

A LOW-COST WIRELESS HEALTHCARE MONITORING SYSTEM AND COMMUNICATION TO A CLINICAL ALARM STATION

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ABSTRACT

A state-of-the-art, pocket PC based, low-cost, portable, wireless health monitoring and alarm system is proposed in this paper. Human's electrocardiogram (ECG), body temperature and heart rate information are acquired and sent to a personal digital assistant (PDA) using IEEE 802.15.1 Bluetooth. If an emergency situation occurs, the PDA sends the information to the central server using either WLAN or GSM/GPRS wireless technology. Through this way, real-time remotely monitoring is achieved. With the developed system, not only people can be monitored from outside of hospitals, but also an early treatment is possible. Furthermore, locational data obtained from GPS receiver is shown on the digital map and sent to the related units. Thus, the proposed system makes the human's daily life easier and more comfortable.

I. INTRODUCTION

Healthcare problems are being more important for societies whose population is getting older. In 2025, 761 million of people in the world will be over 65 years (this estimation is twice of the 1990's rate) [1]. Coronary heart diseases are at the top of the world death cause list and every year 7.2 million people die because of these diseases [2]. Healthcare providers are planning to develop intelligent and low-cost ubiquitous systems to make more comfortable life for people who suffer from chronic diseases like Alzheimer and heart diseases. Because of the advances in wireless communication and embedded computation technologies, remote health monitoring and telemedicine topics become a very active research area recently. Therefore, developing low-cost, portable and wearable remote health monitoring systems enable observing of some diseases outside from the hospitals [3].

The aim of developing remote health monitoring systems is to monitor online medical parameters and to reach this information from everywhere. Because of the lessen cost in wireless communication technologies, implementations of them to monitoring systems have become easier.

In remote ECG monitoring systems, various advanced telecommunication techniques are being used and some standards are determined for ambulatory electrocardiography [4]. The monitoring systems are examined in two groups as real time systems and store-and-forward systems. Today, lots of commercial portable Holter monitoring systems and cardiac event record systems are being sold [5]. But in these types of systems, ECG electrodes are connected to the recording unit with cables. Besides the systems mentioned above, systems that uses wireless local area networks (WLAN) [6] and GSM/GPRS [7] are proposed.

If a simple and wireless ECG sensor can be designed to be used easily for the patient, it is possible to integrate with a portable PC for diagnosing critic cardiac events and heart beat anomalies [8, 9]. Thus, an emergency alarm system can be obtained. Unlike the existing commercial systems, proposed low-cost system can be used easily and monitor real-time ECG signal with alarm capabilities. This solution not only gives patient more freedom, but also provides early diagnosis of cardiac diseases with its alarming properties. Furthermore, it can be used as a Holter device by arrhythmia patients.

In this study, a state-of-the-art portable wireless health monitoring system and communication to a clinical alarm station is presented. In the section 2 the proposed hardware system is explained. Section 3 presents the software architecture, and the last section presents the conclusion and discussion.

II. PROPOSED HARDWARE SYSTEM

This system acquires ECG signal, body temperature, heart rate of the individual locational data by an embedded system known as Portable Monitoring Unit (PMU) and then transfers the data to a PDA used as a gateway via IEEE 802.15.1 Bluetooth wireless communication technology. The PDA displays the information on the screen of the device and stores it. If an emergency situation occurs, the data is sent to the central server by

Internet using IEEE 802.11 WLAN or GSM/GPRS wireless communication technologies. With the developed system, long term storing of the medical parameters, real-time transferring of the data to the central server and informing - alarming of the related institutions on an emergency situation are achieved. In this way, patients obtain more freedom while they are doing their daily activities. General diagram of the proposed approach is given in Figure 1.

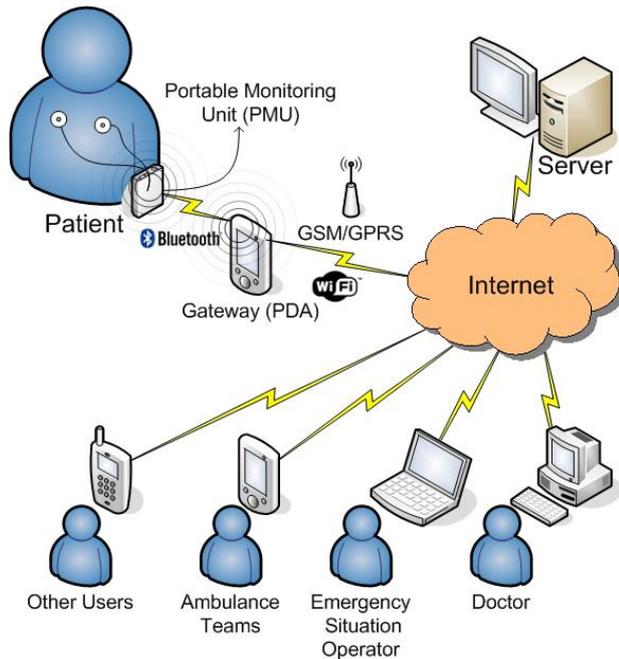


Figure 1. Basic diagram of the proposed system.

ECG AMPLIFIER COMPONENT

ECG signals are received from human body as a result of the electrical activity of heart. The amplitude of the signal varies between 0.05 mV - 10 mV and must be amplified with an amplifier. The noises caused by the 50 Hz interference of the power electricity lines, human body, active and passive circuit components and wires that flow current of the circuit are suppressed with passive low pass and high pass RC filters.

In this study, a 3-electrode driven right-leg ECG amplifier is designed. Signals taken from Ag-Cl electrodes are amplified by Analog Device's AD620 operational amplifier which is being used as an instrumentation amplifier. Then, a simple 0.05 Hz - 35 Hz band pass RC filter is employed. In final step, for adapting the signal to microcontroller's sampling range, a LF353 operational gain amplifier by National Semiconductor is used. The block diagram of the sensor is given in Figure 2.

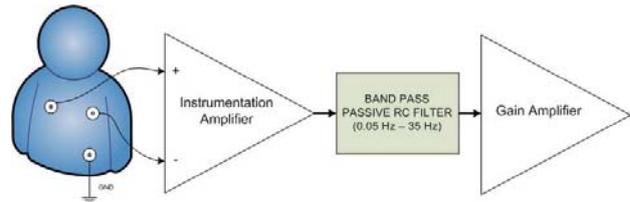


Figure 2. Block diagram of ECG amplifier.

PORTABLE MONITORING UNIT

For sampling, analyzing and transferring the ECG data to PDA, PMU is developed. The embedded software's pseudo code that is running on the PMU is given in Table 1. PMU samples the analog signal that received from the

ECG amplifier with 512 Hz, 8-bit resolution. To suppress the 50 Hz power line interferences completely, a 50 Hz digital IIR Butterworth band-stop filter is designed and implemented by PMU.

Table 1. Pseudo code of the PMU embedded software.

```
#include <PIC16F877.h>
#int_rtcc //TIMER0 (RTCC) interrupt service routine
clock_isr(){ //invoked every 2.048 msec. (~500 Hz)
    sample_ecg();
    filter_ecg();
    detect_heart_rate();
    acquire_temperature(); //invoked every 6 sec.
    build_dataframe_and_send();
}
#int_rda { //USART interrupt service routine
usart_isr()
    change_dataframe_mode(); //mode=0 or mode=1
}
main(){
    set_timer0();
    set_adc();
    enable_interrupts(INT_RTCC/INT_RDA);
    while (true){
        //NOP
    }
}
```

Transfer function of an IIR filter is given in Equation 1.

$$H(z) = \frac{B(z)}{A(z)} = \frac{b(1) + b(2)z^{-1} + \dots + b(n+1)z^{-n}}{1 + a(1)z^{-1} + \dots + a(n+1)z^{-n}} \quad (1)$$

The coefficients of the IIR filter are floating point real numbers between -1 and 1. Because of the limited memory and computation capability of the microcontroller, it is difficult to use floating point real number coefficients in arithmetical operations for the CPU. So, the filter coefficients are multiplied with a

constant integer number and rounded. The coefficients of the implemented IIR filter are given in Table 2.

Table 2. Filter coefficients converted to integer values.

b(1) = 133	b(2) = -219	b(3) = 133
a(1) = 150	a(2) = -219	a(3) = 117

After this step, ECG signal is analyzed and heart rate information is computed. In heart rate computation, distance between the R peaks is determined and frequency of the R peaks for each minute is computed. Developed heart rate detection algorithm runs on 6 seconds duration of the ECG data. The algorithm uses the first 1 second duration of the data for learning and the following 5 seconds to find the R peaks in the signal. Considering the distance between each R peak pair, heart rate is computed and the average of these values is send to the PDA. Steps of the proposed heart detection algorithm are as the following:

- Compute the average value of the 1 second duration of the ECG data.
- Calculate the maximum value of the 1 second duration of the ECG data.
- Determine the adaptive threshold level. (Threshold = (avg+max)/2)
- Find the peak locations that exceed the threshold level for the rest 5 second duration of ECG data.
- Measure the heart rate by using the distances between the peaks.
- If the calculated heart rate is not between 40 and 130, ignore that value.
- Compute the average value of obtained heart rates.
- Repeat these operations in every 6 second.

Figure 3 shows the R peaks on an ECG data and adaptive threshold level which is shown.

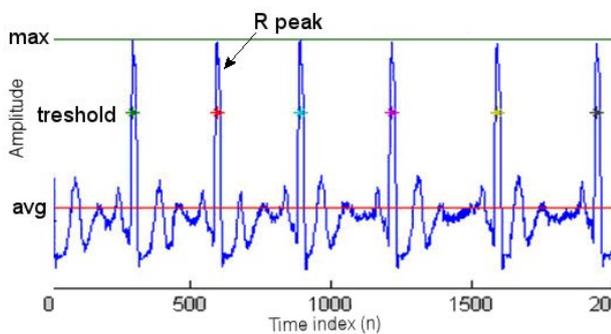


Figure 3. Heart rate detection algorithm.

PMU acquires the body temperature from DS1621 temperature sensor by Maxim-Dallas using I²C serial protocol. Obtained data (ECG, heart rate and temperature) is packaged as frames. The system has two type of data

package frame. Small package is totally 5 byte length, first 3 byte contains the header information, 1 byte is for temperature information and 1 byte is for computed heart rate information. In big package, first 5 byte is similar to the small package and rest contains 240 byte ECG signal. Also, the PDA can select the proper data package mode.

The data is transferred to PDA wirelessly by Bluetooth. In PMU embedded system, Microchip's PIC16F877 microcontroller is used. Block diagram of the PMU is given in Figure 4 and designed prototype is given in Figure 5.

III. SOFTWARE ARCHITECTURE

The software system has 5 different components: web services, a software interface for mobile user, a software interface for emergency situation intervention operator, a software interface for emergency situation ambulance team and web applications for doctors. Additionally there are stored procedures and triggers on the database management system. All relations between software components and database are made by XML Web services infrastructure. The software architecture is designed with Microsoft Visual Studio 2005 environment using .NET technology.

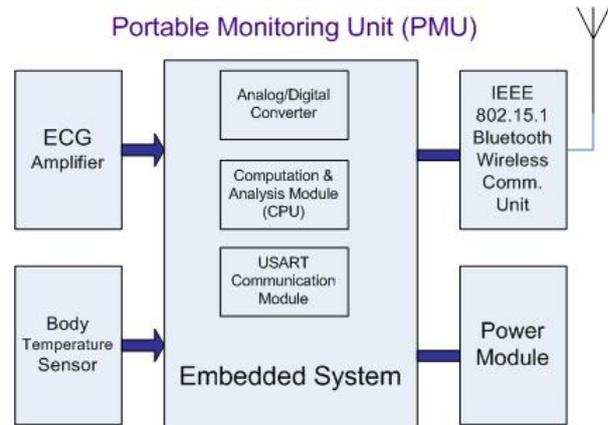


Figure 4. Portable Monitoring Unit block diagram.

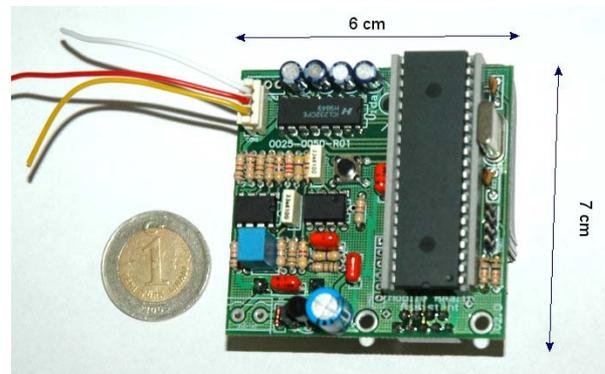


Figure 5. Developed PMU prototype.

Web services enable the communication of the softwares on an industrial protocol standard and are served on World Wide Web. They help for the maximum usability of components. Operations such as security, authorization and identification are executed from a center and this is an advantage for system security.

Software interface for mobile user is an application that runs on patient's portable device (e.g. PDA). This module is very important for the system. Because, all analysis of the emergency situation scenarios are made by this application. The data obtained from user is transferred to the PDA periodically by Bluetooth serial port profile. Activation of standard cryptographic features on Bluetooth protocol can protect the data from unauthorized people. Analysis engine in mobile user software determines the critical level of the information and controls the data if it exceeds the limit. According to critical level, either a warning message is sent to the user or an alarm event occurs and emergency health units and doctors are informed. Additionally, PDA software communicates with a portable GPS receiver via Bluetooth technology and obtains the location information of the user. Also using Microsoft Mappoint Services, it shows the digital map on the screen. Figure 6 contains the mobile user software screen shots.

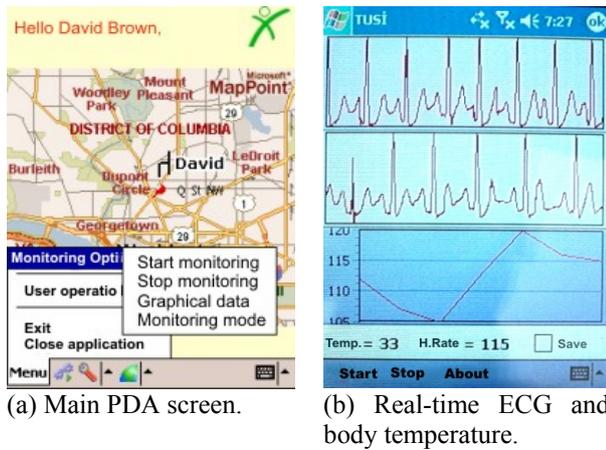


Figure 6. PDA Mobile User Software.

While the obtained data is being shown on the PDA screen, if an emergency situation occurs, the data is sent to the central server by using Internet over WLAN in terms of Web services infrastructure if an emergency situation is occurred. If there isn't any WLAN access point, the data is sent to the central server by PDA's integrated GSM/GPRS module. If there is no GSM operator available then the data is stored on PDA and when the connection is available it is sent to the central server. For reducing the data traffic and increasing the efficiency, the data is compressed by the Gzip algorithm.

The software interface for emergency situation intervention operator, shown in Figure 7, is designed for gathering critical informations of the patients within a medical center. The operator easily monitors the patient and directs the ambulance team very quickly.



Figure 7. Emergency Situation Intervention Operator Software,

IV. CONCLUSION

In this study, a PDA based portable wireless health monitoring and clinical alarm system is performed. Human's ECG, body temperature and heart rate information are acquired and sent to a PDA using IEEE 802.15.1 Bluetooth standard. If an emergency situation occurs, the PDA sends the information to the central server using either WLAN or GSM/GPRS wireless technology. Figure 8 shows the PMU and PDA worn by a patient.



Figure 8. PMU and PDA worn by a patient.

Furthermore, PMU and PDA are separated devices. PMU-PDA and PDA-central server communication is realized by wireless technologies. Therefore, whole system constitutes a distributed architecture and the system

increases the patients' movement freedom. Additionally, PDA's integrated technologies like Bluetooth, WLAN and GSM/GPRS are used in the proposed system. So, there is no need to implement extra hardware for communication. Also, PMU's physical size becomes smaller. On the other hand PMU can communicate any device that uses Bluetooth e.g. smartphone, laptop or desktop PC not only with the PDA.

Easy usage and portability of the system with alarming features has an important role in diagnosing the cardiac diseases and treatment. Also this system can be used to record events for some diseases like cardiac arrest, ventricular tachycardia or arrhythmia. The main advantage of the proposed system is decreasing the intervention time to the patient in an emergency situation. Consequently, proposed low-cost system can increase the life quality of patients.

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