Personalised Health Management Systems
C.D. Nugent et al. (Eds.)
IOS Press. 2005
© 2005 The authors. All rights reserved.

IT-based Diagnostic Instrumentation Systems for Personalized Healthcare Services

Honggu CHUN, Jaemin KANG, Ki-jung KIM, Kwang Suk PARK, Hee Chan KIM
Dept. of Biomedical Engineering, College of Medicine and
Center for Advanced Biometric Research Center,
Seoul National University, Korea

Abstract. This paper describes recent research and development activities on the diagnostic instruments for personalized healthcare services in Seoul National University. Utilizing the state-of-the-art information technologies (IT), various diagnostic medical instruments have been integrated into a personal wearable device and a home telehealthcare system. We developed a wrist-worn integrated health monitoring device (WIHMD) which performs the measurements of non-invasive blood pressure (NIBP), pulse oximetry (SpO_2), electrocardiogram (ECG), respiration rate, heart rate, and body surface temperature and the detection of falls to determine the onset of emergency situation. The WIHMD also analyzes the acquired bio-signals and transmits the resultant data to a healthcare service center through a commercial cellular phone. Two different kinds of IT-based blood glucometer have been developed using a cellular phone and PDA(personal digital assistant) as a main unit. A blood glucometer was also integrated within a wrist pressure measurement module which is interfaced with a cellular phone via Telecommunications Technology Association (TTA) standard in order to provide users with easiness in measuring and handling two important health parameters. Non-intrusive bio-signal measurement systems were developed for the ease of home use. One can measure his ECG on a bed while he is sleeping; measure his ECG, body temperature, bodyfat ratio and weight on a toilet seat; measure his ECG on a chair; and estimate the degree of activity by motion analysis using a camera. Another integrated diagnostic system for home telehealthcare services has been developed to include a 12 channels ECG, a pressure meter for NIBP, a blood glucometer, a bodyfat meter and a spirometer. It is an expert system to analyze the measured health data and based on the diagnostic result, the system provides an appropriate medical consultation. The measured data can be either stored on the system or transmitted to the central server through the internet. We have installed the developed systems on a model house for the performance evaluation and confirmed the possibility of the system as an effective tool for the personalized healthcare services.

Keywords. Telehealthcare, e-healthcare, personalized healthcare, diagnostic medical devices, Electrocardiongraph(ECG), blood glucose meter, blood pressure meter.

Introduction

A new concept of "personalized healthcare" or "personalized medicine" has emerged as a next generation medical service from the advancement and convergence of life science and information technology during the last decade. Even though the recent achievements in genomics, proteomics, molecular biology and bioinformatics are thought to unexpectedly change the shape of future diagnostics and therapeutics, many diagnostic medical devices integrated with increasingly smarter information technology (IT) are now being evaluated as a telemedicine or telehealthcare to provide more cost-effective, user-friendly and higher quality of medical services.

Research activities on telemedicine and telehealthcare in Korea have grown considerably from 1990s with advancement and expansion of the domestic IT infrastructure. As an example, telehealthcare center at the Seoul National University Hospital has been providing telemedicine services to the Seoul National University and 50 model houses using ISDN (Integrated Services Digital Network). Over 1,200 patients have examined and 83% of them replied that the service was satisfactory and 93% replied that the service was easy to use. In spite of this partial success in model telehealthcare services, there remain many technical, societal, and legal problems to be solved before we fully enjoy the advantages of this new medical service system. Standardizing the medical information, protecting the privacy of patients, establishing a guideline for proper level of medical charge, and clarifying the legal obligation are among the issues still unresolved. In technical view point, we need to develop standardized methods to interconnect the existing and forthcoming medical devices and various kinds of IT devices.

There have been a lot of research activities related to integrate various medical instruments with IT devices for telemedicine and/or telehealthcare services in the Department of Biomedical Engineering and the Advanced Biometric Research Center, Seoul National University. Main focus has been concentrated on the development of new IT-based diagnostic instrumentation systems in order to provide easiness in use for the possible users. Two different types of wearable systems and stand-alone systems have been developed for mobile and home use, respectively. Wearable systems include a wrist-worn integrated health monitoring device (WIHMD), three different types of IT-based glucometers. Non-intrusive health monitoring devices and a multi-functional integrated diagnostic system have been also developed and installed in a model house. All developed devices and systems were evaluated their performance to provide real-time automatic diagnosis and medical consultation not only to the patients with chronic disease such as cardiac disease, respiratory disease, diabetes and hypertension but also to the healthy but health-concerned subjects.

1. Materials & Methods

1.1. Wrist-worn Integrated Health Monitoring System for Telemedicine and Telehealthcare

It is recognized that promptness of treatment is the most critical factor in emergency situations. Recent studies have shown that early and specialized prehospital management contributes to emergency case survival. The prehospital phase of management is of critical importance [1]. When an emergency occurs to an old person who lives alone, it's probable that he/she may have fallen and may remain for a long time without any treatment. Therefore, a real-time monitoring system with a tele-reporting function is required and we developed a WIHMD [Figure 1][2]. This system detects the fall and measures blood pressure, ECG, heart rate, respiration rate, body surface temperature and SpO_2. The WIHMD detects the fall of a patient by analyzing signals from a 2-axis accelerometer and an in-house fabricated posture sensor that is composed of a photo-interrupter with a pendulum. NIBP is measured by an oscillometric method based on the pressure signal from a wrist-cuff. Single channel ECG (LEAD I) is measured using textile electrodes which are located on inside and outside of the wrist-cuff for contacts with left and right hand, respectively. Heart rate and respiration are obtained by analyzing the ECG signal. Body surface temperature is measured by a semiconductor temperature sensor which is attached inside of the wrist-cuff. SpO_2 is measured using a finger-clip-type sensor which is connected to the main system. The WIHMD is linked to a cellular phone using an RF module (433MHz) and transmits the measured data to a healthcare center through the cellular phone using a Short Message Service (SMS). We have applied the system to ten volunteers for performance evaluation and confirmed the possibility of the system as an effective tool for telemedicine. Test methods and result are shown in Table 1.

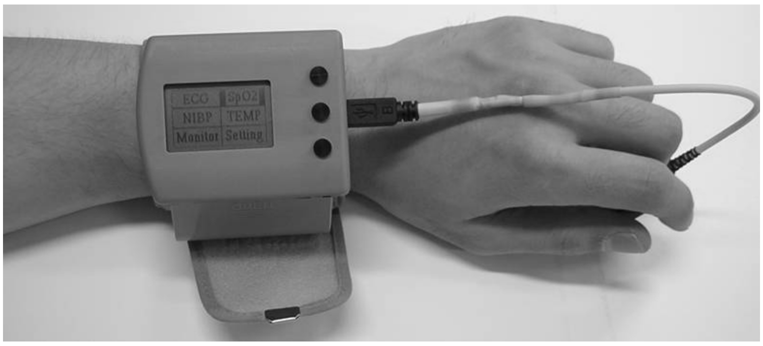

Figure 1. A wrist-worn integrated health monitoring device (WIHMD). This system detects fall and measures blood pressure, ECG, heart rate, respiration, body surface temperature and SpO_2.

Table 1. Summary of performance evaluation results of the WIHMD.

	Evaluation method	Number of tests	Test results
NIBP	Simulator (BPPump2M, Bio_tek, USA)	100	Error within ±4mmHg
SpO_2	Simulator (Oxitest plus7, DNI Nevada Inc, USA)	100	Error within ±2%
Heart rate from ECG	Simulator (PS214B, DNI Nevada Inc, USA)	100	Mean error 0.9%
Respiration from ECG	Human trial (WebDoc Spiro^{TM}, Elbio Inc, Korea)	50	Mean error 1.8%

Body surface temperature	Test set-up (Temperature-controlled chamber)	20	Mean error 1.5%
Falling	Human trial	150	Detection rate 91.3%

1.2. IT-based Blood Glucometers

Frequent measurement of blood glucose level is the most important diagnostic procedure for the diabetic patients. Even though the existing glucometers are portable with storage of a certain amount of measurement data, they do not provide fully satisfactory performance for mobile applications. A new glucometer connected to modern telecommunication devices such as a cellular phone and a PDA phone can remarkably enhance the user interface as well as the measured data management capabilities and can be carried at any time and any place. Once the blood glucose level is stored in such a telecommunicating device, the data can be easily transmitted to a remote server in healthcare service center through the possible combination of CDMA network, wireless LAN, and internet for further processing and services.

As shown in Figure 2, we have developed three different types of IT-based glucometers. In a PDA phone based system, the glucose measurement module was integrated into the PDA's main circuitry internally. For a cellular phone, we developed an external blood glucose measurement module that is interfaced via TTA standard. Therefore, this module can fit any kind of cellular phone produced in Korea. One can measure his/her blood glucose level and blood pressure easily in the third type device where a glucometer is integrated with a wrist-type blood pressure meter. This device also interfaces to a cellular phone via the TTA standard. By using a cellular phone or a PDA phone as a user interface, a larger display and more convenient functions can be achievable. A schematic diagram of the healthcare service model using those IT-based glucometers is shown in Figure 3. Measured data can be transmitted to a healthcare center, which consult with the patient using SMS. This type of service will be fully opened in Korea in April 2005.

(a) (b) (c)

Figure 2. Three different types of IT-based glucometers; (a) PDA phone with an internal blood glucose measurement module, (b) an external blood glucose measurement module using TTA standard, and (c) a wrist-worn module for the measurements of blood glucose level and blood pressure.

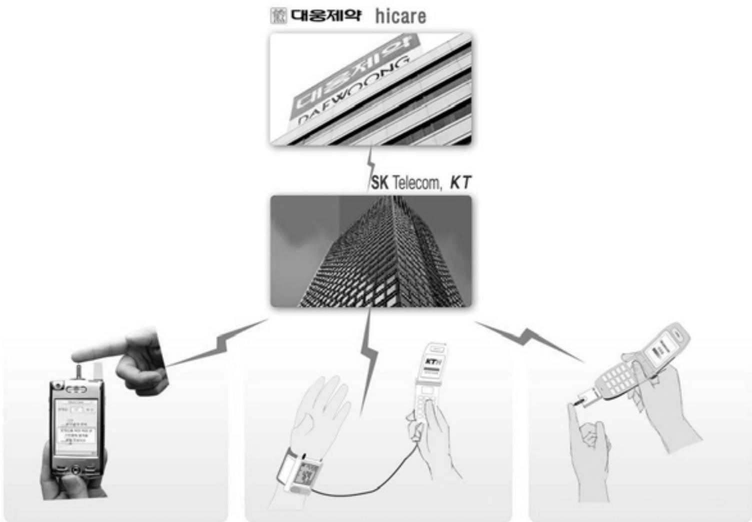

Figure 3. A healthcare service model using a cellular phone. One can measure his/her blood glucose level and/or blood pressure easily with one of the developed IT-based glucometers and then get an medical consultation through short message service (SMS) from the healthcare service center.

1.3. C. Non-intrusive Measurement of Biological Signals

Most of the existing medical instruments need the intention of a user to measure bio-signals and it is usually difficult to use correctly without a medical personnel's assistance. This may restrict the wide application of the personalized healthcare service system. A possible solution to this problem is non-intrusive measurement, which means the measurement of bio-signals without disturbing patient's ordinary activities, without cooperation for the measurement, and without patient's awareness of the measurement. The method can use any device we have to contact in a daily life for the measurement of bio-signals, which includes a bed, a toilet seat, a bath tub, shoes, a watch, a chair, a car seat, a belt, clothes and so on. We developed such non-intrusive measurement systems and installed them in a model house [Figure 4].

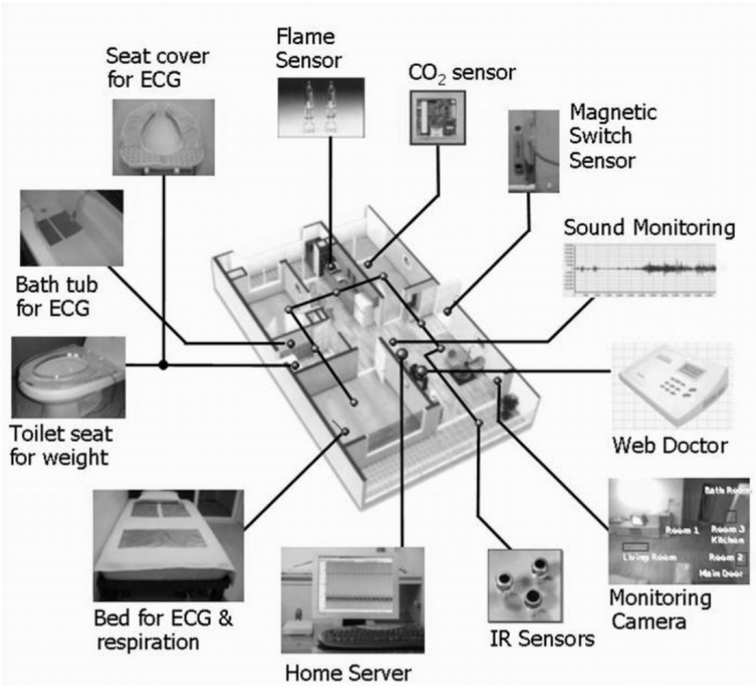

Figure 4. Model house for non-intrusive measurement of bio-signals. One can measure ECG on a bed while he is sleeping; ECG, body temperature, bodyfat ratio and weight on a toilet seat; ECG on a chair; the degree of activity by motion analysis using a camera.

Figure 5 shows a non-intrusive ECG measurement on a bed. The bedcover is made of three electrodes using copper coated conductive polyester textile. The user does not need to attach electrodes on his body to measure the ECG signal without any discomfort. We also successfully extract the respiration signal from the measured ECG waveform.

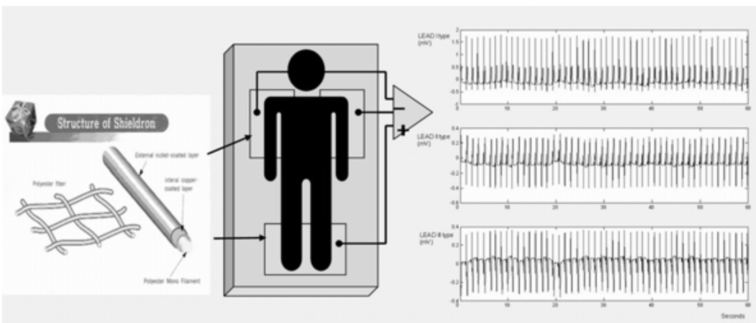

Figure 5. Non-intrusive ECG measurement on a bed using copper coated conductive polyester textile. Respiration signal is obtained by analyzing the ECG signal.

Figure 6 shows parameters that can be possibly obtained using a special toilet seat for non-intrusive measurement. Among those parameters, we developed a system that can measure the heart rate, body weight, body fat, body surface temperature and SpO_2. When a user sits on the toilet seat, it measures the body weight using imbedded load cells, body surface temperature using a temperature sensor, ECG and pulse rate using copper coated conductive polyester textile, and SpO_2 using reflective type oxymetry sensor. All of these measurements are processed non-intrusively and automatically.

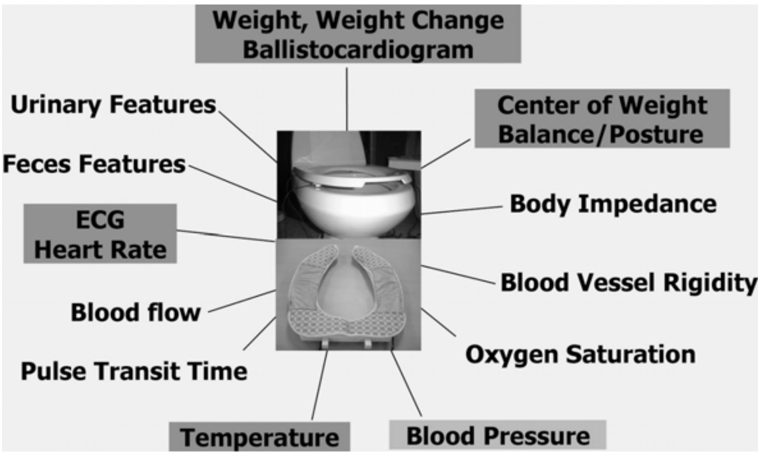

Figure 6. Parameters that can be possibly obtained from a specialized toilet seat. We developed a system that can measure the heart rate, body weight, body fat ratio, body surface temperature and SpO_2.

Copper coated conductive polyester textile was used as a useful material for non-intrusive bio-potential measurement. However, as conventional bio-potential measurement methods, it still requires a good contact between the electrode material and patient's skin. Sometimes, we need to measure bio-potential signal without touching a target object. A possible solution to this situation is a non-contacting capacitive bio-potential measurement. It utilizes insulated conductive plates as sensor to detect the changes in bio-potential [Figure 7]. We developed a non-contacting capacitive ECG measurement system on a chair [Figure 8]. A user can measure his/her ECG during working hours even in normally dressed condition.

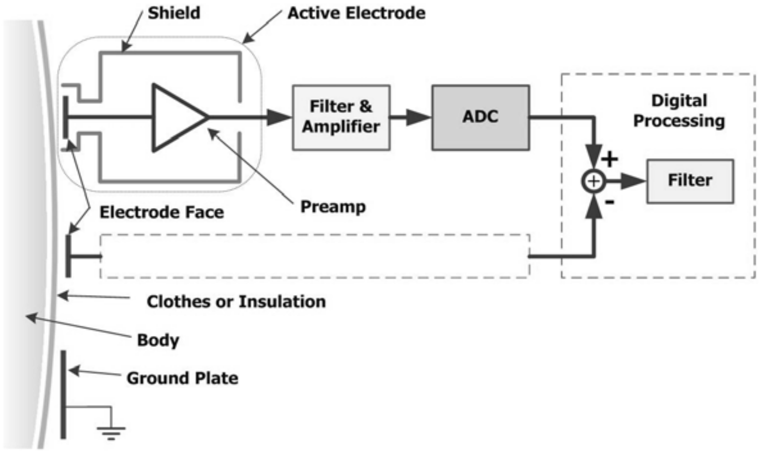

Figure 7. Conceptual diagram of non-contacting capacitive bio-potential measurement. It utilizes insulated conductive plates as sensors to detect the changes in bio-potential.

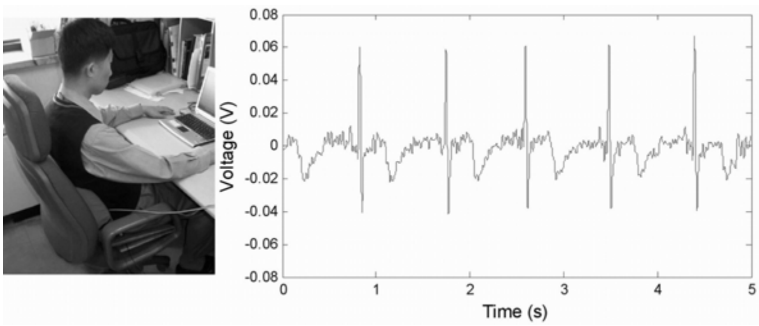

Figure 8. Developed system for non-contacting capacitive ECG measurement. It is installed on the back of a chair.

1.4. Development of an Integrated Home Telehealthcare System

In all the previously described systems, the main function of the developed device is to acquire user's health parameters and to transmit them to the central server in a healthcare service center through the telecommunication network. Then, the central server analyzes the data and diagnoses the current state of the patient, and then provides an appropriate teleconsultation or medical service if it is required. An integrated health monitoring system which not only measure the health parameters but also generate diagnosis and appropriate medical consultation can be useful for home telehealthcare services. This type of system would be especially beneficial to the people living in an area with poor infrastructure of telecommunication network. For this purpose, we have developed an expert health monitoring system for telehealthcare service to be used as a stand-alone system at home without any connection to a central healthcare server. This system is equipped with real-time automatic diagnosis and consultation function for patients with chronic disease such as cardiac disease, respiratory disease, diabetes and hypertension [Figure 9]. The system measures the standard 12-channel ECG, respiratory function, blood glucose level, and NIBP. The measured data are either stored on the system or transmitted to the central server if it is connected through the Internet. If there is any abnormality in the diagnostic result, the system generates a real-time alarm and an appropriate teleconsultation or medical service as well as sends a notice with measured data to the healthcare center.

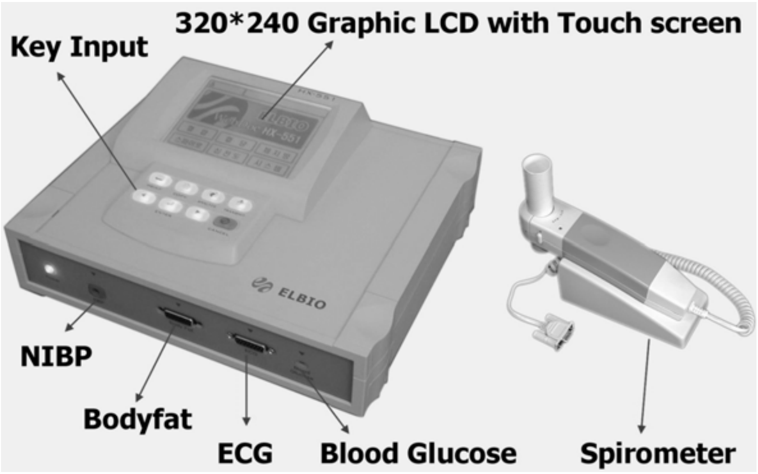

Figure 9. An integrated home telehealthcare system equipped with real-time automatic diagnosis and consultation functions. It measures standard 12ch ECG, respiratory function, blood glucose level and NIBP.

The system offers a convenient guide for the measurement by providing graphical instruction at every stage on a 320*240 graphic LCD with touch screen. Measured data are analyzed in real time and the diagnostic results are shown on the LCD with appropriate medical consultation. ECG measurement is required for the analysis of cardiac function of patient with chronic heart disease. ECG measurement module of the system was designed to meet the safety specification of IEC 60601-1, IEC 60601-2-25 and performance specification of KS P 1202-7. It acquires standard 12-channel ECG data for 10 sec and estimates parameters such as heart rate, PR interval, QRS duration, QT/QTc and P-R-T axes. Then it executes automatic diagnosis for heart abnormality over 200 cases related to rhythm, hypertrophy, QRS axis, conduction abnormality, myocardial infarction and ST-T abnormality. Spirometry is required for the analysis of respiratory function of patients with chronic respiratory disease. Spirometry module was designed to meet the safety specification of IEC601-1 and performance specification of KS P 1222. It can examine FVC(forced vital capacity), SVC(slow vital capacity) and MVV(maximum voluntary ventilation) with specified respiration protocol. At every measurement it estimates about 20 parameters related to volume and flow. Then it provides diagnostic results of the respiratory function of patient. Continued measurement of blood glucose level is required for patient with diabetes. Blood glucose meter module of the system was designed to meet the safety specification of IEC601-1 and the measurement error to be within 6.5%. It uses 0.5 μl of capillary blood collected from a finger. Measured blood glucose level is shown with the history data in a chart form. The system diagnoses the current state of patient considering patient's history on diabetes and postprandial time. Continued measurement of NIBP is required for patient with hypertension. NIBP measuring module of the system was designed to meet the safety specification of IEC601-1 and performance specification of EN1060, KS P 6012 and IEC 601-2-30. And it meets the specification of SP10 recommended by Association for the Advancement of Medical Instrumentation (AAMI). Patient can measure one's blood pressure by wrapping the cuff on left upper arm. The system measures systolic pressure, diastolic pressure and heart rate. Measured blood pressure is shown with the history data in a chart form. The system diagnoses the current state of patient considering patient's history on blood pressure. The measured data can be either stored on the system or transmitted to the central server with the diagnostic result through the internet. The data size of transmission was 96 kbyte per full measurement of ECG, spirometry, blood glucose level and NIBP.

The developed system was installed in a model house and connected to the central server through the Internet. The central server was located at the Advanced Biometric Research Center (ABRC) of Seoul National University Hospital which was 1 km apart from the apartment. Whenever any resident member used one of the measuring modules, the original waveform with diagnostic results are stored on the system and transmitted to the central server everyday. Then, a medical expert at the healthcare service center reviews the transmitted data and offers teleconsultation if required.

2. Conclusion

We have developed the IT-based diagnostic instrumentation systems for personalized healthcare services. Utilizing the state-of-the-art information technologies, various diagnostic medical instruments have been integrated into a personal wearable device and a home telehealthcare system. The WIHMD which measures NIBP, SpO_2, ECG, respiration rate, heart rate, and body surface temperature and the detection of falls can be used for emergency detection for the high-risk patients or old-age people in mobile applications. Three different types of IT-based glucometers were developed to assist the diabetic patients and healthy people to easily measure and effectively manage their blood glucose level together with blood pressure. Another integrated diagnostic system for home telehealthcare services has been developed to include a 12 channels ECG, a pressure meter for NIBP, a blood glucometer, a body fat meter and a spirometer. An expert system measures health parameters and generate real-time diagnoses and appropriate medical consultation.

We have installed the developed systems on a model house for the performance evaluation and confirmed the possibility of the system as an effective tool for the personalized healthcare services. Patients who have used this system showed the response that they felt the sense of security with the real time diagnostic result and medical consultation function of the system. We expect this system will contribute to the realization of the personalized healthcare as a future medical service system.

Acknowledgment

This work is in part the result of research activities of Advanced Biometric Research Center (ABRC) supported by KOSEF.

References

[1] B. Meade, “Emergency care in a remote area using interactive video technology: a study in prehospital telemedicine”, Journal of Telemedicine and Telecare, vol. 8, pp.115-117, 2002.

[2] J. Kang, J. Park, D. Park and H. Kim, “Development of a wrist-worn integrated health monitoring device for emergency telemedicine”, 1st international symposium on e-health care, 2002, pp.5-8

[3] Jeong RA, Hwang JY, Joo S, Chung TD, Park S, Kang SK, Lee WY, Kim HC, “In vivo calibration of the subcutaneous amperometric glucose sensors using a non-enzyme electrode”, Biosens Bioelectron, 2003 Dec 15;19(4):313-9.