

Research Article

A Tele-Electrocardiographic Monitoring System for Patients with Chronic Diseases at Home

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Introduction

Japan is regarded as a super aging society because of its rapid declining birth rate; and will face serious medical cost inflation in the near future unless a comprehensive strategy can be established for care of elderly people with advanced chronic illness. To reduce medical cost due to unnecessary stay in hospitals; tele-healthcare systems using information and communication technology for home medical care have gained attention.

In such situations; a patient with a chronic disease can be carefully nursed at home as in a hospital; and the patient's end-of-life can be decided by a medical doctor if applicable. For this; it is desirable to establish a tele-healthcare system such that a 24hour monitoring service can be provided to the patient at low cost to reduce the family's burden; and the doctor can receive useful information for deciding the patient's end-of-life and medical condition. In general; hospitals have many bed-side monitors with wired communication to detect biological signals; such as the Electrocardiogram (ECG). Recent developments have shown the ECG signals to be monitored through a wireless communication device placed on the patient's chest [1-8]. However; the durability of its battery is extremely low for using at home because a patient's family member should not change the battery of medical equipment [4].

Further; many types of wearable sensors have recently been proposed to detect biological signals; such as photoplethysmogram; acceleration; and temperature in mobile environment using a personal computer or a smart phone for healthcare. However; almost all these devices have been developed for people who are not bedridden with serious illnesses.

In our present study; we developed a smart phone-based wireless ECG system connected through the Internet with a remote server. This system enables medical doctors to monitor ECG signals of patients with chronic diseases at their homes by accessing the server through

Abstract

In this study, a smart phone-based wireless Electrocardiographic (ECG) system connected through the internet to a remote server is developed. This system enables medical doctors to monitor ECG signals of patients with chronic diseases at their homes by accessing the server with ordinary computers anytime and anywhere. The battery of the system is durable for at least seven days, and thus the system is suitable for visiting medical care. The experimental results indicate that long-term monitoring through the smart phone and server will provide rich information on a patient's terminal status for doctors in remote locations. However, it is necessary to collect extensive clinical data to predict the timing of end-of-life more precisely.

Keywords: Tele-healthcare system; End-of-life decision; ECG; Wireless sensor; Bluetooth

ordinary computers or smart phones; anytime and anywhere. The system battery is durable for at least seven days; and thus the system is suitable for visiting medical care.

Materials and Methods

Overall structure

Figure 1 shows the overall structure of the remote ECG monitoring system developed in this study; with the roles of each medical staff. The system consists of wireless ECG sensors and smart phones connected to a data server. The procedure of this system is as follows:

1. A family doctor visits a patient's home and prepares the wireless ECG sensor on the patient's chest.
2. The ECG sensor communicates with a smart phone via Bluetooth.
3. Data transmission through the Internet.
4. Online monitoring of ECG.
5. Treatment in emergencies.
6. Request of Image interpretation.
7. Results of Image interpretation.

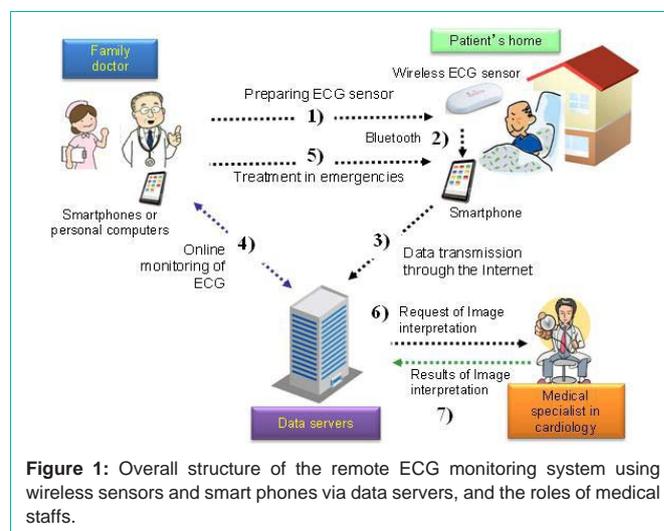


Figure 1: Overall structure of the remote ECG monitoring system using wireless sensors and smart phones via data servers, and the roles of medical staffs.

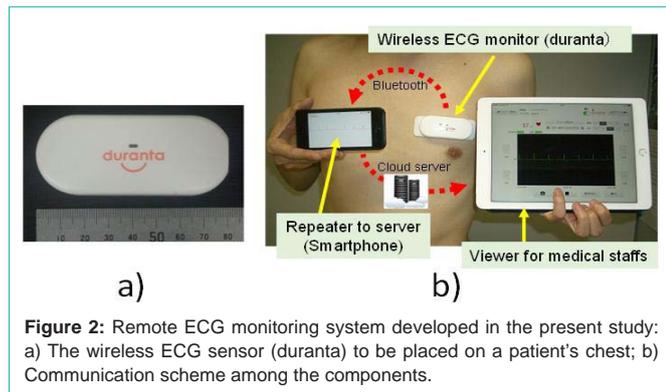


Figure 2: Remote ECG monitoring system developed in the present study: a) The wireless ECG sensor (duranta) to be placed on a patient's chest; b) Communication scheme among the components.

3. The smart phone transmits the ECG waveform data to the data server via the Internet.
4. The family doctor can read the patient's ECG data in any remote place using a personal computer.
5. If the doctor judges an emergency case on the basis of the ECG waveform; the doctor can visit the patient's home and may decide the end-of-life.
6. Medical specialists in cardiology with prior approval can also access the server to read the ECG waveform data from anywhere.
7. The family doctor can obtain advice from specialists if necessary.

The most important condition for the proposed system to perform effectively is that the lifetime of the battery used in the wireless ECG sensor is more than a week. This is because the battery must be changed by a medical staff such as a doctor or a nurse who intermittently visits approximately every week.

The authors have developed the system satisfying the above condition. Each component of the system is described as follows.

Wireless ECG sensor

The developed wireless ECG sensor named "duranta" shown in Figure 2a is used on a patient's chest. Its size is 78.4(W); 35.1(H); 14.7(D) mm³; weight is 35g; and Japanese medical instrument authentication number is 226AIBZX00055000. The sensor has one channel with two electrical poles on the reverse side connecting an electrode sheet with snaps. A 32 bit ARM microcomputer samples the ECG signal at the sampling frequency of 160Hz with a 12bit A/D converter.

The data are sent to a smart phone (i Phone; Apple Inc.) with a Bluetooth 4.0 communication module; which utilizes much lower electric power than Bluetooth 3.0; however; the available communication distance is limited to several meters. To save consumption power as much as possible; new communication and performance algorithms were developed such that the waveform is sent intermittently for every 20 samples and the microcomputer always moves to the stand-by mode except for A/D conversion and wireless communication. A 3.7V and 600mAh lithium ion battery is used; and lasts for more than 7days and a maximum of 10 days after full charge; by applying the aforementioned strategy.

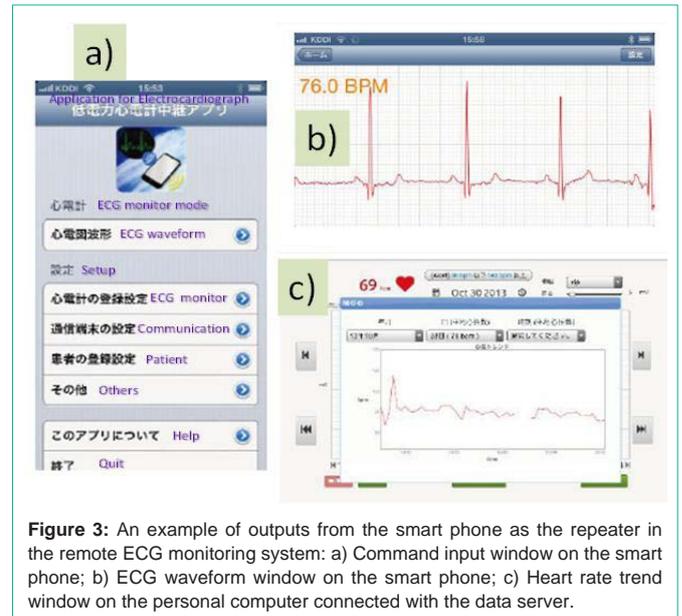


Figure 3: An example of outputs from the smart phone as the repeater in the remote ECG monitoring system: a) Command input window on the smart phone; b) ECG waveform window on the smart phone; c) Heart rate trend window on the personal computer connected with the data server.

In general; electrodes for ECGs are apt to induce a feeling of itching and peel from the body a few days after being pasted. To reduce these drawbacks as much as possible; the authors selected the quality of materials on the basis of the electrodes and components of the conductive glue and jelly; and then new electrodes were developed to be used for more than a week.

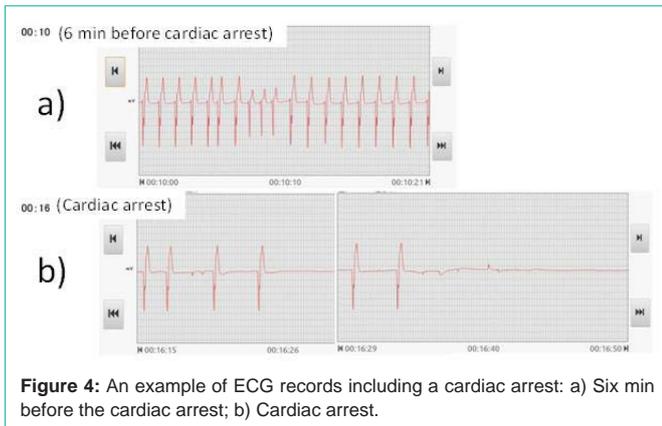
Repeater

As shown in Figure 2b; the smart phone placed near the ECG sensor plays the role of a repeater and sends the patient's data to the remote server through the Internet by using Japanese mobile phone networks with 3G and LTE communication modes. It is necessary for the smart phone to always be supplied with AC electrical power. Of course; a short disconnection with an electrical outlet is allowable because of its battery supply. Figure 3 shows an example of display outputs obtained from the smart phone operating as the repeater; on which an exclusive application is installed for monitoring ECG signals from the sensor. Figure 3a and Figure 3b show windows displaying the command input and ECG waveform; respectively. The total communication volume consumed is approximately 70MB per day.

Remote data server and browsing computers

The ECG waveform data transmitted from several repeaters at different locations are collected in the remote exclusive data server. An SSL cryptographic communication is used in the transmission for sufficient security. Further; another application was developed for the computers to view the ECG data. Obviously; the access to the server is limited to medical staff with an ID/password. Only ID numbers assigned to different patients are used in the sensors; repeaters; and server to prevent access to patient's personal information. Only the family doctor can recognize the connection between the ID number and the patient.

The application installed in the computer for browsing the data can show the current ECG waveforms; heart rate; and residual quantity of the battery. As shown in Figure 3c; the past data; such



as the ECG waveforms and heart-rate trend data categorized by the date and time can also be shown. If the medical personnel have their own computers with an Internet browser (Chrome; Google Inc.) in any Wi-Fi environment; they can view the data from anywhere. The system triggers an alarm and sends an e-mail to the staff if the heart rate goes out of the range set previously. A single computer can browse data from several repeaters.

Clinical Tests

Two medical places in Iwate prefecture; Japan were asked to use the developed system after approval from the ethics committee of the affiliations and agreement of the patients and their families. One is a clinic providing home medical care “Kamaishi Family Clinic” and the other is a nursing home for the elderly “Aizen-no Sato.” After collecting data for five months; four cases were obtained; including records on death beds.

Results and Discussion

Figure 3 verifies that we were able to browse the ECG waveforms anywhere with Wi-Fi connected with the data server; which was prepared in Hokkaido; Japan. We used a chip set of Bluetooth 4.0 to ensure that the lifetime of the battery of the wireless ECG sensor endured for eight days. Figure 4 illustrates a record of a cardiac arrest. Figure 4a shows the browsed data 6min before the cardiac arrest; and Figure 4b shows the data during the cardiac arrest. In this case; tachycardias and extra systoles were observed for several minutes before the cardiac arrest. However; it is difficult to previously judge when the cardiac arrest exactly occurs. In another case; we observed long-term bradycardia lasting for several tens of minutes before death.

Of course; the ECG waveforms vary with the type of illness; and it is quite difficult to exactly predict the last moment; except in the case of a fatal arrhythmia such as ventricular fibrillation. However; it may be useful for the medical doctors with vast experience to estimate if the patient’s medical condition is close to critical condition by viewing the ECG waveforms with the proposed system.

The doctors evaluated that they were satisfied as they could monitor the patients’ ECG data anytime they wanted; and automatically receive e-mails in an emergency. Moreover; most of the patients’ families told that they felt relieved because the medical staff continued to monitor the patients through the communication tool in spite of the remote connection.

Unlike an implantable cardioverter defibrillator; the proposed system cannot perform defibrillation even if the fatal arrhythmia occurs. If there is an Automated External Defibrillator (AED) in the room; the family doctor who received an alarm from the server will be able to instruct someone to use the AED through a telephone.

On the other hand; there are concerns about effects of electromagnetic radiation on the human body. However; the World Health Organization has reported that “to date; no adverse health effects have been established as being caused by mobile phone use” [9]. In addition; the specific absorption rates of Bluetooth 4.0 used in the proposed system are so substantially below the Federal limit that they are insignificant in comparison to cell phone networks [10].

There are many similar studies on wireless ECG monitoring for telemedicine using mobile or Web based communication [1-8]. However; the present study focuses on the practical use of the system by the visiting medical care staff whose visiting period is approximately once a week; and the lifetime of battery and the durability of electrodes are attained as per the design.

Conclusion

The experimental results indicated that long-term and continuous ECG monitoring for more than a week by using the proposed system consisting of the wireless sensor; smart phone; and data server can provide rich information on the patient’s terminal condition to medical staff in remote locations. Notably; with the use of this system; it is possible to reduce physical load and mental stress of not only medical staff but also patients’ families. However; it is necessary to collect much more clinical data for predicting the timing of patients’ end-of-life more precisely.

This study did not solve the problem of the occurrence of radio interference in environments where there are many electronic devices using Bluetooth; such as an exhibition hall for new electronic devices. However; this would be exceptional in the case of usual homes subject to the visiting medical care.

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