Design and Implementation of Portable ECG and Body Temperature Monitor

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Abstract—Electrocardiogram (ECG) and human body temperature are the important physiological parameters in human body. Through monitoring and analyzing ECG and human body temperature, we can know the health condition of human body and achieve the purpose of prevention and diagnosis for diseases accordingly. In this paper, a solution of portable system for monitoring ECG and human body temperature is proposed. As the front-end subsystem of the remote medical monitoring platform, the system can acquire the data of ECG in human body and measure the human body temperature, while sending the measured data to the users’ mobile phones by the Bluetooth in real time. Then, the wireless communication modes such as 3G, Wi-Fi, etc. on the mobile phones are utilized to send the data to the remote server which performs real-time analysis and diagnosis. What’s more, a built-in memory card is provided for data backup in the system. The system realizes the mobile monitoring for the ECG and human body temperature, not only bringing convenience to users, but also saving the medical resources.

Keywords—ECG Acquisition, Body Temperature Measurement, Medical Supervision, Mobile Monitoring, Remote Platform

I. INTRODUCTION

As the society develops and people’s ideology progresses, more and more people start paying attention to their health conditions, and the regular physical examination and hospital monitoring have become the indispensable constituent part for many people in the daily life. However, because the hospital resources are limited, it’s difficult to meet the needs of a large number of people for the medical supervision. In addition, the hospital monitoring usually needs to occupy people’s free time. Therefore, people have new requirements for mobile monitoring. To meet the conditions above, the system of remote medical supervision comes into being, and has developed rapidly in recent years. The remote medical supervision refers to a medical technological approach to transmit the physiological parameters and medical signals detected by the remote sensors through the wireless communication network to the medical supervision center for analysis and diagnosis [1].

After years’ research, the Laboratory of Embedded System and Technology, Graduate School at Shenzhen, Tsinghua University has developed a whole set of remote wireless network platform for real-time monitoring and analysis of physiological multi-parameter on the basis of GPRS/CDMA/3G wireless communication network and the Internet [2], [3]. In this paper, the design and realization of hardware and software for the front-end subsystem of this platform are introduced in details, and a portable system for the real-time monitoring of ECG and human body temperature is proposed. The system can not only acquire the ECG data and measure the human body temperature, but also send the acquired data to users’ mobile phones by Bluetooth. Then, the wireless communication modes such as 3G, Wi-Fi, etc. on the mobile phones are utilized to send the data to the remote server for monitoring and analysis and the memory card in the system is utilized to back up the measured data.

II. OVERVIEW OF REMOTE WIRELESS NETWORK PLATFORM FOR REAL-TIME MONITORING AND ANALYSIS OF PHYSIOLOGICAL MULTI-PARAMETER

The remote wireless network platform for real-time monitoring and analysis of physiological multi-parameter is mainly composed of four parts: front-end subsystems for monitoring, receiving terminals in users’ mobile phones, monitoring server at hospital and database. As is shown in Fig. 1, the front-end subsystem is composed of the measuring systems for the physiological parameters of human body including ECG, human body temperature, blood oxygen, blood pressure and blood glucose, etc. Each subsystem performs the wireless communication with the users’ mobile phones by the Bluetooth. The receiving terminals in users’ mobile phones receive the data sent by the front-end subsystems and send the data to the monitoring platform of hospital by the wireless communication modes such as 3G, Wi-Fi, etc. while preliminarily processing and displaying the data. The monitoring server at hospital analyses the received data in real time and gives the diagnosis suggestions to the doctors for references. The database is used to store the measured data of physiological parameters and diagnosis reports and establishes the personal health archives.

![Fig. 1 The architecture of the remote wireless network platform for real-time monitoring and analysis of physiological multi-parameter](image-url)
III. THE HARDWARE DESIGN OF THE FRONT-END SYSTEM OF ECG AND BODY TEMPERATURE MONITORING

A. The Architecture of Hardware

In this paper, the hardware of the front-end subsystem for ECG and human body temperature monitoring is mainly introduced. In this system, the ECG acquisition circuit and human body temperature measuring circuit are integrated into a PCB board. The main hardware circuits include power module, processor module, ECG acquisition module, human body temperature measuring module, lead off detection module, Bluetooth module and memory card module, etc. The architecture of system hardware is shown in Fig. 2.

The power module provides 3.3 V analog power and 3.3 V digital power for the system, and performs the effective isolation for the analog power and digital power in order to prevent the digital power from generating disturbance to the analog power. In addition, the detection circuit for the electric quantity of battery is designed in the power module, using for detecting remaining electric quantity.

Cortex-M3 kernel processor LPC1758 is used as the processor of this system. For this processor has features of low power dissipation and low cost, it is very suitable for the development and application of portable system. Its working frequency can reach 100 MHz, a built-in high-speed memory card (the flash memory as high as 512 K bytes and SRAM with 64 K bytes) is provided, and abundant enhanced Input/Output (I/O) ports and peripheral equipment connected to the Advanced Peripheral Bus (APB) [4]. This processor includes 4 Universal Asynchronous Receiver/Transmitter (UART) interfaces, 1 Serial Peripheral Interface (SPI), 12-byte Analog to Digital Conversion (ADC) with 8 channels, 4 general timers, 1 external interrupt interface, standard Joint Test Action Group (JTAG) interface and as many as 70 GPIO pins, part of which can generate interrupt [5].

In this system, the analog signal for ECG and human body temperature is converted into digital value through the ADC of the processor. UART communicates with the Bluetooth module and SPI interface operates the memory card. By use of I/O interrupt to response key, multiple GPIOs can realize lead off detection and provide digital signals. The frequency of external main crystal oscillator for the processor is 12MHz.

B. The Circuit of ECG Acquisition Module

ECG is the curve to record the change of the cardiac electric potential over time [6]. The bio-electric signal is detected by placing the electrodes on the skin of human body. The connection mode of electrodes is also called the lead system. At present, the lead system most widely applied for medical use is the standard twelve-lead system. Ten electrodes need to be placed in different parts of human body and the data of eight channels is measured at the same time: two limbs leads and six chest leads. The twelve-lead system can comprehensively reflect the electric activities of heart. However, the number of electrodes is very large, and the portability and accessibility are relatively poor, so it is mostly used for the static ECG inspection in the hospital.

To improve the portability of the system, this design optimizes the standard twelve-lead system by reducing the number of electrodes to five. The data at three channels is measured: two limbs leads and a chest lead. According to the theory of ECG detection, the leads of chest are unipolar leads, and the acquisition mode for six chest leads are the same except the position where the electrodes are placed on the skin of human body. Therefore, only one chest lead electrode is used to substitute six chest leads. All data of chest leads can be detected in different time by changing the position of electrode. The lead system is shown in the Fig. 3, in which letters R, L, F and N represent four electrodes of limbs leads and letter C represents the moveable chest lead.

For the ECG signal acquisition module, the AD8232 single-lead ECG monitoring front-end chip is used as the core chip. AD8232 is an integrated signal conditioning module applied for ECG and other bio-electric measurements with the single power supply of 2.0V to 3.5 V and the built-in lead off detecting circuit [7]. The double-pole high-pass filter is used to eliminate the motion artifacts, and an operational amplifier without the use of restraint is used to create a three-pole low pass filter. An amplifier is built in for the application of Right Leg Drive (RLD) circuit. Moreover, a fast restoration function is included to reduce the original long tail of establishment for high-pass filter.

In this system, it’s required that the five-electrode three-channel is used for ECG acquisition. However, AD8232 is the front-end of single-channel, so three pieces of AD8232 are needed to be used. The amplifying times of the internal operational amplifier of instruments are 100 times, and the
amplifying times of precision operational amplifier is set to 4 times. Therefore, the amplifying times for the ECG signal are 400 times. The 0.5Hz dual-pole high-pass filter and 40 Hz dual-pole low-pass filter are configured, so the disturbance can be filtered effectively, and the RLD circuit can be designed to restrain the common mode interference. The output of three pieces of AD8232 is connected with the ADC interfaces of the processor, and the output of lead off detecting is entered into the GPIO pins of the processor.

C. The Circuit of Body Temperature Measurement

The method of non-contact infrared body temperature measurement is used for body temperature measurement. All objects emit the infrared ray to the outside and the emitting power is in direct proportion to the surface temperature, the infrared radiation quantity of objects can be converted into a voltage signal and the surface temperature of the objects can be obtained by measuring the voltage signal [8]. The infrared temperature sensor is composed of thermocouple and thermistor. The thermocouple is used to measure the energy of infrared ray radiated by human body and the thermistor is used to measure the environment temperature. The output voltage of thermistor is very low, so the amplifying circuit needs to be enlarged to make the linear amplification for the voltage of thermocouple so as to meet the requirements of voltage for ADC at the processor, and the amplifying circuit is the detection circuit of the output voltage for the thermocouple. The detection circuit of thermistor voltage is to connect the thermistor with a resistance in series for voltage diversion, and the voltage on the thermistor is taken and enters the processor after passing through the voltage follower. The two signals (VTP and VRTD as in Fig. 4) are entered into the interface of ADC. Meanwhile, the control pin of processor (SHDN as in Fig. 4) is designed for controlling the awakening and cut-off of the detection circuit, to lower the power dissipation of the system. The measuring circuit is shown in the Fig. 4.

IV. The Software Design Of The Front-end System Of ECG And Body Temperature Monitoring

A. The Architecture of Software

The software of the system includes two parts: driver layer software and application layer software. The driver layer software is composed of the starting program for the processor and the drivers of external equipment. The starting program completes the initiation and time setting of the processor. The drivers complete the initiation of external equipment. The application layer software is used for realizing the main functions of the system, including the operation of ECG acquisition, measurement of human body temperature, communication by Bluetooth and data storage, etc. The architecture of software is shown in the Fig 5.

B. Program Design

In this paper, the software design and realization of several main functional modules are mainly introduced, including the ECG acquisition program, ADC conversion mode setting, human body temperature measurement program, Bluetooth communication program and data storage program.

ECG acquisition program: After the system is booted, the pin is initiated, enabling the acquisition chip AD8232 and enabling the conversion channel of ADC. Then, the conversion data of ADC is read when the timer is in interrupt. The initiating program of the ECG acquisition includes the initiation of ADC, so the program needs to be executed before the initiating program of human body temperature measurement. Otherwise, the setting of ADC conversion channel for body temperature measurement will be invalid.

ADC conversion mode setting: There are two settable ADC conversion modes for the processor. The first one is the mode of hardware automatic scanning, which is the channel selected by scanning successively according to the conversion rate of ADC. The other one is the mode of software controlling, which is programmable to realize the start and stop of single acquisition channel. The mode of hardware automatic scanning is used in this article. The hardware is automatically scanned in turn as ADC conversion frequency and the lead data of three channels is converted. The ECG sampling frequency is set to 250Hz by setting the interrupt frequency of the timer, and the ADC conversion data of three channels is read every 4ms.

Human body temperature measurement program: Press the key to trigger the I/O interrupt to start the human body temperature measurement. Enable the measurement circuit in the interrupt servicing function, read VRTD and VTP for ten times and shut down the measurement circuit to save power. The function of temperature calculation is called to filter the measured data by average value filter, and implement the

![Fig. 5 Architecture of software](image-url)
Moreover, the data can be sent to the server for real-time analysis and being able to monitor anytime and anywhere. The portable monitor for ECG and human body temperature not only creates the convenience for the patients and the general public, making people complete the physical examination and disease diagnosis without going to the hospital, but also reduces the pressure of the hospital greatly, saving a good deal of human and material resources to the hospital and the society.

For the human body temperature, the compensation algorithm of temperature can be referred to, as in (1)

\[ V_{tp} = E \times S \times (T_{obj} - T_{En}) \]  

(1).

\( V_{tp} \) is the output voltage of thermocouple, \( E \) is the radiance of target object (human body is 0.98), \( S \) is a constant, \( T_{obj} \) is the target temperature to be detected (human body temperature), and \( T_{En} \) is the environment temperature.

Bluetooth communication program: The Bluetooth module is operated by sending the AT instruction through UART. The baud rate of the Bluetooth module is set to 115,200bps to send the measured data in real time. The parameters of Bluetooth module must be set before pairing with other module, and the UART baud rate of processor and the Bluetooth module shall be consistent. There shall be enough delaying after the AT instruction for setting parameters is sent.

Data storage program: The driver of storage card is compatible with the SD V1.0 protocol and SD V2.0 protocol and able to recognize the SD card and SDHC card. In addition, the FatFS file system is mounted in the memory card. When the data in the buffer reaches 512 bytes, the write operation is performed once to store the data as the TXT format files.

V. RESULTS OF EXPERIMENT

The ECG simulative generator is used in the system for testing and can generate the standard ECG waveform. The system acquires the ECG signal generated by the ECG simulative generator and sends it to the computer installed with the Bluetooth receiving device by the Bluetooth. The MATLAB program is prepared on the computer to show the acquired original ECG waveform. As shown in the Fig. 6, the ECG waveform contains the apparent disturbing signal and baseline drift.

After the further filtering by the MATLAB program, the waveform as shown in the Fig. 7 is obtained, and this waveform is smooth with little disturbing signal and apparent major characteristics.

In the testing of human body temperature measurement, it is found that the effective distance of the infrared temperature sensor is about 2 cm. If the distance between the skin of human body and the sensor exceeds the distance, the measurement deviation will be large and the distance change is sensitive. If the measurement distance needs to be enlarged, it can be considered to equip the special lenses on the infrared temperature sensor.

VI. CONCLUSIONS

The portable monitor for ECG and human body temperature not only can be used for the long-term convenient monitoring to the people, but also have features of compact structure, easy carrying, low power dissipation, long continuous working time and being able to monitor anytime and anywhere. Moreover, the data can be sent to the server for the real-time analysis by the wireless communication modes, and being diagnosed by the doctors. The realization of portable monitor for ECG and human body temperature not only creates the convenience for the patients and the general public, making people complete the physical examination and disease diagnosis without going to the hospital, but also reduces the pressure of the hospital greatly, saving a good deal of human and material resources to the hospital and the society.

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