Development of a Portable Vital Sensing System for Home Telemedicine[1]

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1. Introduction

Lifestyle diseases such as obesity, hypertension, hyperlipidemia, and diabetes lead to arteriosclerosis, which is one of the risk factors for developing cardiac diseases and cerebrovascular diseases. Because these lifestyle diseases can lead to chronic diseases, both prevention and early detection have become one of the most critical issues [1-4].

In order to prevent arteriosclerosis, aerobic exercise of moderate intensity is important. It has been reported that physical activity is not only a way of preventing life style-related diseases but decreases the mortality of the elderly [5-7] and prevents decline in bodily functions [8-10]. In Japan, the importance of physical activity in middle-aged and elderly people came to be recognized by Japanese researchers [11-13], especially as Japan is confronting with an aging society problem, a serious issue in Japan. According to the medium term variant projections by the National Institute of Population and Social Security Research's Population Projects for Japan, the percentage of the population over 65 years old will reach 26.0% by 2015. Therefore, it is of significance to maintain and promote the physical activity of middle-aged and elderly people.

To prevent or limit the consequences of lifestyle diseases and promote health condition among middle-aged and elderly people, a health management system providing effective exercise prescriptions is required. Since effective and safe prescriptions should be based on evidence from physical data, it is necessary to acquire such daily physical data and vital signs and to evaluate the suitability of this physical information for each user. Therefore, a home medical system to manage and evaluate daily physical activities, and to provide effective exercise prescriptions is desirable. Additionally, such a home medical system can be a provider of a number of healthcare services for those living in remote areas. In this case, the system needs to be a network-based system which enables the people to access the system through the Internet. The conceptual image of such a proposed system is shown in Figure 1 [14]. A medical data server is installed in a data center. The medical data server can handle a lot of physical data and exercise data from the people. Both potable vital sensing systems and exercise equipments are set in home and local community facilities such as fitness centers and healthcare centers. The measurement data are uploaded through the

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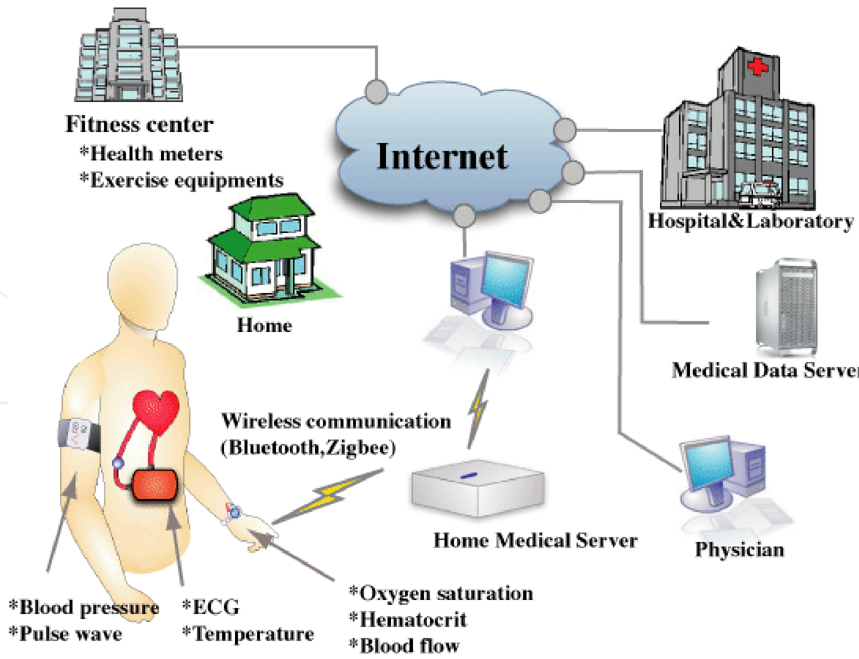

Fig. 1. The conceptual image of a home medical care system using vital sensing system

Internet, and stored on a medical data server. Moreover, an effective prescription program is established to analyze daily physical activity on the server.

To realize such a proposed system, it is necessary to develop a portable vital sensing system capable of measuring daily health conditions such as blood pressure, heart rate, electrocardiogram (ECG), body temperature, oxygen saturation, hematocrit and blood flow non-invasively and easily. Moreover, the medical information should be safely stored on local data server and remote data server. Thus, the purpose of this research is to develop a portable vital sensing system and a home medical server to establish home medical system.

2. Material and method

2.1 System configuration of a home medical system

A home medical system needs to meet highly integrated system requirements, including good portability, high reliability, seamlessly wireless communication and intelligent monitoring algorithm, because it can be used not only to basic health monitoring, but to a critical mission such as artificial heart and diabetes treatments [15,16]. The system architecture of a home medical system is shown in Fig. 2. The proposed home medical system consists of three main components including a home medical server, vital sensing units and a personal terminal. A home medical server can acquire both physiological data and physical data measured by respective portable vital sensing units with wireless communication, and can evaluate the patients' physiological conditions. Each vital sensor unit can be joined in a Wireless Personal Area Network (PAN) established by a home medical server. A Bluetooth PAN is called a piconet, and is composed of up to 8 active devices in a master-slave relationship. Moreover, a common component circuit for a vital sensing unit is independent of other diverse circuits to measure physiological data. It is possible to easily compose various types of vital sensing units like not only a custom sensor unit but also a commercial vital sensing unit with a wire communication line. A personal terminal (personal computer, Internet enabled PDA or cell-phone) is installed in user's home in order to check a current measurement data personally. In addition, a personal terminal enables users to access a remote medical data server through a home medical server. Therefore, users can check health condition from current to past, and diagnostic information form medical specialists.

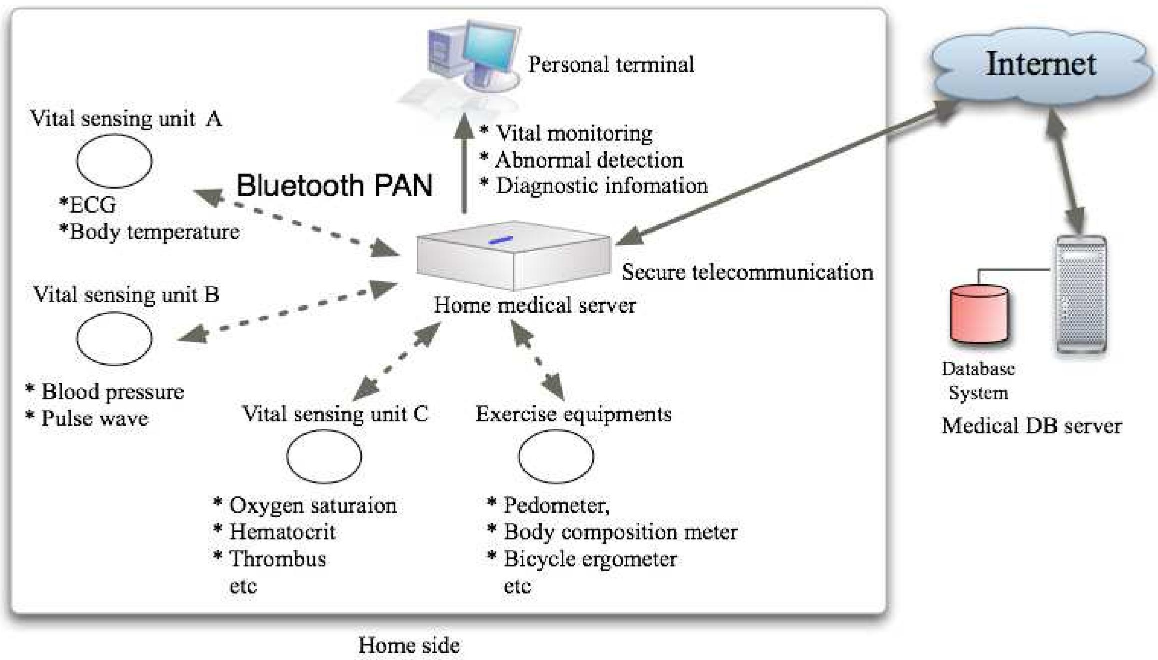

Fig. 2. System architecture of wireless vital sensing system at home

All measurement data are transferred to a remote medical database server by using a secure telecommunication technology, physicians are able to observe and evaluate the patients' condition from a remote place.

In consideration of using a vital sensing system at home, the noninvasive measurement items were decided. The set of physiological sensors described below.

- ECG sensor for monitoring heart activity
- Blood pressure sensor
- Pulse wave sensor for estimating arterial stiffness
- Body temperature sensor

Other physiological sensors and health meters may be added.

- Hematocrit sensor
- Oxygen saturation (SpO2) sensor
- Blood glucose sensor for diabetes patients
- Body composition meter
- Pedometer

2.2 Vital sensing unit

In order to acquire and communicate physiological data, a smart telecom unit was developed specifically for wireless network based data acquisition unit (Fig. 3). We integrated a wireless module (KC22, KC wirefree), a digital signal processor (dsPIC 30F3013, Microchip Technology Inc.) and a battery management circuit into an intelligent signal processing board that can be used as an extension of standard wireless sensor platform. The radio operating range of the Bluetooth module is class 2. Therefore, it is used up to 10 meters. The smart telecom unit has a digital I/O connector that allows two UART (Universal

Asynchronous Receiver Transmitter), I2C interface, and 5 analog input lines. The A/D converter on the smart telecom unit has a high resolution (12bits). A small Li-Ion battery was used as a power supply, whose width, height and thickness are 25 mm, 37 mm and 5 mm respectively. The capacity is 550 mAh.

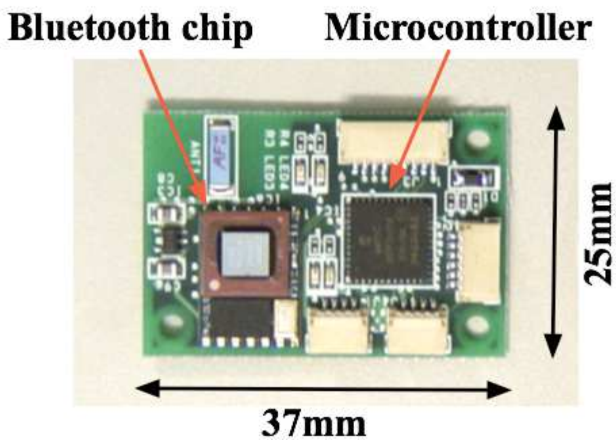

Fig. 3. A smart telecom unit with intelligent signal processing

1. *Blood pressure and pulse wave meter:*

A vital sensing system integrating both blood pressure meter and pulse wave sensor is shown in Fig. 4 and Fig. 5. The commercial wrist type blood pressure meter (HEM-637IT, OMRON Corporation) was used as a portable blood pressure meter. This blood pressure meter can communicate stored blood pressure data to a smart telecom unit with serial RS-232C port. Meanwhile, for measuring a pulse wave, a finger clip sensor with a photoplethysmograph was developed. A photoplethysmograph is a noninvasive method to measure a pressure pulse of finger or toe. The change in volume cased by the pressure pulse is detected by illuminating the skin with the light from a Light Emitting Diode (LED), and then measuring the amount of light reflected to a photodiode. A Infrared LED with a wavelength of 940nm was used. The Pulse wave was obtained from a patient's forefinger. As an anti-aliasing filter, a low-pass filter with cut-off frequency at 250 Hz was used in the end of a signal conditioning circuit. The signal digitized at a sampling rate of 1kHz with 12-bits resolution. Both blood pressure meter and pulse wave sensor connecting to a smart telecom unit, record data were transferred to a home medical server wirelessly.

2. *ECG and body temperature meter:*

The development of a vital sensing unit for measuring ECG and blood temperature is shown in Fig. 6 and Fig. 7. The vital sensing unit can measure both of two physiological parameters by attaching the body skin on left chest. The ECG sensor has two active electrodes and a capacitive ground within the bottom of the sensor case. The two active electrodes have their own preamplifier that transfers the displacement current into the voltage. An Ag-AgCl plated electrode was used as an ECG electrodes probe [17]. In order to measure the body temperature accurately, A small type platinum film thermal sensor (PTFC101A000, Labfacility Limited) was used, and was built in the bottom of the sensor case. This sensor is 2 mm * 2.3mm, which is a sufficient size to be built in the sensor case. Moreover, compared with a thermistor or thermocouples, a platinum thermal sensor has advantages in linearity and reproducibility. As an anti-aliasing filter, a low-pass filter with cut-off frequency at 250 Hz was used in the end of each signal conditioning circuit. The two signals were digitized at a sampling rate of 1kHz with 12-bit resolution.

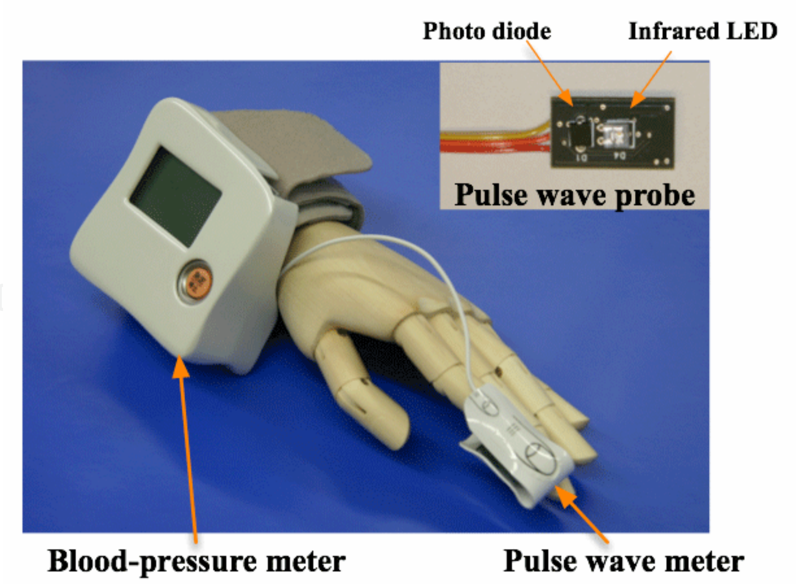

Fig. 4. The portable vital sensing unit for measuring blood pressure and pulse wave

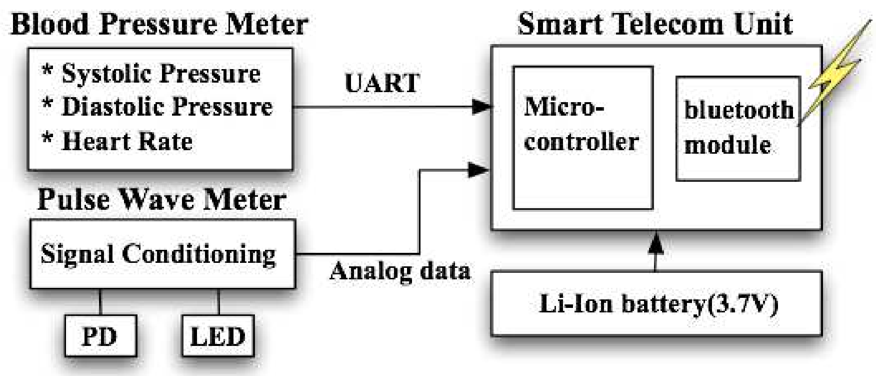

Fig. 5. Block diagram of the portable vital sensing unit (blood pressure and pulse wave meter)

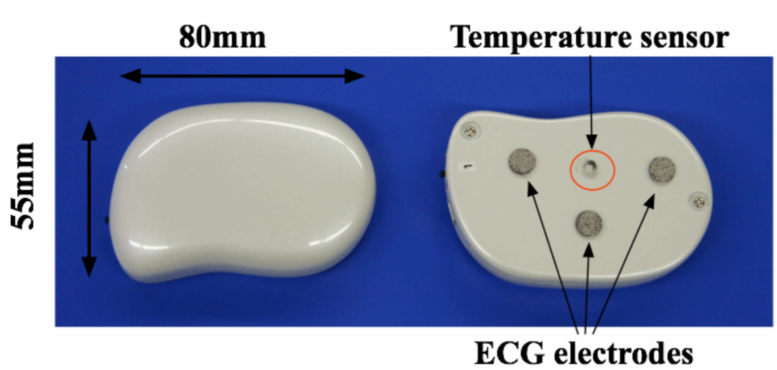

Fig. 6. A portable vital sensing unit for measuring ECG and body temperature. The left hand side is top view and the right hand side is bottom view.

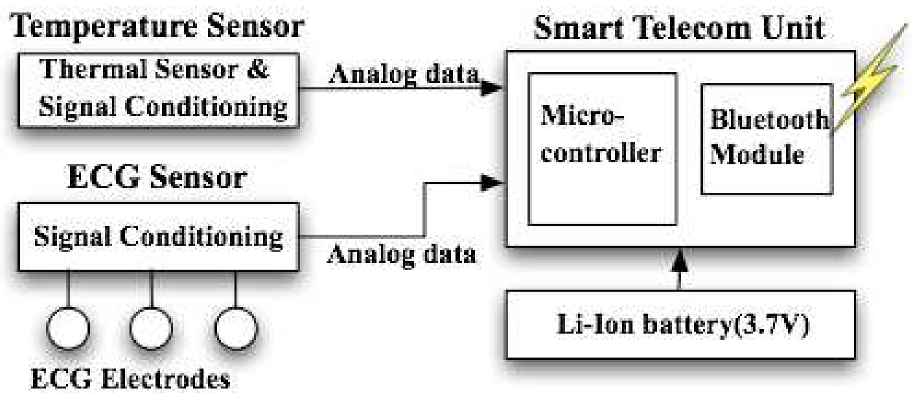

Fig. 7. Block diagram of the portable vital sensing unit (ECG and body temperature meter)

In order to calibrate the temperature sensor automatically, the two points calibration method was used. Generally, the relationship between the measured temperature and output voltage can be expressed as (1).

$$T_s = AV_s + B \tag{1}$$

where T_s is the temperature, V_s is the output voltage measured by a temperature circuit, *A* and *B* are constants dependent on the characteristics of the platinum thermal sensor and the measurement circuit. Although both a parameter "*A*" and "*B*" is unknown, two parameters are determined by using high-precision resistances.

The equations switching to each two reference resistance R_1 and R_2 are expressed by (2), (3).

$$T_1 = AV_1 + B \tag{2}$$

$$T_2 = AV_2 + B \tag{3}$$

where T_1 and T_2 are the temperature using R_1 and R_2 respectively, and V_1 and V_2 are the output voltages using to R_1 and R_2 respectively. Therefore, the unknown parameters A and B are determined by solving the simultaneous equation. These solving parameters describe below.

$$A = \frac{T_1 - T_2}{V_1 - V_2} \tag{4}$$

$$B = \frac{V_1 T_2 - T_1 V_2}{V_1 - V_2} \tag{5}$$

2.3 Home medical server

The home medical server consists of a small computer (MIU-Card 1001,Katoh Denki Co.Ltd Japan) of a size with 124mm*78mm*60mm and a weight of approximately 300g (Fig. 8) The Operating System is RT-Linux, which is globally accepted to be stable. The kernel and control program are installed in compact flush memory card (CF card) as a hard disk. CF card is strong against a shock compared with hard disk. And the home medical server has a wireless-LAN module to connect with Internet and a Bluetooth module to communicate portable vital sensing units. The server not only can transfer the measured data to a remote medical data server but can manage patient's condition by using its own diagnostic function. If an abnormal condition occurred, the home medical server can send the diagnostic information to remote medical server. Additionally, in order to protect user information through the Internet, cryptographic end-to-end secure sessions, that is Hypertext Transfer Protocol Security (HTTPS), that reduces risks by providing data confidentiality and integrity protection was established.

The medical data management server consists of a database system to handle user information and a web-based user interface to access diverse information like health conditions and prescriptions. The design of the system architecture of a medical data server is shown in Fig. 9. We adopt Tomcat and Apache as a web application deployment environment and PostgreSQL as a database system in consideration of the security, the easy development and deployment. Tomcat has a function that a comprehensive suite of tools and frameworks for quickly developing standards-based Web services and Java server applications. PostgreSQL offers high-speed access to structured data, fault tolerance

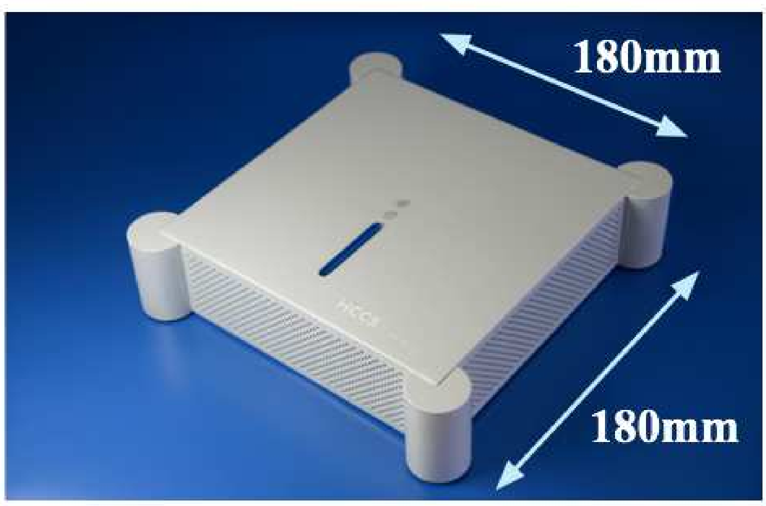

Fig. 8. Home medical server

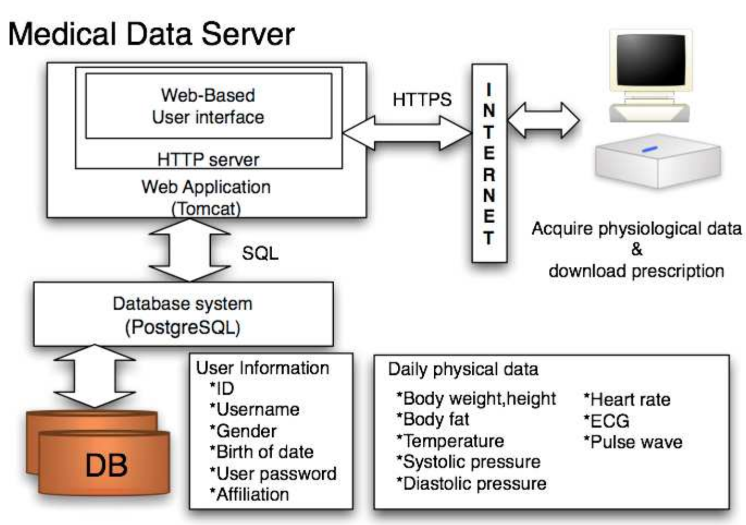

Fig. 9. System architecture of a medical data server for managing vital records

function, the clients never wait whenever the access is increasing and a unique multi-file journaling architecture ensures fault-tolerance and data integrity without compromising database performance.

The data viewer showing in Fig. 10 is able to monitor physiological data in real time. The waveform of ECG and pulse wave can be checked in the time of measurements.

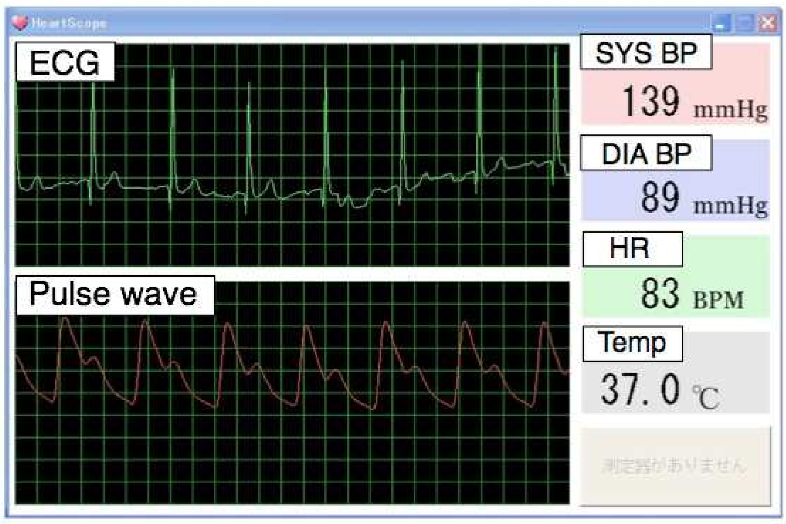

Fig. 10. Data viewer for portable vital sensing units

3. Result and discussion

3.1 Evaluation of measurement accuracy and stability

The vital sensing system was applied to a basic measurement test in order to evaluate its effectiveness.

Firstly, we evaluated the accuracy of the body temperature sensor by using a platinum thermal resister. The two coefficients were determined by using two points calibration method. The following coefficients were obtained at 40ºC, A = 18.9 and B = -14.79. By using these parameters, an accuracy test was performed. In consideration of the range of human body temperature, temperature was controlled from 32ºC to 45ºC. The profile of controlled temperature was shown in Fig. 11. And the result of accuracy test was shown in Fig. 12. This figure shows the differences between a referenced temperature and a measured temperature. The maximal error was 0.3ºC and the mean error was -0.08ºC. Therefore, the result shows that the accuracy of a temperature sensor was suitable to measure a body temperature at the range from 32ºC to 45ºC. However, the response time of the temperature sensor was relatively long. It is because a thermal capacity increased, directly attaching the thermal sensor to the unit case.

Secondly, the stability of ECG and pulse wave was evaluated. The waveform of ECG measured by portable vital sensing system was shown in Fig. 13. According to this waveform, the hum noise level of ECG was quite low. Because Ag-AgCl electrodes were used, it is possible to maintain good electrical conductivity between the electrode and the skin without any conductive paste. As another reason, it is because of battery driven circuits. Compared with AC/DC power supply, DC battery supply dose not generate power-supply noise or hum noise. Therefore, it is suitable to measure a biological signal. However, the movement of the baseline was observed. The problem was mainly caused by

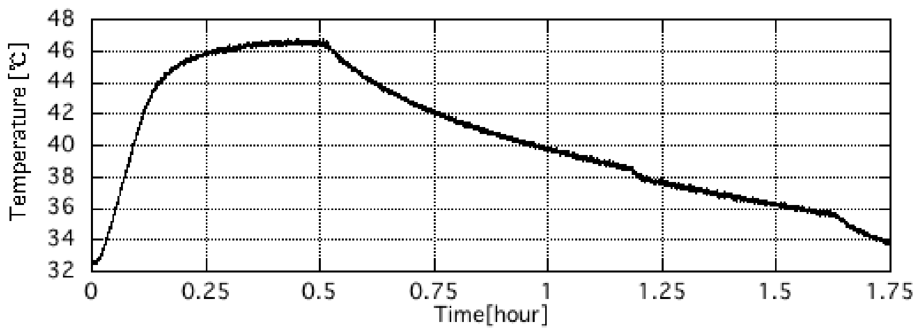

Fig. 11. The profile of a temperature accuracy test

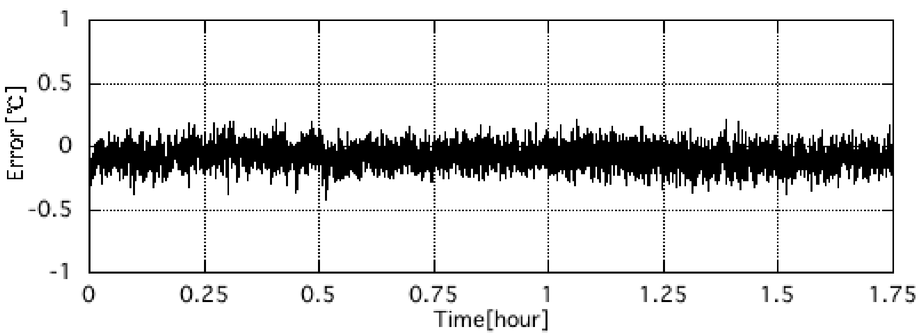

Fig. 12. The difference between a referenced temperature and a calibrated temperature using a platinum thermal sensor

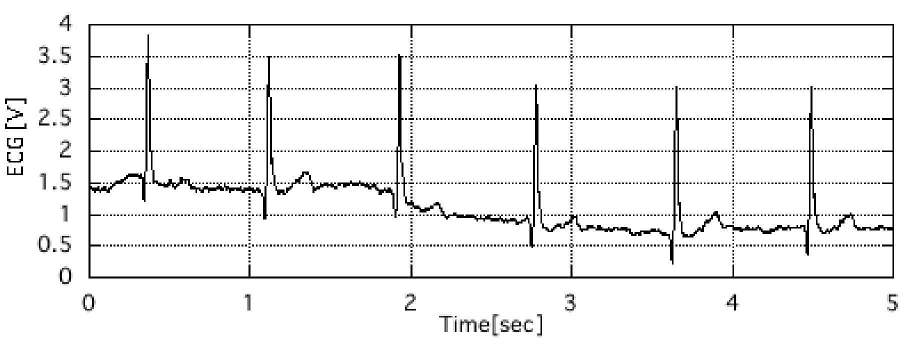

Fig. 13. The waveform of ECG measured by vital sensing system.

the change of electrical conductivity during breathing and body motion. In order to remove the baseline movement, a digital notch filter with notch frequencies at 0, 50 and its harmonics was implemented in the data acquisition program. An application of notch filter was shown in Fig.15 and Fig.16. Notch filter is generally a bond stop filter in a very narrow band. Since the designed notch filter was a comb type filter, having a frequency at o Hz, DC offset and baseline movement could be removed.

The waveform of pulse wave measured by a portable vital sensing system was shown in Fig. 14. It would be confirmed that it was stable to measure volume pulse wave by using a finger-type photoplethysmograph.

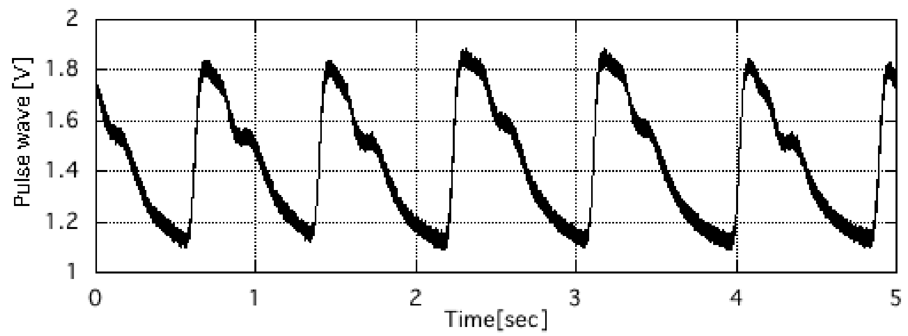

Fig. 14. The waveform of pulse wave measured by vital sensing system

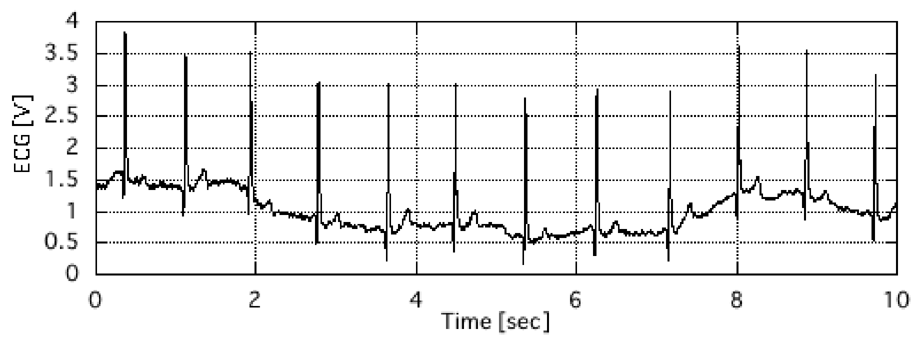

Fig. 15. The waveform of ECG without a notch filter

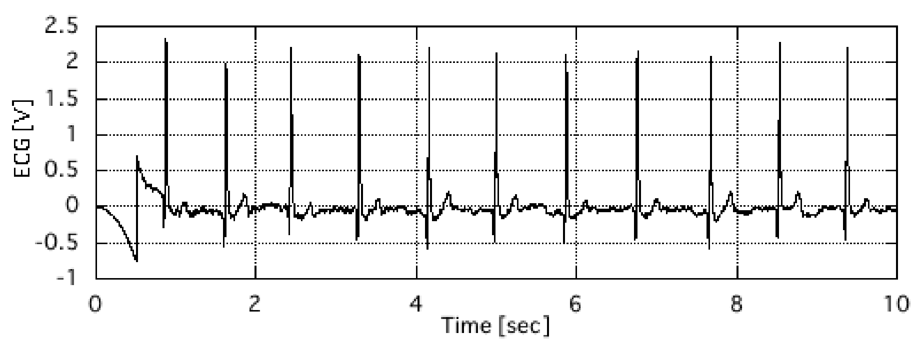

Fig. 16. The waveform of ECG with a digital notch filter: The designed notch filter has a notch frequency at 0 Hz, 50 Hz, and its harmonics.

3.2 Interoperability of home telemedicine

A home telemedicine system is a network-based and distributed information system to connect home patients to medical specialists. Therefore, it is of significance to consider interoperability of telemedicine systems. Regarding device connectivity to the home medical server, the proposed vital sensing system has the advantage of being easily connected to a Bluetooth PAN composed by the host medical server. However, considering network connectivity between a home medical server and a remote data server, more sophisticated system architecture is required in terms of data formats and communication protocols. Especially, HL7 (Health Level 7) which is a standard for exchanging information or DICOM (Digital Imaging and Communications in Medicine) which is a standard for medical imaging specification should be considered to improve interoperability of home telemedicine.

4. Conclusion

We developed a set of portable vital sensing system and a home medical server to establish a home telemedicine system. In order to develop a portable vital sensing system, physiological sensing circuit, digital signal processor and wireless communication device are integrated into a small electrical circuit, called "smart telecom unit" with a size of 25mm * 37mm. By using a smart telecom unit, noninvasive vital sensing units including blood pressure, electrocardiograph, pulse wave and body temperature were developed. Meanwhile, a home medical server consists of a small computer and virtual physiological model to estimate health conditions. These sensing units are able to communicate vital records to a home medical server, which can seamlessly connect to the Internet.

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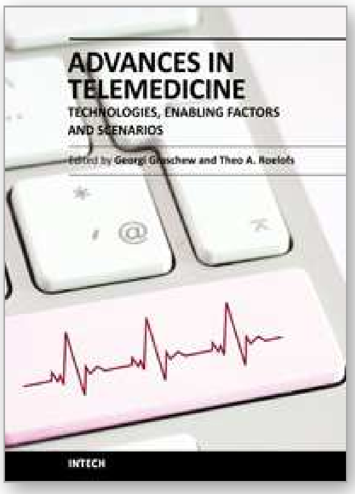

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Innovative developments in information and communication technologies (ICT) irrevocably change our lives and enable new possibilities for society. Telemedicine, which can be defined as novel ICT-enabled medical services that help to overcome classical barriers in space and time, definitely profits from this trend. Through Telemedicine patients can access medical expertise that may not be available at the patient's site. Telemedicine services can range from simply sending a fax message to a colleague to the use of broadband networks with multimodal video- and data streaming for second opinioning as well as medical telepresence. Telemedicine is more and more evolving into a multidisciplinary approach. This book project "Advances in Telemedicine" has been conceived to reflect this broad view and therefore has been split into two volumes, each covering specific themes: Volume 1: Technologies, Enabling Factors and Scenarios; Volume 2: Applications in Various Medical Disciplines and Geographical Regions. The current Volume 1 is structured into the following thematic sections: Fundamental Technologies; Applied Technologies; Enabling Factors; Scenarios.