Ubiquitous Monitoring System for Chronic Obstructive Pulmonary Disease and Heart Disease Patients

Il Hyung Shin, Jae Ho Lee, and Hee Chan Kim, Member IEEE

Abstract— The Purpose of this paper is to report a code division multiple access (CDMA) based wireless device that is able to measure pulse oxygen saturation (SpO2) and Electrocardiogram (ECG) during chronic obstructive pulmonary disease and heart disease patients’ daily life at home. Global Positioning System (GPS) and a specific database system are also included in this device to trace patient’s location. Unlike the pre-reported devices using wireless network like Bluetooth™ or Zigbee™ which has a limited connection area, the developed system enables the literally ubiquitous service in reporting the patient’s data to their doctors at any time and any place using the CDMA-based cellular phone network.

I. INTRODUCTION

CHRONIC obstructive pulmonary disease (COPD) and heart disease patients after treatment in hospital need a continuous monitoring device to measure SpO2 and ECG during their daily life at home. Devices to be used for that purpose should be small in its dimension and have low power consumption as a portable one. Furthermore, they must be linked to a telecommunication network in order to ubiquitously transmit the measured data to healthcare providers.

The purpose of this study was to develop a device that is able to monitor the COPD and heart disease patient’s health state continuously during their daily life and transmit the measured data to the designated doctors.[1] To achieve this, we have developed a portable device connected to the CDMA cellular phone network because the CDMA network provides a wide range of connection and a broad bandwidth for ubiquitous telecommunication. We have also included a GPS module to trace patient’s location and developed the monitoring software including a server program and a database.

II. MATERIALS AND METHODS

A. PDA with CDMA module

A PDA (POZ X510, Cyberbank, Korea) was selected as a base station to store the measured bio-signal data (SpO2 and ECG) internally and transmit them to external TCP/IP server. The PDA is based on the Microsoft Pocket PC 2003 Platform and the size and the weight are 52mm X 112.5mm X 22mm and 151g (including battery), respectively. It has a 240 X 320 TFT LCD and a 64MB internal flash type memory. The power source of the PDA is 1380mAh Li-Polymer battery. The PDA is connected to the bio-signal measurement modules through a RS-232 linkage. Using the included CDMA module, it connects with a cellular phone network for data transmission to a remote server through calling the remote access server (RAS) protocol, which has been programmed using embedded visual C++ 4.0 (Microsoft, USA) with Platform Builder 4.2 (Microsoft, USA).

Moreover, it has a function of sending character messages to doctor’s cellular phone when the measured values of SpO2 and ECG exceed the maximum value that is set up by the doctor. We have used an arm band so that a patient easily put the PDA in his/her arm for a long time.

B. SpO2 measurement module

The module to measure the SpO2 is Nonin OEM III
Module (Nonin, USA) that has the size of 34mm X 24mm, the weight of 6.6g and the power consumption of 29mW in normal operation. A reusable and flexible rubber type SpO2 sensor (8000SM, Nonin, USA) was selected for patient’s convenience.

In order to investigate any correlation between patient’s SpO2 data and specific behavior, we have provided 4 selection buttons on a touch screen LCD of the PDA which corresponds to walking, eating, going to the restroom and resting states. After the patient chooses one of these 4 selections, the PDA performs 4 second data acquisition (photoplethysmographic (PPG) data sampled at 75Hz and SpO2 values) and save the data into internal flash memory. Then, it starts data transmission and after that the PDA falls into a power saving mode automatically for reducing power consumption. At every 5 minutes under power saving mode, the PDA wakes up automatically and repeats the same operation. Additionally, whenever the measured SpO2 value exceeds a predetermined limit set by a physician, the PDA sends a short message to the physician automatically.

C. ECG measurement module

An ECG measurement module was developed in house. Its size and weight are 39.6mm X 47.8mm and 16.1g, respectively. A standard lead-II waveform of ECG is measured using gel-type Ag/AgCl electrodes. For the purpose of easy application, the electrodes were integrated into the ECG module which is attached to the middle of chest as shown in Fig. 3. The ECG module has a 14bit A/D converter which digitizes the measured ECG waveform at 100Hz sampling rate.

Like the SpO2 module, the ECG module also measures and transmits ECG data for 4 seconds at every 5 minutes and generates an alert message to the doctor when an emergency situation is recognized based on the measure ECG data.

D. GPS Module

GPS module was included in order to provide the patient’s exact location when emergency situation happens. We used a commercial GPS module (BU-353, GSAT, Taiwan) connected to the PDA via USB interface. The GPS data in NMEA protocol are parsed in the PDA before transmitted to a remote server.

E. Monitoring program including data collection module and database module

At the doctor’s office we need a monitoring program to check the selected patient’s condition based on the transmitted data. The monitoring program includes a user interface function[2] and 2 modules of data collection and database for efficient storage of the transmitted data via wireless network.

Basically, it shows in real-time the transferred SpO2 data and ECG data via graphs and tables and also enables the doctor to retrieve any past data for reexamination. The monitoring software is programmed on MS .NET Framework (Microsoft, USA) using visual C#.

The data collection module is a general TCP/IP server which prepares fora sudden disconnection from client and has a function of demilitarized zone (DMZ) client for a DMZ server typically incorporated in most hospitals for security purpose.

The database module saves the data as MS Access™ (Microsoft, USA) format. The saved data include SpO2 value, heart rate, ECG, PPG, patient ID, measured date, measured time and patient’s state. Both data collection module and database module is made on Microsoft Foundation Class (MFC) platform using visual C++ (Microsoft, USA).

III. RESULTS

A. SpO2 data transmission

Fig. 4 shows the SpO2 data transmitted from a patient’s home via CDMA network for 24 hours. This patient with an idiopathic pulmonary fibrosis was put on a respirator at all times to keep the SpO2 values always above 90%. From the results of Fig. 4, we could see that there existed a period of relatively low SpO2 values during outside walking, which
would not be possible to find out without using a system like one developed in this paper.

**B. ECG data transmission**

Fig. 5 shows the transmitted ECG data from the PDA via CDMA network. In Fig. 5, each red line indicates the starting point of data acquisition at every 5 minute. The data length between two red lines is 4 seconds. The data in Fig. 5 was acquired from the same COPD patient in the SpO2 transmission case above who has a normal sinus rhythm.

**C. Usefulness of GPS information**

As shown Table I, the GPS information was good enough to trace the patient’s location and events and there was no single event of data missing unless the patient was inside of the building. In Fig. 6, the measured GPS information is overlayed onto a real map to see the actual trajectory of the patient’s movement.

### TABLE I

<table>
<thead>
<tr>
<th>Test</th>
<th>Area</th>
<th>Number of Events</th>
<th>Found</th>
<th>Not Found</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Urban</td>
<td>84</td>
<td>84</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Suburban</td>
<td>120</td>
<td>120</td>
<td>0</td>
</tr>
</tbody>
</table>

**D. Monitoring Program**

Fig. 7 shows a typical display of the developed monitoring program for the SpO2 measurement.
IV. DISCUSSION

From the results of performance evaluation test with real patients, we found that the developed system is very useful for monitoring the COPD and Heart Disease patients. Moreover, it is verified that the system can be also applied to emergency reporting based on the reliability of the component modules and tracing function of the patient’s location. Since the patient wearing device is not so expensive, many patients can be monitored simultaneously by one medical doctor.

For further improvements, we are working on the increasing the total operating time without battery change by reducing the power consumption level of the bio-signal measurement device as well as increasing the battery capacity. More intelligent data analysis algorithms will be included to provide the clinical decision support.

V. CONCLUSION

In this paper, we have developed a wireless ECG and SpO₂ measurement device for the COPD and heart disease patients during their daily life at home. From the preliminary performance tests, we confirmed that the developed system will greatly help the quality of patients’ daily life by providing ubiquitous healthcare services.

REFERENCES


