Development of ZigBee-based Life Recording and Management System on Mobile WiMAX Network in Azumino City

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ABSTRACT

In this paper, firstly, a ZigBee-based sensor network is realized and evaluations are carried out in order to clarify the fundamental performance of this sensor network. The following evaluations are carried out: first one is an evaluation of the effect on communication time by the co-channel interference, and second one is an evaluation of relationship between throughput and distance. Next, the life recording and management system as an application of ZigBee-based sensor networks is developed based on the results of evaluations, and the system is introduced into the mobile WiMAX network in Azumino city in order to solve some medical problems in local cities. Finally, this paper shows both some examples of visualized physical condition data and the results of field trial test; and the effectiveness and future works of this system are clarified.

Keywords: Life recording and management system, Wearable sensor terminal, ZigBee, Mobile WiMAX, Data visualization.

1. INTRODUCTION

Recent drastic advancements in wireless technology are realizing the environment allowing us to connect to networks at any time and from anywhere. Wireless sensor network technology plays an important role as one of the technologies which realize the above-mentioned environment.

Although wireless sensor networks do not require high speed communication of sensors or control devices, the following characteristics are required to easily develop systems allocated a lot of devices; Low power, Low cost and Interconnectivity. IEEE802.15.4 (ZigBee)[1] satisfying the above characteristics has been formulated by ZigBee alliance[2]. Products complying with ZigBee are provided by various vendors[3][4].

ZigBee-based wireless networks are applied to disaster prevention, security, transportation, logistics, medical services, public welfare, information appliance and so on. In this paper, life recording and management system is introduced as one of the ZigBee applications.

In recent year, Japanese people have concerned about the lifestyle diseases, since the law concerning introduction of medical check and health direction for the prevention of lifestyle diseases came into force in April 2008. They begin to consider it important that they record and manage their own physical condition. However, to record and manage their own physical condition is a troublesome task. Here, this paper introduces the life recording and management system that physical condition is measured by sensors automatically, and the measured data are stored on servers through sensor networks. If these data can be shared with medical experts, people can not only escape from the troublesome task, but they can also correctly comprehend their own physical condition.

Firstly, following evaluations are carried out using a ZigBee-based sensor in order to clarify the fundamental performance of the sensor.

- Evaluation of the effect of the co-channel interference on communication time
- Evaluation of the throughput performance at each distance

Next, the life recording and management system is deployed in the mobile WiMAX network in Azumino city[5] in order to solve some medical problems in local cities. Finally, from some examples of visualized physical condition data and the results of field trial test, the effectiveness and future works of this system are clarified.

The rest of this paper consists of the following five sections. Section II denotes the overview of the life recording and management system. Then, in Section III, performance evaluation results are denoted. Section IV shows the network configuration of the system. Section V shows examples of visualized physical condition data. Section VI shows the results of field trial test. Finally, Section VII concludes this paper.

TABLE I
CONFIGURATION OF LIFE RECORDING AND MANAGEMENT SYSTEM.

Parameters	Contents	Quantity
Wristwatch-type sensor terminal	ZigBee-based sensor Hitachi Ltd. AirSense02Plus	2
Base station for ZigBee	Linux-BOX 1. Data receive and accumulation software 2. Ethernet LAN interface	1
	3. USB-type receiver	1
Life recording and management system server	Linux-BOX 1. Life information visualization software	1
Client PC	Web browser (for displaying life data)	1

2. OVERVIEW OF THE LIFE RECORDING AND MANAGEMENT SYSTEM

The developed system can manage physical condition data recorded by "Hitachi Ltd. AirSense02Plus[6][7][8]" via TCP/IP network. The system provides the following functions.

- Measurement of temperature and amount of activity (acceleration)
- Visualization of daily life rhythm
- Share of physical condition data via TCP/IP network

The system consists of the elements shown in Table I; Table I shows the configuration of life recording and management system. A base station for ZigBee can distinguish up to 2 wristwatch-type sensors. It is a Linux-BOX customized for data receive and accumulation software. A life recording and management system server is also a Linux-BOX customized for life information visualization software.

Wearable wristwatch-type ZigBee sensor

Wearable wristwatch-type ZigBee sensor is employed for measuring various physical condition data, because users can wear it like a wristwatch. Thus, to wear the sensor is not a burden for users.

Table II shows the specification of the wristwatch-type ZigBee sensor. Besides, Fig. 1 shows the pictorial image of the wristwatch-type ZigBee sensor. The wristwatch-type sensor equips triaxial acceleration and temperature sensors. Various physical condition data can be measured by these sensors. Measured data by the sensors are automatically stored on life recording and management system server via wireless network.

The reason why the battery life and data storage capacity depend on usage environments is that "differential compression" is employed for store of the measurement data. Thus, measured data size depends on the amount of changing of activity. Battery life become shorter by transmitting the all data stored on the internal data storage of wristwatch-type sensor.

Visualization of physical condition data

Measured data by a wristwatch-type sensor are analyzed by the life recording and management system server, and these data can be displayed by web browsers. This system can display the amount of activity for a day, a week and three months. Examples of visualized data are shown in the following section.

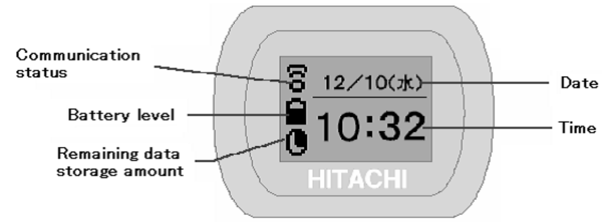

Fig. 1. Wearable wristwatch-type ZigBee sensor.

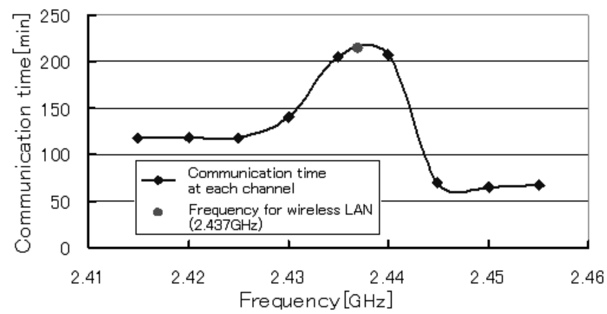

Fig. 2. Effect of co-channel interference on communication time.

3. FUNDAMENTAL PERFORMANCE OF ZIGBEE-BASED WRISTWATCH-TYPE SENSOR

Evaluations are carried out in order to clarify the fundamental performance of a wristwatch-type sensor complying with ZigBee. Firstly, an evaluation is carried out in order to clarify the effect of the co-channel interference on communication time. Next, the relationship between the communication distance and the throughput is evaluated.

Evaluated is the effect of co-channel interference of wireless LAN, which is based on IEEE802.11g, to the wristwatch-type sensor on communication time. Channel of wireless LAN is fixed to 6ch (2.437GHz) during the evaluation; besides the transmission power is 10dBm. On each channel of wristwatch-type sensor between 13ch (2.415GHz) and 21ch (2.455GHz), communication time until the end of transmission of all data stored on the data storage of wristwatch-sensor is measured. Figure 2 shows the communication time. The abscissa of Fig. 2 denotes the channel frequency[GHz] and the ordinate denotes the communication time[min]. From this figure, it can be seen that the communication time becomes longer when the channel frequency of wireless LAN is close to that of wristwatch-type sensor.

The effect of the distance between a wristwatch-type sensor and a receiver on throughput is evaluated under an indoor non-line-of-sight condition. Channel frequency is fixed during this evaluation. Throughput is measured at each position where the distance between a wristwatch-type sensor and a receiver is between 1m and 7m by 1m. Here, the throughput is calculated from the communication time until the end of transmission of all data stored on the data storage of wristwatch-sensor. Figure 3 shows the measurement result. The abscissa of Fig. 3 denotes the communication distance[m], and the ordinate denotes the throughput[kbps]. From this figure, although throughput is constant when the communication distance is between 1m and 6m; throughput measured at the distance of 7m is decreased because

TABLE II
SPECIFICATION OF WRISTWATCH-TYPE ZIGBEE SENSOR.

Parameters	Contents	Remarks
Wireless communication system	IEEE802.15.4	
Channel	16ch(2405MHz∼2480MHz)	Communication distance ∼20m(Indoor)
Communication speed	250kbps	Maximum speed
Transmission power	0dBm	
Sampling interval for triaxial acceleration measurement	20samples/s	
Sampling interval for temperature measurement	1sample/s	
Data storage capacity	14-day data (Maximum)	Capacity depends on usage environments.
Power supply	Internal battery（Rechargeable）	Charging time is about 2 hours.
Battery life	14 days (Maximum)	Battery life depends on usage environments.

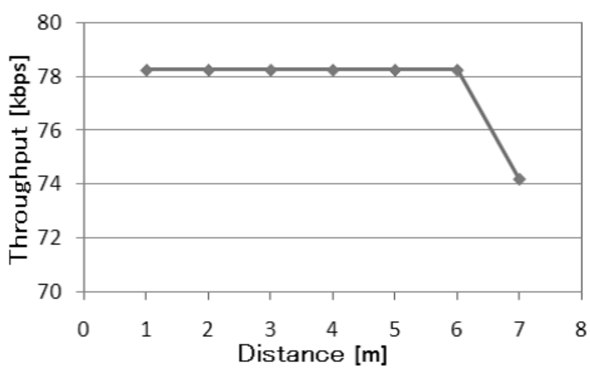

Fig. 3. Throughput vs. communication distance.

the communication link capacity is getting small.

Comparing the transmission power of ZigBee with that of wireless LAN, it is clear that the transmission power of ZigBee, or wristwatch-type sensor, is smaller than that of wireless LAN. Thus, wristwatch-type sensor which has small transmission power is easily affected by the co-channel interference. As a result, communication time becomes longer, and the communication link is easy to be disconnected when the distance between a wristwatch-type sensor and a receiver is over 7m.

4. NETWORK CONFIGURATION OF LIFE RECORDING AND MANAGEMENT SYSTEM

In Japan, the 2.5GHz frequency band has been allocated to two telecommunication carriers for wireless broadband systems at the end of 2007. Also, 10MHz frequency band called “local band” has been allocated to local carriers in order to improve public services or to eliminate digital divides. An experimental system connecting with the Internet using the “local band” has been deployed in Azumino city. Base stations complying with mobile WiMAX are deployed in 2009 and 2010, respectively. Problems in local cities are solved using the mobile WiMAX system. Concretely, current problems of informatization in local cities are shown as follows:

- P1: Expansion of the services demanded by citizens
- P2: Increase of the Internet utilization rate at home and edification of the effectiveness of Internet services
- P3: Elimination of digital divides
- P4: Improvement of information literacy

The following services will be provided using the mobile WiMAX network in order to solve the above-mentioned problems.

- S1: High speed Internet access service

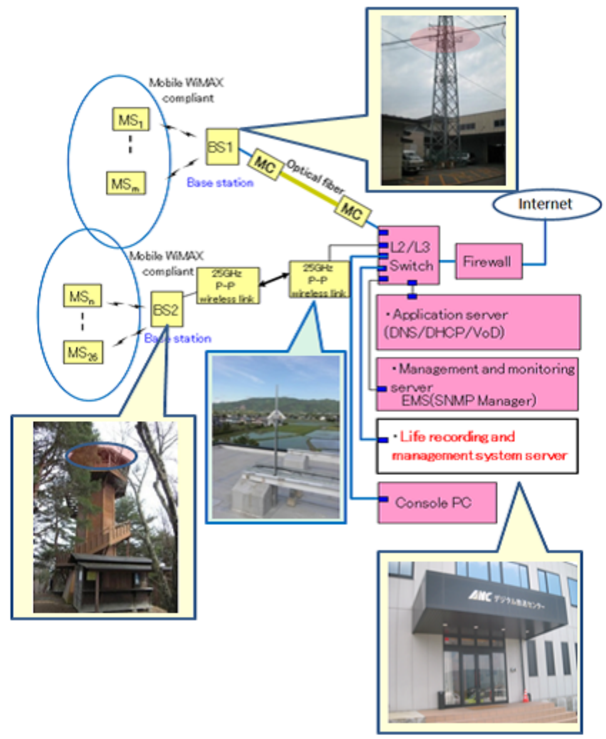

Fig. 4. Network architecture of the mobile WiMAX network in Azumino city.

- S2: Mobile VoIP (Voice over IP) telephonic service
- S3: Mobile VoD (Video on Demand) service
- S4: High quality image transmission service using live cameras
- S5: Life recording service
- S6: ICT disaster prevention system

Figure 4 shows the network architecture of the mobile WiMAX network deployed in Azumino city[5]. In this paper, the life recording and management system as one of the above services is introduced.

The life recording and management system consists of two networks as shown in Fig. 5. One is a ZigBee-based sensor network for collecting the data measured by a wristwatch-type sensor; the other one is a WiMAX-based infrastructure network for transferring the collected data to a server and for visualizing them.

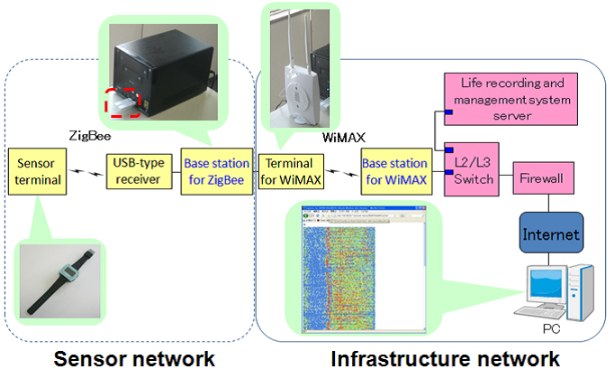

Fig. 5. Network architecture of the life recording and management system.

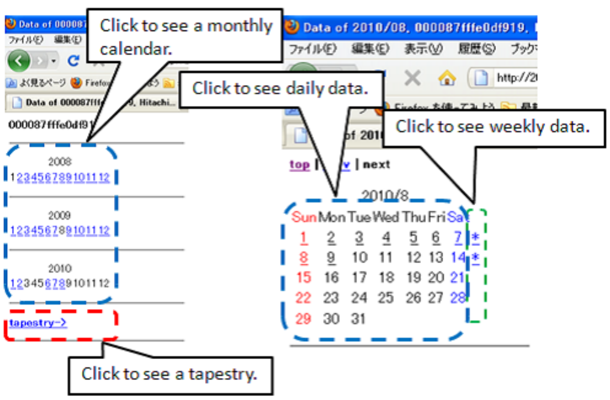

Fig. 6. Web pages for the life recording and management system. (Underlied figures indicate the existance of physical condition data)

ZigBee-based sensor network

The network rounded by dotted line in Fig. 5 is a ZigBee-based sensor network. Communication between a wristwatch-type sensor and a USB-type receiver attached with a base station is performed by ZigBee. Amount of activity and temperature as physical condition data are transmitted to a base station. The base station for ZigBee connects by cable to a terminal for WiMAX, and the measured data are transmitted to a life recording and management system server via WiMAX network.

WiMAX-based infrastructure network

The network rounded by solid line in Fig. 5 is a WiMAX-based infrastructure network. In this network, a base station complying with IEEE802.16e is employed. The frequency is 2587MHz which is an open frequency band for local communities and the band width is 10MHz. Transmission power of the base station is 33dBm per an antenna. The base station consists of two antennas for transmission and four antennas for reception and can perform antenna beam-forming and space diversity. The frame structure is OFDMA-TDD with 47 OFDM symbols per a frame. Frame interval is 5ms. Moreover, the symbol ratio between down link and up link is 29:18. A sub-channel allocation method is employed PUSC (Partial Usage of SubChannels). In a down link frame, 720 sub-carriers are split into 30 sub-channels. On the other hand, in an up link frame, 560 sub-carriers are split into 35 sub-channels.

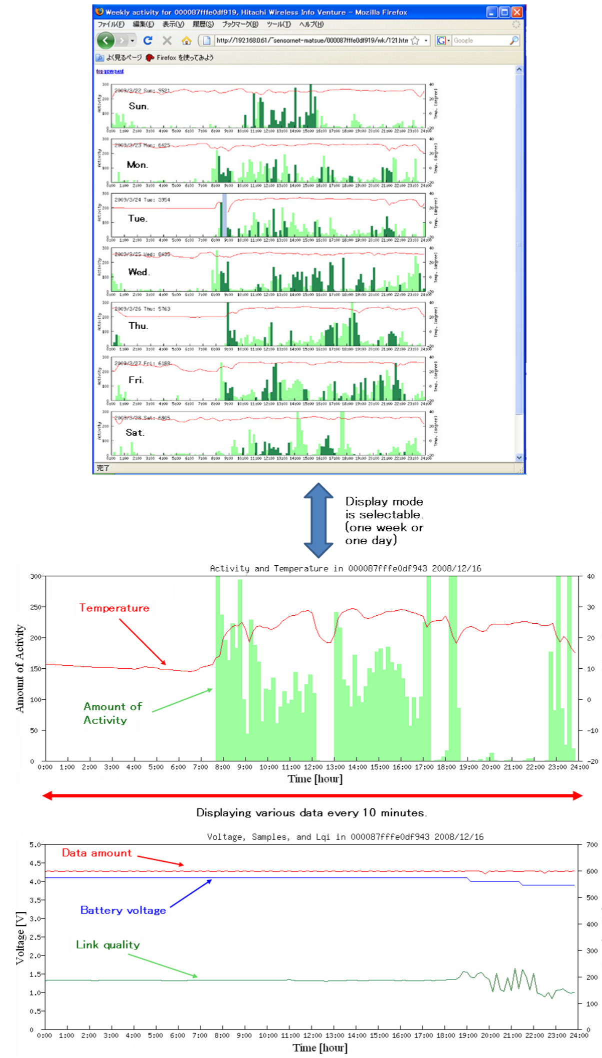

Fig. 7. An example of various physical condition data and sensor information (Upper: one week data, Bottom: daily data).

Firstly, a base station for WiMAX receives the physical condition data transmitted from a base station for ZigBee. Next, these data are stored on the life recording and management server; and life tapestry etc. are generated by the life information visualization software. Finally, users can confirm their own physical condition data by web browsers.

5. REPRESENTATIVE EXAMPLES OF VISUALIZED PHYSICAL CONDITION DATA

Measured data by a wristwatch-type sensor are analyzed by the life recording and management system server, and these data can be displayed by web browsers. Figure 6 shows web pages of the life recording and management system. In this page, users can check the daily data, weekly data and the life tapestry. Figure 7 shows an example of various physical condition data and sensor information of one week, upper, or one day, bottom. The bottom graph of Fig. 7 shows various physical condition data. The abscissa of this graph denotes the time, the left ordinate denotes the amount of activity which is displayed by a value between 0 and 300, and the right ordinate denotes the

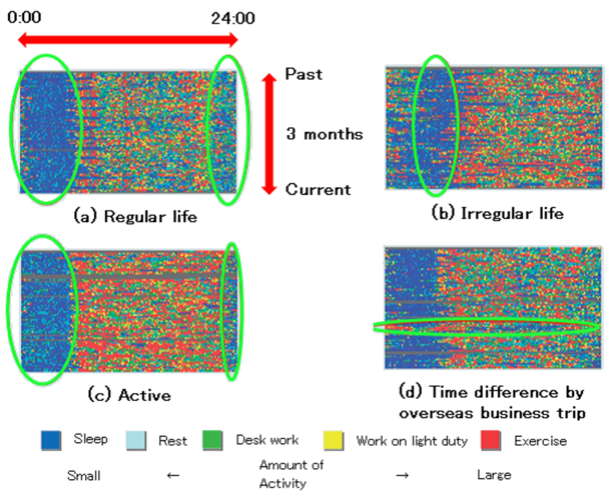

Fig. 8. Four examples of life tapestries.

temperature between -20 degrees and 40 degrees. The line plot indicates the temperature, and the bar graph indicates the amount of activity. From this graph, it can be seen that there is high correlation between the temperature and the amount of activity. Moreover, it can be seen that user removed the wristwatch-type sensor between 12:00 and 13:00 and between 18:30 and 22:30 because the temperature drops and there are little amount of activity.

The bottom graph of Fig. 7 also shows the sensor information. The abscissa of this graph denotes the time, the left ordinate denotes the voltage between 0 and 5.0, and the right ordinate denotes both the number of transmitted data samples between 0 and 700 and the Lqi (Link quality indicator) between 0 and 255.

Figure 8 shows four examples of life tapestries. Life tapestry indicates the amount of activity for 3 months, and it is painted by 5 colors. The abscissa denotes the time and the ordinate denotes the date for 3 months. From each life tapestry, the following things are clarified.

(a) Regular life: It can be seen that the user sleeps between 22:00 and 6:00 every day because the color of life tapestry is dark.

(b) Irregular life: It can be seen that the user stays awake until midnight because the light color exists at midnight.

(c) Active: It can be seen that the user spends active life because the light color exists more than (a) between 6:00 and 23:00.

(d) Time difference by overseas trip: It can be seen that the user went to overseas trip during a week surrounded by circle because the user acts between 0:00 and 6:00, sleeps between 10:00 and 18:00.

If users wear the wristwatch-type sensor every day, they can correctly comprehend their own life rhythm[9][10][11].

6. RESULTS OF THE FIELD TRIAL TEST BY CITIZENS

In this section, results of the field trial test on the life recording and management system are shown. Total 151 citizens participated in the trial test. Firstly, the result of five-grade evaluation is shown in Table III. From Table III, the average evaluation score is about 3.5; consequently it is clear that citizens satisfy with the life recording and management system.

TABLE III
EVALUATION RESULTS OF 151 CITIZENS.

	Evaluation	Rate (%)
5	Very good	15
4	Good	35
3	Normal	38
2	Poor	12
1	Very poor	—

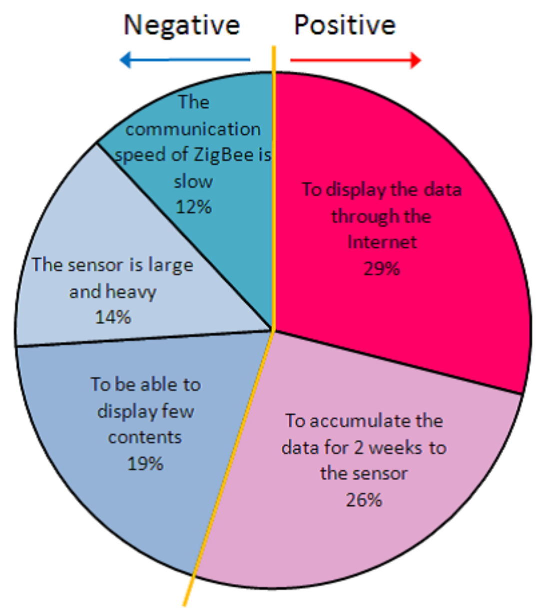

Fig. 9. Positive and negative comments from citizens.

Figure 9 shows comments from citizens which are largely classified into five types. From Fig. 9, about 55 % of the comments is positive one; on the other hand, about 45 % of them is negative one. The function of the system which was highly evaluated by citizens is to be able to confirm the history of physical condition data via the Internet. The secondly evaluated function is to be able to accumulate the measurement data for 14 days to the sensor terminal. On the other hand, some requests from citizens are to increase the contents sensed by the sensor terminal, to realize the more close-fitting sensor terminal and to accelerate the communication speed of sensor network.

7. CONCLUSION

In this paper, ZigBee-based life recording and management system is developed; and the overview, network structure and fundamental performance of the system are denoted. ZigBee-based life recording and management system automatically collects daily physical condition data, and it can visualize these data. Users can easily comprehend their own physical condition.

On the other hand, some problems for practical use have been clarified by evaluations. Firstly, the communication time becomes longer when the channel frequency of wireless LAN is close to that of wristwatch-type sensor. Secondly, wristwatch-type sensor which has small transmission power is easily affected by the co-channel interference. As a result, communication time becomes longer. Finally, when the distance between a wristwatch-type sensor and a receiver is over 7m, the communication link is easy to be disconnected because the transmission power of a wristwatch-type sensor is small. Hence, users need to care about the distance from the appliance which emits the signal having same frequency with a wristwatch-type sensor. Or, users have to set the different channel frequency to each appliance.

In this paper, we realized the life recording and management system using the wearable wristwatch-type sensor as the sensing technology, both ZigBee and WiMAX as the wireless technology and the data visualization technology. The system fulfills three operational modes of wearable computing [12]. The first one is constancy. The system is always ready to interact with the user because the system can accumulate the physical condition data to the server using wireless technologies automatically within the range where the sensor can communicate with the base station. On the other hand, the system can also accumulate the sensor data for 2 weeks to the sensor even if the sensor cannot communicate with the base station. The second one is augmentation. In this system, the user is not required to control the sensor to sense and to transmit the physical condition data. Moreover, the user can wear the sensor as same feeling as when the user wears the wristwatch. So, the user gets relief from stress, and users can be doing something else at the same time as doing the computing. The third one is mediation. The system plays a role as mediator between a user and the outer world. In this system, the user's physical condition data, or internal data, is collected by the sensor automatically. And the system visualizes the user's physical condition data, and shares them through the Internet among the user and the people of the outer world, for example medical experts.

Currently, in Japan, PHR (Personal Health Recorder) project has been conducted by the Ministry of Internal Affairs and Communications; the Ministry of Health, Labor and Welfare; and the Ministry of Economy, Trade and Industry. This project aims to develop an infrastructure of electronic health record system. The data collected by the system includes the health information recorded at hospitals, pharmacies and homes. In this project, the life recording and management system shown in this paper is corresponding to a system which records the personal physical condition data at each home.

In the future, aging societies will increase the demand for systems like a life recording and management system. Thus, we will improve the system to be able to sense the various physical data through some wearable computer, and we will realize a system which can help the personal health care.

8. ACKNOWLEGEMENT

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