Wearable Technology (2021) Volume 2 Issue 2, *pp.* 2–11.
doi: 10.54517/wt.v2i2.1635

ORIGINAL RESEARCH ARTICLE

Functional requirements analysis and design of wearable multi-channel sensing system

Xingyu Ma, Hengzhen Shi, Yuehui Hu*[*], *Yini Ren, Wuwei Kang, Tao Jin, Yang Wang, Piao Dai

Academy of Photoelectric Technology, Hefei University of Technology, Hefei 230000, Anhui, China. E-mail: jthu@hfut.edu.cn@gmail.com

ABSTRACT

In recent years, a large number of wearable devices have emerged; and users have higher and higher functional requirements for wearable devices. However, the realization of complex functions of wearable devices often depends on the real-time acquisition of multi-channel sensing signals. Taking the wearable 8-channel PVDF sensor system as an example; this paper studies the functional requirements of this kind of system. It is found that the flexible ultra-thin and long endurance time are two obvious characteristics of this kind of equipment. The key technical problems of the system are completed, such as the selection of MCU, the coding design of multi-channel sensing data, the transmission mode design of multi-channel sensing data and the low power consumption design of the system. A practical design scheme of reliable wearable multi-channel sensor system is designed. This scheme also provides a reliable reference for the design and development of wearable multi-channel sensor system.

Keywords: wearable equipment; system design; demand analysis; multi-channel; PVDF sensor; coding method; mode of transmission

1. Introduction

In recent years, a large number of wearable devices have emerged, such as Google glasses, Codoon bracelet, iWatch and so on. Wearable devices generally refer to electronic communication intelligent devices embedded in clothing or in the form of accessories, which can be worn comfortably by users and play the role of expanding perception and monitoring all kinds of signs. It is essentially an intelligent design of daily equipment such as glasses, watches and shoes[1], so that it has a friendly human-computer interaction function. The market demand for wearable devices is growing rapidly; and users have more and more functional requirements for wearable devices. However, the realization of complex functions often depends on the real-time acquisition of multi-channel sensor signals. Multi-channel sensor system is an important component of wearable devices and a source of information for wearable devices. It has the functions of monitoring data; transmitting data and so on. For a wearable device, it generally includes two parts: Sensor and data computing chip. The update frequency of sensor is low, and there may be no major upgrade in a few years. The replacement frequency of the computing

ARTICLE INFO
Received: March 19, 2021 | Accepted: April 29, 2021 | Available online: May 16, 2021

CITATION
Ma X, Shi H, Hu Y, et al. Functional requirements analysis and design of wearable multi-channel sensing system. Wearable Technology 2021; 2(2): 2–11.

chip is very high, so the hardware device itself should be more regarded as a super sensor system, and the computing part should be handed over to the mobile phone or cloud computing independently. Therefore, it is necessary to study the wearable multi-channel sensor system.

Wearable device users require comfortable wearing and good flexibility. PVDF (polyvinylidene fluoride) piezoelectric sensor just meets the characteristics of good flexibility and light weight[2]. Therefore, taking the wearable 8-channel PVDF sensor system as an example, this paper studies the functional requirements of this kind of system, designs a set of evaluation and selection system, and puts forward a practical and reliable design scheme of multi-channel sensor system.

2. Functional requirements analysis of wearable multi-channel PVDF sensor system

Wearable multi-channel sensor system needs to collect multi-channel sensor data, simply process and package it, and transmit it to other devices in real time and reliably[3]. Due to the wearable characteristics of this kind of equipment, that is, the equipment needs lightweight and low power consumption, as well as the real-time and reliability of data transmission, the wearable multi-channel sensor system has special requirements for the MCU part, data coding mode, data transmission mode and low power consumption of the system[4].

2.1. System MCU demand analysis

The data of the wearable multi-channel sensor system needs to be transmitted to other devices, which are often Android system or IOS system. If the system does not have this MCU, the system needs to be directly connected with the ARM chip of Android system or the microprocessor of other systems, which will cause a lot of inconvenience. Taking the sensor system as the lower computer and the ARM chip of Android system as the upper computer as an example, the inconveniences are as follows: The target signal collected by the sensor system is the human physiological signal, such as the motion signal generated by the muscle when the human wrist or ankle moves. The sensor signal output by the system is weak and has strong interference. If there is no preprocessing such as amplification, it cannot be directly connected with the arm of a droid system. Therefore, the pre signal preprocessing circuit is needed. The designed pre amplification circuit includes amplification, filtering and other functions. Even if the ARM chip of Android system has an amplification module, it cannot meet the requirements. Amplifying such sensor signals generally requires instrument amplifiers with high performance requirements. If 8 sensors in the sensor system collect 8-channel sensing signals, at least 8 signal lines need to be input into MCU. Considering the reliability and convenience of the system, it is not convenient to connect directly with the ARM chip of Android system. For the consideration of modular design, it is also necessary to use this MCU in the multi-channel sensor system. To sum up, we can find that the selected MCU needs to complete the functions of signal transceiver, A/D conversion, integration and serial output, and connection with the preprocessing circuit of sensor signal in the early stage.

Therefore, for the selected MCU, it is necessary to have at least 8 A/D conversion channels in function and meet certain accuracy requirements. In terms of hardware structure, considering the portability of wearable devices, the size of MCU should be small and the thickness should be thin. In addition, low power consumption is a key feature of portable electrical equipment. In order to achieve this goal, the power consumption of MCU should be low.

2.2. Demand analysis of system data coding mode and transmission mode

The most important and final function of wearable multi-channel sensor system is to provide a set of sensor data containing various information. The format of these data can match the data format of some mainstream communication protocols. The data can be easily and reliably transmitted to the Android system in real time.

The wearable 8-channel PVDF sensor system designed in this paper mainly collects human physiological signals. These signals are mainly concentrated in 0-100 Hz, that is, the frequency range of each channel signal of the sensor system is 0-100 Hz, and the maximum of 8 channels is 800 Hz. During A/D conversion in engineering application, the sampling frequency is at least 10 times the maximum frequency of the input analog signal, so the sampling frequency we adopt is 10 KHz, which meets the requirements of signal processing in digital domain in the later stage. Considering the requirements of real-time data transmission, the data frame is set to 10ms, that is, the lower computer sends a frame of data to the upper computer every 10ms. In fact, the data received by the upper computer each time is the data sampled by the lower computer in the first 10ms. When the sampling frequency is 10 KHz, a total of 100 data are sampled in 10ms. Because the resources and processing capacity of MCU are not enough, it is necessary to send the collected data to the host computer for processing in real time. However, if the data is sent directly after data collection, the packet will be lost due to the large amount of data collected in real time and the small buffer. Therefore, appropriate coding protocol and communication protocol are needed to ensure the reliability of communication. In this case, the lower computer is mainly responsible for collecting and packaging, which can meet the requirements of simplification, accuracy and real-time. The data to be calculated is handed over to the host computer for processing. At the same time, considering the slow updating of sensors and the fast updating speed of host computer processing chip, this scheme can also reduce the cost to a certain extent.

For the system data coding method, what we need is a real-time and reliable coding method and communication protocol. In addition, the transmitted data format should match the mainstream communication protocol data format. At the same time, the coding mode and transmission mode also need to consider the requirements of low power consumption.

2.3. Low power consumption demand analysis of the system

For wearable devices, the endurance time must be considered. The endurance capability is mainly determined by two factors: battery capacity and power consumption. The higher the battery capacity, the better, and the power consumption needs to be minimized. Unfortunately, before the emergence of new battery technologies or materials, the space for battery capacity improvement was very limited, and the size requirements of wearable devices were relatively strict, so it was impractical to increase the battery life by replacing large capacity batteries. Therefore, the pressure almost falls on how to reduce power consumption, which requires low-power design to meet the needs of users.

The low-power requirements of the system mainly include the following aspects. Firstly, try to use products with low voltage and low power consumption in the hardware development of sensor system[5]. For example, the amplification, filtering and preprocessing circuit of the sensor system generally selects a low-power chip. At the same time, in the selection of main control chip, we generally choose the main control chip with power-saving mode. Secondly, as the main controller of the system, MCU also needs low-power design. The work of MCU mainly includes A/D conversion of multi-channel sensor signals, simple processing and packaging of data and data transmission. Finally, it is required to have flexible low-power management mode and simple and fast sleep wake-up mechanism, so that MCU can quickly switch to different depths of sleep state in idle period and wake up in time. We can choose the way to wake up the main control chip or related modules. That is to optimize the software algorithm according to the demand of low power consumption while realizing the basic functions.

3. Design of wearable multi-channel PVDF sensor system

According to the above demand analysis and research on the system, it is found that the most significant characteristics of this kind of wearable devices are flexible, ultra-light weight and long service life. Therefore, wearable multi-channel PVDF sensor system should be designed around these two remarkable characteristics.

3.1. System MCU selection

According to the functional requirements analysis of wearable multi-channel sensor system, focusing on the two characteristics of low power consumption and high integration of wearable multi-channel PVDF sensor system, this paper compares and analyzes some mainstream MCU products in the market, and finally obtains the appropriate MCU selection.

Table 1 and **Table 2** select the mainstream MCU products in the current market, and compare their power consumption parameters and system indicators. Firstly, the wearable 8-channel PVDF sensor system needs at least 8-channel A/D conversion channels, and the MCU in **Table 1** meets the requirements. However, because the collected target signal is human physiological signal, the general signal is very weak, so the higher the accuracy of ADC, the better. The two MCU with high ADC accuracy are STM32. Compared with STM32F1 series, stm32L1 series has lower sleep power consumption, wider working voltage range and more A/D conversion channels. Secondly, according to the strict requirements for the size of the wearable system, the size of the tfbga64 package of STM32L151R6 is only 5 mm*5 mm*1.2 mm, the size fully meets the requirements. Finally, STM32L151R6 is a 32 bit core MCU of Cortex-M series, but its power consumption level is equivalent to that of traditional 16 bit low-power MCU, but its processing capacity is better than that of 16 bit MCU. Moreover, the price of STM32L151R6 is also moderate[8]. STM32L151R6 also has a great advantage in that STM company has a perfect system scheme based on STM32 and finished software and hardware modules, which has formed a relatively perfect ecosystem, low development threshold, rich reference resources and direct experience sharing[6]. The various advantages of STM32L151R6 prompted us to finally choose STM32L151R6 as the MCU of the wearable 8-channel PVDF sensor system in this paper.

3.2. Coding design of multi-channel sensing data

Because the collected 8-channel PVDF sensor data needs to be transmitted to the host computer in real time and accurately, the collected data needs to be encoded and simplified. In this paper, ADPCM coding is selected to compress the data, and then CRC$_{1}$6 and convolutional coding are used to error correct the data. The target signal we collected is very similar to the voice signal.

Table 1. Comparison of typical microprocessor system indexes

Manufacturer model	Bus width (bit)	Kernel architecture	Core efficiency (coremark/mhz)	Core efficiency (coremark/mhz)	Number of A/D conversion channels	ADC accuracy (bit)	Dimension (mm) × mm × mm)	Price (yuan)
RL78/Renesas RL78G13[10]	16	RL78	0.89	1.6-5.5	20	8/10	QFP64 sealed 14x14x2.25	22.5
PIC24F/Microchip PIC24FJ256GB110[11]	16	PIC24	0.93	3.0-3.6	16	10	TQFP100 sealed 12x12x1	57.2
MSP430F/TI MSP430F5229[12]	16	MSP4 30	1.11	1.8-3.6	16	10	VQFN64 sealed 9x9x1	45
STM32F1/STM STM32F103R8[7]	72	Cortex -M3	1.2	2.0-3.6	20	12	LQFP 64 10x10x1. 4/ TFBGA 64 5x5x1.2	13
STM32L1/STM STM32L151R6[9]	32	Cortex -M3	2.61	1.65-3.6	42	12	LQFP 64 10x10x1. 4/ TFBGA 64 5x5x1.2	19.2

Table 2. Comparison of absolute power consumption of typical microprocessor

MCU series	Maximum dominant frequency (mhz)	Operating power consumption (UA/mhz)	Sleep power consumption (UA)	Wake up time (US)
RL78/Renesas	32	66	0.24@Stop	>18-65
PIC24F/Microchip	32	150	0.42@LVS	70
MSP430F/TI[15]	25	195	1.2@LPM3	3.5-4.5
STM32F1/STM	72	373	1.7@Stop	50
STM32L1/STM	32	185	1.2@Stop	8.2

The correlation between the data is relatively strong. There is a lot of redundancy, and the final use of the sensing signal is mainly to analyze the shape of the signal, rather than obtain accurate values. ADPCM algorithm comprehensively uses the algorithm principle of differential pulse coding (DPCM) and Adaptive Incremental coding (ADM). On the premise of ensuring the speech quality of PCM, the rate of speech data is only half of that of PCM, and has better anti error performance. The core idea of ADPCM is: 1) use the adaptive idea to change the size of quantization order, that is, use the small quantization order to encode the small difference, and use the large quantization order to encode the large difference. 2) The predicted value of the next input sample is estimated using the past sample value, so that the difference between the actual sample value and the predicted value is always the smallest[13]. ADPCM compression algorithm is adopted in this paper, and the compression ratio of data can reach 4:1.

In order to improve the reliability of data, some error detection and correction coding should be carried out after data compression and coding. Although cyclic code CRC can only detect errors and cannot correct errors, it has low computational complexity, strong error detection ability and less redundant bits[14]. The convolutional code has strong error correction ability. Although the computational complexity is high, the computational complexity can be greatly reduced by looking up the table. In this paper, CRC_16 check coding and (2,1,4) convolutional coding are selected for error detection and error correction coding. Cyclic redundancy check (CRC) algorithm is one of the commonly used error detection methods. It is evolved from the branch of block linear code. Its main application is binary code group. The coding is simple and the error probability is very low. Using CRC algorithm for data at the receiver can effectively eliminate the error code in data transmission. CRC16 coding adopts look-up table method in algorithm implementation. The CRC16 code consists of two bytes. At the beginning, each bit of the CRC register is preset to 1, and then XOR the CRC register with 8-bit data. Then, the CRC register is shifted from high to low and zero is filled in the position of the highest bit (MSB). If the lowest bit (LSB, which has been moved out of the CRC register after shift) is 1, XOR the register with the predefined polynomial code, otherwise if the LSB is zero, no XOR is required. Repeat the above shift from high to low for 8 times, and the first 8-bit data is processed. Use the value of CRC register at this time to XOR with the next 8-bit data, and perform 8 shifts like the previous data. After all characters are processed, the value in the CRC register is the final CRC value. Every shift division operation of CRC_16 coding is replaced by look-up table method, which has low computational complexity. Every time a frame of data is encoded by CRC_16, a 16-bit check code is obtained. The 16 bit CRC algorithm can ensure that there is only one undetected error in 1014 bit symbols. Convolutional code is a kind of error correction coding. It compiles the input K information bits into n bits for output. It is especially suitable for serial transmission with small delay. It includes: an input shift register composed of N segments, each segment has k segments, a total of NK registers, a set of N modules 2 and adders, an output shift register composed of N stages, corresponding to the input sequence of k bits per segment, outputs n bits[16]. (2,1,4) convolutional code is to encode the 2-bit information input each time into 4 bits. Convolutional code has a large amount of computation and high complexity. In this paper, the look-up table method is used for convolutional coding of data. Firstly, the coding table of (2,1,4) convolutional code is generated by using convenc (msg, t) function in MATLAB. The size of the coding table is 2^8*16 bits, and then the table is directly looked up in the MCU of the lower computer for coding, which greatly improves the coding speed, reduces the complexity of the algorithm, and reduces the running power consumption of MCU.

The specific coding method of 8-channel sensing data is shown in **Figure 1**: It can be seen from the above that the data frame is sent every 10ms, and there are 100 original sensing data in each frame. Since the ADC accuracy of STM32L151 single chip microcomputer is 12 bits, the collected data is actually 100*12 bit, accounting for only the lower 12 bits of a word. The highest bit, i.e. the 16th bit, is set as a control bit. When the control bit is 0, it means that the current data is a data signal, when it is 1, it indicates that the current data is a control signal. The channel number code of 8 channels is 000-111, occupying the 13^{th}-15^{th} bits, and 100 data occupy 200 bytes in total. Firstly, ADPCM code the 200 bytes of data, and compress the encoded data to only 100*4 bit, occupying 100 bytes. Then the data is combined into an 8 bit. The data frame has been compressed to 50*8 bit, occupying only 50 bytes. Secondly, the data frame is encoded by CRC16, that is, a 16-bit check value is obtained. When the check value is added, the data frame is 52 bytes in total. Finally, the data frame is (2,1,4) convolutional coded, and the convolutional coded data frame has a total of 104 bytes.

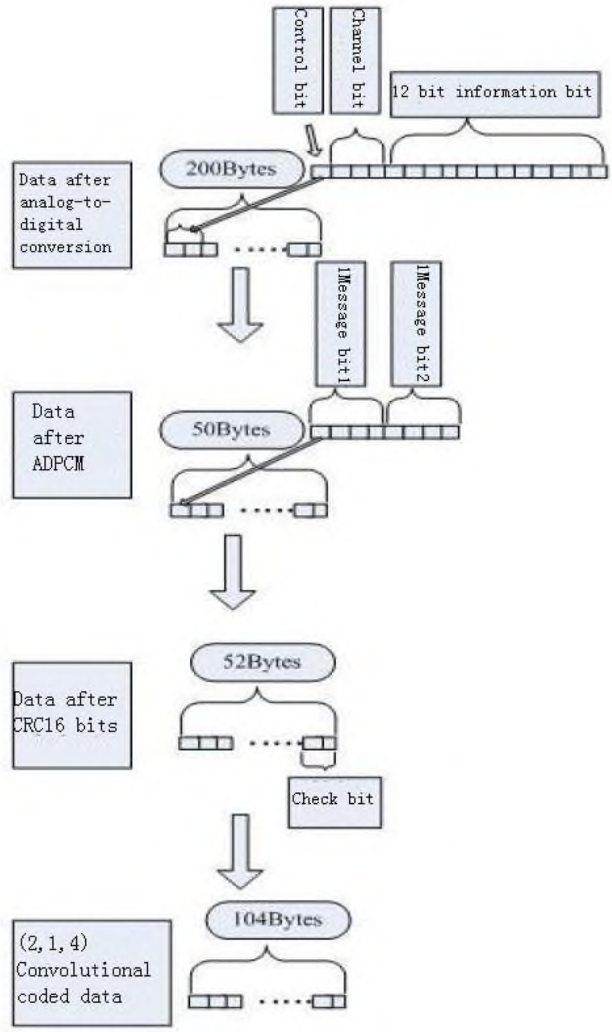

Figure 1. Flow chart of data coding scheme.

3.3. Design of sensing data transmission mode

Real time and reliable data transmission, in addition to relying on a real-time and reliable data coding method, the data transmission method is also very important. Considering the compatibility and application of the wearable multi-channel sensing system, two sensing data transmission methods are designed in this paper. One is wired transmission and the other is wireless transmission.

Design of wired transmission mode of sensing data

As for the choice of wired transmission scheme, we select four common transmission schemes such as I2C, USB, SPI and RS232 for comparison. By analyzing and comparing these common wired transmission modes, we finally choose I2C as the wired transmission mode of the system. I2C has the following significant advantages: 1) simple hardware and less resource consumption. There are only two bus lines: A serial data line (SDA) and a serial clock line (SCL), which save line space and increases the stability of the system. Therefore, in terms of size, since USB and SPI have four wires, RS232 has nine pins. Compared with I_2C, which has only two bus lines, it will inevitably lead to the problem that the connection and peripheral circuits occupy too much space. In terms of size, I2C should be our ideal choice in these wired transmission modes. 2) It is a real multi host bus, which locks the slave device through the address information on SDA. If two or more hosts initiate data transmission at the same time, the data can be prevented from being destroyed through conflict detection and arbitration. SPI bus has only one master device, and the master device determines the slave device through CS chip selection. 3) The 8-bit bidirectional data transmission rate of I2C serial can reach 100 Kbit/s in standard mode, 400 Kbit/s in fast mode and 4.4 Mbit/s in high-speed mode. In this scheme, at least 104 bytes are transmitted every 10ms, and the transmission mode adopted is at least 83.2 Kbit/s. The transmission speed of I2C fully meets the requirements. 4) Compared with RS232, I2C has another outstanding advantage: I2C sampling synchronous communication and RS232 asynchronous communication. The overhead of synchronous communication control characters is small and the transmission efficiency is high, in the asynchronous communication character frame, assuming that there are only start bits, 8 data bits and stop bits, the overhead of control bits in the whole character frame reaches 20%, and the transmission efficiency is low. 5) It is widely used. Now almost all IC manufacturers have integrated I2C on their chips[17].

Design of wireless transmission mode of sensing data

As for the selection of wireless transmission schemes, we choose ZigBee, NFC, infrared, Bluetooth and other four common transmission schemes for comparison[18,22]. In terms of service distance, infrared transmission is a point-to-point wireless transmission mode, which cannot be too far away, should be aligned with the direction, and there should be no obstacles in the middle, so it is almost impossible to control the progress of information transmission[23]. Bluetooth can transmit about 10 meters. After strengthening the signal, it can be up to 100 meters. It can detour, misalign, and cannot be in the same room. The maximum number of links can be up to 7, and the hardware can be distinguished at the same time. ZigBee is a cheap, low-power short-range wireless networking communication technology. However, due to the low transmission speed of ZigBee, it is not suitable for the application of multi-channel PVDF sensor system with high data volume. At the same time, due to the high cost of hardware resources when using ZigBee[24], mobile phones are not supported in the short term, which is not conducive to the promotion of products. NFC has the advantage of simple configuration. However, due to the short use distance and the ultra-thin size of the wearable device we use, NFC will produce high-frequency skin effect[25], and there may be some potential health and safety problems. And the compatibility of NFC is not very good at present. Many mobile phones do not support NFC. These problems prompted us to choose the final wireless transmission mode for Bluetooth, the specific scheme is the i484e-s module. This product integrates two chips: the Bluetooth chip is CSR8811 (based on Bluetooth 24 GHz radio and baseband chip system) and STM32F401 (32-bit RISC based on high-tech ARM Cortex-m4). The size is only 15.7*12*2.3 mm. It supports Bluetooth standard 4.0 low-power mode and downward compatibility. It can be switched to Bluetooth mode through I2C wired mode. The speed can reach 32 KByte/s, i.e. 256 KBit/s. When transmitting data at full speed, the power consumption is only 2 mA, and the standard button battery can run for one or even several years.

3.4. Low power design

The power consumption of a sensor system is determined by many factors. The overall power consumption depends on many factors, such as product performance, power supply voltage and so on. In practical application, the higher the dwelling frequency, the greater the power consumption, the higher the voltage, the greater the power consumption. For the design of low-power detection system, we should mainly consider the selection of chips and devices, the technical indicators of the system and the working mode of the system.

Selection of devices and chips

For low-power systems, the selection of devices and chips used in the circuit is very important, which directly affects the power consumption of the system from the hardware circuit. Therefore, in order to reduce power consumption, devices and chips must be selected reasonably. 1) Selection of power supply part. Due to the high-energy conversion efficiency of lithium battery, the power supply used in wearable devices is generally lithium battery. The battery selected in this scheme is polymer lithium battery, the specific model is 803040, the capacity is 1,000 mAh, and the size is only 40*30*8 mm. A 200 mA, low IQ, low noise and low voltage drop regulator chip for portable equipment is selected. The model is TLV707 and the size is only 1*2 mm[26]. 2) Low power microprocessor is selected. In this paper, STM32L151R6 with low power consumption is selected, which has a compact and efficient CPU core, so as to maintain the balance of performance, power consumption and cost. CMOS circuit technology, low voltage power supply system, power supply voltage of 1.65-3.6V. Flexible low-power management mode and simple and fast sleep wake-up mechanism enable MCU to quickly switch to sleep states with different depths during idle period and be awakened in time. Independent peripheral clock control switch, multiple internal and external clock sources. The operating power consumption is only 185 uA/MHz, and the sleep power consumption is only 1.2uA. 3) For the preprocessing circuit of sensor signal, MAX9618 operational amplifier of Meixin company is selected to build the preprocessing circuit of each channel sensor signal, including amplification part and low-pass filter part. Max9618 is a low power, zero drift operational amplifier, which provides space saving. It adopts 2 mmx2 mm, 8-pin SC70 package design and supports full swing CMOS input and output. The power supply current is only 59 μA in the whole time and temperature range, and the maximum offset voltage of zero temperature drift input is only 10 μV. It is not often suitable for wearable devices[27].

Selection of working mode of low-power system

The MCU of wearable 8-channel sensor system is a low-power device, and has various working modes to reduce power consumption, such as sleep, power failure and so on. When designing a low-power system, we should make full use of these characteristics to make the system work in these working modes as much as possible. 1) MCU uses the lowest clock frequency for A/D conversion and coding to reduce power consumption. The coding algorithm is the simplest. CRC16 and (2,1,4) convolutional coding adopt look-up table method, which shortens the execution time of each program. 2) When the wearable multi-channel sensor system in this paper is used as the lower computer, whether it collects data or not is controlled by the upper computer. When the upper computer sends a command, the MCU is awakened, and the system starts to work again to collect data.

4. Overall system design scheme

The overall scheme of the wearable multi-channel PVDF sensor system designed in this paper is shown in **Figure 2**. Firstly, multi-channel sensors collect human physiological signals. The collected data are amplified and filtered and sent to STM32L151 single chip microcomputer for A/D conversion, and the analog signals are converted into digital signals that can be easily processed[28]. STM32L151 single chip microcomputer encodes and packs the 8-channel data obtained after A/D conversion, and then sends it to the upper computer. Due to the compatibility of transmission mode, the upper computer can be Android platform or IOS platform.

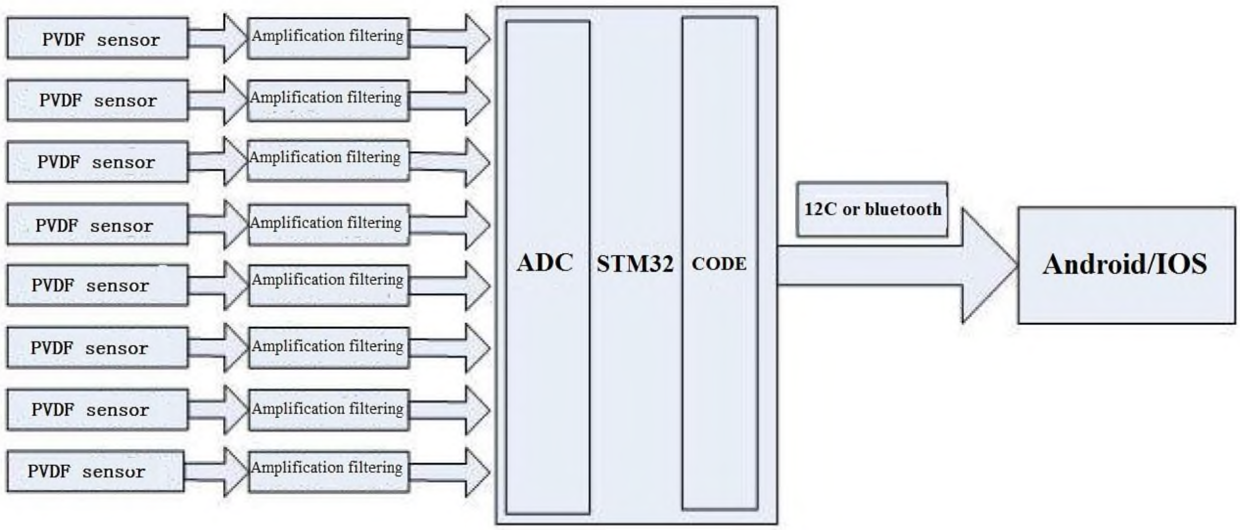

Figure 2. Overall system block diagram.

5. Conclusions

Since several scientists at MIT put forward the concept of wearable devices in the 1960s, people began to explore the application of wearable technology to design and develop daily wearable products in order to develop wearable intelligent devices. With the progress of technology and the change of user needs, the form and application hotspots of wearable intelligent devices are also changing. In this context, it is of great practical significance to analyze and design the functional requirements of wearable multi-channel sensing system. Taking wearable 8-channel PVDF sensor system as an example, this paper studies the functional requirements of this kind of system, and finds that flexibility, ultra-light weight and long service life are the characteristics of this kind of equipment. Based on this, a set of evaluation and selection system is designed to complete the MCU selection of the system; the coding mode of sensing data A practical and reliable system design scheme is obtained. This scheme also provides a reliable reference for the design and development of wearable multi-channel sensor system.

Conflict of interest

The authors declare no conflict of interest.

References

1. Shui Z. Printing electronic technology sets off a revolution in intelligent wearable applications. Integrated Circuit Application 2015; (11): 16–18.
2. Zhu J. Preparation and properties of PVDF piezoelectric film and its sensor [Master's thesis]. Harbin: Harbin Institute of Technology; 2011.
3. Xiao Y. Functional requirements analysis of automatic driving signal system. Railway Communication Signal 2014; 50(12): 39–42.
4. Yu W, Xie Z. Design of ECG monitoring system based on wearable. Sensors and Microsystems 2015; 34(9): 65–68.
5. Qian C. Design and application of a multi-purpose low-power detection system [Master's thesis].

Qingdao: Shandong University of Science and Technology; 2003.
6. Liu M. Analysis of MCU selection in portable medical electronic instrument design. Comprehensive Review of Chinese Journal of Medical Devices 2014; 38(3): 202–206.
7. Reference Manual of STM32F 10XXX Series Products Based on Arm32-Bit Kernel, 10th ed. STMicroelectronics; 2010 January; Grenoble, France.
8. STM32F 103xx Datasheet, 10th ed. STMicroelectronics; 2009 April; Grenoble, France.
9. STM32L 100XX; STM32L 151xx; STM32L 152xx and STM32L 162xx Series Reference Manual. STMicroelectronics; Grenoble, France.
10. RL78/G13Datasheet, 3.30 ed. Renesas Electronics Corporation; 2016 March; Tokyo, Japan.
11. PIC24FJ256GB110 Series Data Manual. Microchip Technology Inc.; 2009; Chandler, USA.
12. MSP430F522x/MSP430F521x Mixed Signal Microcontroller Data Manual, 5th ed. Electronics Corporation, Tokyo, Japan.
13. Chen S. Analysis and Simulation of ADPCM speech compression coding. Western China Science and Technology 2008; 7(32): 52–54.
14. Liu X. Rapid software implementation of CRC verification in single chip microcomputer system. Journal of Fujian Institute of Engineering 2007; 5(1): 76–78.
15. Zhang S. Implemented with MSP430_ 2_ 1_ 4_ Convolutional code coding and Viterbi decoding. Journal of Beijing Broadcasting Institute 2005; 12(1): 24–30.
16. Xu W. Joint source and channel coding [Master's thesis]. Hefei: University of Science and Technology of China; 2002
17. Wu M. Design and implementation of underlying software of several sensors based on I2C bus protocol in Android system [Master's thesis]. Xi'an: Xidian University; 2012.
18. Meng X. Research on data acquisition system based on USB interface [Master's thesis]. Qingdao: Shandong University of Science and Technology; 2004.
19. Yang M, Li X. SPI interface and its application in data exchange. Communication Technology 2007; 40(11): 385–387.
20. Wu W, Hu B, Zhang M. Two implementations of I2C bus driver in embedded system. Modern Electronic Technology 2007; (8): 56–58.
21. Xu Y, Hu C, Yao G. Design and implementation of infrared transmission function based on object exchange protocol in handheld terminal equipment. Electronic Devices 2007; 30(1): 215–218.
22. Zhang F, Zhang C. Research on short-range wireless communication technology and its fusion development. Electrical Measurement and Instrumentation 2007; 44(10): 48–52.
23. NFC Industrial Network Discuss the prospect and future of NFC wearable devices from the perspective of application. Golden Card Project 2013; (11): 40–41.
24. Guo Y. Preparing for wearable devices Bluetooth 4.1 analysis. Computer Fan 2014; (6): 64.
25. Zhou Y. Application research on lithium battery management system of electric vehicle based on smart phone [Master's thesis]. Changchun: Jilin University; 2014.
26. TLV707xx, TLV707xxP Datasheet. Texas Instruments; 2015; Dallas, Texas.
27. MAX9617-MAX9620 Datasheet, 7th ed. Maxim Integrated, San Jose, CA, USA; pp.19–4753.
28. Zhang X. Design of power data acquisition system based on STM32. Electronic Measurement Technology 2010; 33(11): 90–93.
29. Lu Z. Research on key technologies of wearable health monitoring and interpersonal interaction [PhD Thesis]. Hefei: University of Science and Technology of China; 2014.