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# Design of a Multichannel Biomedical Signal Acquisition System Based on Cortex-M4 Processor

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***Abstract*— a multichannel biomedical signal acquisition system based on core processor STM32F405 of the Cortex-M4 is presented in this paper. The paper describes the system mainly from the perspective of hardware and software design. The hardware design includes three major parts – the power conversion circuit, the signal acquisition circuit and the signal processing circuit. For the software module, data collection and transmission, and design of digital filters are of the research focus. It is demonstrated in experimental tests that the system can extract and collect a variety of human physiological signals in complex environments. In addition, data transmission between the system and PC is supported by Ethernet, which enables remote monitoring of biomedical signals of humans.**

***Keywords—Cortex-M4; STM32F405; digital filters; Ethernet***

## I. INTRODUCTION

Due to the development of computer and communication technology, telemedicine has been more widely used and achieved good social benefits, which gradually become a new health care model [1]. Some telemedicine systems are equipped with the physiological information collecting terminals, the mobile and remote monitoring terminal, and can achieve patient positioning based on the Google Map. Some remote monitoring systems based on the Android mobile phone have also achieved promising results [2].

However, the traditional acquisition system of medical signals still has some shortcomings, such as being too bulky and thus inconvenient to move, or demanding a more lasting power supply to satisfy more than 24 hours of continuous acquisition, or being too costly, etc. This work designs a multichannel biomedical signal acquisition system which attempts to address some of the issues and possesses the following advantages, including being small and easy to move, requiring low power consumption and being suitable for long-time uninterrupted signal acquisition, etc.

The remainder of the paper is organized as follows. The Section II describes the multichannel biomedical signal acquisition system and gives the overall architecture. Then the design of the hardware system is shown in the Section III. The design of the software system based on Contex-14 is presented in the Section IV. The Section V gives the test results and the Section VI concludes the paper.

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## II. THE SYSTEM DESIGN

The architecture of the multichannel biomedical signal acquisition system is shown in Fig.1.

The system is divided into the circuitry of hardware acquisition and the module of the PC software. The hardware acquisition circuit includes sensors of physiological signals, a 12V rechargeable lithium battery, a power panel, a front-end analog signal processing card, and a signal acquisition card. The PC software gets the hardware information by way of UDP packets, which can display waveforms and save data.

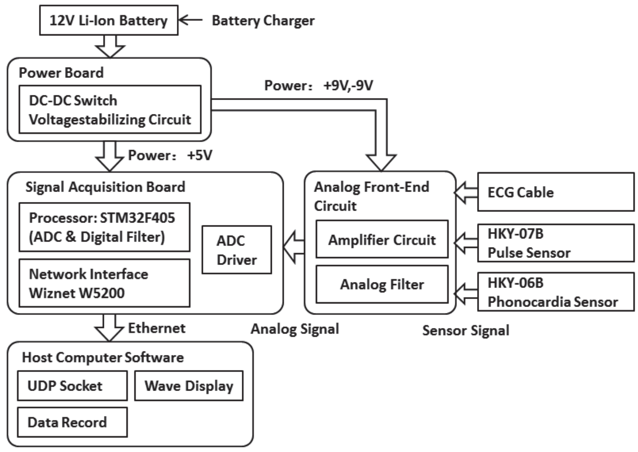



Fig.1.The architecture of the multichannel biomedical signal acquisition system

This paper uses a relatively simple hardware to implement the system. Firstly, the sensors and the electrode signal are processed by the analog front-end circuit, and ADC driver converts them to digital signals for the acquisition of the processor. Then the processor converts the digital signal into data, and reduces noise by digital filtering. Lastly, the PC receives the data for display.

This system in this paper collects three types of physiological signals of human, namely ECGs, pulses and heart sounds.

## III. THE HARDWARE DESIGN

The hardware circuitry contains three parts, i.e. the power conversion circuit, the analog front-end signal processing circuit, and the signal acquisition circuit. Power conversion circuit converts 12V lithium battery voltage into a set of positive and negative 9V voltage for the analog circuit, and outputs a set of 5V voltage for the digital circuit.

### *A. The analog front-end circuit*

The analog front-end processing board is responsible for the signal amplification and filtering, as shown in Fig 2. The ECG signal is acquired through the right leg drive single-lead mode. An AD620 instrumentation amplifier completes the first-stage amplification, and then the OP97 the high-magnification by OP97 in the second stage. The heart sound sensor and the pulse sensor are integrated in the front-end amplifier circuit, so that the output signal can be stronger and only needs to go through a low-gain and AC-coupling amplifier.

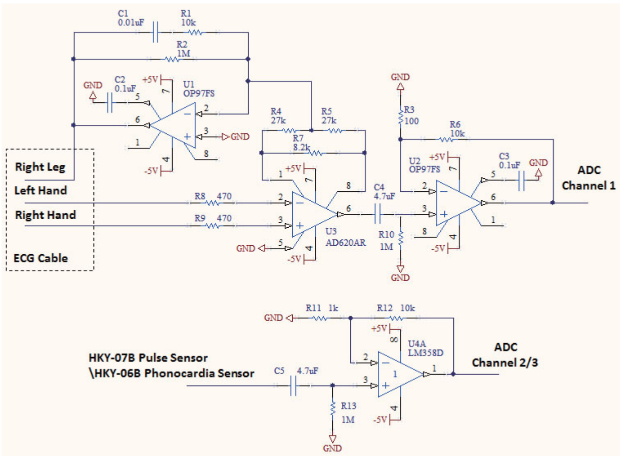


Fig.2.The Schematic Diagram of the Analog Front-End Circuit

### *B. The signal acquisition circuit*

The main part of the hardware design is signal acquisition circuit, which uses the STM32F405RGT6 [3] as the main chip. This chip has a 168MHz clock speed, is equipped with a floating point arithmetic unit. An analog signal is first converted to a digital signal in ADC driver and then sampled by the processor. The processed data is sent to the PC by the W5200 network chip with hardware IP protocol. The diagram of the signal acquisition circuit is shown in Fig.3.

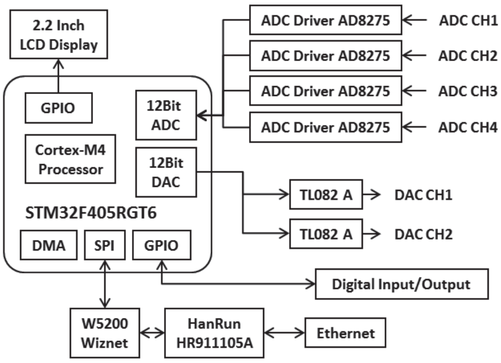



Fig3. The block diagram of Signal Acquisition Board

## IV. THE SOFTWARE DESIGN

The software module includes the program design of this system, the implementation of data collecting and transmitting, and design of digital filters.

After the front end processing, the original signal is sampled by the STM32F405 chip. Then the interference with a frequency of 50Hz is removed by the digital notch filter, and the baseline shifts suppressed by a 0.1Hz high-pass filter. The noise is reduced by a Savitzky-Golay (SG) smoothing filter. After all the filtering the data is sent to the network buffer area and then to the PC. When the PC monitors that the UDP port receives data packets, the waveforms of the data packets are displayed in real-time, and the data are recorded into the document at the same time. The diagram of signal flow is shown in Fig.4.

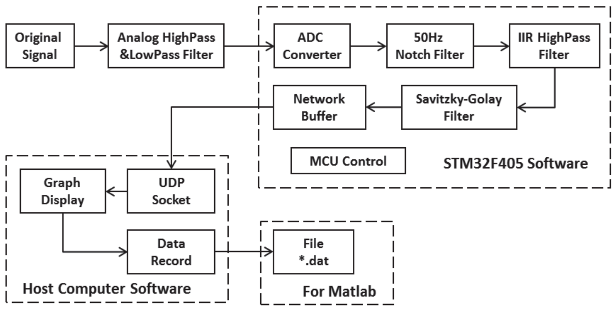



Fig.4.The signal flow diagram

### *A. The implementation of STM32F405 Software*

The STM32F405 software design is hierarchical. The underlying system consists of the display, the network chip driver, and the STM32 hardware libraries. The upper layer contains the digital filter, the buffer management, and the network port management. The processor of signal acquisition card is triggered by the timer, and the system clock ticks are provided by the Systick. The block diagram of the software system is shown in Fig.5.

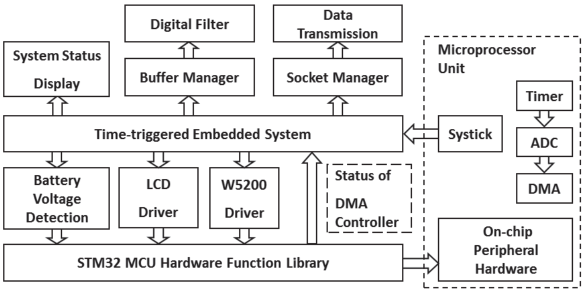
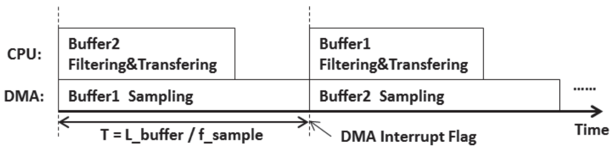


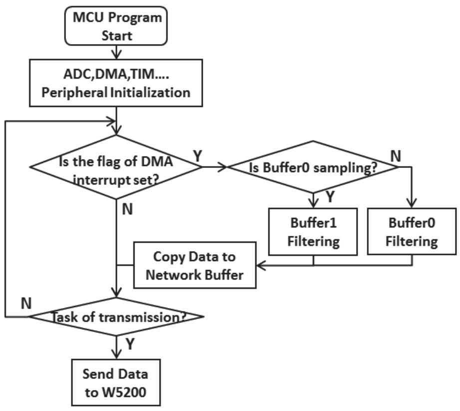

Fig.5.The Block Diagram of the Embedded System on STM32F405RGT6 Processor

*B. The implementation of data collecting and transmitting*

The STM32F405 processor supports double buffering automatic switching operation that can be automatically switched over to the other data buffer if full. So the system's CPU processing unit can be released and does not need to participate in the process of data collection. The block diagram of realization of real-time data acquisition and transmission is shown in Fig.6.




(a).The Sequence Chart of DMA Ping-Pong Operation




(b).The Flowchart of the Main Function
Fig.6.The Block Diagram of DMA Ping-Pong Operation

*C. The design of digital filter*

The ECG is the weakest signal in this paper. The main interference that the signal suffers is that of power frequency. The baseline drift is mostly due to respiration or the surface of the electrode, which generally refers to signals below 1Hz. In addition, this paper selects Savitzky-Golay filter to smooth signals.

The power frequency interference can be removed by a 50Hz digital notch filter. The results are shown in Fig7. The baseline drift is suppressed by a 0.1 Hz high-pass filter to eliminate frequencies below 0.5Hz. The ECG waveform data from MIT-BIH database [4] is used as the test data with a sampling rate of 360Hz. The results are shown in Fig.8.

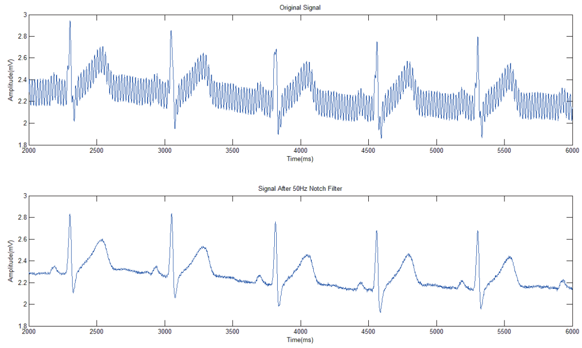



Fig.7.The Result of Applying 50Hz Notch Filter

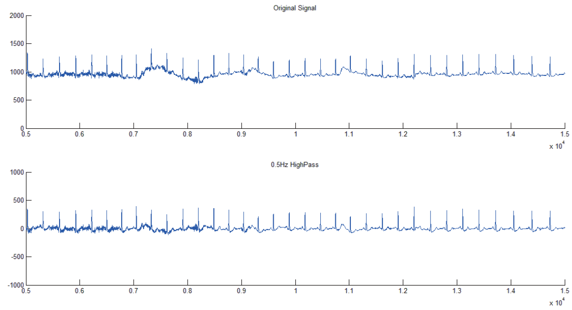



Figure.8.The Result of Removing Baseline Shift

The Savitzky-Golay filters are widely used for Smoothing [5]. In 1964，Savitzky and Golay proposed a method of data smoothing based on local least-squares polynomial approximation. They showed that fitting a polynomial to a set of input samples and then evaluating the resulting polynomial at a single point within the approximation interval is equivalent to discrete convolution with a fixed impulse response, and they demonstrated that least-squares smoothing reduces noise while maintaining the shape and height of waveform peaks. The Savitzky-Golay filter in the frequency domain is to some extent equivalent to a low pass filter [6]. The result of applying Savitzky-Golay filter to a real ECG signal is shown in Fig.9.

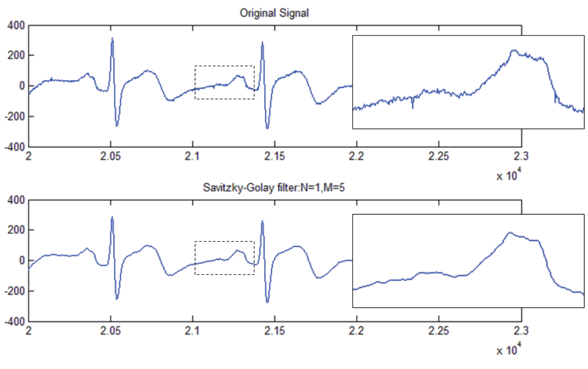



Fig.9. The Result of Applying Savitzky-Golay Filter to a Real ECG signal

## V. THE PHYSICAL HARDWARE AND TEST RESULTS

### *A. The Physical Hardware*

The physical hardware circuit is divided into a power strip, an acquisition card and a signal front-end processing board. All boards are made of double-board design. The Fig.10-Fig.12 show the individual modules. The Fig.13 gives the appearance of the overall hardware system, and the Fig.14 demonstrates the connection of modules.

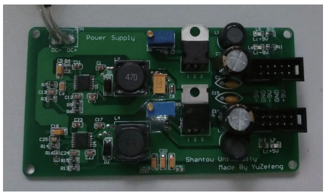


Fig.10.The power board

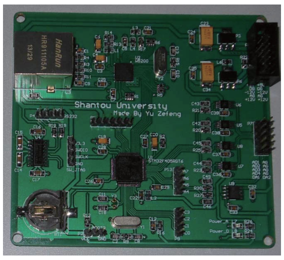


Fig.11.The acquisition card

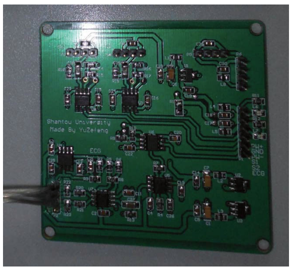


Fig.12.The signal front-end processing board

Fig13 The appearance of the hardware

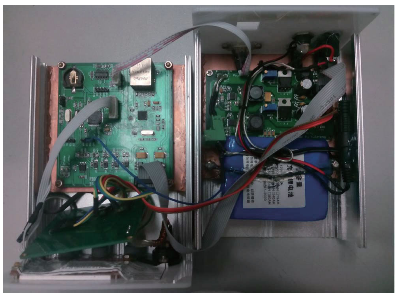


Fig.14.The connection of modules

### *B. The System Test*

This system was debugged in the LAN, the network equipment used for TP-LINK TL-WR742N wireless router. As shown in Fig.15, the real-time waveforms, which include the ECG, the pulse and the heart sound signal of a volunteer are displayed in a PC environment.

Fig.15. The view of real-time signal acquisition

### *C. Comparing the test results*

Many volunteers were invited for data acquisition in experiments. Signals to be acquired include single-lead limb ECG, finger pulse and heart sounds. Sampling frequency of the test system is 1KHz. In all experiments, the three physiological signals were simultaneously acquired. An example of the three acquired waveforms is shown in Fig 16-Fig.18.

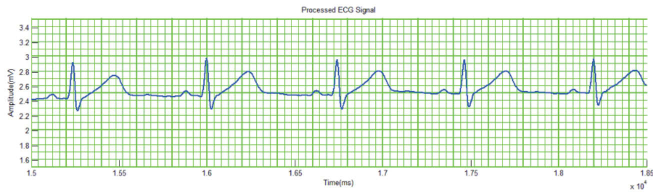



Fig.16.The ECG signal from a male volunteer aged 25

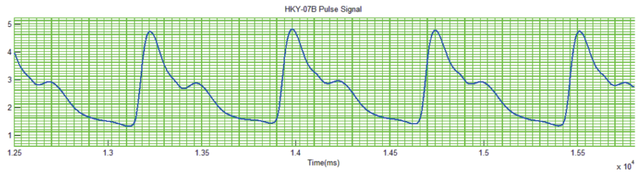



Fig 17.The pulse signal from a male volunteer aged 25

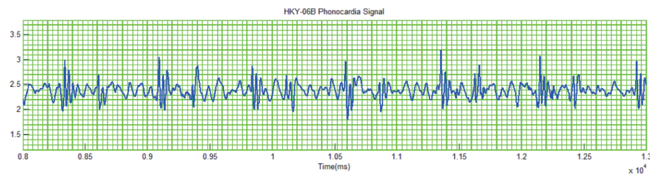



Fig .18.The heart sound signal from a male volunteer aged 25

In order to verify the loyalty of the signal acquired by the system of ECG waveform acquisition, the ECG signal of the volunteer collected by the electrocardiograph made from NIHON KOHDEN is compared with the signal taken by the system of this paper. The experimental site is the No. 1 Affiliated Hospital of the Medical College of the Shantou University, and the test object is a healthy male volunteer, who is 50-year-old. The test results are shown in Fig.19 and Fig. 20.

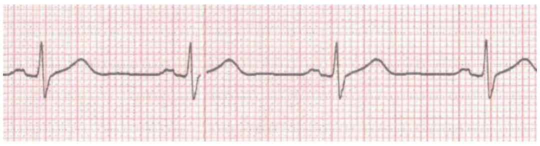


Fig.19.The ECG signal from an electrocardiograph made by NIHON KOHDEN (man, 50)

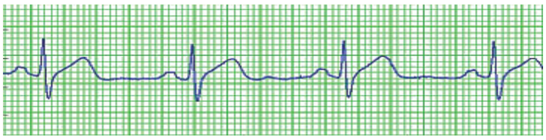


Fig.20.The ECG signal from this designed system (man,50)

The grid coordinate of the waveform diagram of this system is the same to a typical machine for ECG measurement. Each small cell expresses 0.1mV, and each large grid is 0.5mV in Y-axis direction. In X-axis direction, each small cell is 0.04s, and each large grid is 0.2s. It can be observed from the from Nihon Kohden ECG waveform chart that 23 small grid spacing represents 0.92s, which is also the representation of the R-R interval. In addition, the R peak point is 0.5mV, which is away from baseline six small cells. Likewise, it can be observed from the Fig. 20 that the R-R interval is also 23 small cells that represents 0.92s, but the R peak point is 0.6mV by the system developed in the paper. By comparison, it is concluded that this system acquired a ECG waveform consistent with that of a commercial machine in terms of R-R interval, but with a slight difference in terms of peak point.

## VI. CONCLUSION

In this paper, a whole system of multichannel biomedical signal acquisition is designed and built, which is based on core processor STM32F405 of the Cortex-M4. The system is verified by large number of tests, which demonstrate that this design works well for acquisition of ECG, pulse and heart sound signals. The system can serve as a front-end terminal for data collection in a smart home environment, with the collected data being further processed by various algorithms of machine learning and data mining in big data applications.

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