Preliminary study of unobtrusive monitoring to increase safety in daily living

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***Abstract*—An unobtrusive system for monitoring the activities of daily living was developed to improve safety and quality of life. The system was used to monitor walking and safety while bathing. To monitor waking, a matrix array of pyro-electric sensors was installed on the ceiling; to prevent drowning, an accelerometer was installed in the bathtub. The matrix of pyro-electric sensors estimated the walking speed at home and the accelerometer detected the respiratory rate (RR) and apnea. This system might be effective for promoting health in the home**

I. Introduction

In our aging society, the quality of life is an important issue for the elderly and their relatives. In Japan, two major reasons that the elderly need nursing care are lifestyle-related disease and disorders of the locomotive organs.

Beginning in April 2008, insurance companies must perform Specific Health Checkups to identify lifestyle-related disease risk factors in the insured and provide specific health guidance for persons-at-risk to prevent lifestyle-related disease. We have devised specific checkups for people older than 45 years to prevent lifestyle-related diseases such as hypertension, diabetes, and dyslipidemia. To encourage this, several healthcare providers have developed automatic, web-based home healthcare systems.

People age 65 years and over now account for 23% of the population of Japan; this figure will reach 41% by 2055. This will greatly affect the country's social system. The Japanese Orthopedic Association (JOA) has coined the term "locomotive syndrome" to bring attention to the importance of the locomotor organs. The JOA developed a simple questionnaire for self-assessment of locomotive ability, and simple home exercises involving standing on one leg and half-squats. This new concept has stimulated social awareness and shown methods by which disorders later in life can be avoided.

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We are developing a web-based system to prevent various risk factors. Devices for monitoring blood pressure (BP), body weight (BW), and walking were installed in a home and the data transferred to a database via the Bluetooth SIG Health Device Profile (HDP) [1]. A pedometer was incorporated to prevent locomotive syndrome. The advantages of this system are that the data are transmitted automatically to a server, and a physician can examine the weekly or monthly data. However, it was difficult to motivate clients to continue the measurements and there was difficulty logging into the system. We also found that the participants monitored their BP with decreasing frequency. Most participants measured their BP for only 3 days after starting [2].

In addition, safety and security are important issues. Japanese customarily bathe frequently, and accidental drowning while bathing is a possibility. It is difficult to evaluate whether the cause of such deaths is drowning or a cardiovascular disorder. Consequently, early detection is desirable in the care of elderly persons.

We proposed an unobtrusive monitoring system for use in the home. Although laboratory-based unobtrusive monitoring has been developed [3-6], it has not been adopted in the home because of a lack of evidence of the benefits of monitoring in terms of health promotion and the reliability of long-term monitoring. In daily living, the many unforeseen incidents make it difficult to process continuous data.

In this study, we propose unobtrusive monitoring for health promotion and safety. We focused on monitoring daily activity and preventing bathing accidents. In addition, the reliability of the obtained signals is discussed..

II. Experimental Set-up

A. The system

Figure 1 shows the concept of a smart house. The important concepts are safety and security. Sensors were installed at sanitary items and furniture in the home. These included a magnetic sensor at the front door to determine when the subject enters and leaves, pyro-electric sensors for detecting and tracking human movement, magnetic sensors on the refrigerator door to monitor food intake, an accelerometer in the bathtub to prevent accidents, and environmental sensors to monitor temperature, humidity, atmospheric pressure, and the carbon dioxide concentration. All data were collected via a domestic server by means of Bluetooth HDP. The subject's BP and BW were also uploaded via Bluetooth HDP.

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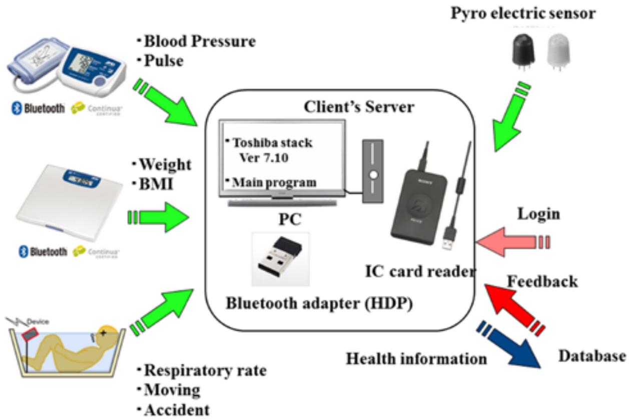


Figure 1 Proposed system

B. *Monitoring activity inside the house*

Human movement was detected using a matrix-array of pyro-electric sensors installed the ceiling. In a preliminary study, a 36-m^2 showroom was divided into six blocks with a sensor installed at the center of each block. The matrix array of sensors could then be used to determine walking speed. The sampling rate was 1 Hz and the distance between two adjacent sensors was 1 m. If the subject was walking at 1 m/s, two signals were activated simultaneously, so the walking speed was estimated using non-adjacent sensors.

C. *Bathing accident detection system.*

Respiration was monitored during bathing. An accident detection system consisting of a floating accelerometer was installed in the bathtub (Figure 2). When the client bathed, the level of the acceleration signal changed and the system started to operate. Respiration was detected by means of changes in the acceleration signal after it had stabilized.

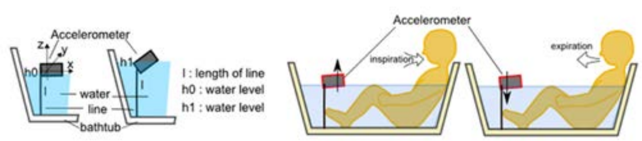


Figure 2. The principle of respiratory monitoring in the bathtub

The respiratory signals were obtained from the changes in vertical acceleration. Figure 3 shows an algorithm of respiratory detection. Form the obtained acceleration signals, the noise in the acceleration signal was eliminated using 0.06–0.40- and 0.40–1.20-Hz bandpass filters. The frequency bands were determined in a preliminary study and were found to be able to detect bradypnea and tachypnea. The output signals were rectified and low-pass filtered at 0.01 Hz. The amplitudes of the two waveforms were compared and the larger amplitude signal was selected.

The accident detection system based on the two signals combined the respiratory signal and body movement in the bathtub. If the respiratory rate (RR) was zero and the body movement was zero, the system triggered an alert.

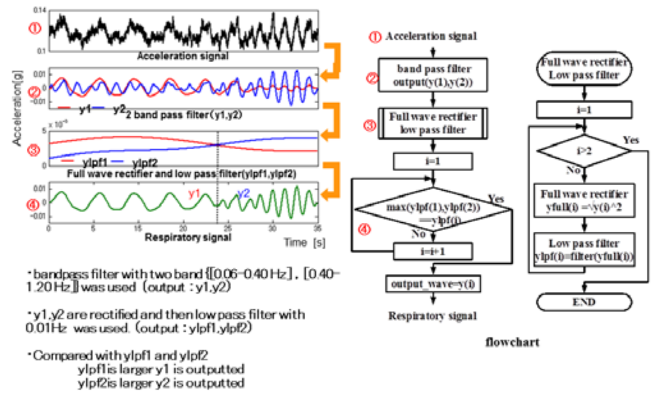
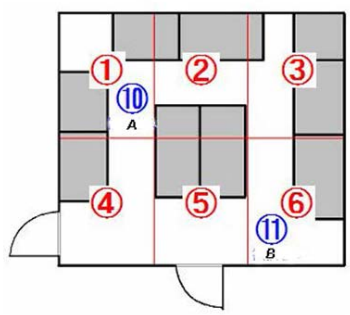


Figure 3 Detection of the respiratory rate (RR)

D. *Experimental show room.*

1. Monitoring activity inside the house.

The walking speed while in the home was evaluated using signals obtained from pyro-electric sensors placed on the ceiling(Fig.4(a)). Two subjects performed an experiment based on the predetermined movements shown in Fig. 4(b). The rising edge of two signals was used to calculate the walking speed.



(a)

Subjects	A	B
Epoch 1	5	
2	6	
3	5	
4	2	
5	1	
6		5
7		6
8		3
9		2
10		5
11	2	
12	3	
13	2	
14	5	
15	4	

(b)

Figure 4. (a) Showroom and sensor locations (red). Numbers 10 and 11 represent the two subjects. (b) The pre-determined track of the two subjects.

2. Bathing accident detection system

The accuracy of the RR monitor was determined from a simultaneous thermistor recording of the RR. The subjects performed normal respirations and simulated bradypnea and tachypnea. The experimental protocol comprised 1 min of normal breathing, 30 s of tachypnea, 30 s of normal breathing, 30s of bradypnea, 30 s of normal breathing, 30s of no breathing, and 1 min of normal breathing.

An accident was simulated in which 10 young healthy subjects (age 23.0±0.9 years, height 169.2±3.6 cm, and weight 61.2±6.8 kg) mimicked drowning. The experimental protocol comprised 1 min of rest, 1 min of movement, 1 min of rest, and face down for 30–60 s with no breathing. This protocol was repeated with a face-up posture.

These experiments were approved by the institution Ethics Committee and informed consent was obtained from all participants.

III. Results

A. Monitoring activity inside the house.

Figure 5 shows the signals from the predetermined walking routes. The speed of subject A was 5.2±0.9 km/h. However, it was difficult to track a subject when two subjects were in the same room.

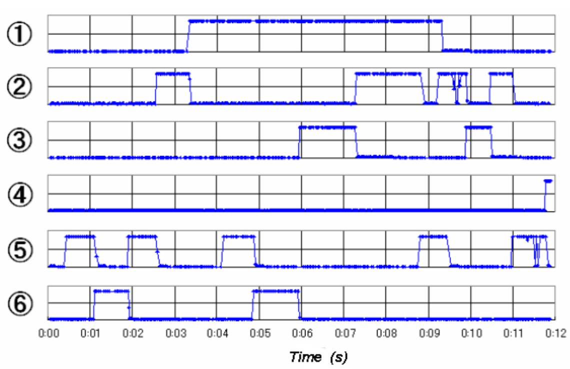


Figure 5 Tracking of walking.

B. Bathing accident detection system

A typical example of simultaneous respiratory recordings is shown in Fig. 6. The different respiratory patterns could be classified. The upper figure shows the RR obtained with the nasal thermistor and the lower shows the RR obtained using accelerometry. No respiration signal was obtained during breath holding, indicating that accelerometry can be used to monitor apnea.

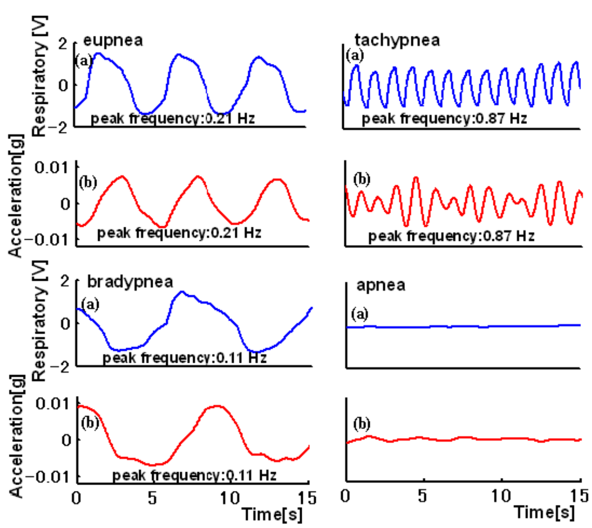


Figure 6 Typical respiratory signals obtained using accelerometry and nasal thermistors.

Figure7 shows the Bland–Altman plots of accelerometry versus the nasal thermistor, with the linear regression line. The RR error was within 10%, although the error increased with a higher RR, such as in the presence of tachypnea.

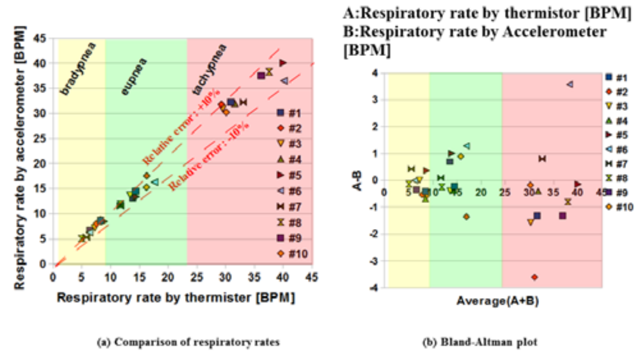


Figure 7 A comparison of respiratory monitoring using a nasal thermistor and accelerometry: (a) linear regression, (b) Bland-Altman plot.

Figure 8 shows the accident detection results. Both face down and face up, the system could recognize the situation without difficulty. While resting, the RR was detected; however, while moving, the system recognized the body movement, but not the RR. For all individuals, the detection rate was 100% and the error rate was 0%. Table 1 shows the response times in this experiment. The response time for simulated drowning averaged 30 s, but differed among individuals and no tendencies were found in the obtained data..

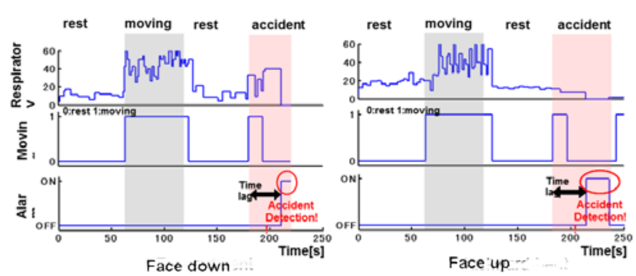


Figure 8 A typical example of accident detection system

Table 1 Response time for detection of drowning

	Shortest time (s)	Longest time (s)	Average (s)	STD (s)
Face down	28	37	31	6.4
Face up	19	39	30	4.7

IV. Field Study

We performed a field study in a family with four members. To obtain continuous records, we also measured the BP and BW using the accident detection system installed in the bathroom. Figure 9 shows the room in which the experiment was performed. In this experiment, we did not monitor the walking speed.

Figure 10 shows a typical example of monitoring. The upper figure shows normal activity and the lower figure shows simulated drowning.

Figure 8 An experimental show room

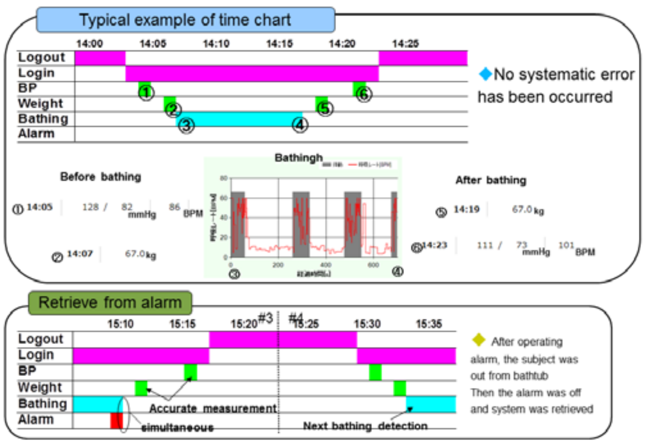


Figure 9. An example of a web-based monitoring record. The upper figure shows normal daily activity with physiological monitoring and the lower figure shows an accident in the bathroom. Numbers are the BP and BW.

V. Discussion

We attempted to develop two unobtrusive monitoring systems. During preliminary and field studies, several problems were encountered.

A. Monitoring activity inside the house

Theoretically, we were able to estimate the walking speed. However, based on our results, the algorithm requires improvement. One major issue is how to track individuals from multiple signals. If the walking speed differs among subjects, the trace can be predicted, but if the speeds are identical, development of filter technics is necessary. In addition, overlapping signals were classified as edge signals when several subjects were in the room simultaneously. Further consideration will be need to apply non-linear analysis such as Kalman and particle filters, SVM, etc. [7-9].

B. Bathing accident detection system

Our results confirmed that the RR could be measured using accelerometry. The error was large in the case of tachypnea because high-frequency respiration has a small-amplitude acceleration wave, so that some peaks were lost, yielding a falsely low RR. In addition, the wave front changed frequently and the acceleration signal was not synchronized with the RR. Nevertheless, the overall accuracy was within 10%. Therefore, accelerometry could be used to measure the RR while in the bathtub. It is difficult to measure RR while the subject is moving. However, the purpose of measuring respiration is to detect apnea.

In emergency medicine, the 'golden hour' refers to the 1-h period following a traumatic injury or medical emergency, during which time the likelihood that prompt medical treatment will prevent death is highest. When respiration stops, however, the survival rate is higher if cardiopulmonary resuscitation is started with 3 min. Therefore, a 30-s response time should be sufficient to save a life, making this system effective for monitoring accidents during bathing..

VI. Conclusion

We have developed an unobtrusive monitoring system to estimate walking speed and detect bathing accidents. The estimation of walking speed was difficult, while the bathing accident detection monitor operated with no issues. Use of this system will improve the safety and quality of life of elderly individuals.

Acknowledgment

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