Application Paper

A Belt-type Biomedical Mobile Device

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Abstract

Objective: To investigate a belt-type, biomedical mobile device capable of measuring patients' biomedical signals and sending the biomedical data to a remote medical server. This device was designed to measure and record ECG and motion signals continuously for a moving subject and, on in the event of an emergent situation, to notify a remote doctor of the situation by transmitting data on the emergent situation to a remote server through a CDMA network. **Methods:** The developed system is composed of three parts: biomedical signal acquisition, biomedical data recording, and data transmission. We conducted four types of experiment in order to evaluate the developed system's accuracy, reliability, operability, applicability to daily life, and SMS alarm function. First, we tested the accuracy of the R-R interval by comparing the signals measured via the developed system with those via a commercialized ECG system while the subjects were sitting, standing, lying or cycling. Second, we tested the reliability of the transmitted data to the remote server when two types of emergent events are generated in the developed system using a patient simulator, and measured the battery life to determine the system life. Third, we experimentally examined the accuracy of the corresponding data transmitted to the remote server via the CDMA network when two types of event are generated for each of seven types of action (sitting, standing, standing up from the seat, ordinary walking, fast walking, cycling, and running) during daily life. Lastly, we tested the SMS alarm function. **Results:** The acquisition and comparison of the subjects' biomedical signals and motion signals confirmed the accuracy, reliability, operability and applicability of the developed system to daily life. The ability of the system to monitor the ECG signals and motion signals during daily life was also demonstrated. **Conclusion:** The system was demonstrated to be very applicable to subjects requiring continuous monitoring for chronic disease and health management. Therefore, the developed system is expected to play an important role in building ubiquitous healthcare systems in Korea in the near future. ***(Journal of Korean Society of Medical Informatics 15-3, 351-358, 2009)***

Key words: Biomedical Mobile Device, CDMA Network, ECG Signal, Motion Signal, SMS Alarm

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I. Introduction

With the rise of living standard and the advance of medical technologies today, human life is being extended and the number of living-alone elders is increasing. In this situation, the importance of medical services for improving their life quality is highly recognized. That is, the paradigm of medical services is changing from the diagnosis and treatment of diseases to the prevention and management of diseases. This change is particularly remarkable in the area of mobile healthcare, which can manage diseases and health at any time and in any place during daily life. Mobile healthcare is a technology that acquires various biomedical data using wearable biomedical signal monitoring devices, analyzes the data, and provides services such as the treatment of diseases and health management, and it is applicable to chronic disease patients, emergent situation monitoring, health management for ordinary people, etc. Research on wearable biomedical signal monitoring devices to be used in daily life is being made actively in Korea and other countries. The Harvard University in the U.S. is conducting the CodeBlue Project that develops wireless sensor network technology to be used in various medical applications including the management of emergent medical services before and during hospitalization and the rehabilitation of stroke patients[1)]. The AMON Project developed a wearable personal health system that monitors and evaluates biomedical signals using bio-sensors. This system can be worn on the wrist, and transmits vital sign data such as heart rate, ECG, blood pressure, and body temperature to a remote server through GSM so that patients or ordinary people can get services[2)]. Besides, LifeShirt of Vivometrics Company developed a garment-type system for monitoring biomedical signals. It measures various parameters including information on breath, heart rate, and posture using 1-channel ECG sensor, 2-axis accelerometer, respiration sensor, etc.[3)]. LifeGuard is a biomedical monitoring system developed jointly by NASA and Stanford University in the U.S. This system is composed of sensors to measure ECG, respiration, SpO2, blood pressure, etc., a portable device to process and record the measured biomedical signals, and tablet PC or PDA to display and analyze recorded biomedical signals[4)]. Jovanov at Alabama University proposed a health monitoring system using Wireless Body Area Network (WBAN) for monitoring biomedical signals and motion signals[5)].

It was implemented for monitoring individuals' biomedical signals and motion signals during their movement. This system used two accelerometers to measure motion signals, and had a 1-channel bio-amplifier to measure patents' heart rate. Table 1 compares the characteristics of portable or wearable monitoring systems developed until now. The four types of portable or wearable systems presented in Table 1 are superior in functionality itself but they need many further improve-

Table 1. The characteristics of portable or wearable monitoring systems

Form	Characteristics	Strengths	Weaknesses	Developed systems
Ring-type	All functions including transmission and reception function, sensors, and battery are built in.	Easy to carry.	Difficult to develop because of small size. Battery life is short, and recharge is required.	Ring sensor[9)]
Bracelet-type	Transmission and reception function, memory, and various sensors are built in.	Easier to develop than the ring-type. Battery life is longer than the ring-type.	Inconvenient transmit the stored data (use PDA or PC).	Pluto mote[10)]
Portable-type	Composed of various sensors set on the chest and data recorder.	Easier to develop than the bracelet-type. AA battery usable	Inconvenient to carry.	CPOD device[4)11)]
Garment-type	All biomedical sensors are set inside the clothesand data recording and processing use a different devices.	Acquire and process biomedical data stably and precisely.	Large in size.	Life shirt[3)]

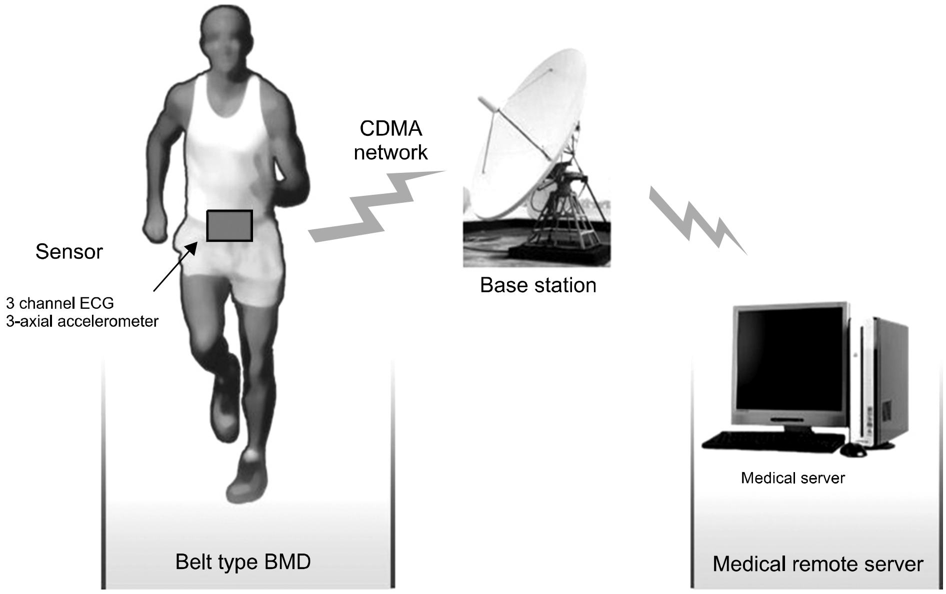

Figure 1. The schematic diagram of the system using the developed device.

ments in order to provide continuous healthcare services. The ring-type is convenient to carry, but battery life is short. The bracelet-type is easier to develop and uses the battery longer than the ring-type, but it has to use PDA or PC to transmit data. In addition, the portable-type is easier to develop than the bracelet-type, but is inconvenient to carry. Lastly, the garment-type sets all the biomedical sensors inside the clothes, and thus it is stable and acquires precise biomedical data, but the system is large in size and heavy. Thus, to solve these problems, the present study designed a system that, using a belt-type integrated device, can measure ECG and motion signals continuously at any time and in any place during daily life and, on the occurrence of an emergent situation, inform a remote doctor of the situation by sending emergent situation data to a remote server through CDMA network. In addition, this study purposed to build a system usable in real life through performance evaluation of the developed system.

II. Materials and Methods

Figure 1 is the schematic diagram of the system that uses the developed device. This system is composed of a biomedical mobile device and a remote medical server. The belt-type biomedical mobile device developed in this study was designed to collect the user's biomedical signals continuously and, on the occurrence of a problem, to send the data immediately to a remote medical server through CDMA network. Among various biomedical parameters, ECG was used, which is studied most frequently as an indicator of cardiovascular diseases. Also, in order to measure the user's daily movements in addition to ECG, the system was embedded with an accelerometer. This device was designed to measure both ECG and acceleration signal simultaneously. By measuring the user's ECG and motion signals such as sitting, walking, and running, it can figure out the user's current situation.

1. Hardware-biomedical mobile device

The developed device is composed of the biomedical signal acquisition part, the biomedical data recording part, and the data transmission part. Figure 2 is a block diagram of the device for measuring ECG and motion functions continuously while the user is moving. This device has microcontroller, 3-channel ECG amplifier, SD card, 3-axis accelerometer, and CDMA module.

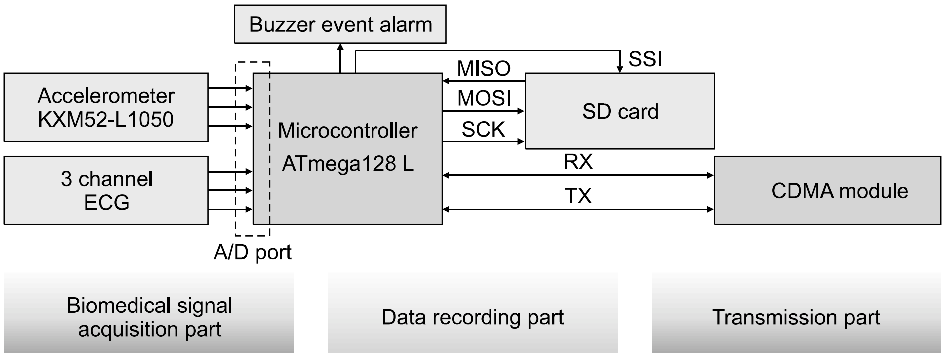

Figure 2. Block diagram of the biomedical mobile device.

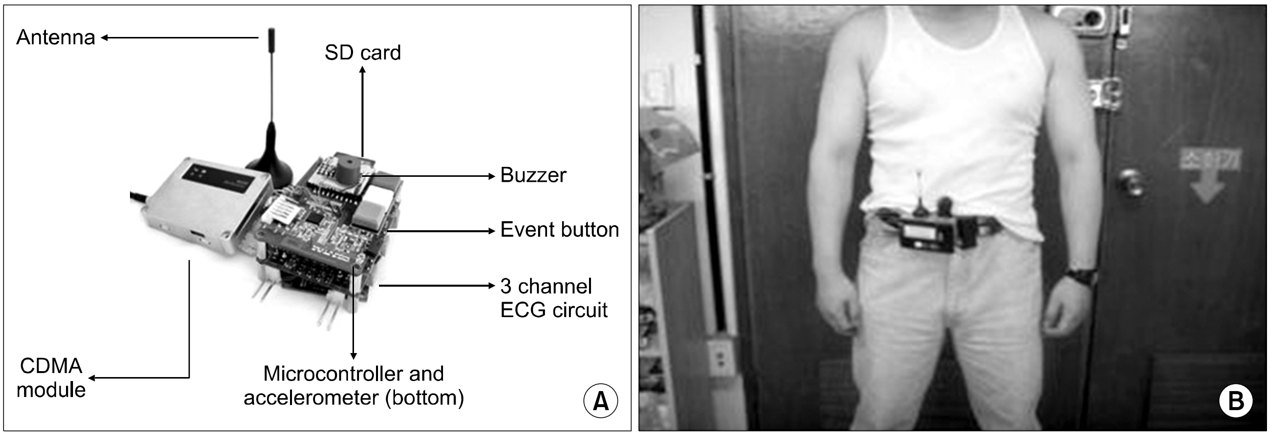

Figure 3. Belt-type biomedical mobile device. (A) Biomedical mobile device. (B) The device worn by a user.

Input signals of the microcontroller go through A/D conversion and are recorded in the SD card, and on the occurrence of an event, the data are transmitted to a remote server through CDMA network.

Figure 3 shows the implemented belt-type biomedical mobile device. (A) shows the detailed parts of the biomedical mobile device, and (B) shows the device worn by a user. As the developed device is small in size and of highly wearable belt type, it is easy to carry and can measure signals while the user is moving. In addition, because it measures the holter function, the event-recorder function, and the motion function simultaneously, it can cope with emergent situations quickly.

2. Software-two types of operation mode

The belt-type biomedical mobile device is programmed to operate in two modes. One is event- recorder automatic mode in which ECG and acceleration data are recorded in the SD card in real-time and when the patient's heart rate is under 40 or over 180 or when the ECG lead wire has fallen off, an event is generated and 30 seconds' previous data are transmitted to a remote server. The other is event-recorder manual mode in which if the patient feels his/her heart abnormal he/she generates an event by pressing the button. Data are recorded in order of header, 3-channel ECG, and acceleration. ECG is recorded continuously, and accele-

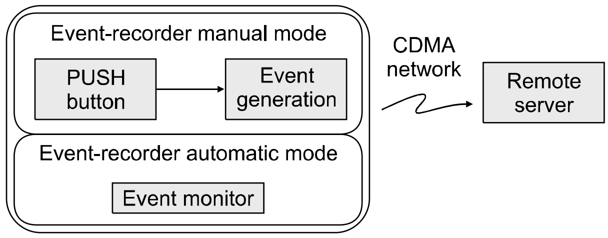

Figure 4. Conceptual diagram of the two operation modes.

ration signal is recorded once in every 10 times together with ECG (Fig. 4).

3. Experiment method

In order to evaluate the performance of the developed device, we tested its accuracy, reliability and operability, applicability to daily life, SMS alarm function, etc. with healthy subjects. First, using the developed device and a biopac ECG system (reference system), we measured signals in 4 men and 4 women while they were sitting, standing, lying, or cycling, and then analyzed the signals comparatively and tested the accuracy of R-R interval. In this experiment, the sampling rate was 1,000 Hz for the biopac system and 200 Hz for the developed device. Second, we tested if data are transmitted reliably to the remote medical server when two types of emergent events (the falling off of the electrode, the pressing of the event button) are generated in the developed device using a patient simulator, and measured battery life to see if the device is usable for a long time. Events were generated once an hour, and at that time, battery life was measured together. Third, we tested whether the device transmits the corresponding data accurately to the remote server through CDMA network when two types of events are generated for each of seven types of action (sitting, standing, standing up from the seat, ordinary walking, fast walking, cycling, and running). Lastly, we tested the SMS alarm function to see if the device can cope with an emergent situation promptly.

III. Results

1. Correlation between R-R intervals calculated using signals from the developed ECG device and Biopac ECG system

Figure 5 shows Bland-Altman plot for seated posture. R value was 0.9999 and the number of R-R intervals was 8852. The percentage of heart beats with R-R interval error less than 5 ms was 99.9% for seated posture, so the experiment verified the accuracy of the developed device. Table 2 shows accuracy and error rate for sitting, standing, lying, and cycling. As in Table 2, the percentage of heart beats with R-R interval error less than 5 ms was 99.9%, 99.8%, 99.9%, and 99.7%, respectively, for the postures, and the maximum error was 6 ms for sitting, standing, and lying, and 8 ms for cycling.

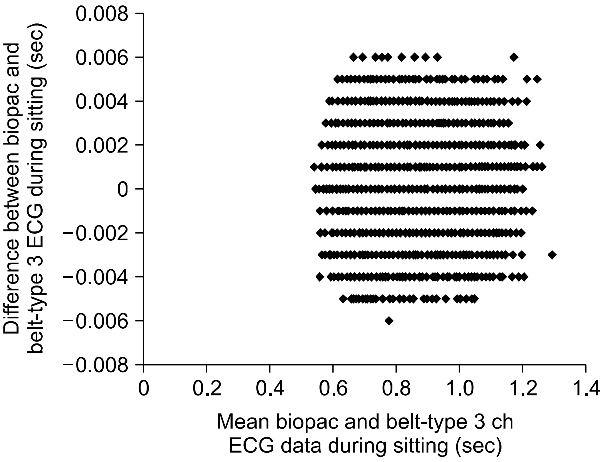

Figure 5. Bland-Altman plots of the R-R intervals for seated posture measured in the two devices.

Table 2. The parameters representing r-r interval accuracy

Type	# of HB	# of HB {error ≤5 ms}	Percentage (%)	R
Sitting	8,852	8,841	99.88	0.9999
Standing	10,699	10,675	99.78	0.9996
Lying	8,524	8,512	99.86	0.9999
Cycling	7,919	7,895	99.70	0.9996

Table 3. Battery life according to event type

Battery	Operating time without events	Operating time with button pressing events	Operating time with electrode falling-off events
3 AAA's	About 14 hours	About 13 hours	About 13 hours
3 AA's	About 25 hours	About 24 hours	About 24 hours

2. Results of testing the reliability and operability of the developed device

We tested if data are transmitted reliably to the remote server when two types of events are generated in the developed device, and measured battery life to see if the device is usable for a long time. In the experiment, events were generated once an hour and the result was examined and summarized in Table 3.

3. Results of generation biomedical signal events using CDMA network

The following are the results of testing whether data are transmitted accurately to the remote server when events are generated by action type using CDMA network. In the experiment, 8 subjects performed seven types of action for the two types of event. Figure 6 shows the results of transmission to a remote server on the occurrence of two types of event in Subject 1.

Figure 6 shows 3-channel ECG signal and motion signal transmitted to the remote server on the occurrence of events (button pressing and electrode falling-off) during running and walking. It shows that data are transmitted accurately to the remote server not only in actions without positional change but also in actions with positional change like running. This means that the subject's biomedical signals can be monitored continuously not only at home but also while moving, and the occurrence of an event can be coped with immediately. In addition, because motion signals can be monitored together with ECG, the user's situation can be figured out.

The following are results on the accuracy of data transmission to the remote server when events were generated for each behavior pattern using CDMA network. In the experiment, each of eight subjects tested for two kinds of events out of seven patterns (sitting, standing, standing up from the seat, ordinary walking, fast walking, cycling, and running), and experiment time was five minute per type. In all the subjects (Subject 1-8), 48 KB of data was transmitted to the remote medical server without error.

4. Results of testing the SMS alarm function

Figure 7 shows the results of testing the SMS alarm function. In (A), a remote doctor sends an emergent message to a subject carrying the belt-type biomedical mobile device. The remote doctor sends 13 byte RS0001:RP0001 text message, in which RS0001 is a

Figure 6. The results of transmission to a remote server on the occurrence of events during Subject 1's running and walking (button pressing (A) and electrode falling-off (B))

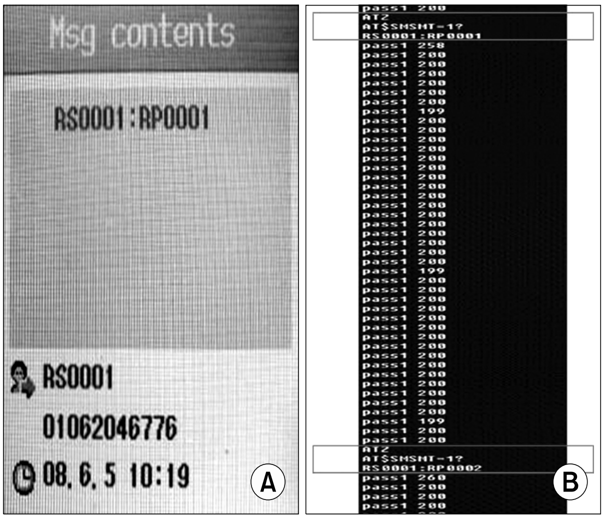

Figure 7. Results of receiving a SMS alarm. (A) SMS alarm message. (B) Screen of terminal emulator.

Table 4. SMS message sent by remote doctor

Type	Code	Byte
Remote service code	RS0001	6
Delimiter	‘:’	1
Recommended procedure code	RP0001	6

remote service code and RP0001 is a recommended procedure code as shown in Table 4. (B) is the results of testing with a terminal emulator whether the emergent message is transmitted accurately to the subject carrying the device. The results show that the device receives ECG signal continuously using a patient simulator for the experiment and when a message comes from the remote doctor it receives the message and sounds an alarm in the buzzer fixed on the device to inform that it is an emergent situation.

IV. Discussion

The present study developed an integrated system that can measure ECG and motion signals continuously while the user is moving and, on the occurrence of an emergent situation, transmits emergent situation data to a remote medical server through CDMA network and reports the situation, and tested the system’s accuracy, reliability and operability, applicability to daily life, and SMS alarm function through experiments. First, we examined the accuracy of R-R interval through comparative analysis of signals obtained using the developed device and a commercialized ECG system while the subjects were sitting, standing, lying, or cycling. In the four types of gesture, the percentage of heart beats with R-R interval error less than 5 ms was over 99%, proving that the device is as good in measuring heart rate as commercialized non-portable systems. Second, we tested whether data are transmitted reliably to the remote server when two types of emergent events are generated in the developed device using a patient simulator, and measured battery life together to see if the device is usable for a long time. The device operated for around 13 hours with 3 AAA batteries, and around 24 hours with 3 AA batteries. This results show that the developed system can perform both the holter ECG function and the event-recorder function at the same time. Third, we tested whether the corresponding data are transmitted accurately to the remote server when two types of events are generated using CDMA network for each of seven types of action in daily life. The existing holter system recorded the variation of ECG waveform continuously and detected cardiovascular diseases based on the variation of waveform in the recorded data. A shortcoming of this system is that the user’s current situation is unknown. Therefore, we tried to measure 3-axis acceleration signal together with ECG in order to figure out the user’s current state. This is expected to make health state evaluation and treatment more meaningful, and produced data are considered quite useful in evaluating patients’ behavior[6-8]. In addition, remote management using CDMA network will enable a prompt action in emergency. Lastly, this study tested the SMS alarm function. This function was designed for the old, the weak or chronic disease patients to get prompt rescue or first aid services through the biomedical mobile device. That is, medical staff examines the waveforms of ECG and acceleration transmitted to a remote medical server, and if they find any problem they let the patient know the situation by sending an emergent message to the patient.

The present study developed a belt-type biomedical mobile device and concluded as follows. When the subjects' biomedical signals and motion signals were collected and compared, the device showed high accuracy, reliability and operability, applicability to daily life, and SMS alarm function to be used during daily life. It is also considered usable to cope with emergent situations promptly and applicable to patients who need to be monitored continuously for chronic disease management and health management. In addition, the device may be integrated into systems for monitoring ordinary people or the old and weak in daily life, and a remote server will enable continuous monitoring of patients' state and prompt help in emergency. The system will be improved further to be applicable to real patients by adding various types of heart disease information, and the size will be reduced further. In addition, it will be studied in connection to injuries caused by falling that is frequent in elders and physical impaired people, and the existing algorithm will be extended to detect falling as well.

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