, Seoul, Republic of Korea, 110-799 (corresponding author to provide phone: +82-2-740-8585;fax:+82-2-744-7446;e-mail:bshwang97@bmsil.snu.ac.kr).

II. Materials and Methods

A. The monitoring system

This study is based on sensor network system, and used several types of environmental sensors to avoid privacy problems. For a easy implementation and to reduce system complexity, Bluetooth communication protocol was used.

Sensor modules were consisted of BUMUS (Bluetooth-based Ubiquitous Monitoring Unit for Sensors) which is a standard sensor module at BMSIL SNU. Fig. 1. shows structures of the BUMUS.). The function of this unit is converting analogue signals to digitized data and transmitting these data to the Home server using Bluetooth.

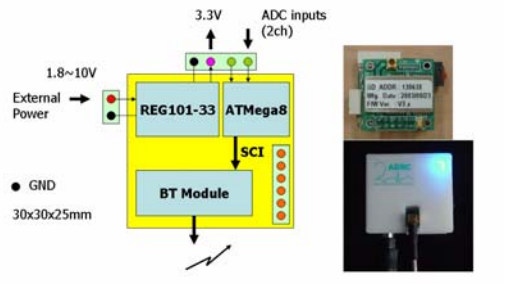

Fig. 1. BUMUS
(Bluetooth-based Ubiquitous Monitoring Unit for Sensors)

And Fig. 2. shows a real picture of the BUMUS for IR sensor.

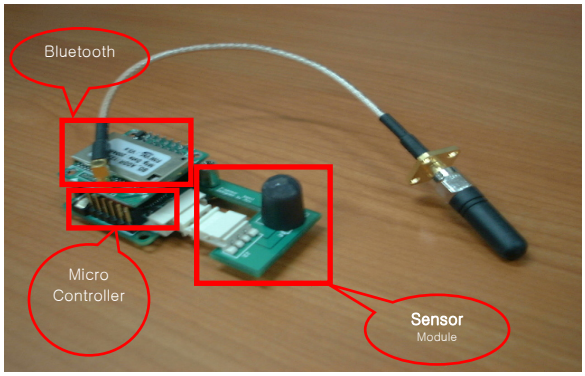

Fig. 2. BUMUS for IR sensor

The whole system was consisted of minimum number of sensors to avoid complexities of system, and Table 1. shows the types and the number of sensors.

Sensor	Event	Unit(s)
Passive Infra-red	Motion Detected	7
Magnetic Switch	Main Entrance Open	1
Sound Detector	TV Turned On	1
Cds Sensor	Light Turned On	2
Flame Sensor	Gas Range Used	1

Table 1. Sensor constitution

The following functional sensors were used as environmental sensors :

a. Door Sensor

Magnetic switch is attached to the door and hinge. It can detect whether the door is opened or closed. However, the door often remains opened without any relation of the patient's movements. For this reason, magnetic switch is only attached on the main entrance door.

b. Motion detector

Pyroelectric infrared (PIR) sensor is used for detecting body movement through doors of rooms. It has been widely used for monitoring daily living style of the elderly or disabled. It can sense the radiation of a thermal object like a man and an animal.

c. Flame Detector

The subject sometimes uses the gas range in order to cook in a daily life. Flame sensor can detect flames very quickly by sensing ultraviolet ray. Due to its fast response pulse, the sampling rate is a little faster than that of other sensors.

d. Sound detector

Using a microphone together with RMS-to-DC converter, we can detect sound level. It is designed not to classify sounds into speech or washing sound, but to notice whether there is sound or not. It is used to have information whether a TV is turned on or off.

e. Light on-off detector

Cadmium Sulphide (CdS) resistor can be used for light detection. If a subject goes to the room and turns on the light, light sensor can detect this activity.

Fig. 3. shows the position of each sensor.

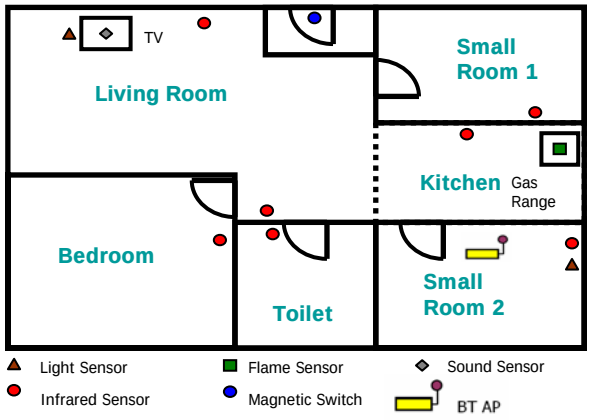

Fig. 3. Sensor configuration and each position

The following Fig. 4. shows the whole sensor network system structure.

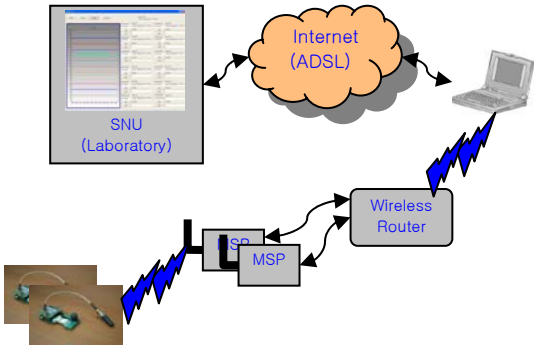

Fig. 4. The whole system structure

Sensor data were stored by the Data Acquisition Viewer Program coded using Microsoft Visual Studio .Net 2003.

Fig. 5. shows the dialog based application program which can show a real time data acquisition and store data each channel as a text format.

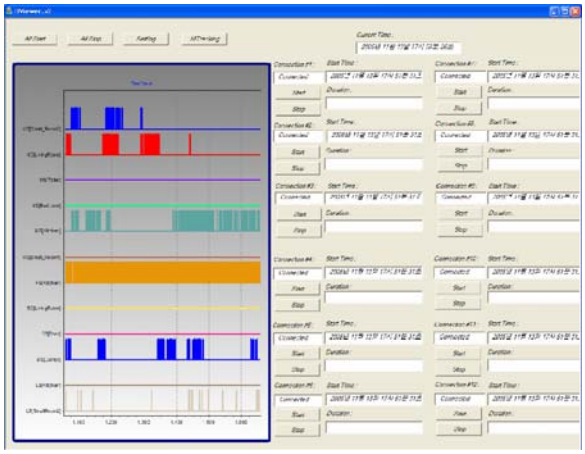

Fig. 5. The data acquisition viewer program

B. The environment of quantitative activities measurement

IR sensors were used to validate of measurement on quantitative activities of single room indoor situation. The three BUMUS for IR sensor were installed to detect human motion more precisely. Because the possibility of missing motions, three sensors were chosen. The installed positions were different. They were installed on the ceiling, the front wall, the side wall respectively. Fig. 6. shows the experimental environment.

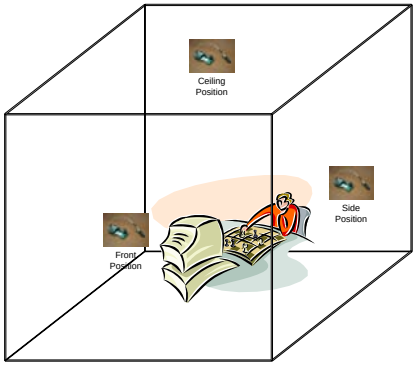

Fig. 6. Validation environment of quantitative indoor activities

When subjects took a experiment, they wore a actigraph (Sleep Watch, AMI, USA) on the waist and also wore a portable metabolic energy expenditure measuring system based on the gas analysis of oxygen consumption (K4b2, Cosmed, Italy). They were used as comparative equipments. Fig. 7. shows them.

Fig. 7. The comparative equipments (Sleep Watch & K4b2)

C. Experimental Protocol

Experiments were consisted of two protocols. One was the position tracking in a house, and the other was the validation for quantitative measurements of indoor activities using IR sensor counts compared with the actigraph and the gas analyzer. The following statements are about the each protocol.

a. The Position Tracking

The position tracking algorithm was designed to track the subject's positions in a house. This enabled us not only to know the subject movement pattern, but also to avoid any errors. Because it was based on the state transition, so when the subject was detected in a room, it could transit next state if condition were proper. Fig. 8. shows the position tracking algorithm.

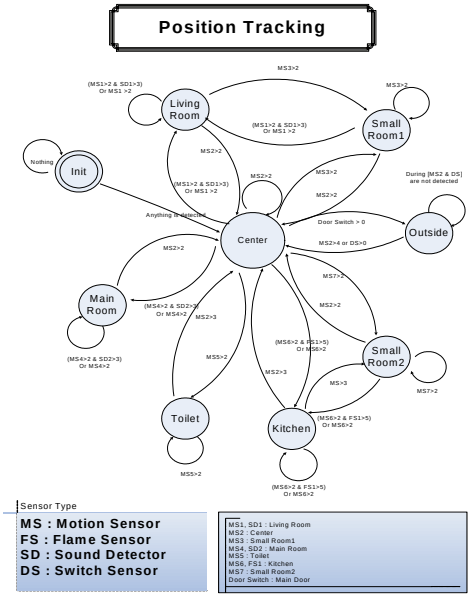

Fig. 8. The position tracking algorithm

To validate the accuracy of the algorithm and the monitoring system, a scenario was made and 10 experiments were taken by following it. Fig. 9. is the position tracking scenario. The accuracy was calculated by how many states were missed.

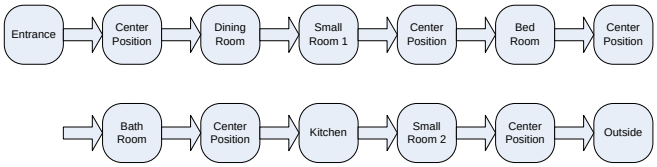

Fig. 9. The position tracking scenario

We also took an experiment to validate the system reliability and to know the possibility of long-term monitoring we installed sensors in a participant's home and monitored three days. The subject was 77-year-old woman who had a light cirrhosis. She had maintained her modern life style during experiment was taken. We announced the experiment and she did agree the experimental condition. During it was been taking, we'd been checking the system state, and storing the data of the sensor outputs.

b. Quantitative Measurements of Indoor Activities

Four men participated in the quantitative measurements of indoor activities experiments. To validate proposed system is proper as a measuring system of quantitative activities, we installed 3 IR sensors. To avoid missing motions, each sensor was attached on different position. Later, the output data of the 3 sensors were gathered by 'OR' operation. We focused on moderate behaviors as experimental protocols, because most indoor activities are consisted of light and moderate behaviors. The protocol was made of 8 behaviors. The experimental time was 6-min respectively, and between each protocol, 3-min rest time was given.

The following is the behaviors of the experimental protocols for the validation :

Watching TV, Study, Computer Working, Filing, Brushing Teeth, Vacuuming, Walking around in the room, Free Exercise

During doing the experiments, subjects wore the actigraph which can measure subjects' motions on waist, also the gas analyzer which can measure standard energy expenditure. All three systems were synchronized and all outputs were made as 1-min epoch.

III. RESULTS

A. *Position Tracking*

Table 4. shows the position tracking result. The accuracy rate was 91%. The total states were 120 states and the missed states were 11 states.

Experiment Number	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Total
Error(s)	3	1	3	1	0	0	0	0	3	0	11

Table 2. The position tracking experimental results

Fig. 10. shows the detail results followed by each experiment.

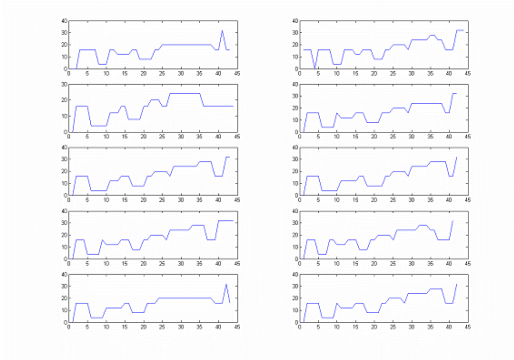

Fig. 10. The position tracking results plots
(Y-axis numbers represent the different positions)

The following Fig .11. shows the movement patterns for 3-day. And Table 3. shows the detection counts of each room.

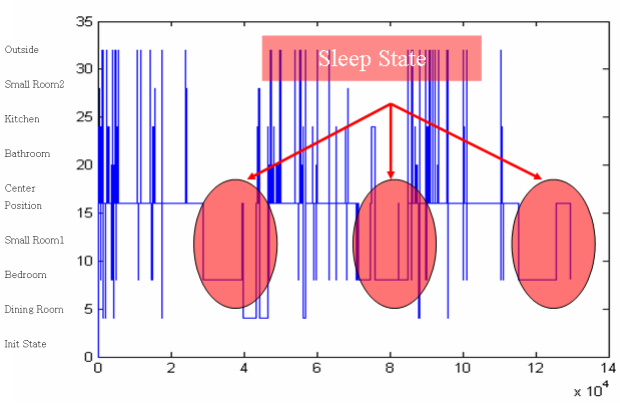

Fig 11. Position Tracking Result for 3-day

	Living Room	Bed Room	Small Room1	Center	Toilet	Kitchen	Small Room2	Outside
1st Day	3778	11114	4	27420	55	297	128	140
2nd Day	2919	12637	0	25588	451	1326	169	110
3rd Day	377	10175	0	31800	229	332	137	150

Table 3. The detection counts of each room for 3-day

B. *Quantitative Measurements of Indoor Activities*

To validate the results, the correlation and regression analysis were taken. The correlation coefficients of between the proposed system and the metabolic energy expenditure measuring system was 0.8274 which was averaged 1-min from 6-min. And the correlation coefficients of between the actigraph and the gas analyzer was 0.7280. The following results show the regression equation of the proposed system to the metabolic energy expenditure measurements system.

Fig 12. shows the relation between the actigraph and the gas analyzer. VO2 means oxygen consumptions (ml/min). The correlation coefficient was r = 0.7280, and the regression equation was y = 0.028337*x + 283.1898.

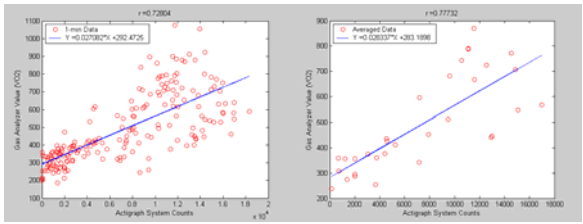

Fig. 12. The regression analysis between the actigraph and the gas analyzer

Fig. 13. shows the relation between the proposed activity monitoring system and the gas analyzer. The correlation coefficient was r = 0.8274, and the regression equation was y = 2.3937*x + 154.6568. The results showed the proposed activity monitoring system is more proper than the actigraph as measuring system of the indoor quantitative energy expenditure.

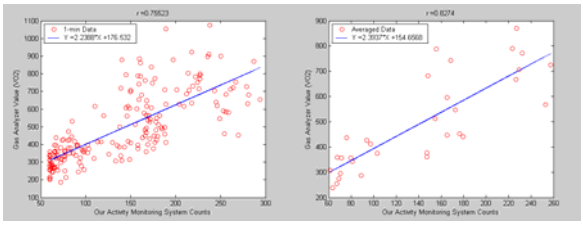

Fig. 13. The regression analysis between the proposed activity monitoring system and the gas analyzer

Finally, the relation between the actigraph and the proposed activity monitoring system is showed in Fig. 13. The correlation coefficient was 0.8915, and the regression equation was y = 70.7537*x + 2598.2935.

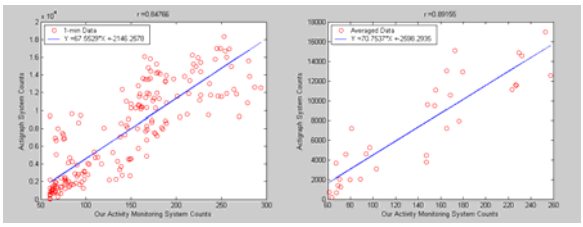

Fig. 14. The regression analysis between the proposed activity monitoring system and the actigraph

IV. Discussion

The proposed system showed good results as a movement pattern parameter extractor. So we could monitor the subject's movement patterns as real-time via the Internet. The system showed also the possibility for the daily movement patterns using detection counts of each sensor.

The second experiment results showed the sensor-based system is more proper to measure quantitative activities than the actigraph for indoor activities. Until now, the metabolic energy expenditure measuring system has been used as a standard equipment to get the activities. The result showed the high correlation coefficient (r = 0.8274) compared with the actigraph (r = 0.7280). The actigraph has been used as an another indirect method to measure the activities. But, most actigraph don't provide a real-time monitoring and they should be worn on the specific position of a body. So it is conscious and impossible to monitor the subjects' activities as real-time.

In future, the automatic real-time quantitative measurement system should be developed. And the automatic feedback response system should be also developed to alarm an emergency situation using the indoor activities data.

Acknowledgment

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