Wireless Sensing System for Healthcare Monitoring Physiological State and Recognizing Behavior in Daily Life

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Abstract. This paper describes the basic system concept for pervasive healthcare and presents a wireless sensing system for healthcare to monitor physiological state in the living environment. The importance of constantly monitoring, analysing and utilizing human daily information has been growing in the area of healthcare. The introduction of ICT in the areas of medicine and welfare has created new systems and services for healthcare and can help promote disease prevention and health maintenance through wirelessly delivered healthcare and ubiquitous medicine. The availability of information about a person's daily physiological state and activity makes it possible to judge their health condition and behaviors and provide predictive diagnoses and treatment.

The objective of the work is to establish a wearable wireless body area network (BAN) system that is useful in pervasive healthcare. In this work we developed a wireless sensing system to monitor thermal physiological state. Sensors which make up a wireless system are varied depending on the purpose of use of the system. Wearable small-sized and wireless sensors which consume little power have to be developed to measure the desired vital signals or human data. Moreover, reliable wireless communication network is needed to obtain the data of multiple wearable sensors in real time. BAN can realize wireless connectivity among sensors deployed on human body.

The important indicators for monitoring the thermal physiological state are core body temperature, microclimate within clothing, skin temperature, heart rate and movement. To develop the monitoring system, ear-worn temperature sensors, thermo-hygrometers and skin temperature sensors were newly developed. The ear-worn temperature sensor enables a continuous non-invasive measurement of the equivalent of core body temperature in daily life. The thermo-hygrometer can measure microclimate within clothing. These sensors transmit data wirelessly in synchronization with each other. Data can be obtained reliably in daily life without restraining wearers' movements using multiple networked wearable sensors with a reasonable battery life. The level of data loss in wireless communication was low making it possible to estimate physiological state using more than 10 sensors simultaneously, even though both the IEEE 802.15.4 radio and the low power radio coexist.

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The application system for the prevention of heat stroke was evaluated on two situations. One is for the prevention of heat stroke and feeling sick during exercise in conditions of high ambient temperature and humidity. The other is for the prevention of indoor heat stroke among the elderly. It is necessary to recognize individual behaviors to be able to provide appropriate support based on the context. Some activities to be recognized at home were learned and identified using the location data. Experiments showed that the detection of the abnormal level of several kinds of physiological data and their change was effective in judging the physiological state and giving a warning on the health condition in the context of the activities and surroundings. This system will be broadly applicable to healthcare in everyday life such as temperature control for heat stroke prevention and lifestyle management based on the circadian rhythm and health condition.

Keywords: wireless network, wearable sensing, BAN.

1 Introduction

Due to the development of ICT (Information and Communication Technologies) and MEMS (Micro Electro Mechanical Systems) technologies, sensors have become sophisticated. Pervasive healthcare techniques which consist in sensors embedded in environments can provide global health information by continuously monitoring and analyzing people's home activity. The pervasive systems can provide long-term monitoring of users without the burden of wearing sensors. However, their support is still limited to a closed environment and they do not sense vital signals directly. On the other hand, sensors that measure vital signals and human daily movements have also grown in performance and become small enough to be wearable throughout the day. Sensors deployed on human body can obtain biological information, store the information and send it in real time to healthcare administration agencies via networks. The real-time information makes it possible to sense signs of change and sudden changes in the health condition. By monitoring and analyzing the real-time data along with the historical data stored on the server, doctors or experts could detect pathological change in its early stage, provide corresponding healthcare advices to the users, or enforce emergency actions if necessary. It is possible to estimate the everyday health condition, energy expenditure and lifestyle pattern of a person and recommend proper exercise, diet, rest and treatment. Therefore, the importance of regularly monitoring biological information has become recognized and is rising in the area of healthcare.

The human body gives out various bio-signals. Data to be measured is determined depending on each demand and purpose. Heart rate (HR) is often continuously measured to monitor physical and mental condition and exercise intensity. Blood pressure and body temperature are generally measured about once a day for assessing health condition. However, blood pressure and core body temperature vary during the day and over many days reflecting the medical and health condition, the state of activity and the circadian rhythm. There is also a need for measuring them continuously in daily life.

Some previous studies have attempted to monitor thermal physiological state through wired and wireless communication continuously. However, each vital sign such as core body temperature and ECG has been measured using stand-alone devices [1]. The data obtained cannot be easily utilized in real time because the data have to be integrated with other data to put to practical use. As regards core body temperature, it is desirable to measure the level continuously within the context of activity and environment in order to monitor the state of health and disease. In particular, in conditions of high ambient temperature and humidity, the elderly and children are at increased risk of heat stroke, causing increase in core body temperature due to deterioration or underdevelopment of the body's heat regulating mechanism and need to be watched over. It is expected that an integrated system that enables usual and non-invasive measurements of human thermal state will be developed.

We have developed some biological information measurement systems [2]-[4]. The systems consist of a number of wearable wireless sensors, some were ones we developed newly and others were existing ones. When commercial devices are incorporated into a system, some different types of wireless methods, such as ZigBee, Bluetooth, UWB and a low power radio, may have to coexist in the system. When multiple wireless sensors are used simultaneously, it is thought that data loss occurs if there is any interference between the sensors because of collision of transmission time and multipath. As the reliability of data is critical when human vital signals are being monitored, it is important to ensure that the data can be correctly obtained. Moreover, it is required that the necessary information is obtained depending on the intended application. Therefore, systems have to be properly designed to ensure the reliability and availability of the data. In this paper I introduce a wireless sensing system that monitors thermal physiological information in daily life for prevention of heat stroke and feeling sick.

2 Motivation

With the increasing medical expenses resulting from the coming very aged society, it will soon become impossible for the nations to pay huge medical expenses. In Japan the medical expenses for elderly people aged over 65 years old exceed 55% of citizens' medical expenditure in 2009 [5]. In addition, the trend of nuclear families is increasing and many elderly people who live alone need support. In Japan's aging society with a falling birthrate, it has become necessary to work on prevention of disease and health maintenance in order to improve in quality of life (QOL) and reduce medical care expenditure.

The Japanese medical system has been centered on the care in hospitals for ill patients. However, because of the situation, the government is starting to place importance on preventive healthcare and the use of medical care at home. Wireless sensing systems will become helpful tools to establish it. For remote diagnosis and home healthcare, it is required to be able to collect a very large amount of biological information and monitor them efficiently. Daily vital signals can provide useful clues as to health condition. It is possible to provide continuous remote monitoring, consulting and more flexible healthcare by using wearable sensors and the networked system.

In recent years, the number of the victims of heat stroke has been increasing, which has become a social problem. Heat stroke is a physical disorder caused by a sudden rise in body heat due to high environmental temperature and humidity. Even young people suffer heat stroke and are taken to hospitals, in particular during exercise. The guidelines for heat stroke prevention use wet bulb globe temperature (WBGT) as an assessment index of thermal environmental conditions in order to estimate the effect of temperature, humidity, wind speed and solar radiation on humans. This index has become widely accepted for heat stress measurements. However, its use as a model for human response to heat has not been always effective in heat stroke prevention because physiological factors are not taken into account. In addition, the effects of the four environmental factors on the WBGT do not necessarily affect humans under all conditions. It is thought that it becomes possible to take measures to prevent heat stroke by measuring each physiological state. Therefore, we aim at measuring each state of persons in order to prevent from getting out of shape and support daily activities including exercise in thermal environments.

3 Wireless Sensing System

Figure 1 shows the basic system concept for pervasive healthcare. First, wearable sensors which consume little power are needed to measure the desired vital signals. Second, reliable wireless communication network is needed to obtain the data of multiple wearable sensors in real time. Body area network (BAN) can realize wireless connectivity among sensors deployed on human body (Fig.2). The local controller can collect vital signals and environmental information and give feedbacks based on the information covering sensors' data of those who stay at home without carrying a cellular phone (coordinator).

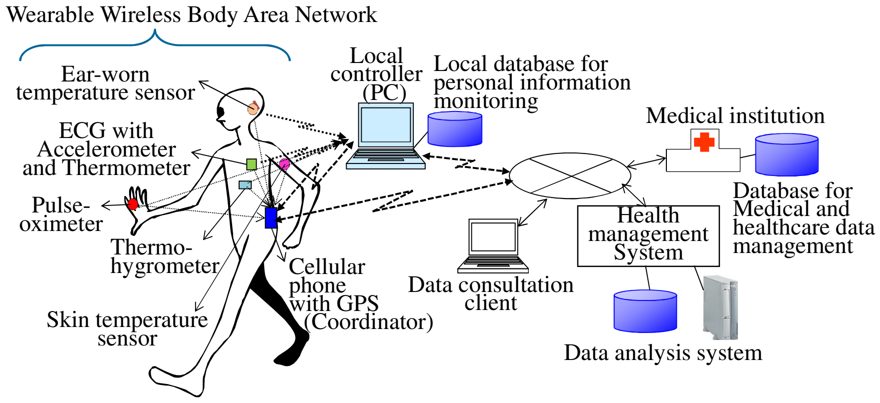

Fig. 1. System concept for pervasive healthcare

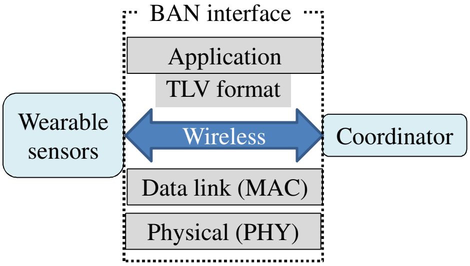

Fig. 2. BAN interface

In this work we developed a wireless sensing system that monitors thermal physiological information in daily life for prevention of heat stroke and feeling sick. The important indicators for monitoring the physiological state of humans under thermal environments are considered to be core body temperature, skin temperature, microclimate within clothing, HR and the amount of activity. Core body temperature is the operating temperature of an organism. It is an important parameter for checking the overall health condition, in particular in hot and humid conditions. HR derived from ECG is one of the indices of heat strain [6]. HR increases to compensate for the decrease in blood flow back to the heart, which is the result of increased blood flow to the skin as it gets hot. The amount of activity can be also calculated by measuring HR and acceleration [2]. The microclimate within clothing and skin temperature are commonly used to assess thermal comfort [7]. The temperature and humidity in the space between clothes and the skin are measured as microclimate within clothing. The skin temperature reflects the amount of heat dissipation, which is a quantitative measure of thermoregulatory responsiveness. The temperature of the surface of the body is not uniform. Therefore, the mean skin temperature is used as the index; it is calculated from the measured temperature at four areas of the body, namely, chest, forearm, thigh and calf based on a simple weighting formula (1) [8].

$$T_{skin}=0.3\times(T_{chest}+T_{forearm}) + 0.2\times(T_{thigh}+T_{calf}) \quad (1)$$

To measure these important indicators, the system developed consists of an ear-worn temperature sensor, two thermo-hygrometers, four skin temperature sensors and an ECG sensor with a tri-axial accelerometer. Additional sensors can be easily installed as up to 32 sensors are supported by this system.

Wireless micro-controller modules (ST Microelectronics, STM32W) were incorporated into ear-worn temperature sensors, thermo-hygrometers and skin temperature sensors. The micro-controller performs the functions of A/D conversion, data processing, and data transmission. It integrates a 32-bit ARM® Cortex™-M3 microprocessor and a 2.4 GHz, IEEE 802.15.4-compliant transceiver. The IEEE 802.15.4 radio has the characteristics of ease of installation, reliable data transfer, short-range operation, low cost and reasonable battery life. The maximum transmission distance is approximately 10m without requiring special antenna.

The sensors transmit data wirelessly in synchronization with each other based on the timer of the coordinator. The 2.4 GHz, IEEE 802.15.4 communication has the beacon mode, in which normally sleeping network sensors wake up periodically to receive a synchronizing beacon from the coordinator. For the sensors with a 2.4 GHz, IEEE 802.15.4-compliant transceiver which has very low duty cycle, a TDMA type contention free protocol in the MAC layer is used to avoid multiple access interference and guaranteed time slots were provided in a scheme. Each data packet is transmitted up to 3 times to compensate for data loss.

To enhance the security and reliability of data transmission, we are also considering the introduction of ultra wideband (UWB) for BAN. UWB has the characteristics of high data transfer rate and low transmission power. Due to the low power spectral density (PSD) in conforming to the FCC specifications and the regulations of each country the probability of intercept is low. In February 2012, the IEEE802.15.6 standardization group has approved a new standard for wireless BAN use, which adopted impulse radio UWB communication. The circuit system of IR-UWB needs less semiconductor chip area due to its simplicity. As a result, the production cost could be reduced compared to other radio systems if it is mass-produced. Establishment of the standard will speed the development of UWB modules that are following the standard. We are now introducing UWB communication to other wireless healthcare systems and have examined them.

The followings are the sensor devices at present.

3.1 Ear-Worn Temperature Sensor

Ear-worn temperature sensors were developed for continuous noninvasive measurement of core body temperature. The temperature of blood in the pulmonary artery (PA) is considered to be the true core body temperature. However, this site is not suitable for monitoring temperature during human daily activities. Temperature readings obtained with a tympanic membrane thermometer are very close to core body temperature [9]. A thermopile is an electronic device that converts thermal energy into electrical energy. The infrared noncontact thermometer using thermopile receives infrared radiation from the tympanic membrane and can measure the temperature.

Figure 3 shows the outside appearance of the ear-worn temperature sensor. The sensor consists of a temperature sensing part, a wireless micro-controller module and a battery. It can transmit data wirelessly at an interval of one second or more. The sensor is powered by a 3.7V rechargeable lithium-ion button battery. The battery life lasts for more than 100 hours of continuous operation when the data is transmitted at an interval of one second. The sensor has a specified accuracy of ±0.2 ºC in the range 32ºC≤T≤42ºC and resolution performance of 0.02ºC. The size is 38mm in diameter and 13mm thick excluding the sensing part and the part that hangs from the ear. The length and direction of the sensing part can be adjusted to fit into a person's auditory meatus and to receive infrared radiation from the tympanic membrane. It was designed to be similar to an ear-hook type earphone to make it wearable in daily life.

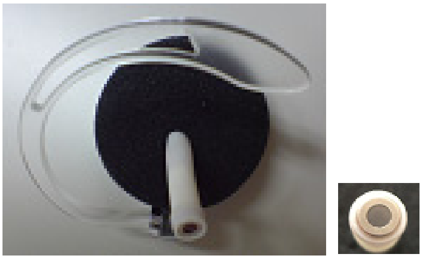

Fig. 3. Ear-worn temperature sensor (left) and its sensing part (right)

3.2 Thermo-hygrometer and Skin Temperature Sensor

Thermo-hygrometers and skin temperature sensors were developed using relative humidity and temperature multi sensor modules from Sensirion AG. Figure 4 shows the outside appearance of the first version of thermo-hygrometer and skin temperature sensor. The sensing part of skin temperature sensor is situated outside the main unit to be in close contact with skin. It is a single chip relative humidity and temperature sensor module incorporating a calibrated digital output. The module includes a capacitive polymer-sensing element to measure the relative humidity and a band-gap temperature sensor. They are seamlessly coupled, to a 14-bit and a 12-bit analog to digital converter respectively, and a serial interface circuit on the same chip. The sensors have the accuracy of about ±0.3ºC, ±1.8%RH and resolution performance of about 0.01 ºC, ±0.03%RH . The first version of the sensors is 45mm×32mm×9.5mm in size including the power source. Using the prototype product of a smaller high-performance button battery, they became less than half the size of the first version.

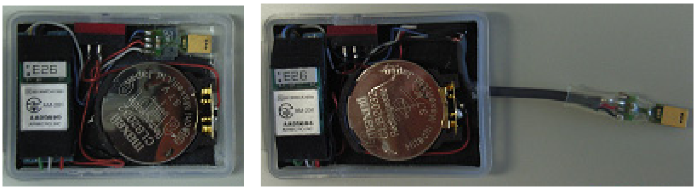

Fig. 4. First version of thermo-hygrometer (left) and skin temperature sensor (right). (The cases are opened.)

3.3 ECG Sensor with Accelerometer and Thermometer

An existing wearable small-sized RF-ECG from Micro Medical Device Inc. was used since its measurement accuracy has been validated [10]. It wirelessly transmits ECG signals, as well as tri-axial acceleration and surface temperature. It utilizes low power radio transmission (2.4GHz). The maximum transmission distance is approximately 20m. The sampling rate is 204 or 100Hz, its size is

40mm×35mm×7.2mm, and its weight is 12g. The power source (a 3V lithium-ion button battery, CR2032) has a life of about 48 hours of continuous operation.

Using these sensors, the system for monitoring thermal physiological information was constructed as shown in Fig.5. Measurements and graphs of core body temperature, skin temperature, temperature and humidity within clothing, ECG, heart rate and accelerations can be monitored in three windows. Figure 6 shows a screen image of the display for monitoring. These sensors could work continuously for more than 24 hours in everyday life.

To examine the rate of data loss, measurement experiments were carried out during desk work in an ordinary office environment and during everyday life in a home environment. The data from an ear-worn temperature sensor, two thermo-hygrometers, four skin temperature sensors and an ECG sensor was continuously measured for 3 hours in each environment. The sampling rate of the ECG sensor was 204Hz and that of the other sensors was 1Hz. The coordinator was placed on the desk in the office and in the middle of the room in the home.

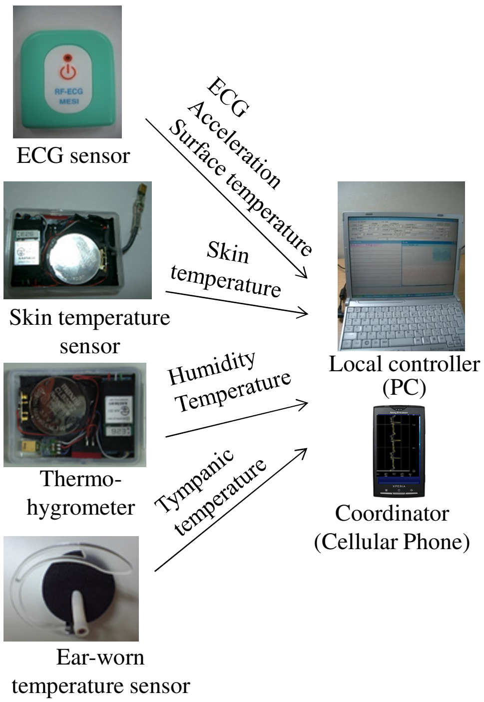

Fig. 5. Basic system configuration

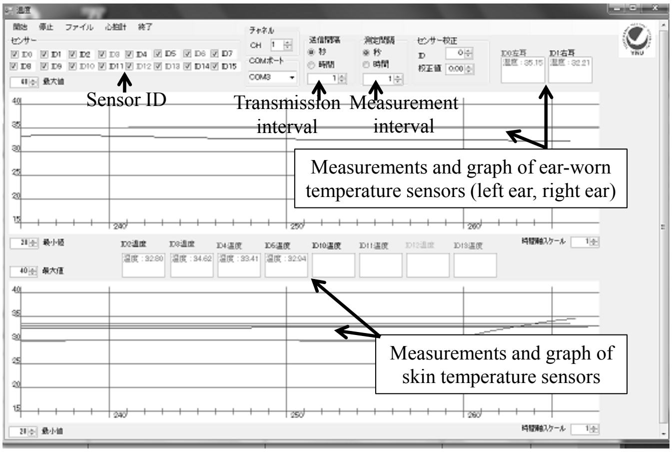

Fig. 6. Screen image of measurement software

The result was that the mean rate of data loss from the sensors apart from the ECG sensor was about 0.01% in the office environment and the data loss was discontinuous. 6.7% of the data was not received correctly from the first transmission, however data loss was almost completely eliminated by retransmitting data once or twice. The data loss rate of the ECG sensor was about 0.42% due to the high data rate and imperfect error control.

We think that there was little interference between the sensors because a TDMA type contention free protocol in the MAC layer was used, however writing errors sometimes occurred. In this situation, the distance from the sensors to the coordinator ranged from 0.2m to 3m. On the other hand, the mean rate of data loss was less than 0.02% in the home environment due to data retransmission, though data loss was 7.1% for the first transmission. There was little continuous data loss. The data loss rate from the ECG sensor was 0.65%. The distance from the sensors to the receiver ranged from 0.3 to 5m.

The data from multiple sensors could be continuously sent and recorded though two different wireless methods of IEEE 802.15.4 radio and low power radio were used. Since changes in temperature are not sharp, we think this level of data loss is acceptable. We also think that the data loss rate of the ECG sensor is acceptable since HR can be calculated using interpolated data due to the high sampling rate.

4 Application of System

An application system was made up for the prevention of heat stroke and feeling sick during exercise. The system comprises sensors which measure important indicators, core body temperature, skin temperature, microclimate within clothing on the chest and back, HR, amount of activity and environmental conditions. The thermo-hygrometer developed can also monitor environmental temperature and humidity to be easily set up into the ambient surrounding. In sunny outdoor environment such as grounds that get a lot of sun, a WBGT measurement system is also expected to be installed in order to take into account the effect of solar radiation. Therefore, the system was configured as shown in Fig.7.

Experiments were performed under two different conditions. In one experiment, the physiological state of a subject (male in his 20's) and the environmental condition were measured while exercise was performed in a room controlled at a temperature of 32ºC and at a humidity of 55%. In the other experiment, the physiological states of two subjects (male and female in their 20's) and the environmental condition were measured while exercise was performed in a room controlled at a temperature of 28ºC and at a humidity of 65%.

The subjects had a rest for 10 minutes at the beginning, pedaled cycle-ergometer at 20W for 10 minutes of warm-up exercise and then pedaled it at the workload of 50% of maximal exercise stress for 20 minutes. After exercise, they had a rest for 20 minutes of recovery. In the experiments, the subjective assessment of the level of comfort and wetness feeling was also made verbally. The subjects participated in these measurement experiments after providing informed consent for the experimental procedures. This study was conducted in accordance with the Helsinki Declaration of 1975 and was approved by the local Ethics Committee of Yokohama National University (Japan).

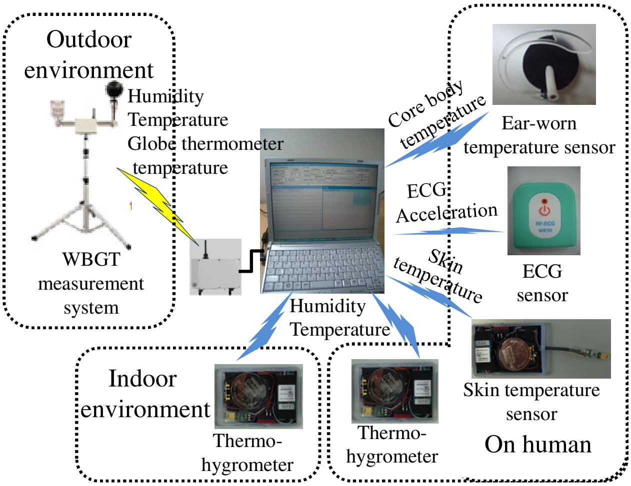

Fig. 7. Total configuration of the monitoring system

One subject's example of the changes in core body temperature, mean skin temperature and microclimate within clothing, the indicators of sympathetic function and parasympathetic function and subjective assessment during exercise is shown in Fig.8 - Fig.10. The indicators of sympathetic function and parasympathetic function are calculated as LF/HF and HF/(HF+LF) from low-frequency (LF, 0.04 - 0.15 Hz) power component (reflecting a mixture of parasympathetic and sympathetic activity) and high-frequency (HF, 0.15-0.4 Hz) power component (reflecting parasympathetic nerve function) in heat rate variability (HRV) obtained from ECG, respectively. Rapid increase in humidity within clothing caused by the increase in exercise intensity and gradual increase in core body temperature, mean skin temperature and temperature within clothing were monitored. As the intensity of exercise was not so high, the core body temperature did not get raised too much compared with mean skin temperature and temperature within clothing. However, the levels of discomfort and wetness feeling in the subjective assessment increased with the increase in humidity within clothing after the intensity of exercise was increased. At the same time, the indicator of sympathetic function (LF/HF) increased and the indicator of parasympathetic function (HF/(HF+LF)) dropped relatively. The results show that there seems to be a correlation among the subjective discomfort level, the indicator of sympathetic function and humidity within clothing. There was not much difference between the results of the experiments under two conditions.

It can be said that the system enabled real-time monitoring and evaluation of the physiological condition during exercise. However, the index and threshold for giving warnings against heat stroke couldn't be found from these experiments. A lot of data need to be collected during exercise performed in conditions of high ambient temperature and humidity to use the values of core body temperature, LF/HF and humidity within clothing as the indicators for a warning against heat stroke.

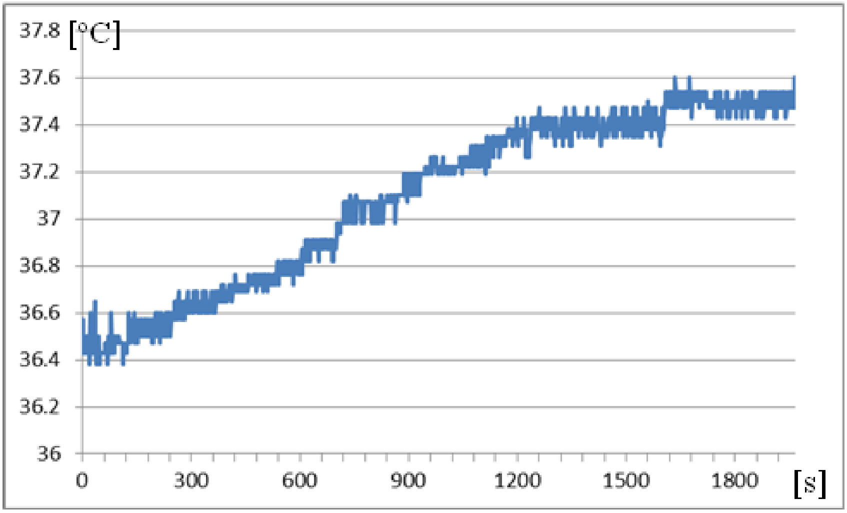

Fig. 8. Example of change in core body temperature

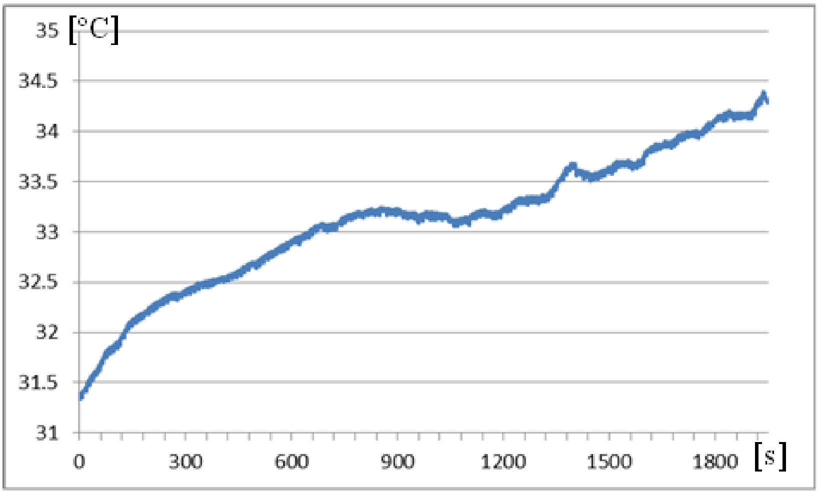

Fig. 9. Example of change in mean skin temperature

Moreover, the system was applied for the prevention of indoor heat stroke among the elderly.

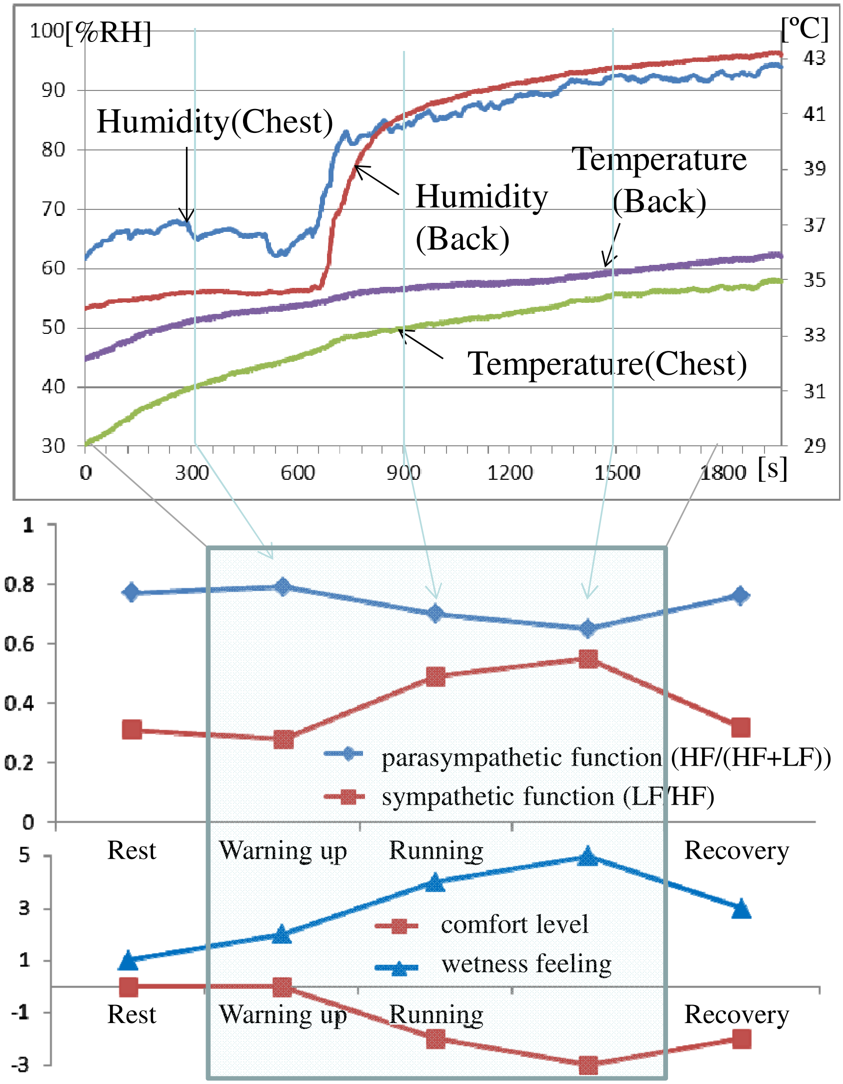

Fig. 10. Example of changes in microclimate within clothing (above) and the indicators of sympathetic function and parasympathetic function and the subjective assessment (bottom)

To prevent indoor heat stroke, it is critical to monitor their physiological data along with the activities. If activities such as food intake, fluid intake, fluid elimination, and going outside are monitored; and if the frequency and occurrence of each activity are recorded from when a person gets up, then warnings such as "Drink enough fluid" or "Rest due to heat" could be given appropriately. Therefore, a prototype system that monitors the thermal physiological state and the ambient temperature and humidity, recognizing the wearer's behaviors was constructed as shown in Fig.11. As home activities are considered, it is expected that there will be a relation between the activity and the location. To monitor daily activities without hindering mobility, the location data obtained with the impulse radio UWB positioning system was used [11]. The method to recognize individual behaviors is as follows.

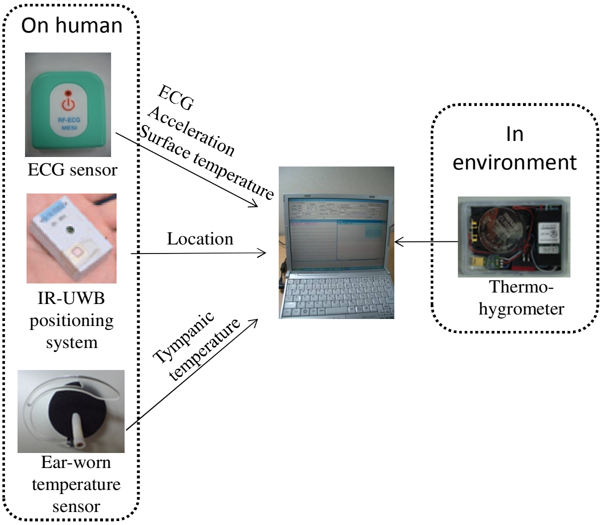

Fig. 11. Prototype system to prevent indoor heat stroke

When the sensor data is obtained, the time-series data is divided into equal time periods for the input time span. It is converted to a sequence of 4-dimensional feature parameters, the location (x-axis, y-axis) and its variation. Next, clustering is applied to the constructed space and the resulting clusters are labeled. Clustering is performed by the k-means algorithm by incrementing the number of clusters by one, starting at one until the variance of each cluster is below the threshold. Then, while the activity is being observed, the obtained feature parameters are projected into the 4-value space and the cluster with the shortest Euclidean distance is determined. By outputting the cluster labels successively, the state is represented as a symbol sequence. Similar symbol sequences are extracted for the same behavioral state. In order to recognize not only a state but also activity expressed by the state sequences, the hidden Markov model (HMM) is used to learn similar states and label them as the same state. The HMM is suitable for learning symbol sequences with large individual differences as in this case, since it is robust to shifts and to contraction or expansion along the time axis. For the recognition of activities using HMM, models are prepared by being trained beforehand using a training set; and then which model the input is most similar to is determined.

In the following algorithm, activities performed in the learning period are classified and the learning process is carried out for each activity. The Baum–Welch algorithm was used for learning.

(Step 1) A HMM is constructed using all observed symbol sequences as the training data.

(Step 2) All symbol sequences of the training data are obtained from the HMM of Step 1. A histogram is constructed by representing the output probabilities of the symbol sequences on the number axis.

(Step 3) Discriminant analysis is applied to the histogram and a minimum is found near the reference value. This value is used as the threshold.

(Step 4) If the output probability is not less than the threshold, a flag is set to one for the symbol sequence. If it is less than the threshold, the flag is set to zero.

(Step 5) For each set of symbol sequences with the same flag, a HMM is constructed using that set as the training data.

(Step 6) Using each of the constructed HMMs, the output probability of each symbol sequence is examined. The symbol sequence is projected into the space with the output probabilities in the HMM as the axis. The base vectors are determined by principal component analysis.

(Step 7) The base vector axes for which the cumulative contribution exceeds the threshold are used. For each axis, the histogram and the threshold are determined by repeating Steps 2 and 3 and the flag for the symbol sequence is determined.

(Step 8) Steps 5 to 7 are repeated until the combinations of symbol sequences to which the same flag is assigned in Step 7 are the same as the combinations obtained in the previous loop.

In this algorithm, the processing classifies all activities observed in the learning period as different kinds of activities. Similarity of output probabilities is used as the index for activity classification since similar state transitions are performed in the HMM when similar symbol sequences are obtained from the HMM. The output probability of the symbol sequence was defined as the symbol output probability derived by the Viterbi algorithm.

To recognize the activities, the symbol sequences of the observed activities are obtained from among all HHMs and symbol sequences are projected into the space made by the base vectors. The flags are determined and the activity whose flag is the same as the stored activity is output as the recognized result.

An experiment for learning and recognizing the activities in a house was conducted. Figure 12 shows the layout of a temporary house used in the experiment. This type of house is common in Japanese facilities for the elderly. It was assumed that the activities that should be recognized are fluid intake, having a meal, fluid elimination and going outside. Eight different activity patterns of fluid intake, an activity pattern of having a meal, six different activity patterns of liquid elimination, two different activity patterns of going out and eight other different activities were considered. Each activity was repeatedly carried out and the data were collected for learning. The relations between the numbers of states of HMM and the recognition rate were investigated changing the number of clusters and the optimal number of clusters was found out. The symbol sequences were learned through the constructed HMMs. Using the HMMs after learning, the symbol sequences for recognition were output.

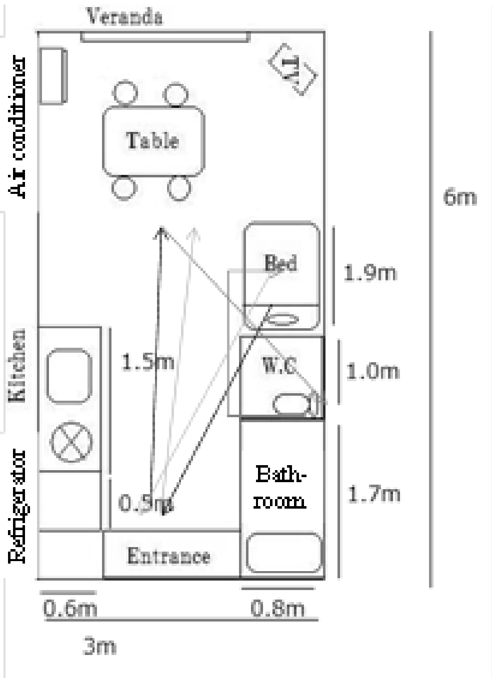

Fig. 12. Layout of one-room house

The recognition rate changes with the number of states corresponding to the number of clusters. The case of drinking is shown in Fig.13.

As the number of clusters increased, the recognition rate was improved. When the number of states got more than 5 in the case of 5 clusters, the recognition rate reached 100%.

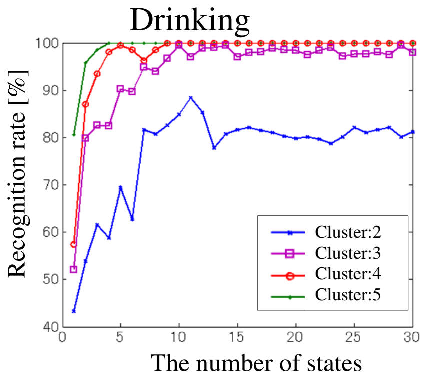

Fig. 13. Recognition rate with changing the number of states (Drinking)

The number of clusters was set to 5 for all of the activities. When the number of states is 5 for having a drink, having a meal and going out and 10 for eliminating, the recognition rate reached 100% as shown in Fig.14. Therefore, the values were adopted to recognize the activities.

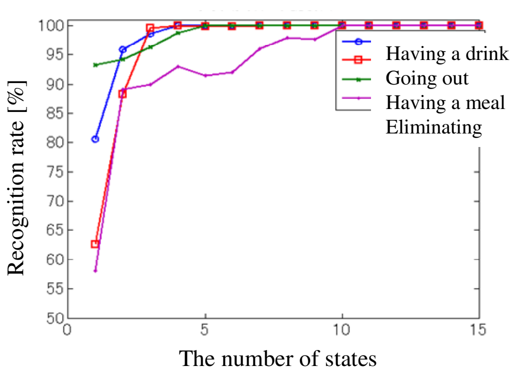

Fig. 14. Recognition rate (The number of cluster is 5)

A prototype system which gives advice for the prevention of heat stroke was developed. Warnings against lack of fluids are given following the rules below if the either core body temperature or HR is more than the threshold under high ambient temperature and humidity above a certain level.

1. When both activities of having a drink and having a meal are not detected for 2 hours,
2. When both activities of having a drink and having a meal are not detected for 10 minutes after eliminating,
3. When coming home.

The system was demonstrated based on a scenario following the schedule (Fig.15). In the room, core body temperature, HR, location, and environmental temperature and humidity were measured at the same time. The system could recognize activities correctly, record the number and interval of occurrence of each activity and give warnings at the appropriate timing. The elderly can get advice based on each thermal physiological state and living situation by using such kind of system when they stay in a room with high temperature and humidity.

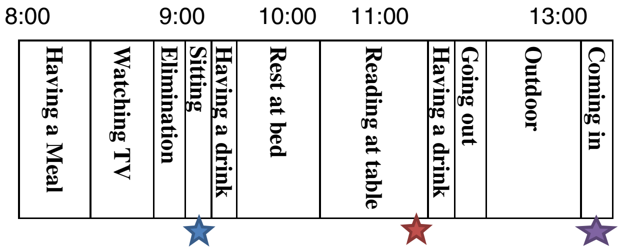

Fig. 15. Scenario's schedule

5 Conclusion

A wireless sensing system for monitoring physiological information in daily life was developed based on a basic system concept for pervasive healthcare. The data of wearable sensors can be continuously measured using wireless BAN in living environments. It makes possible to give remote diagnosis and health management in real time. The system can monitor a person's thermal physiological state. An application system for prevention of heat stroke and feeling sick was designed and the possibility to help prevent heat stroke was shown in the experiments. In the future, we will do longer-term measurements for data accumulation in daily life including during exercise in conditions of high ambient temperature and humidity, improve the algorithm to give a warning against heat stroke using data collected and evaluate the effectiveness.

The spread of Internet of Things (IoT) makes it possible to create a dynamic global network. Physical and virtual things are seamlessly integrated into the information network and come to interact and communicate among themselves and with the environment by exchanging the sensed data. It facilitates creation of services without direct human intervention. When human beings take part in the network by pervasive sensing, a lot more services could be expanded into. Ubiquitous healthcare is one of the services. The infrastructure to realize it is being developed rapidly. Social requirement and economic necessity will encourage the trend. The challenge is how to provide the services. As data sets collected through pervasive sensing grow in size, the big data have to be efficiently processed within tolerable elapsed times. Information security has also become a critical issue. Technologies to analyze the data, predict the possible event and utilize the information are required depending on the kind of services. The business models to provide services are also needed. Pervasive sensing will become accepted through essential services by overcoming these challenges.

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