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Design of multi-channel wireless array wearable surface electromyography testing equipment

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Abstract. Since there are few researches on multi-channel surface electromyography (EMG) devices, this paper presents a new design scheme. The system uses highly integrated chips and designs a new wearable electrode array. Also, the data is transmitted by wireless WiFi with a high bandwidth. Scalable modular architecture is also applied to make the system suitable for different scenarios. Through experimental tests, the device can work for more than 5 hours, effectively collecting the EMG signals generated when the hand muscles move.

1. Introduction

The surface EMG signal refers to the detection of the EMG signal obtained on the surface of the skin. Surface electromyography has great application value in human-computer interaction, medical diagnosis, human biomechanics and other fields. For example, Jian Wu et al. use surface electromyography and accelerometer fusion to identify sign language[1]. P. Sbriccoli. used surface electromyography to detect muscle damage and recovery[2]. Catherine Disselhorst-Klug uses surface electromyography techniques to measure the muscle strength[3].

The signal detected by the surface electromyography is the superposition of the electrical signals when the multiple muscles contract. The more the number of channels collected, the better information collection and better noise reduction. Array multi-channel surface electromyography can be used for spatial filtering and feature extraction, and improve system resolution[4]. The array electrode can effectively record the spatial information of muscle activity in addition to the time domain information of the measured muscle activity, making it possible to detect new muscle characteristics, especially in the muscle fiber conduction velocity and single motion unit (Single motor unit).It has unique advantages in feature evaluation[5]. In summary, the multi-channel array acquisition method is very important for surface myoelectric testing equipment.

Wearable devices can enhance portability and make human-machine synergy closer[6]. For the application of surface electromyography, it is necessary to design a wireless wearable device. Many surface electromyography devices currently do not for multi-channel array acquisition and has wearable feature at the same time. For example, Delsys' Trigno series wireless surface electromyography system, although wirelessly transmitted, is small enough to meet certain wearability, but it has few acquisition channels. Italy's OT Bioeletronica EMG-USB2+ collector has 256 channels of acquisition, but the device and electrodes are connected by wires, during measurement the tester's activity is limited.

In the traditional surface electromyography system design, it is generally done in the hardware to complete the amplification, filtering, remove the power frequency interference, and achieve the acquisition of signals, which makes the system more components, large volume, and complicated debugging process. Such as the design of the 32-channel surface EMG acquisition system designed by Pengfei Zuo[7].

This paper designs a multi-channel wireless transmission wearable surface myoelectric detection device. The system uses flexible wearable array electrodes and the data is transmitted wirelessly. The acquisition module uses a highly integrated chip that reduces volume and enhances stability and integrity. Scalable modular design for applications in different scenarios. It provides a stable and reliable surface electromyography detection system for applications such as human-computer interaction, motion detection, and medical diagnosis.

2. Design scheme

The work of collecting myoelectric signals is divided into two steps: hardware signal acquisition and upper computer processing. The system flow is shown in Figure 1. The measurement site here is the surface EMG signal of the human arm part. After the array electrode collects the original surface electromyogram signal, the preprocessing circuit of the data acquisition board filters out some of the low frequency noise and performs overvoltage protection. The data acquisition board then performs

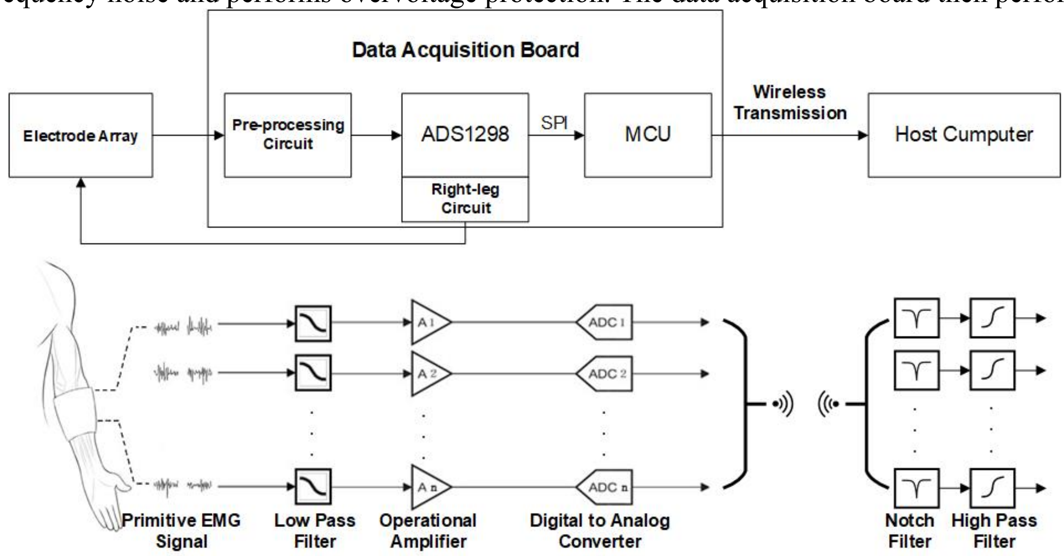

Figure 1 System workflow diagram

acquisition amplification and analog-to-digital conversion on the surface EMG signals. The MCU control board controls the multiple data acquisition boards to work together and obtain the values measured by the data acquisition board via SPI bus, and the data is summarized and transfer the data to the upper computer wirelessly. The upper computer uses a digital filter for high-pass filtering, uses a power frequency notch filter to suppress 50Hz power frequency and its harmonic interference, finally obtains real-time surface EMG signals and displays and saves them in files.

The hardware part has a flexible electrode array, a data acquisition board and an MCU control board. The data acquisition board integrates the front-end second-order filter circuit and the ADS1298 system circuit. The MCU control board integrates the STM32 microcontroller system circuit, WiFi wireless communication system and so on.

The software part is the MCU program and the host computer program. The MCU program is responsible for controlling the data acquisition board and transmitting the collected data to the upper computer wirelessly. The upper computer performs digital filtering to display waveforms, storage, and the like.

2.1. Flexible electrode array design

Figure 2 shows a set of flexible electrode arrays including a flexible substrate, a silver chloride electrode, and a wiring port. A set of flexible electrodes has 20 electrodes that can be connected to the data acquisition board through the adapter plate. When measuring, the flexible electrode is bound to the tester's arm by a strap.

The substrate used a 150μm polyimide(PI) flexible material. Polyimide can be stretched to make the substrate follow the skin for small amplitude movement, reducing motion artifacts. The flexible substrate is more comfortable to wear than a rigid, non-stretchable substrate.

The electrode adopts the traditional JK-1 type silver chloride electrode, which has a signal-to-noise ratio of about 45 dB at the main frequency of the surface electromyography signal, and the noise is small[8]. The silver chloride electrode has a diameter of 9 mm and a thickness of 2 mm. Each of the flexible electrode arrays has 20 channels, and the silver chloride electrode is fixed to form an electrode array on the pads of the substrate.

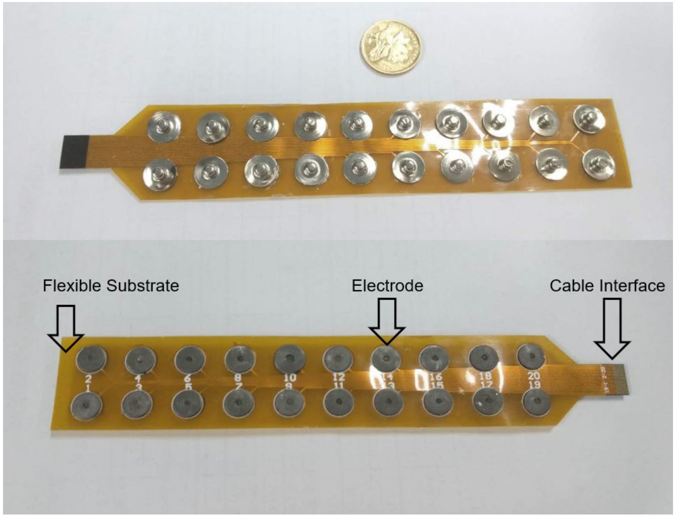

Figure 2 flexible electrode array

The size of the polyimide substrate is 30mm× 150mm, and the 20 copper pads on the substrate are divided into upper and lower rows, each row is spaced.

15mm apart, and the pads are arranged at a lateral interval of 15mm. The inner diameter of the pad is 3 mm and the outer diameter is 6 mm. There are contact points on the upper and lower sides. The electrodes are attached to the pads by snaps. In order to ensure the conduction between the pad and the electrode, the contact point is coated with a conductive silver paste. The middle layer of the substrate is provided with wires, and the pads are led out through the wires to the cable interface on one side. After measurement, the resistance of the silver chloride pad to the cable interface is 15-20Ω, which can meet the surface electromyography detection requirements.

2.2. Data acquisition board

The data acquisition board consists of two parts: the front-end preprocessing circuit and the ADS1298 system circuit. The pre-processing circuit performs preliminary processing on the surface myoelectric raw signal. The ADS1298 system circuit is responsible for controlling the initialization of the chip and communicating with the MCU control board.

The pre-processing circuit consists of a second-order passive RC filter circuit and a Zener diode circuit. The pre-processing circuit functions to filter out part of the high-frequency noise and over-voltage protection. The second-order RC filter removes high-frequency noise above 30 kHz. The Zener diode turns on when the input voltage is too large, protecting the data acquisition board.

The data acquisition board needs to collect high-quality surface EMG signals with hardware filtering noise, and should have a scalable data interface. This paper selects the ADS1298 chip as the acquisition chip. The ADS1298 chip is an analog front end of a high-performance test biopotential released by TI. It has an 8-channel analog acquisition channel. The SPI data interface has a built-in right-leg circuit that suppresses the power frequency, and the power frequency noise is suppressed on the hardware. ADS1298 can be used to collect weak physiological signals such as ECG signals and surface EMG signals. Such as Dunqiang Lu, Wei Wang and other surface electromyography acquisition systems designed using ADS1294 chip[9].

The ADS1298 system circuit uses the officially provided system circuit. Use 0Ω resistor isolation between analog ground and digital ground. The data acquisition board has a 20-pin interface, of which 16 pins are 8 positive and negative input interfaces, and 4 pins are right leg circuit interfaces. The adapter board is connected to the flexible electrode, and the MCU control board and the data acquisition board are connected by a pin header. The data acquisition board has a sampling frequency of 500 Hz and a preamplifier amplification factor of 6.

2.3. Wireless transmission module and MCU control board

Bluetooth can be used for communication in devices with a small amount of data transmission, such as a wristband real-time gesture recognition device made by Shuo Jiang using Bluetooth to transmit the acquired four-channel surface EMG signals and single-channel IMU signals to the host computer[10]. Bluetooth transmission bandwidth cannot meet the needs of more channels to transmit data. The Bluetooth transmission rate is up to 115200 baud and can transfer 14KB of data per second. Under the sampling frequency of 500Hz/s, the 8-channel data of each data acquisition board of the system needs to occupy 13.5KB/s transmission bandwidth, and the Bluetooth data transmission speed only supports one data acquisition board (8 channels) data transmission. Using the WiFi module to wirelessly transmit data baud rate up to 921600, the transmission rate can reach 112.5KB / s, can support 8 data acquisition board (64 channels) data transmission at 500Hz / s sampling frequency.

The MCU control board needs to configure the ADS1298 chip register through the SPI protocol, read the measurement data, control multiple data acquisition chips to work together, and transmit the data to the host computer through the WiFi. The MCU processor should have an SPI interface, a serial interface, and a faster main frequency. The MCU processor selects the STM32F103 series, which can achieve a processing speed of 72MHz and an internal SPI interface. The data on the data acquisition board can be received simultaneously via the SPI.

2.4. Implementation of multi-channel acquisition

The single data acquisition board only has 8 surface EMG acquisition channels. For more channel application scenarios, this paper designs a multi-data acquisition board to work together. The ADS1298 chip itself supports multi-chip cooperative working mode and can be connected through Daisy-chain or Cascade. The Daisy-chain method uses less wiring, but the right leg circuit cannot be used to remove the power frequency, which reduces the quality of the surface EMG signal. Cascade's method has good versatility and simple principle, but there are many wiring ports and complicated circuits. It is necessary to use the MCU control board to control the timing of multiple data acquisition boards, which requires high synchronization and program processing. Based on the quality of the acquired signal, the Cascade connection is selected to achieve multi-channel acquisition.

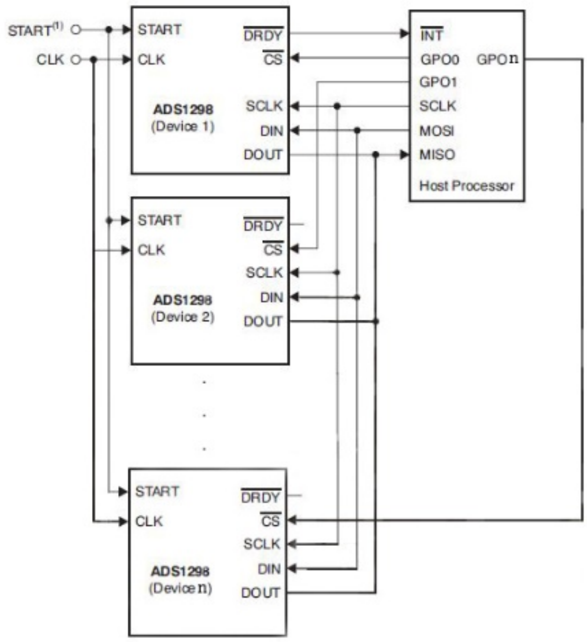

Figure 3 multi-chip cascade circuit connection diagram

When using Cascade connection mode, you need to select each ADS1298 chip from the MCU control board, and connect the three SPI data transmission lines of each chip and the common START and CLK signal lines together. The circuit connection diagram is shown in Figure 3-1.

When Cascade is connected, it needs to use an external clock frequency for synchronization. The data acquisition board must use the internal clock to use the external clock when configuring the register. The MCU control board program controls the switching data acquisition board to use the clock to realize the multi-data acquisition board coordination jobs.

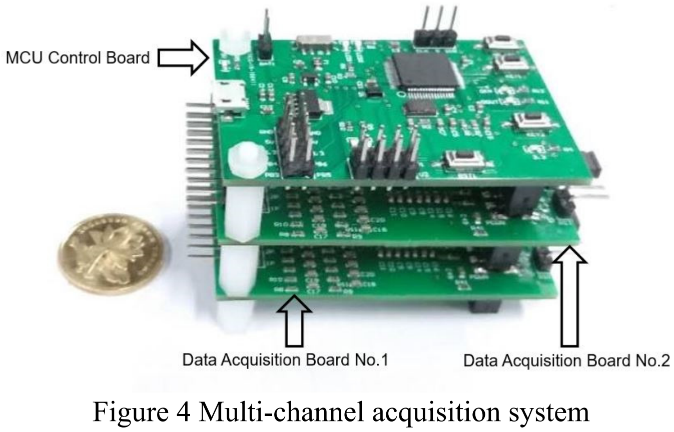

Figure 4 Multi-channel acquisition system

The SPI data line of each data acquisition board, the common START and CLK signal lines are connected by pin headers. An acquisition system consists of the topmost layer of the MCU control board and the following layers of data acquisition boards. Figure 4 shows the physical connection diagram of the 16-channel acquisition system of two data acquisition boards. Changing the number of connected data acquisition boards, modify the MCU control board and the host computer program to meet the needs of different numbers of acquisition channels.

2.5 Software programming

The MCU control board completes the data acquisition board, collects data through the SPI interface, sends data to the upper computer through WiFi, and controls multiple data acquisition boards to work together. After each system startup, the MCU control board needs to re-initialize the settings, and then the data is read through the SPI interface. The ADS1298 chip generates an interrupt by setting the DRDT pin high level, and informs the MCU control board that the EMG data acquisition of the 8 channels is completed, and the MCU control board continuously reads 27 bytes of data information to complete the acquisition.

The upper computer program is responsible for sending instructions to set the working mode of the data acquisition board, accepting the data packet uploaded by the MCU module, and then performing filtering processing to display in real time. Increase the cross-platform and portability of the host computer, and write it on the QT platform in C++.The upper computer program sends instructions to control the MCU control board. The command protocol is similar to the data packet sent by the MCU control board. Send different command characters to configure the data acquisition board mode. In order to make the signal processing speed and fast real-time performance, the system uses an infinite-length unit impulse response digital filter. The model of the high-pass filter and the notch filter is constructed using MATLAB, and the model parameters are calculated, which is used in the upper computer program. A part of the high-frequency noise in the surface EMG signal has been filtered by hardware, and the low-frequency noise in the host computer is filtered by the high-pass filter. The high-pass filter has a cutoff frequency of 5Hz and an order of 5, and the acquisition frequency of the system is between 5Hz and 500Hz. In this interval, the 50Hz power frequency interference has been suppressed by the right leg circuit, but the upper computer uses the digital notch filter to filter again. The notch order is 7, and the quality factor is 5.

3. experimental design and results

3.1. Experimental design

In order to verify that the system can effectively collect surface EMG signals, a set of experiments was designed.

Four data acquisition boards (32 channels total) and MCU control board were used, and the flexible electrode plus position machine was used to build the experimental system. The hardware acquisition system operates at approximately 90mA and can operate for more than 5 hours with a 500mA battery. The volume is 90mm × 80mm × 50mm, and the weight is 300g. The PC software runs in the environment where QT is configured.

In the test acquisition, four sets of flexible electrode arrays were fixed to the left forearm of the subject by a band. The first set of electrodes (1 channel to 8 channels) are attached to the shallow and deep flexors. The second set of electrodes (9 to 16 channels) were attached to the radial flexor of the wrist. The third set of electrodes (17 to 24 channels) are attached to the extension finger muscles. The fourth set of electrodes (25 to 32 channels) is attached to the elbow muscle. The subjects were in a standing state when tested, and the left arm was a pronation. In 18 seconds, the fist is made, the palm is opened, the palm is bent forward, the palm is bent backwards, the palm is bent to the inside of the body, and the palm is bent to the outside of the body for six movements.

3.2. Experimental results and analysis

The raw data of one channel surface EMG signal (1 channel, 9 channels, 17 channels, 25 channels) from each of the four data acquisition boards is integrated into a graph, as shown in figure 5.

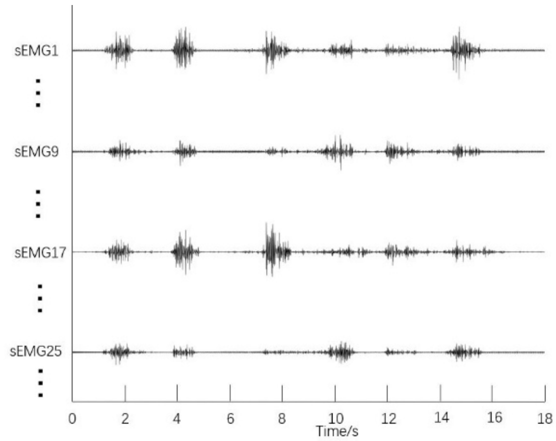

Figure 5 Multi-channel surface EMG signal

It can be seen from the electromyogram that the myoelectric signal of the shallow, deep flexor and extensor muscles is obvious when the fist is applied and the palm movement is extended. The muscles that stretch the finger muscles and allow the fingers to straighten out. The shallow and deep flexors are responsible for pulling the tendons and making the hands grasp the fists. This is consistent with the moment when the sEMG1-8 channel signal has a peak, and the waveform is obvious and the noise signal is less. Experiments show that the system is effective in collecting surface electromyography.

3.3. Conclusion

This paper designed a wearable multi-channel array surface electromyography acquisition device. The system effectively filters out high frequency, low frequency and power frequency noise, and can collect real-time stable surface EMG signals. The flexible electrode array makes it easy to wear and is suitable for collecting surface EMG signals from complex muscle groups. It is convenient for the measurer to use in the form of wireless transmission. The system can be applied in the fields of human-computer interaction gesture recognition, medical diagnosis, rehabilitation medicine, motion detection and the like.

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