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Design of a Wireless Multi-channel Surface EMG Signal Acquisition System

Rong Zhou[1, 2], Qiang Luo[1, 2,*], Xiaorong Feng[1, 2], Chenglong Li[1, 2]
[1] Key Laboratory of Fiber Optic Sensing Technology and Information Processing,
Wuhan University of Technology, Wuhan, China
[2] College of Information Engineering, Wuhan University of Technology, Wuhan, China
e-mail: whut_fxr@163.com, 173904606@qq.com, xrong_feng@whut.edu.cn, 1398512758@qq.com

***Abstract*—The EMG signal acquisition techniques have attracted much attention, and have been widely applied. Most EMG acquisition systems use the wired transmission mode, so signals are easily contaminated by power line frequency interference. In addition, the sEMG is relatively weak .It is essential to make amplifying, filtering and denoising for sEMG pre-processing. In this paper, a four-channel wireless sEMG acquisition system with high accuracy, low latency, portable, lithium battery and wireless data transmission is designed. And it integrates lithium battery charging and discharging system, acquisition of weak signal as well as pre-processing of filter circuit. Besides, this system's interference of noise is small. And high single channel SNR can avoid power frequency interference. It can provide EMG signal processing with convenient platform, which creates the hardware condition for the research of the follow up surface EMG signal processing.**

Keywords-sEMG; EMG acquisition; wireless communication

I. INTRODUCTION

The sEMG (surface electromyogram signal) characterizes the functional state of the human nerves and muscles to a certain extent. Through extracting and studying the characteristics of surface EMG signal, we can predict the strength of force, recognize human movements, and diagnose muscle disorders effectively. In addition, the study of combining the sEMG and rehabilitation has also become a focus. It is not only widely used in rehabilitation medicine [1], [2], artificial limb [3], prosthesis control [4], [5] and other fields, but also used as a novel intelligent human-computer interactive input mode which has received great concern [6].

At present, the EMG (electromyogram signal) acquisition technology becomes more mature and popular [7-10]. Hardware products related to sEMG acquisition system are also emerging. However, most EMG acquisition systems use wired mode, and this wired mode is easy to cause the power frequency interference, besides, the wired electrode will restrict the human body and unsuited to use in the movement. In order to meet the sEMG acquisition system requirements of more portable, convenience, good electrode wear ability and can be placed in the whole body, a set of EMG data acquisition cards with high precision and low latency, portable wireless Wi-Fi data transmission and battery powered by lithium battery is designed in this paper. The experimental results show that the data acquisition system has less noisy interference, higher SNR (Signal Noise Ratio). And the effective data collected can be used for EMG signal analysis and processing.

II. IMPLEMENTATION METHOD

A. System Hardware Design

The sEMG acquisition system realizes the processing and recording of the surface biological signals. The bioelectrical signal collected from the skin surface of human skeletal muscle is transformed into a digital signal sequence which is transmitted to the corresponding processing unit after amplification, filtering and other processing. The schematic diagram of the EMG acquisition system is shown in Fig. 1.

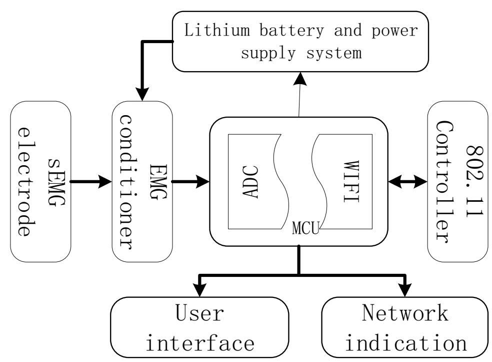

Figure 1. EMG acquisition system design.

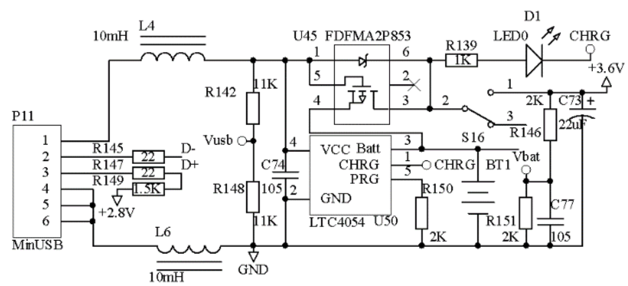

Figure 2. Lithium battery charging management circuit and the use of components.

In this scheme, the weak surface EMG signal collected by the surface electromyography electrode is transformed into a unipolar AC(alternating current) signal by the signal conditioning unit, and then through the ADC(analog-to-digital converter) sampling in the central control unit (MCU) to get the original sEMG sequence which is then transmitted to the processing platform by MCU-driven 802.11. The whole system uses 2000 mA lithium battery as the main power supply, the design of a dedicated lithium battery charging management circuit is shown in Fig. 2.

The EMG signal conditioning module, shown in Fig. 3, is the core part of the EMG signal acquisition system, which directly affects the accuracy and effectiveness of the acquisition system. The sEMG signal can be regarded as an AC signal with a frequency range of 50~150Hz and a amplitude range of 100 V ~ 2mV. And most of the energy of signal is concentrated in the range of 50~150Hz, and there is a large amplitude 50Hz frequency interference and common mode DC (direct current) signal. This module mainly completes the functions of amplification, filtering and lifting of EMG signal, including preamplifier, independent circuit unit, band-pass filter, power frequency notch, post amplifier and right leg drive circuit.

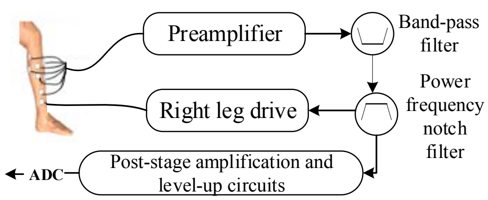

Figure 3. EMG signal conditioning module structure.

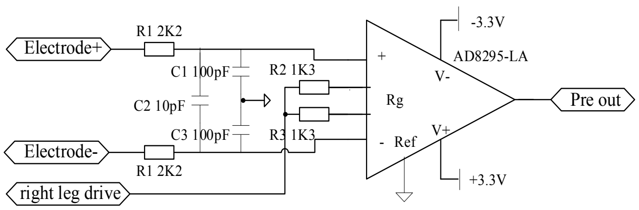

Figure 4. Pre-amplifier circuit.

According to the characteristics of EMG signal and environmental noises, the preamplifier should have the characteristics of low noise, low offset, high CMRR (common mode rejection ratio), high input impedance and so on, and it must adopt the differential input amplifier structure. The specific circuit design of the preamplifier is shown in Fig. 4, and the input impedance up to 100M, CMRR of 110db, and voltage gain of 20db.

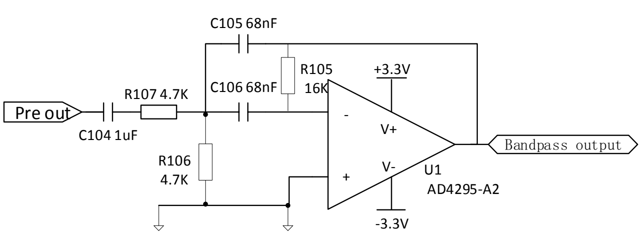

Figure 5. Band-pass filter circuit.

The main energy of the EMG signal is concentrated in the range of 10 ~ 1000Hz, of which 20Hz and below the signal show great instability in the muscle contraction process, and the EMG signal energy in the range of 500~1000HZ account for a small proportion of the useful signal. In order to improve the SNR of EMG acquisition system, the EMG acquisition band should be between 20 ~ 500Hz, therefore, a two order active Butterworth band-pass filter is adopted shown in Fig. 5. The power frequency interference is inevitable in the sEMG, and the signal amplitude is larger than the EMG signal itself, which should be filtered in signal processing by frequency filter to improve SNR of the EMG signal acquisition system. This paper, using monolithic operational amplifier and RC (resistance capacitance) circuits to build an active notch filter shown in Fig. 6.

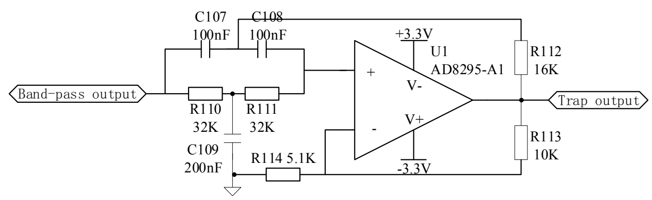

Figure 6. Notch filter circuit.

After the pre-amplification and filtering, the EMG signal is amplified again in the post-amplifier circuit shown in Fig. 7 to meet the ADC sampling accuracy and sampling dynamic range, and the gain is set to 40db. The DC component voltage of the adder's input is provided by the DAC unit within MCU. The LM324 operational amplifier is used to meet the requirement of gain and bandwidth.

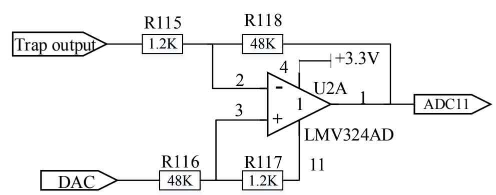

Figure 7. Post amplification and level-up circuits.

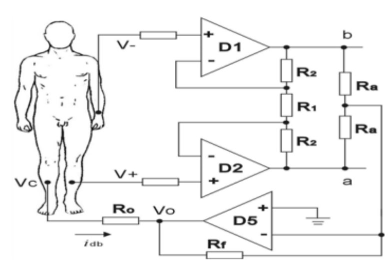

Figure 8. Right leg drive circuit.

The right leg drive circuit can effectively decrease the power frequency interference and increase the common mode rejection ratio. Typical right leg drive circuit model is shown in Figure 8. The common mode gain of the circuit is composed of D1 and D2 is 1.The common mode signal $V_C^{'}$ at a, b is equal to the common mode signal V_C on the body to be measured, $V_C = V_C^{'}$. $V_C = i_{db} \times R_0 + V_0$:

$$V_C = i_{db}R_0 - \frac{2R_f}{R_a}V_C' \tag{1}$$

$$V_C = \frac{i_{db}R_0}{1+ {2R_f}/{R_a}} \tag{2}$$

From the formula (1) and (2), when the reference electrode is grounded directly, $V_C = i_{db} \cdot R_g$, therefore, the use of right leg drive circuit can reduce the common mode interference $(1+2R_f)/R_a$ times. In order to ensure that the current flowing through the body is absolutely safe, such as 10uA below, the value of R_0 should be very big. However, if too large, R_0 will affect the effect of right leg drive, or even offset the role of right leg drive.

B. System Software Design

In EMG signal acquisition system software data flow program is shown in Fig. 9. The original EMG signal sequences transformed by ADC are transferred to the buffers through the DMA, then encapsulated into UDP datagram and transmitted to the network by the network driver, and its sampling and transmission using double-cache structure, namely Buffer1 and Buffer2. When the Buffer1 is full, the ADC changes the destination address of the DMA to the Buffer2. At the same time, the network driver module reads the Buffer1 data and completes the packet transmission, so alternately, until the end of the sampling period.

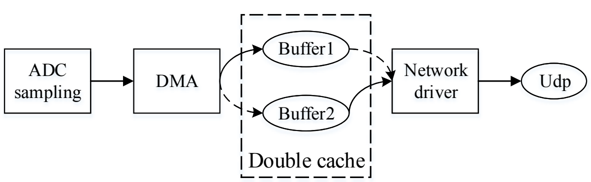

Figure 9. Software data flow diagram.

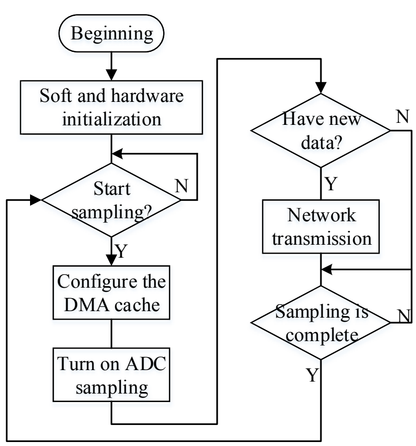

Figure 10. EMG acquisition system software flow chart.

The ADC control unit inside of the MCU realizes 4 channel interleaved sampling, and sets the dedicated DMA transmission channel. After the sampling, the ADC controller interrupts processor to read the sampled data and reset the new DMA buffer. Therefore, in the entire sample period, there is no user intervention. According to the hardware design of the bandpass filter bandwidth and Nyquist sampling theorem, the minimum sampling frequency is 1KHz. In this paper, ADC is set in the software, the clock frequency is 10 KHz, and the sampling accuracy is 12bit, so the sampling rate of the single channel is 2.5KHz, which meets the requirements of sampling. The software flow chart of the EMG acquisition card is shown in Fig. 10.

III. Experiment and System Performance Test

In this paper, the four-channel wireless EMG signal acquisition system was designed. The experiments of performance test, the four channels CH1, CH2, CH3 and CH4 are connected with the volunteers of the lower limb long peroneal muscle, tibia muscle, extensor digitorum longus and peroneus brevis muscle respectively. Two groups samples of sEMG of 4 muscles in resting state and contraction state were collected. The SNR of the two groups samples was calculated by the power spectrum distribution of the two sets of samples in the resting and contracting state. The signal-to-noise ratio and the frequency band of the EMG card were given.

The two groups of signal samples of muscles in the resting and contracting state are analyzed off-line in the frequency domain, and the power spectrum of each channel of the two groups was shown in Fig. 11 and Fig. 12.

Muscle does not release the action potential in the resting state, so the power spectrum energy of each frequency component approaches zero. Especially near the 50Hz, the total energy should be significantly lower than other noise power, and there is no power frequency interference. From Fig. 11, the resting state power spectrum shows that the noise performance of the EMG acquisition system's CH2 and CH3 channels are stable, and the CH1 and CH4 channels have noise interferences in a certain degree, which must be further filtered in the subsequent software processing. While the muscle release action potential in the contraction state, and the muscle contraction power spectrum energy mainly will concentrate in the 50 ~ 500Hz, The fig.12 shows the power spectrum in the contraction state, the energy of each frequency component of CH2 channel is the largest, and the muscle contraction is obvious, mainly concentrating in the Normal energy range of EMG. Because different muscles have different contraction range, power spectrum energy shows different intensity, which conforms to the essence of EMG signal. In addition, the 50~500Hz bandwidth was designed in the EMG signal acquisition system, and other signal are seen as noise signal. According to the power spectrum under contraction energy, the single CH2 channel's SNR can be calculated by the calculation method, which is shown in formula (3).

$$SNR = 10\log(\frac{P_s}{P_n}) = 24db \tag{3}$$

According to two parts analytical results above, the EMG acquisition system designed in this paper accurately reflects the distribution of the EMG signal, smaller noise interference; and higher single channel SNR. Therefore, the data collected by this acquisition system is valid, and it can be used for analysis and processing the EMG signal.

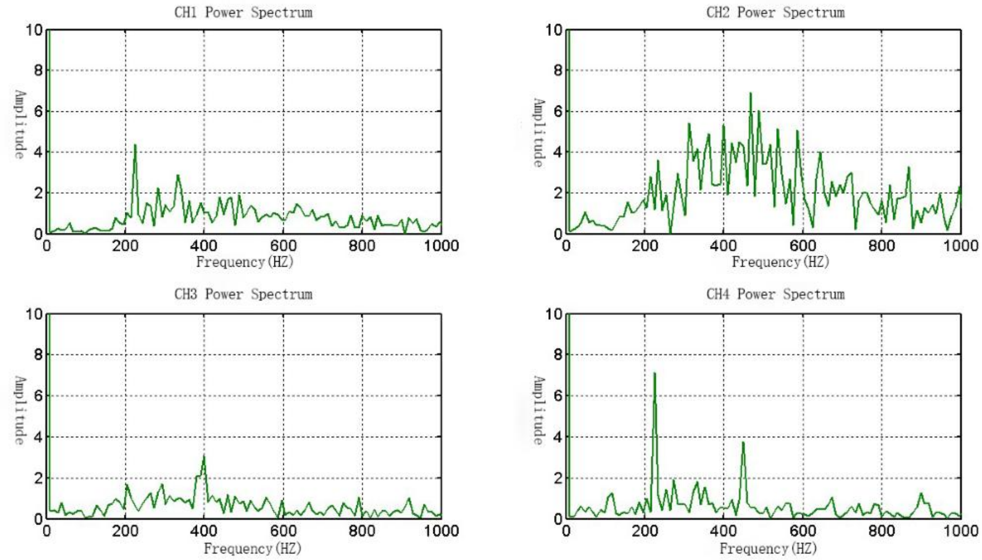

Figure 11. The power spectrum in the resting state.

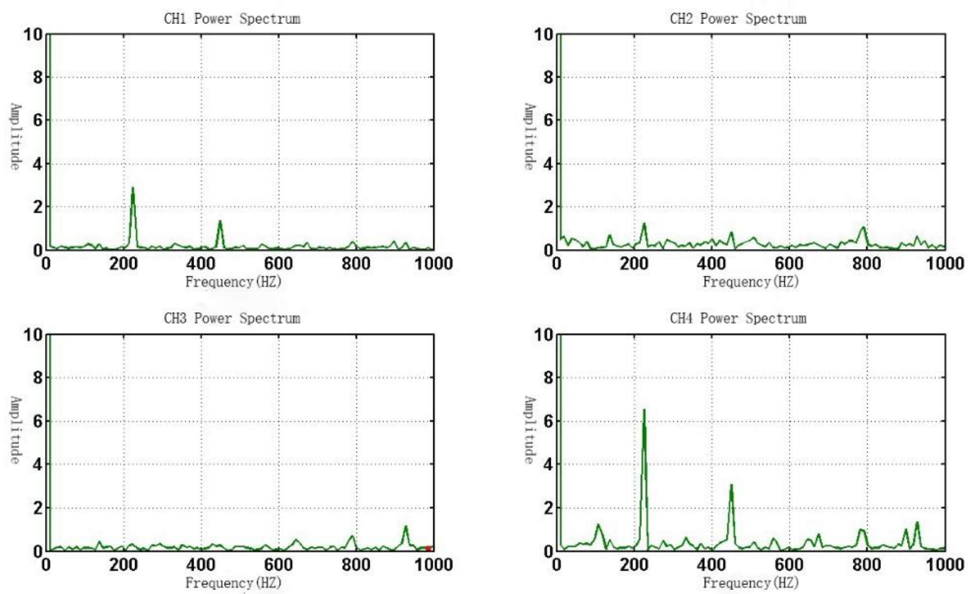

Figure 12. The power spectrum in the contraction state.

IV. CONCLUSION

In this paper, a four channel sEMG acquisition system with high precision, low latency, portability, lithium battery power supply and wireless data transmission is designed. The design of acquisition system integrates lithium battery charge and discharge management and efficient power supply system, wireless network communication, the preprocessing filter circuit. This small noise interference, with single channel high SNR, avoiding frequency interference system makes EMG signal acquisition a portable, high sampling rate and diversified processing platforms. The experimental results show that the data acquired by the system is effective and can be used for the analysis and processing of EMG signals, which creates the hardware condition for the research of the follow up surface EMG signal processing.

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