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Medical Remote Monitoring of Multiple Physiological Parameters Based on Wireless Embedded Internet

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ABSTRACT In view of the current situation, that physiological parameter monitoring systems can only achieve local monitoring, and the multi-physiological parameter monitors are large, expensive, and disadvantageous to remote monitoring. This paper combines embedded and mobile communication technologies to develop a new type of multi-physiological parameter medical monitoring system with remote data transmission function. First, through the analysis of embedded system principles, an embedded computer system based on ARM is designed. Secondly, the human-computer interaction interface, data acquisition, and analysis module are designed. Finally, by connecting to the Internet network to communicate with the medical center server, the remote transmission of local detection data and the issuance of alarm signals when dangerous situations occur are realized. The system can collect and display multiple physiological parameters such as heart rate, blood pressure, blood oxygen saturation, and body temperature in real time. The simulation experiment results show that the system's monitoring function and remote data transmission function meet the design requirements, can quickly and accurately find out-of-standard data, and perform remote alarm. The system is small, easy to expand, stable in data transmission, high in reliability, convenient for remote monitoring and data sharing, and is an ideal monitoring device for hospitals and community medical centers.

INDEX TERMS Embedded, Internet, multiple physiological parameters, medical remote monitoring.

I. INTRODUCTION

The acceleration of the population aging process is a serious social problem facing our country at present [1]. As a special vulnerable group, the health of the elderly has received widespread social attention. Heart disease, high blood pressure, and other cardiovascular diseases are the biggest threat to the health of the elderly, and early diagnosis and treatment of these diseases should be based on early prevention. Human physiological parameters are the main basis for judging personal health [2]. Through the special physiological parameter monitoring equipment, the real-time monitoring and analysis of the user's main physiological parameters is of great significance in the process of disease prevention, diagnosis and treatment [3].

Since the introduction of the single-function monitoring device in the 1970s, it has gradually been widely used in clinical monitoring. However, due to the limitations of its monitoring function, single-function monitoring equipment can no longer meet the needs of clinical applications, which seriously restricts the hospital's rescue of the critically ill patients [4]. In the 1990s, with the development of sensing technology and electronic technology, the monitoring parameters continued to increase, from the single parameter monitoring in the past to the multi-parameter monitoring [5]. For example, from a single electrocardiogram (ECG) monitoring, blood pressure monitoring, and blood oxygen saturation monitoring, it has gradually developed into multiple parameters including ECG, blood pressure, blood oxygen saturation, body temperature, end-respiratory carbon dioxide, cardiac output, and anesthesia gas analysis. Monitors, these devices are playing an active role in the clinical diagnosis of hospitals.

With the development of medical measurement technology, sensor technology and computer technology, the physiological parameter monitoring system has shown the development

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trend of intelligence, family, and network [6]. The United States, Japan, and some European developed countries are leading the research on physiological parameter monitoring systems, and have developed various types of physiological parameter monitoring equipment. The multi-parameter monitor based on the PC platform is currently widely used, which is expensive, bulky, and not easy to move [7]. Mao *et al.* [8] studied miniature portable multi-parameter monitors. However, most of them are implemented with low-grade single-chip microcomputers and have simple functions. They can only collect and display ECG signals, they cannot analyze data in real time, and it is not convenient for medical staff to monitor. Liang *et al.* [9] studied a PC 104-based multi-parameter monitor. However, the multi-parameter monitor based on PC 104 is expensive, consumes large power, and cannot achieve long-term field monitoring. For some relatively simple monitors, this is a waste of resources. Compared with domestic countries, medical technology in developed countries has developed earlier, and the acquisition and processing of weak physiological signals is more mature [10]. At present, there are three major brands of foreign monitors: GE Marquette, SpaceLabs and Philips, which occupy a large share in the monitor market [11]. For example, the IntelliVue MP2 developed by Philips can monitor four physiological parameters: blood pressure, ECG, blood oxygen, and temperature. At the same time, it can freely configure the reality mode according to the environment and can display three waveforms. It is a lightweight, flexible, durable, and convenient mobile monitor. With the rapid development of domestic electronic technology, some outstanding monitor brands have also appeared in China, mainly including Shenzhen Mindray, Guangdong Baolite, Shenzhen Keruikang, and Libang [12]. For example, the MEC1000 monitor can analyze 13 kinds of arrhythmia, and at the same time can view the 72-hour heart rate, blood oxygen, blood pressure, body temperature and other parameters. At the same time, dual-screen display can also be achieved through the VGA expansion interface. Data communication is a vital part of remote mobile monitoring. From the current development of communication technology, the more popular communication methods are computer network and wireless GPRS data communication [13]. GPRS is a perfect service to solve the mobile communication information service. It has been widely used because of its advantages such as data flow charge, wide coverage, and fast data transmission speed [14]. GPRS is a wireless data transmission system composed of new components such as the packet control unit (PCU), service support node (SGSN), and gateway support node (GGSN) based on GSM. Its users can send and receive data in end-to-end packet mode.

With the development of microelectronic technology, the application of embedded systems has developed rapidly. In the remote monitoring system, the embedded computer can give full play to its powerful real-time monitoring and network communication capabilities. Moreover, low cost and reliable performance. In these occasions that do not require high data processing capabilities, they can completely replace the traditional large and expensive industrial control computers. The powerful processing ability and network communication ability of the embedded computer system can easily realize the access of GPRS and Internet. It is of practical significance to apply the embedded computer system to the remote medical monitoring system. Embedded computer-based remote multi-parameter monitoring system is not only small, low in power consumption, convenient to carry, but also cost-effective.

Based on the ARM embedded platform, this paper develops a new type of multi-physiological parameter medical monitoring system with remote data transmission function. The system communicates with the medical center server by connecting to the Internet network to realize the remote transmission of local detection data and the release of alarm signals when dangerous situations occur. At the same time, it can collect and display multiple physiological parameters such as heart rate, blood pressure, blood oxygen saturation, and body temperature in real time. The simulation experiment results show that the system's monitoring function and remote data transmission function meet the design requirements, can quickly and accurately find out-of-standard data, and perform remote alarm.

Specifically, the technical contributions of our paper can be concluded as follows:

Based on the ARM embedded platform, this paper develops a new type of multi-physiological parameter medical monitoring system with remote data transmission function. The system is small, easy to expand, stable in data transmission, high in reliability, convenient for remote monitoring and data sharing, and is an ideal monitoring device for hospitals and community medical centers.

The rest of our paper was organized as follows. Embedded systems was introduced in Section II. Section III described the overall design of the multi-parameter monitoring terminal. Experimental results and analysis were discussed in detail in Section IV. Finally, Section V concluded the whole paper.

II. OVERVIEW OF EMBEDDED INTERNET

A. INTRODUCTION TO EMBEDDED SYSTEMS

An embedded system is a system that combines software and hardware, with a microprocessor or microcontroller as its core. It has strong applicability in specialized special fields and can be embedded in various products and applications. The embedded system can be simply said as a special computer system embedded in the object system [15], [16]. The embedded system includes three parts: hardware platform, operating system and application software, as shown in Figure 1.

Hardware includes hardware devices such as microprocessors, input/output interfaces, and various device interfaces.

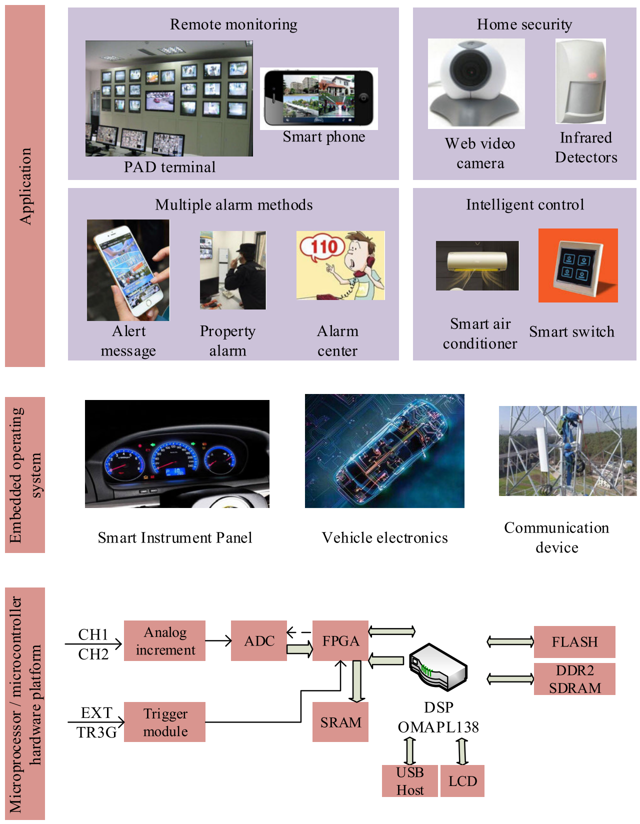

FIGURE 1. **Embedded system architecture.**

Application software can control the objects that need to be controlled. Usually, there is a human-machine interface that it is easy to operate, and it makes more use of the interaction between the user and the object [17]. In the past, embedded systems were mostly independent applications, but with the rapid evolution of microprocessors and software technologies, the functions and applications of embedded systems have been expanded, and the number of embedded systems has continued to increase. During the operation of embedded systems, new methods need to be connected and continuous innovation, and this innovation is particularly obvious in distributed environments [18], [19]. Embedded system technology is developing rapidly. Embedded systems are used in many areas of industry, instrumentation, and vehicles and they are an indispensable part and have a very important status. Embedded systems can truly realize wireless remote transmission and control of data by accessing Internet [20]. The main technology of embedded Internet is embedded TCP/IP protocol stack, embedded Web server, and embedded gateway [21]. The TCP/IP protocol stack in an embedded system is small and can run without an operating system. The embedded Web server is very powerful, very complete, and widely used. The embedded gateway realizes the connection of network communication equipment such as RS232 and Internet.

B. IMPLEMENTATION OF EMBEDDED INTERNET TECHNOLOGY

Embedded Internet technology is a technology that combines embedded system and Internet to achieve system network [22]. The embedded Internet system focuses on two aspects. They are data communication between fieldbus devices and gateways, gateway protocol conversion and data analysis. The combination of embedded system and Internet technology makes people's resource sharing more extensive, communication is more convenient, and remote control functions are better realized.

There are three main ways for embedded Internet access [23], [24]:

1) DIRECT ACCESS METHOD

This access method is mainly for embedded systems of 32/64-bit high-end MCUs, which can run on RTOS and realize the processing of TCP/IP. Connect directly to the Internet by adding network interface hardware, which belongs to the direct access model. The use of high-end microcontrollers is costly and requires a long time to develop, and the complexity is relatively high, which requires high skills for developers.

2) INDIRECT ACCESS METHOD

The indirect access method is suitable for 8/16-bit MCU embedded systems. The embedded system is connected to the Internet by connecting to the embedded gateway. The communication between the embedded gateway and the embedded system uses protocols such as RS232 and RS485. The gateway can realize TCP/IP protocol finding and connect to the Internet to complete the information transmission of the embedded system and the Internet. The technology based on this access method also has the EMIT technology proposed, which solves the problem of 8/16-bit embedded systems accessing the Internet. In this way, 8/16-bit low-end MCUs can be connected to the Internet. Users can remotely access 8/16-bit single-chip microcomputer systems and interact with lower-level computers.

3) USE A DEDICATED CHIP WEB CHIP

Web chip is a kind of network interface chip, it is a kind of special-purpose chip, does not need to depend on the microcontroller. The MCU is connected to the Web chip through the SP interface, and the Web chip is connected to the gateway through the RM32/RS485 interface. The Internet transmits commands to the MCU, which they are received and executed by the MCU. Moreover, they are finally sent by Web chip.

The embedded Linux system is a version of the standard Linux system transplanted on the embedded platform. It inherits all the features of the standard Linux system, has the advantages of open source code, the kernel can be tailored, stable, and efficient, and does not need to pay

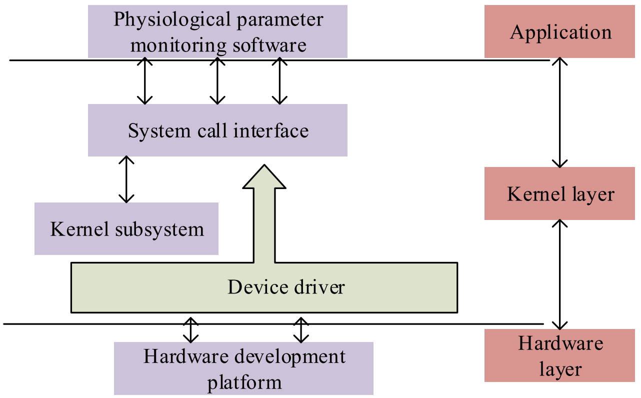

FIGURE 2. Platform hierarchy based on embedded Linux system.

any fees when used. It is currently the most widely used operating system for embedded system development [25]. In order to develop a small-sized, low power consumption, and powerful-performance embedded system, this article completes the construction of an embedded Linux operating system on a hardware platform with an ARM microprocessor as the control core. The platform hierarchy structure based on the embedded Linux system is shown in Figure 2.

C. CONSTRUCTION OF EMBEDDED LINUX OPERATING ENVIRONMENT

The boot loader, the Linux kernel, and the root file system are necessary components of the embedded Linux system's operating environment. The completion of the embedded Linux system's operating environment is a prerequisite to ensure the normal operation of user applications [26].

Because the hardware resources of the embedded system are limited, the development model of ''host machine-target machine'' is usually adopted. That is, the cross-compilation tool chain is used to complete the compilation work in the host machine, and the generated executable file is loaded into the target machine and run. The host computer of this system runs the system of Ubuntu 16. Aiming at the ARM hardware development platform used, the boot loader Ubuntu transplantation, Linux kernel transplantation, and file system production were completed. Then develop the physiological parameter monitoring software on this basis.

III. GENERAL DESIGN OF MULTI-PARAMETER MONITORING TERMINAL

A. THE OVERALL DESIGN OF THE TELEMEDICINE MONITORING SYSTEM

In the clinical medical monitoring system, the multi-parameter monitor based on the embedded computer system is used to monitor multiple key physiological parameters of the human body in clinical monitoring [27]. Figure 3 is a principle block diagram of a multi-parameter monitor based on an ARM-based embedded computer system.

As can be seen from Figure 3, the multi-parameter monitor is mainly composed of a multi-parameter detection and

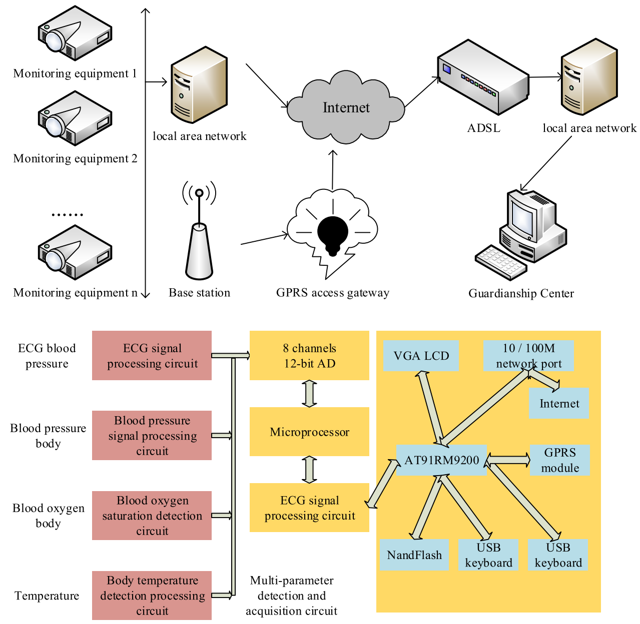

FIGURE 3. Functional block diagram of a multi-parameter monitor for an embedded system.

acquisition circuit and an embedded computer system based on ARM. The multi-physical parameter detection and collection circuit is mainly used to complete the detection and collection of physiological parameters such as the electrocardiogram, blood pressure, blood oxygen, and body temperature of the human body. The collection and detection of these physiological parameters are realized by the high-speed single-chip microcomputer C8051F020. C8051F020 transmits the collected physiological data to the embedded computer system through the optically isolated RS232 serial port. The embedded computer system mainly sends commands to the C8051F020 control multiple physiological parameter detection circuit through the RS232 serial port to complete the collection and processing of these physiological data [28]. At the same time, the embedded computer system completes the display and storage of the collected data. Complete data analysis of multiple physiological parameters according to the needs of users, to achieve on-site monitoring. By transmitting these collected data through the Internet or wireless GPRS module, remote multi-parameter monitoring can be realized.

B. HUMAN-COMPUTER INTERACTION INTERFACE MODULE

The human-computer interaction interface is a window for information interaction between the monitor and the user. The system has designed the following interfaces in total: the main interface, the system-setting interface, the PCA setting interface, the patient information setting interface, and the ECG setting interface. As shown in Figure 4, the system-setting interface and the PCA setting interface are switched from the main interface. The patient information setting interface and the ECG setting interface are sub-interfaces of the

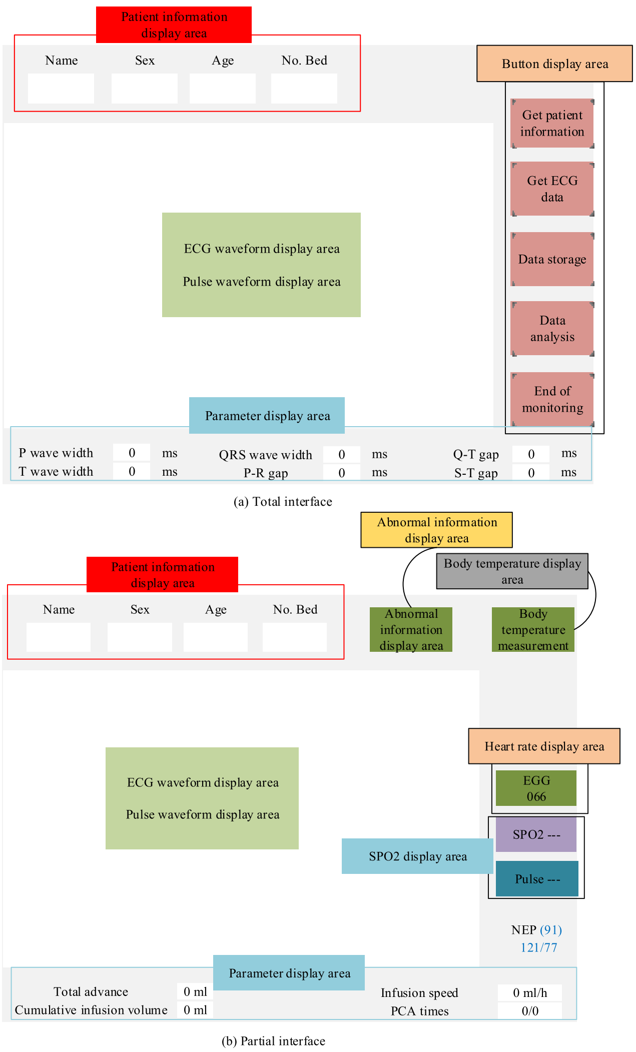

FIGURE 4. Layout of the main interface of the monitor's soft panel.

system setting. These interfaces can be switched from the system settings interface. The main interface designed in this article is mainly composed of four parts: function measurement area, parameter setting and display area, waveform display area, and measurement result display area. Among them, the parameter setting and display area mainly includes system setting button, PCA setting button and so on.

The functional measurement area includes a blood pressure measurement function (NBP button) and a temperature test function. The display area of test result mainly includes the heart rate, blood oxygen, pulse, blood pressure parameter display area, and abnormal information display area. The waveform display area mainly includes ECG waveform display and pulse waveform display. The main interface mainly completes blood pressure measurement functions, waveform and measurement result display, and alarm information display.

Press the "NBP" button in the main interface, the UI thread will start the blood pressure data collection thread. The blood pressure data collection thread sends data collection commands to the hardware through the serial port. The hardware starts to collect data after receiving the data acquisition command. After the hardware acquisition is completed, the blood pressure data is sent to the blood pressure data analysis thread through the serial port. The blood pressure data analysis thread completes the calculation of blood pressure parameters such as diastolic blood pressure, systolic blood pressure, and mean blood pressure. Finally, an update measurement result display message is sent to the UI thread. After the UI thread receives the display message of the updated measurement result, it starts the waveform refresh thread to update the blood pressure parameter measurement result in the main interface. At this point, the main interface has completed a blood pressure measurement process.

C. DATA ACQUISITION AND ANALYSIS MODULE

The data acquisition module is mainly responsible for ECG data acquisition, blood oxygen data acquisition, blood pressure data acquisition, and body temperature data acquisition. The data acquisition module is mainly composed of an ECG data acquisition thread, a blood oxygen data acquisition thread, and a blood pressure data acquisition thread. The central electrical and blood oxygen data acquisition threads complete the real-time acquisition of ECG and blood oxygen data, respectively, and the blood pressure data acquisition thread completes a single blood pressure data acquisition.

1) COLLECTION AND ANALYSIS OF ECG DATA

There are many ways of ECG detection [29]–[31]. The ECG waveforms obtained by different leads are different. Individual differences between people are also great. However, all ECG waveforms can be divided into some common parts. As shown in Figure 5, a typical ECG waveform is composed of P, Q, R, S, T, U waves, P-R interval, S-T segment, Q-T interval, and so on.

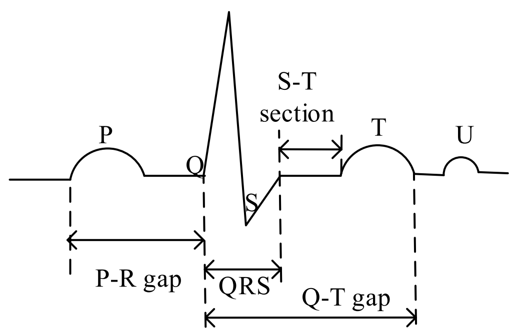

FIGURE 5. Typical ECG waveform.

In the ECG waveform, the P wave represents the potential change during depolarization of the atrial muscle and is called atrial activation wave. The width of a normal P wave does not exceed 0.11 second, and the amplitude does not exceed 3.5 mm.

The three waves of Q, R, and S are generally called QRS complexes, which represent the potential changes of all ventricular muscles during depolarization.

The T wave represents the change in potential of the ventricular muscle when it rapidly resumes polarization. On an electrocardiogram dominated by R waves, the T wave should not be lower than the R wave by 1/10.

The P-R interval tends to increase with age. The normal range for adults is between 0.12 and 0.20 seconds.

The S-T segment represents the weak electrode change formed during the repolarization process after ventricular depolarization, and refers to the segment from the end of the QRS complex to the beginning of the T wave. The horizontal position of the normal human S-T segment is close to the baseline, and the vertical distance from the baseline is generally not more than 0.5 mm.

The Q-T interval is the time from the beginning of the QRS complex to the end of the T-wave. It represents the entire process of ventricular depolarization and repolarization. Under normal circumstances, the Q-T interval is no more than 0.40 seconds.

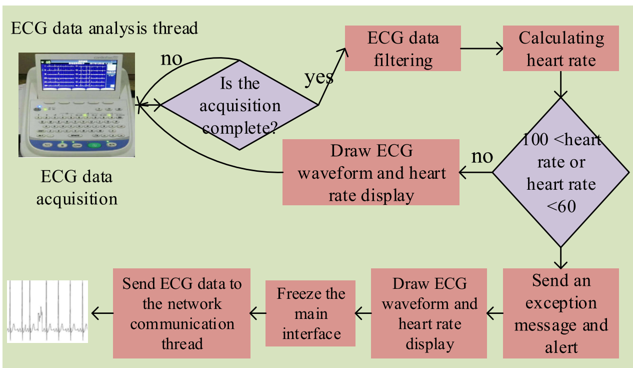

FIGURE 6. Flow chart of ECG data analysis design.

The design flow of ECG data collection and analysis thread is shown in Figure 6. It can be known from Figure 6 that the ECG data analysis thread first waits for the ECG data acquisition thread to finish data acquisition, and receives the latest ECG data sent by the acquisition thread. After receiving the ECG data, the ECG data analysis thread uses the wave detection algorithm to determine the magnitude of the heart rate. The principle of this method is to find the time of two waves in two consecutive ECGs. Its reciprocal is the heart rate. Among them, the R wave is the wave with the largest amplitude in the ECG waveform.

When the heart rate is greater than 100 or less than 60, an abnormal message is sent to the abnormal alarm thread. When the heart rate is greater than 100, the abnormal message is "heart rate too fast." When the heart rate is less than 60, the abnormal message is "bradycardia" [32]. At the same time, the ECG data analysis thread controls the buzzer to alarm, and the data analysis thread displays the abnormal heart rate and the ECG waveform on the main interface. In addition, freeze the main interface, and send a save waveform message to the main thread. Finally, the ECG data is sent to a network communication thread, and the network communication thread sends the ECG data to a remote server for analysis through the network. If the heart rate is greater than 60 and less than 100, it is in the normal range, and the heart rate and ECG waveform of the data analysis thread are sent to the main interface for display.

When the multi-function monitor detects an abnormal ECG message, the first local processing is to check whether the ECG electrodes are loose, or whether the monitor's ECG excuse contact is good. Looseness or placement of ECG electrodes is usually inappropriate, which can lead to misdiagnosis [33]. Therefore, the patient's ECG electrodes are repositioned, and the upper and lower limbs are pressed tightly. Retest two or three times. If it is still abnormal, request remote monitoring.

2) COLLECTION AND ANALYSIS OF BLOOD PRESSURE DATA

Blood pressure data acquisition is played in the blood pressure data acquisition thread. The blood pressure data collection process is shown in Figure 7.

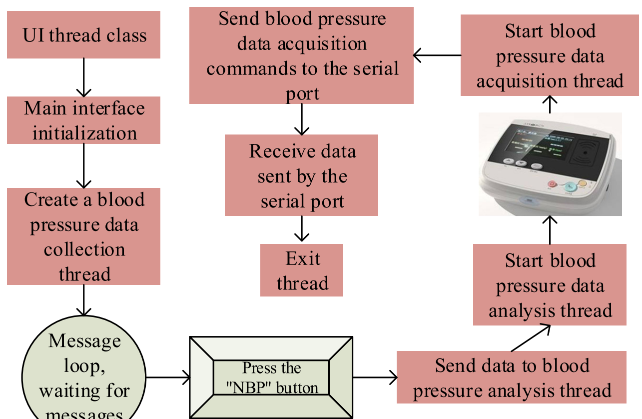

FIGURE 7. Blood pressure data acquisition flowchart.

It can be known from Figure 7 that the blood pressure data collection thread sends the blood pressure data collection command to the underlying hardware control chip through the serial port. After receiving the control command, the underlying hardware control chip starts to inflate the cuff and collect blood pressure data. After the acquisition is completed, the blood pressure acquisition data is sent to the monitoring software through the serial port. After the blood pressure data collection thread receives the blood pressure data, it starts the blood pressure data analysis thread and sends the blood pressure data to the blood pressure data analysis thread. Finally exit the blood pressure data acquisition thread. This completes a blood pressure data collection process.

The blood pressure data analysis thread mainly calculates blood pressure parameters such as systolic blood pressure, diastolic blood pressure, and mean blood pressure. Through the analysis of these parameters, the judgment of blood pressure status is made. The blood pressure data analysis thread design is shown in Figure 8. As can be seen from Figure 8, after the blood pressure data analysis thread receives the

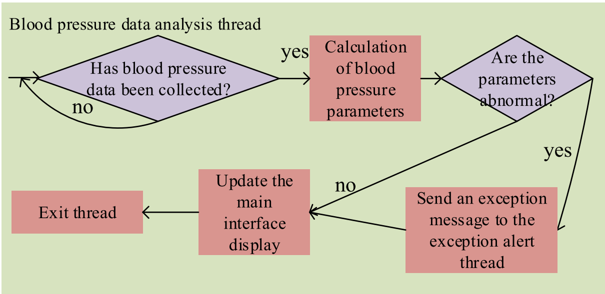

FIGURE 8. **Blood pressure data analysis design.**

blood pressure data. First, the blood pressure parameters are calculated. Here, the amplitude coefficient method is used to calculate the systolic pressure, diastolic pressure, and average pressure of blood pressure. The amplitude coefficient method first obtains blood pressure data through a cuff and calculates the average pressure. The average pressure can be directly determined from the blood pressure data. The systolic and diastolic blood pressure is proportional to the mean pressure, respectively, so that the systolic and diastolic blood pressure can be calculated. When the systolic blood pressure is greater than 140 mmHg and the diastolic blood pressure is greater than 100 mmHg, the blood pressure value at this time is hypertension. The blood pressure data analysis thread sends a ''hypertension'' abnormal message to the abnormal alarm thread. When the systolic blood pressure is less than 80 mmHg and the diastolic blood pressure is less than 60 mmHg, the blood pressure value at this time is hypotension. The blood pressure data analysis thread sends a ''hypotension'' abnormal message to the abnormal alarm and controls the buzzer to alarm. After the analysis is completed, the main interface is updated to display the measured blood pressure parameters, and finally exit the thread.

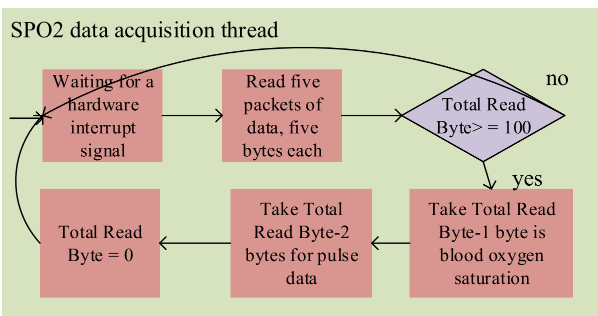

FIGURE 9. **Flow chart of blood oxygen data collection.**

3) COLLECTION AND ANALYSIS OF BLOOD OXYGEN DATA

The collection of blood oxygen data is completed in the blood oxygen data collection thread. It is a real-time collection process like the ECG data collection. The program obtains blood oxygen saturation and pulse data by reading the port. The data collection process of blood oxygen is shown in Figure 9. SPO2 data is read by means of a hardware interrupt response.

When the program receives a hardware interrupt signal, it starts to read five data packets continuously; each data packet contains five bytes. The thread then enters again waiting for a hardware interrupt signal. If the total number of bytes of data received by the program is less than 100 bytes, the blood oxygen data collection thread returns to the place where it started waiting for the interrupt, and waits for the next interrupt to read the data. If the total number of bytes of data received by the program is greater than or equal to 100 bytes, the data of the last byte of the last data packet received is used as the value of blood oxygen saturation. Use the data from the penultimate byte of the last packet as the pulse value. At the same time, the blood oxygen saturation and pulse are sent to the blood oxygen data analysis thread for analysis. Finally, set the total number of bytes of data received by the program to zero, and start counting again.

The analysis of blood oxygen data mainly completes the analysis of blood oxygen saturation and pulse. Oxygen saturation reflects the concentration of oxygen in the human blood, and it is a very important physiological parameter for patient monitoring. In the analysis of blood oxygen data, when the blood oxygen saturation is greater than 100%, it indicates that the blood oxygen saturation is too high and the human body's metabolism is too fast. The blood oxygen data analysis thread sends an abnormal blood oxygen saturation message to the abnormal alarm thread, and controls the buzzer to alarm. When the blood oxygen saturation is less than 90%, it indicates that the blood oxygen saturation is too low, and the oxygen supply in the human blood is insufficient. This situation is more dangerous. Severe cases can seriously threaten the lives of patients. The blood oxygen data analysis thread sends an abnormal message of ''blood oxygen saturation too low'' to the abnormal alarm thread, and alarms.

Pulse is usually consistent with heart rate. Therefore, when the difference between the pulse value and the heart rate of the program is greater than or equal to five and the heart rate is in the normal range, the blood oxygenation data analysis thread sends an ''abnormal pulse'' abnormal message to the abnormal alarm thread and controls the alarm.

D. NETWORK COMMUNICATION MODULE

The network communication module is the interface between the monitor and the remote server. It mainly includes server connection communication part and server command parsing part. Among them, the connection and communication branch of the service department mainly completes the monitoring and actively sends a link request to the remote server. The server command parsing section mainly completes the parsing of the commands sent by the remote server. Two separate threads implement the network request server part and the parsing remote server command part. This article establishes an Internet connection by using GPRS.

1) ANALYSIS OF THE PRINCIPLE OF GPRS ACCESS TO THE INTERNET

GPRS is to add new components to the original GSM (Global System for Mobile Communication) system to provide data services on wireless systems. The three added components are Packet Control Unit (PCU), Service GPRS Supporting Node (SGSN), and Gateway GPRS Supporting Node (GGSN). The principle of using the GPRS network to access the Internet is shown in Figure 10. The MCU data is converted into packet data through the GPRS module. After the base station system, the service support node reaches the gateway support node, and the gateway support node encapsulates the data and sends it to the Internet. Conversely, the data on the Internet can also be received by the MCU.

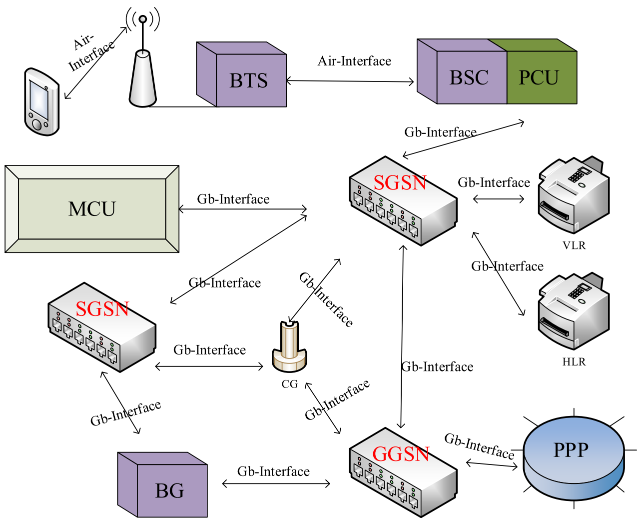

FIGURE 10. Schematic diagram of GPRS network access to the Internet.

GPRS access to the Internet uses the Point-to-Point Protocol (PPP) protocol at the link layer. The PPP protocol is a mechanism for running IP and other network protocols on serial lines. PPP protocol consists of two parts: frame structure and LCP, PAP, IPCP protocols. The frame structure is the structure of the PPP message. Link Control Protocol (LCP) is used to establish, construct, and test link connections. Password Authentication Protocol (PAP) authentication protocol is used to handle the password authentication part. Internet Protocol Control Protocol (IPCP) Internet control protocol is used to set the network protocol environment and assign an IP addresses. In this paper, the process of using GPRS module access is shown in Figure 11. First, the MCU initiates a connection to SIM300, and then the GGSN responds to the connection, and performs PPP negotiation with the MCU. After the implementation of the LCP, PAP, and IPCP protocols, the wireless terminal obtains an IP address, and the two parties establish an Internet connection.

Because there is no packaged tool under the embedded operating system like the PC operating system, many functions must be implemented from the ground up by themselves. Two components of the PPP protocol: frame structure

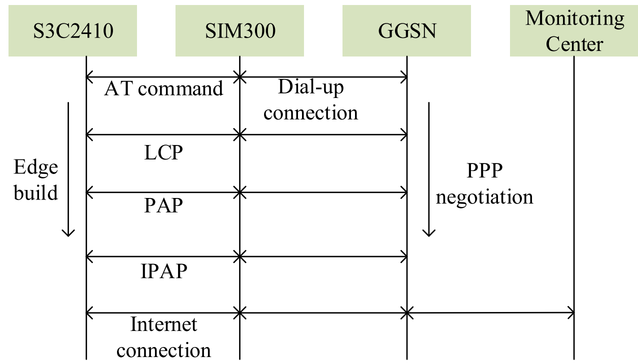

FIGURE 11. Internet connection between wireless terminal and monitoring center.

and LCP, PAP, IPCP protocols. The implementation in Linux corresponds to the kernel part and the user level part. The Linux kernel has provided support for PPP. It has two main functions:

1) Establish communication link in the early stage of operation.

2) Establish a socket interface and process data packets such as LCP and IPCP.

In the kernel part, the PPP driver completes the PPP protocol header encapsulation of the IP data packet, and other applications directly call the Socket interface to send the IP data packet.

E. ABNORMAL ALARM AND DATA STORAGE MODULE

The abnormal alarm part mainly completes the display of the abnormal signal and controls the buzzer to sound the alarm. Data waveform storage mainly completes the timing storage of heart rate, blood oxygen, pulse, and abnormal ECG waveforms.

1) ABNORMAL ALARM DESIGN

In the design of the monitor, the abnormal alarm is a key part; it can prompt people to remind the patient's condition. Abnormal alarms are caused by abnormal messages. The abnormal messages mainly include abnormal ECG messages, abnormal blood oxygenation messages, and abnormal blood pressure messages.

a: ECG ABNORMAL MESSAGE

ECG abnormal messages are mainly caused by two situations. The shedding of the ECG patch electrodes causes one, and the other is caused by the heart rate measurement.

During monitor monitoring, the measured heart rate value is zero when the lead is disconnected. At this time, the monitor sends a "lead off" exception message to the main interface for display. In addition, control the buzzer to alarm. When this happens, simply reposition the ECG electrodes and turn off the alarm reminder.

During the monitoring process of the monitor, when the measured heart rate exceeds the set threshold, the program will issue an abnormal message. When the heart rate is greater than 100, the abnormal message displayed on the program interface is "heart rate too fast." When the heart rate is less than 60, the abnormal message displayed on the program interface is "bradycardia." When encountering this situation, the abnormality caused by the patient's sleeping posture or loose ECG electrodes must be ruled out. First, observe whether the patient is pressing the ECG electrode. Secondly, observe whether the ECG electrodes are loose. Finally, lay the patient flat, reposition the ECG electrodes, and measure the heart rate again. If the ECG abnormality still occurs, send a link request to the remote server to request remote monitoring.

b: BLOOD PRESSURE ABNORMALITY MESSAGE

Abnormal blood pressure messages are mainly caused by blood pressure parameters. Blood pressure measurement parameters include systolic, diastolic, and mean pressure. When the systolic blood pressure is greater than 140 mmHg and the diastolic blood pressure is greater than 100 mmHg, the blood pressure value at this time is hypertension. The abnormal message display area of the program interface displays "Hypertension." When the systolic blood pressure is less than 80 mmHg and the diastolic blood pressure is less than 60 mmHg, the blood pressure value at this time is hypotension. The program interface displays "Low Blood Pressure."

c: BLOOD OXYGENATION MESSAGE

SPO2 messages are mainly caused by abnormal blood oxygen saturation. When the program detects that the blood oxygen saturation is greater than 100%, the program generates a "blood oxygen saturation" abnormal message. When this happens, it means that the patient's metabolism is too vigorous, which is not a critical situation. When the blood oxygen saturation is less than 90%, first exclude whether the blood oxygen-measuring probe is loose, remove the probe, and measure the blood oxygen saturation again. If the measurement result is still lower than 90%, the program generates an "Oxygen saturation too low" exception message to be displayed on the main interface and controls the buzzer to alarm. When the blood oxygen saturation is far below 90%, the patient's life may be critical at this time and must be treated immediately.

2) DATA STORAGE

The data waveform storage function mainly completes the storage of the monitor's heart rate, blood oxygen saturation, and pulse and ECG waveform.

Heart rate, blood oxygen saturation, and pulse data are stored at regular intervals. The program runs every 10 minutes to save heart rate, blood oxygen saturation, and pulse in text. With limited memory, it is impossible for the program to store the monitor's parameters in real time. If you continue to store parameters, the file will become very large and eventually cause the program to crash. At the same time, it is not necessary to save it every 10 minutes; you can see the trend of the patient's physiological parameters on the day.

ECG waveform storage is performed when the monitor detects an abnormal ECG. When the heart rate measurement is outside the normal range, an abnormal ECG signal is generated. After the data waveform storage thread detects this abnormal signal, it saves the electrocardiogram waveform of the current measurement as a picture in the local.

By observing these stored data and waveforms, medical personnel can make more judgments that are accurate on the patient's body.

IV. EXPERIMENTS AND RESULTS

A. DATA ACQUISITION TEST

The system transmits the physiological parameters to be transmitted to the system through the module, and the system sends the received data to the wireless LAN terminal machine for data storage by wireless LAN.

The front-end ECG and blood oxygen acquisition subsystem is responsible for collecting ECG and blood oxygen signals. The collected data is sent through the system. The sampling rate of the data is 200Hz, and the sampling accuracy is 12 bits. Therefore, data is also transmitted wirelessly at a frequency of 200 Hz. Each data packet includes a 2-byte ECG signal and a 2-byte blood oxygen saturation signal. The system is responsible for wirelessly receiving data, buffering the data, and sending the data out in a wireless local area network. The receiving program is run on the terminal computer of the wireless local area network for real-time data storage. The data is saved in a file on the terminal. Figure 12 shows the result of extracting the data from the file and displaying it.

Because the module's timing control is simulated by the I/O port, its CLK level width is completed by the delay instruction. Therefore, the program is affected by multi-task and multi-process under the operating system and the CLK level width is not accurate, resulting in a low receiving data speed, which cannot fully utilize the module's transmission speed advantage. In the experiment, we tested the speed of the module in practice. The transmission speed is limited by the data transmission speed of the front-end acquisition node and the transmission speed of the receiver.

B. ECG DATA ANALYSIS

ECG data analysis includes heart rate measurement and ECG waveform.

1) ANALYSIS METHOD

Connect the ECG signal simulator to the ECG measurement of this instrument. The ECG signal simulator can simulate the output of ECG signals with different heart rates and amplitudes. ECG signal simulator uses SKX-2000K series ECG signal simulator. The simulator can simulate ECG signals of various amplitudes and frequencies, and can be used to detect whether various parameter indexes of ECG products can meet the relevant index requirements. Moreover, it is an important tool for developing ECG measurement products.

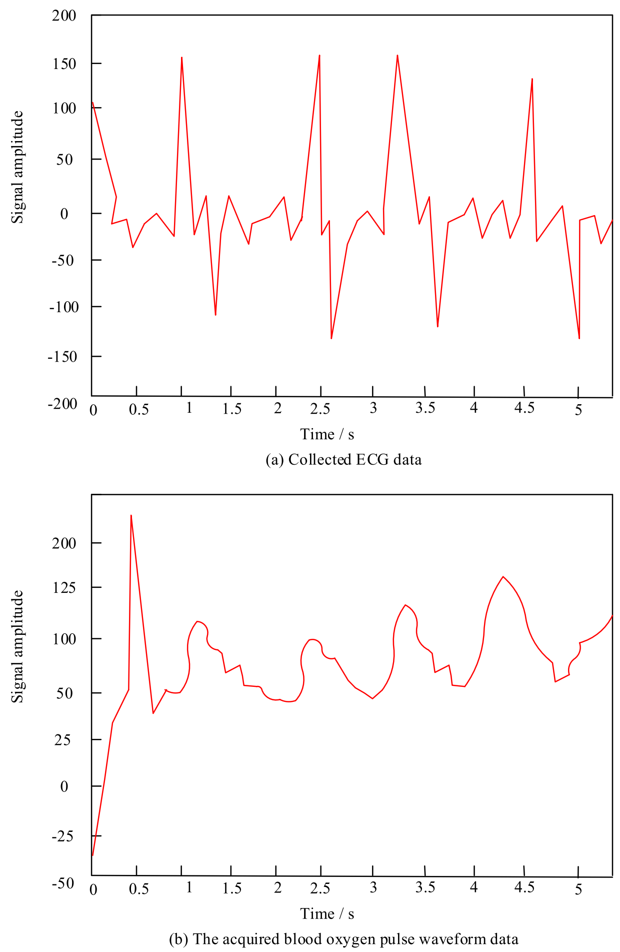

FIGURE 12. Data received on a wireless LAN terminal.

2) ANALYSIS STEPS

a) Connect the ECG signal simulator to the multi-function monitor ECG measurement interface through three lead wires.

b) Set the ECG signal simulator to output ECG signals with amplitude of 4mV and heart rate (bpm) of 30bpm, 60bpm, 120bpm, 180bpm, and 200bpm respectively. Then, record the heart rate measurement results of this instrument, as shown in Table 1.

TABLE 1. Heart rate measurement record sheet.

Category	Standard value (bmp)	Measured value (bmp)	Error
1	30	29	0.033
2	60	60	0
3	120	113	0.016
4	160	160	0
5	200	200	0

By analyzing the measurement results in Table 1, the instrument meets the index requirements of a heart rate measurement range of 30-200bmp and a measurement error of ± 5%.

3) ECG WAVEFORM TEST

By controlling the lead switching circuit, three different electrocardiogram waveforms can be obtained by switching different lead combinations. The ECG waveforms of leads II, III, and I are shown in Figure 13 below.

As shown in Figure 13, the ECG waveforms measured by the monitor in leads I, II, and III are the same as the ECG waveforms output by the standard ECG signal simulator, which shows that the ECG measurement function of this monitor has reached the expected effect.

C. ANALYSIS OF BLOOD PRESSURE DATA

1) ANALYSIS METHOD

By connecting the blood pressure simulator with the instrument through the trachea, the blood pressure simulator can simulate and output different blood pressure signals. Test the blood pressure measurement range, measurement error, and measurement time of the instrument by using the blood pressure signal simulator to output a simulated blood pressure signal with a range of 0-200 mmHg. For the convenience of testing, the six values in the range of 0-200 mmHg are tested, and the size interval is 40 mmHg.

2) ANALYSIS STEPS

a) Connect the blood pressure signal simulator to the blood pressure measurement interface of the multifunctional monitor through the trachea.

b) Set the blood pressure simulator to output six different simulated blood pressure signals. Each of the following values represents systolic/diastolic blood pressure (average pressure). Record the measurement results and measurement time of the instrument, as shown in Table 2 below. By analyzing the measurement results in Table 2, the instrument meets the requirements of the blood pressure measurement range of 0-200 mmHg, the allowable measurement error ± 5%, and the measurement time is less than 100 seconds.

D. REMOTE SERVER MONITORING SOFTWARE TESTING

The remote server software test mainly completes ECG analysis and ECG waveform test. The monitor collects the ECG signals output by the standard ECG signal simulator and sends the ECG signals to the monitoring software of the remote server. The monitoring software calculates the P wave width; QRS wave width, T wave width, and P-R gap, S-T gap, and Q-T gap of the ECG through the ECG waveform algorithm, and compare it with the output standard value of the ECG signal simulator.

The function testing process of remote server monitoring software is similar to that of monitor. First, the ECG signal simulator sets the output P-wave width, QRS-wave width, T-wave width, P-R gap, S-T gap, Q-T gap, and other widths.

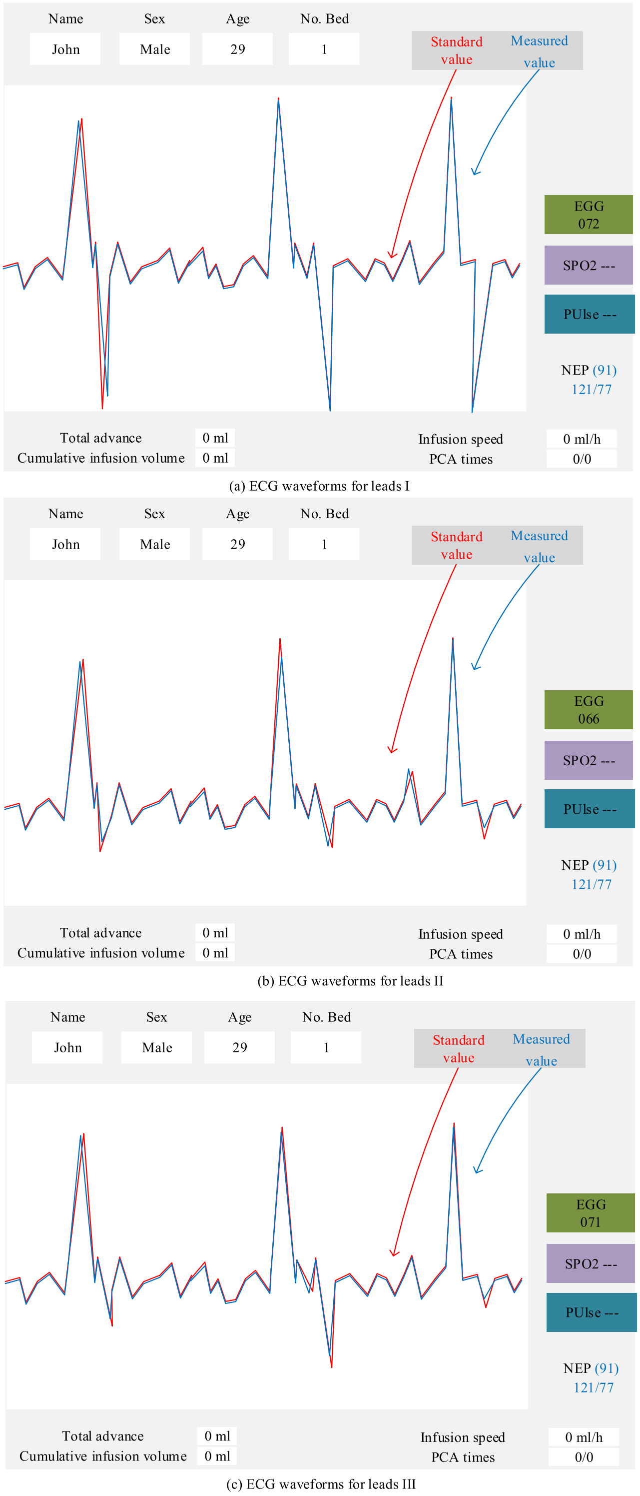

FIGURE 13. ECG waveforms for leads I, II, III.

TABLE 2. Blood pressure test results.

Category		1	2	3	4	5	6
Standard value (mmHg)	Systolic pressure	50	80	100	115	160	200
	Diastolic pressure	30	48	65	80	90	140
Measured value (mmHg)	Systolic pressure	51	78	105	110	165	203
	Diastolic pressure	30	50	10	84	88	135
Error	Systolic pressure	0.02	-0.025	0.05	-0.043	0.031	0.015
	Diastolic pressure	0	0.042	0.046	0.05	-0.023	-0.035
Measurement time (s)		28	31	31	32	35	38

FIGURE 14. Remote server monitoring software ECG lead I waveform analysis.

TABLE 3. P wave width test table.

Standard P wave width output (ms)	40	80	120
Measure P wave width output (ms)	39	82	123
Error (ms)	-1	2	3
Error percentage	-0.025	0.025	0.025
Standard error percentage	±0.08		

ECG analysis tests are shown in Figure 14, Figure 15, and Figure 16.

The six parameters of the central electrical waveform and the standard output values of the measured values are shown in the following table.

It can be known from Figure 14, Figure 15, and Figure 16 that the ECG waveform diagram drawn by the program of the remote server is consistent with the standard signal ECG

FIGURE 15. Remote server monitoring software ECG II leads waveform analysis.

FIGURE 16. Remote server monitoring software ECG III leads waveform analysis.

TABLE 4. T wave width test table.

Standard T wave width output (ms)	75	150	225
Measure T wave width output (ms)	76	146	222
Error (ms)	1	-4	-3
Error percentage	0.013	-0.026	-0.02
Standard error percentage	±0.08		

waveform diagram output by the ECG signal simulator. The test results in Table 3, Table 4, Table 5, Table 6, Table 7, and table 8 were analyzed. The parameters of P wave width, waveform width, T wave width, P wave width, S-T gap, and Q-T gap of ECG waveform were all within the error range of standard error. Therefore, the measurement accuracy and reliability of ECG waveform parameters can be proved by the remote monitoring program.

TABLE 5. QRS wave width test table.

Standard QRS wave width output (ms)	30	60	90
Measure QRS wave width output (ms)	29	62	94
Error (ms)	-1	2	4
Error percentage	-0.033	0.033	0.044
Standard error percentage	±0.08		

TABLE 6. P-R gap test table.

Standard P-R wave width output (ms)	115	230	345
Measure P-R wave width output (ms)	114	226	344
Error (ms)	-1	-4	-1
Error percentage	-0.08	-0.017	0.03
Standard error percentage	±0.05		

TABLE 7. S-T gap test table.

Standard Q-T wave width output (ms)	100	200	300
Measure Q-T wave width output (ms)	101	196	296
Error (ms)	1	-4	-4
Error percentage	-0.01	-0.02	-0.013
Standard error percentage	±0.05		

TABLE 8. Q-T gap test table.

Standard Q-T wave width output (ms)	60	120	180
Measure Q-T wave width output (ms)	61	119	182
Error (ms)	1	-1	2
Error percentage	0.016	-0.08	0.011
Standard error percentage	±0.05		

V. CONCLUSION

In telemedicine, the embedded computer system can analyze and judge the patient's physiological information in time. In addition, transfer these data to the monitoring center through the Internet or wireless GPRS. This allows doctors in the hospital to understand the patient's health status in a timely manner, thereby providing protection for the patient's life safety. With the increase of people's awareness of health care, healthy people will also become the object of family monitoring. The use of multi-parameter monitors to monitor and detect multiple physiological parameters of healthy people is helpful for the early detection and timely treatment of diseases. Based on the ARM embedded platform, this paper develops a new type of multi-physiological parameter medical monitoring system with remote data transmission function. The system communicates with the medical center server by connecting to the Internet network to realize the remote transmission of local detection data and the release of alarm signals when dangerous situations occur. At the same time, it can collect and display multiple physiological parameters such as heart rate, blood pressure, blood oxygen saturation, and body temperature in real time. The simulation experiment results show that the system's monitoring function and remote data transmission function meet the design requirements, can quickly and accurately find out-of-standard data, and perform remote alarm.

Although the system proposed in this paper works in a home environment, it can monitor multiple human physiological parameters in real time. However, although data on human physiological parameters can be obtained, there is no corresponding alarm module. Therefore, the next work of this paper is to continue to improve the alarm-processing module to realize the alarm processing of physiological parameters that exceed the standard value.

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