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Embedded Programmable Web-based ECG Monitoring & Detection System Using a Fast Algorithm

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Abstract - The physicians have to interpret this large amount of ECG data to search for only a few abnormal beats in the ECG. Physicians may overlook some abnormal cycles due to fatigue and human error in interpreting such a large amount of data. Therefore, there is an urgent need for an automatic ECG interpreting system to help to reduce the burden of ECG interpretation. This proposed system is expected to monitor the electrical activity of heart of the patient under critical care more conveniently and accurately for diagnosing.

Keywords : *Medical Measurement System, ECG, Embedded Circuit Board, Web Server Characteristics Point; Microcontroller; Embedded Interface Circuit; Ethernet Network.*

I. INTRODUCTION

An electrocardiogram is generated by a nerve impulse stimulus to a heart, whereby the current is diffused around the surface of the body surface. The tiny current at the body surface will build on the tiny voltage drop, which is a couple of IlV to mV with an impulse variation.

This very small amplitude of electrocardiograph, needs to be amplify a couple of thousand times for recording and displaying. Simultaneously, the amplified signal is then inputted into an analog to digital conversion and through the digital interface inputted into an embedded circuit board. The embedded circuit board uses client-server network programming to transmitting this digital medical signal to the remote database by wireless or wire networks.

Based on the current software and hardware technology, our design provides a convenient operational procedure to conduct a remote electrocardiograph measurement from designed and implemented and they can be compatible with the currently used systems. In 2003, people used a GSM Module to transmit this digital medical data [1], In our design, we used an embedded circuit board network module to transmitting this digital medical data. Moreover, due to the improvement of the current software and hardware technology of both computer systems and networks, a remote medical system needs to be redesigned by using more modem technologies, such as: a Web server, the Internet and wireless networks and an embedded circuit board. Hence, Our design includes several modules: an interface circuit board, an embedded circuit board, the software on the embedded circuit board for wireless or Internet transmission, and the software for the remote medical servers.

II. HARDWARE IMPLEMENTATION

The Hardware design should follow the principles of low power consuming, high integrated, low cost and high Electro Magnetic Compatibility (EMC).

The Hardware implementation method is shown in Figure 1. We used an ECG ASIC called CHEFREN to measure ECG signals. A microcontroller based on ARM architecture was chosen to receive, record, display, send and analysis the ECG signals with a NAND Flash chip, a GSM/GPRS module and a LCD connected to it.

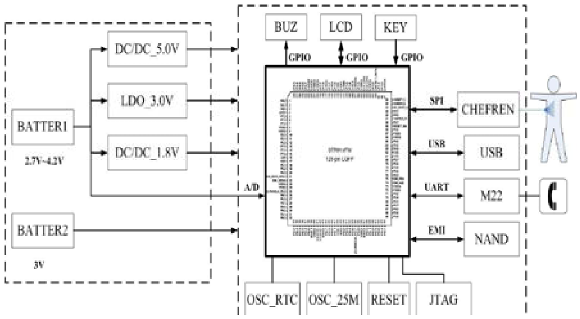

Figure 1. Hardware architecture of the PIEM

There are two forms of circuit for measuring the ECG signals. One is to use amplifier ICs, resistors and capacitors to design a circuit board. The other is to use ASIC to achieve the measuring, in which A/D converter and serial communication ports were integrated [2]. In this design, we chose the ASIC called CHEFREN (Chip aimEd FoR hEalth moNitoring).

This ASIC was provided by Aurelia (in Italy) and it is an Integrated Circuit developed mainly for the acquisition of electrocardiographic signal. This single chip permits the implementation of ECG systems with up to “12-lead” and its power counsumption is 14 mA (max) with the die size of 5.8 x 5.1 mm2. It is very suitable for this PIEM. For ECG tracing, we chose the sample frequency at 1000Hz and sample bit at 10 bits.

Recorders utilize 10 electrodes attached to the chest, which record the signal from 8 bipolar leads onto 12 channels, to supply the patient with a portable care device that will allow him to monitor his health status and early detect cardiac events such as ischemia and arrhythmia.

The Microcontroller

There were lots of microcontrollers that were used in ECG monitor, from 8-bit to 32-bit microcontroller, as well as DSPs[3]. In this design, we chose an ARM based microcontroller called STR9xx, which is the production of STMicroelectronics. It brings the power of an ARM9E™ processor core to the world of general purpose Flash microcontrollers, opening endless opportunities to embedded system designers by making networking and other demanding applications easy and affordable.

It runs at up to 96 MIPS peak performance while executing code directly from its Flash memory, executes single-cycle DSP instructions within its ARM966E-S® core, and includes Ethernet, USB, and CAN interfaces. These features, combined with Flash memory sizes reaching 544Kbytes and a vast 96Kbyte SRAM. It is an ideal single-chip solution to transform embedded control applications into low cost nodes on a local network, or on the Internet [4]. It made the hardware design easy, stable and low cost.

There are several wireless technologies we could use to transmit ECG signals, such as GSM/GPRS, Bluetooth, ZigBee, WLAN IEEE 802.11 and so on. They have their own characteristics (Bandwidth, Latency, Availability, Security, Ubiquity and so on). Mobility can be divided into two classes: High and Low level of mobility.

A echnology with a high level of mobility can be accessed within a wide geographical area, and a technology with low level of mobility has limited geographic range and the user is therefore confined to a limited area of equipment operation. According to the characters of ECG monitoring, a high level mobility and transmission accuracy are necessary.

So we chose a GSM/GPRS module (called M23G provided by BENQ) with built-in TCP/IP protocol stack to be the transmitter/receiver so that the user could send his/her ECG signals at anytime wherever GSM coverage is present. Its communication port is UART and it can be used as a modem in a computer system to connect to Internet, even there is no TCP/IP protocol stack in the software. These ensure the security of data transmission. GPRS facilitates instant connections whereby information can be sent or received immediately as the need arises.

EMC consideration

This PIEM is very tiny, and there are both analog signals and high frequency digital signals. The clinical bandwidth used for recording the standard 12-lead ECG is 0.05 – 100 Hz and the standard bandwidth for GSM/GPRS is 900/1800 MHz. The microcontroller is working at 48MHz.

The high frequency may cause the ECG signal anamorphic and the microcontroller program run away. In order to forbid these problems, the crystal is replaced by an oscillator to be the source for the main oscillator input. The PCB board was designed to be 4 layers which include the 0V plane layer and 3V power plane layer.

A decoupling capacitor (typically 10 - 100nF) was placed between the power and ground very near to each power/0V pair of connector pins. A bulk decoupler was located at where the main power enters the PCB. To prevent unintended oscillation, unused input pins were pulled up using a resistor of 10KΩ [5].

A. Interface Circuit Board

The operation procedure shown in Fig. 2 can be explained as follows:

In Fig. 2, the ECG sensor is used as the input stage, which requires very high impedance that is often attained by using a CMOS input circuit in order to both match the impedance of the ECG signal source and to pick up larger amplitude of the ECG signal.

Due to the difficulty of the reduction of the noise in the very small amplitude of an electrocardiogram signal, we need to use a differential amplifier to suppress the common mode noise. In addition to preventing any electrical shock to the tested body, we use an isolated amplifier that can not only amplify the ECG signal but also provide DC power supply isolation by means of a magnetic coupling mechanism. To amplify the electrocardiogram signal further, we use a main amplifier.

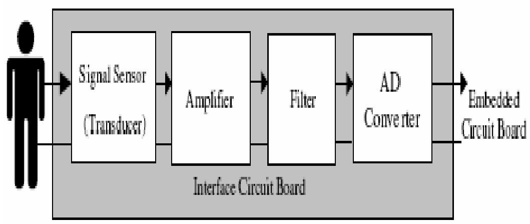

Fig 2.The function of the interface circuit board

However, because the DC offset voltage could saturate the amplifier, we must adjust the DC offset voltage of the amplifiers very carefully. Because the medical signal can induce the noise nearby the location of the ECG, we need to use a 60 Hz band rejection to suppress this noise and a low pass filter to reduce the high frequency noise. In addition, to minimize the error of any component, we shall use an adjustable component in order to locate the best band rejection frequency. Usually, the bandwidth of the medical signal is low frequency; we, therefore, use a high-order low pass filter to suppress the high frequency band.

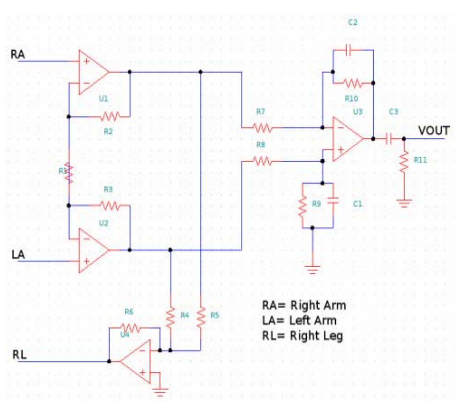

Fig 3. Amplifier Interfacing Circuit

The sampling rate of the analog to digital conversion will decide the resolution of the medical signal. The embedded circuit board is used to control the analog to digital converter, to receive the data of conversion, and to send out the digital data to the embedded circuit board.

III. SOFTWARE IMPLEMENTATION

Fig. 4 shows the software flowchart of our embedded circuit board for the ECG measurement system from remote distance incorporating the web-based networksystem.

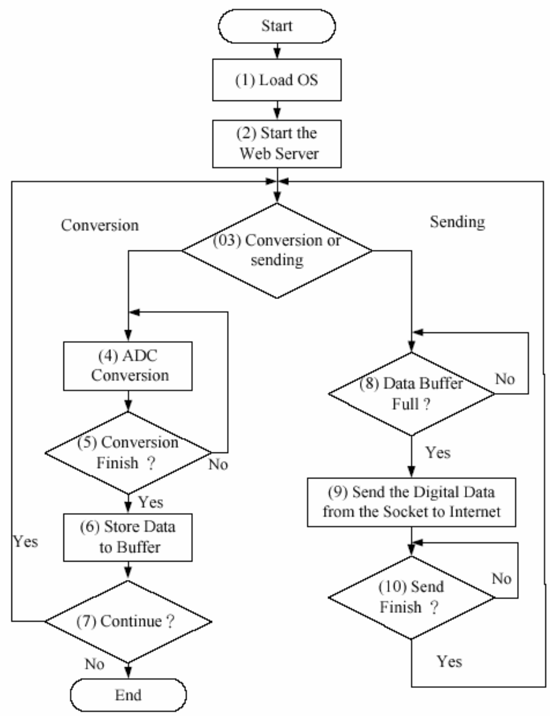

Fig 4.Flowchart on the embedded circuit board for the ECG data collecting and sending.

The major functions of this program are to collect the ECG digital data into the remote medical server from the embedded circuit board through the Internet. In addition, our software modules can also store the digital ECG signal data and display the ECG on the LCD display of the embedded circuit board, and transmit information to the remote medical server through either the Internet or wireless networks.

The basic operational steps of Fig. 4 may be briefly described as follows: (1) Load Operation System and reset the system; (2) Start the Boa web server; (3) Analog to Digital Conversion; (4) If Converted, finish; (5) Store the digital data to buffer; (6) If Continue, convert; (7) If Data buffer full; (8) Send the digital data from the socket to Internet; (9) Send finish and wait.

IV. FAST ALGORITHM FOR ON-LINE ECG INTERPRETATION

The difference between this ECG device and Holter is that it includes a fast intelligent algorithm for detecting arrhythmias such as VE, SVE and Missed Beats. We have developed a kind of computerized serial ECG analysis method that was compliant with the clinical scenarios, and determined the most relevant ECG measurements for the detection of arrhythmia.

The algorithm could be divided into 2 parts: (1) R wave peak detection and QRS duration calibration; (2) Heart diseases diagnosis. The position and direction of R wave peak and the duration of QRS complex are the most important features for analyzing an ECG segment. There are multifarious methods for QRS complex detection. Here we developed a combined method which had the advantages of both differentiation techniques and template matching techniques. As shown in Fig 5, firstly, we use the differentiation technique to find the positions of possible R wave, and then, the direction, duration and area are calculated, the information from priori templates established by hand are used to confirm whether it is really a QRS or noise.

After the features of QRS complex are extracted, a computer program mimics the human expert's decision process using a rule-based expert system which is used to make the diagnosis for every QRS complex.

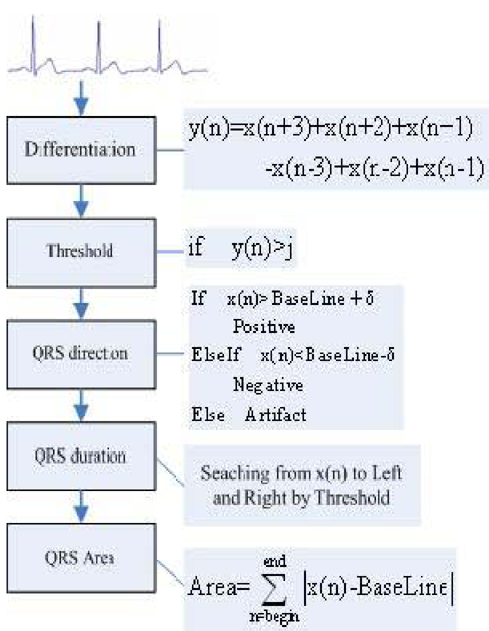

Fig 5. QRS complex detection

Those abnormal QRS complexes are marked and could be displayed on the LCD or transmitted to the service center via GPRS network.

V. EXPERIMENT AND RESULTS

When using a multi-parameter biosimulator, the QRS detection rate isalmost 100% accurate. More than 97% arrhythmia ECG segments can be recognized and automatically marked in the abnormal database. And this information could be transmitted to service center via GPRS network. Any medical device should be authorized and pass some certification such as CE or FDA before it goes into the market. The author has just accomplished a prototype of this PIEM. Figure 6 shows some results from our prototype Radio Frequencies (RF) interfere from the GSM/GPRS module could be reduced. When other unexpected abnormity occurred, the PIEM could reset itself and continue work. On the other hand, this PIEM have been used in the clinical hospital for one month. About 20 cardiac patients have used this device. The cardiologists and patients gave a high praise to this PIEM.

Figure 6. Experiment results of the PIEM

VI. CONCLUSIONS

It will be an important part of wireless remote monitoring system in the future when healthcare is done anywhere at anytime. However, there are also some problems existed in the device itself and other aspects. A prototype of a PIEM has been developed and tested. The measurement is accurate and the cost is affordable for most patients. The intelligent ECG interpretation algorithm could pick out the abnormal ECG segments and these segments can be transmitted to the Remote Service Center via wireless network. The electrodes and lead-wire cause the patients uncomfortable, the Artificial Intelligent algorithm for ECG analysis is far from cardiologists' diagnosis.

Now, the healthcare service is moving into the mobile age, and wireless remote monitoring systems are at the cutting edge of this development. Any change in the way one thing is done results in changes in other areas. Implementing remote monitoring systems results in introducing new technology into the health care system, and thus sparks change to how health care is conducted in many ways.

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