Design of monitoring terminal for SAS based on flexible fabric electrode

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Abstract. Sleep apnea syndrome is a serious threat to the life and health of patients. In this paper, we designed a sleep apnea monitoring system based on flexible fabric electrode, and completed the specific hardware design including flexible fabric electrode, ECG signal conditioning module, microcontroller module and Bluetooth module. Among them, ADS1292 is mainly used for ECG signal conditioning, and EFM32 is selected as microcontroller. Finally, the experimental results show that the collected signal can clearly identify the ECG characteristics such as QRS wave, and meet the requirements of the subsequent research of ECG signal. The terminal equipment we designed is low cost, comfortable to wear, and can be monitored for a long time, which is suitable for daily household monitoring.

1. Introduction

Sleep apnea syndrome (SAS) is a common sleep disease, which can induce hypertension, diabetes, coronary heart disease and many other diseases, so it needs to timely treat. According to research, nearly 3000 people die in SAS every day. SAS showed that more than 30 times of apnea occurred in 7 hours sleep every night, or the apnea hypoventilation index (AHI) was more than 5 times [1]. When sleep apnea occurs, the end of respiratory airflow stops or the basic level of airflow intensity decreases by more than 30%, and the degree of decline of blood oxygen saturation exceeds 4%, lasting for more than 10 seconds.

At present, the polysomnogram (PSG) is the most authoritative diagnostic detection methods of SAS, which can not only diagnose the incidence of SAS, but also quantitatively analyze the sleep structure of patients. In addition, PSG has a high detection accuracy and can be used for multiple sleep monitoring, which is of decisive significance in sleep research. Although the existing algorithms used to detect SAS have achieved good results, they often have some shortcomings, and most of them are in the field of off-line research, which is not effective in practical applications. With the in-depth study of biomedical and embedded development and other related fields, medical monitoring system has gradually turned to portable, wearable, home-based, intelligent development. Many researchers at home and abroad have also carried out the design of portable SAS monitoring instrument.

Among them, Roopa [2] and other scholars designed a breathing sensor integrated on glasses, which is easy to carry. It can not only detect the breathing signal of sleep state, but also detect the daily breathing, so it is easy to identify SAS. The disadvantage is that it only detects the breathing signal, and the recognition of SAS is not accurate enough. Choi and sunao [3,4] made monitoring belts and monitoring mattresses respectively by using piezoelectric membrane sensors and the principle of pressure detection. However, this method has high requirements for the experimental environment and is easy to generate noise.
Based on the analysis of the current situation at home and abroad, the detection of SAS is a hot issue. However, the products still have a series of problems, such as poor comfort, high cost, low detection accuracy and poor stability, which are not suitable for the general population and limit the application range. Therefore, the development of a wearable, low-cost, comfortable, accurate detection and high signal stability SAS detection system has certain research significance and commercial value. The main content of this paper is the construction of the wearable SAS detection system.

2. ECG signal acquisition and conditioning

2.1 Flexible fabric electrode

ECG signal is a kind of low frequency signal with low amplitude, not more than 5mv and frequency between 0.05 and 100Hz. In clinic, most of the ECG signals are collected by standard 12 lead, but for the SAS detection system, the number of 12 lead electrodes is too much, which does not meet the requirements of portable and comfortable wearable system. Therefore, the system adopts the method of single lead and double electrodes to simulate the standard lead, so as to realize the acquisition of ECG signal.

The commonly used electrode in clinic is the traditional patch electrode, but it can cause skin allergies. In addition, the impedance between the electrode interface and the skin will increase with the extension of the detection time, thus reducing the signal sensitivity and the signal-to-noise ratio [5]. To sum up, this system uses flexible fabric electrode instead of traditional patch electrode. For flexible fabric electrode, it is made of conductive materials and conventional textile materials, most of which are adhered to yarn or fabric by coating technology [6]. Compared with the traditional patch electrode, the flexible fabric electrode can adapt to the surface of the body very well, can fit closely with the skin surface, and will not reduce the signal sensitivity and signal-to-noise ratio with the extension of the monitoring time.

The flexible fabric electrode from the inner side of the elastic chest band to the skin is the base layer, the elastic support layer and the conductive fabric sensor layer, which greatly reduces the thickness of the electrode and improves the wearing comfort. In addition, the electrode can be washed and reused, which is easy to be integrated with clothing, and will not make people feel abrupt [7,8]. It is suitable for dynamic and long-term ECG monitoring. The flexible fabric electrode is shown in Figure 1.

![Flexible fabric electrode](image1)

Figure 1. Flexible fabric electrode

In the detection system designed in this paper, two flexible fabric electrodes are tightly sewn to the left and right inner sides of the elastic chest belt near the controller box, so that they can closely fit with the skin. The ECG signal collected by the flexible fabric electrode needs to be conditioned before the next processing.

2.2 ECG signal conditioning module

In the acquisition process of ECG signal, certain noise must be introduced. In order to obtain effective signal, it requires a high CMRR of the circuit and a high accuracy ADC for A/D conversion [9]. If separate electronic components are used to build the signal conditioning circuit, the volume and power consumption of the circuit do not meet the design requirements of the wearable detection system, and
may introduce new noise. In order to avoid the above problems, the system uses ADS1292, a high-precision special medical measurement chip, to build the ECG signal conditioning circuit.

ADS1292 is a low-power integrated chip, which has multiple 24bit synchronous acquisition A/D conversion channels inside. Compared with the common A/D conversion, firstly, ADS1292 integrates the components needed for ECG acquisition, reducing the circuit volume; secondly, the low power consumption characteristics of ADS1292 are very consistent with the technical requirements of wearable devices; thirdly, in addition, the accuracy of ADS1292 is higher, including two low-power programmable benefit amplifiers and two high-resolution D/C conversion, and the A/D conversion rate is 125sp/s ~ 8K sps; at the same time, ADS1292 has the right leg drive circuit and electrode drop detection function, the right leg drive circuit can effectively reduce the common mode interference, and the electrode drop detection function can continuously detect the electrode drop; ADS1292 also has the oscillator, reference voltage and SPI data interface, which greatly facilitates the design of hardware circuit.

Pin configuration and peripheral circuit of ADS1292 are shown in Figure 2. ADS1292 has two signal input terminals, i.e. in1n and in1p of ch1 and in2n and in2p of CH2, which can be used as the input of ECG signal. In this system, CH2 channel of ADS1292 is used as the input terminal of ECG signal. After the input of ECG signal, ADS1292 chip will realize the amplification of ECG signal and A/D conversion through internal modulation circuit, where the gain is set to 1000. However, due to the characteristics of ECG, which is easy to be interfered by the external environment, it is necessary to configure the right leg drive circuit of ADS1292 chip to reduce the influence of common mode interference on ECG. Because the wearable terminal of the system adopts double electrode detection, the system directly feeds the output of the right leg drive to two detection electrodes to realize the function of the right leg drive circuit. After being processed by ADS1292 chip, ECG signal will be transmitted to microprocessor through SPI communication interface.

![Figure 2. The circuit diagram of ADS1292](image)

### 3. Microcontroller circuit

For wearable systems, the choice of microprocessors is particularly important, which need to have the characteristics of small size, low power consumption, fast processing speed and so on. The microprocessor of this system is EFM32, and its minimum system is shown in Figure 3.
EFM32 is a miniaturized, ultra-low power arm chip, which consumes only a quarter of the existing 8-bit, 16 bit, 32-bit MCU, and contains a variety of peripheral interfaces, including low-power USART, I2C serial interface, 8-Channel high-resolution ADC and dual channel high-resolution DAC. USART is a very flexible serial I/O module, which can support full duplex asynchronous UART and SPI communication. Compared with other microprocessor chips, EFM32 chip has a peripheral reflection system (PRS). PSG can not only operate in parallel with the standard 32-bit arm bus, but also can control the peripheral itself to operate and communicate actively without opening the controller, reducing the power consumption of the system operation [10].

The microprocessor EFM32 in this system is responsible for the overall control of the system and is the core component of signal processing. Including crystal oscillator circuit, debugging circuit, reset circuit and so on. For the debugging circuit, the system adopts the SW mode download debugging method, which reduces the size of the board and increases the comfort of the equipment.

As the main control unit of the system terminal, the microprocessor will first judge the switch status of the system, and then carry out a series of initial chemical works such as internal initialization of EFM32 which includes clock, SPI port, UART port and ADC, register assignment of ADS1292 and configuration of Bluetooth module. Then the external interrupt is opened and it waits for the interrupt request of ADSA_DDY of ADS1292. After receiving the request, the microprocessor will read the ECG data converted by ADS1292 through SPI interface and store it. At the same time, the microcontroller will read the data sent by TLV_2464 chip, trigger the ADC interrupt and perform A/D conversion and store it. Finally, the stored ECG and respiratory data are packaged and transmitted to the Bluetooth module through the serial port. The Bluetooth module will send the data to the upper computer to realize the communication between the lower computer and the upper computer.
4. Results and discussion

In order to achieve the overall test of the system, this paper selects 5 men, 5 women and 10 volunteers to verify the relevant experiments. The subjects are adults, and do not have any respiratory and heart diseases. The subjects will know the content of the experiment in advance, agree and sign a letter of understanding.

For the acquisition and test of the system terminal, this paper randomly selects one of ten subjects for the experiment. The subjects first turn on the power button of the wearable terminal and connect the Bluetooth, put the terminal on the chest position, and pay attention to the direction of the sensor box. The subjects were then asked to lie on the bed in a supine position while keeping the outside environment as quiet as possible. The signals collected by the terminal will be transmitted to the upper computer through Bluetooth and saved, and the corresponding waveform chart will be drawn with MATLAB software.

The first step of the collection and test experiment is to collect and test the ECG and respiratory signals under the normal state. The test process is: the subjects close their eyes to simulate the sleep state, breathe at the normal rate and keep the heart rate stable. The timing is 6 minutes. For the acquisition of ECG signal, the hardware system adopts the standard single lead double electrode mode. Although there are body movement and electrode slip in the process of measurement, there will be baseline drift and EMG interference in the ECG waveform, but the signals collected by the terminal designed in this paper can still clearly identify the ECG characteristics such as QRS waves, which meet the requirements of the subsequent research of ECG signals. The collected ECG shape is shown in Figure 4.

![Figure 4. The ECG waveform in normal state](image)

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![Figure 5. The ECG waveform in SAS state](image)
5. Conclusion
In this paper, SAS monitoring terminal research, the development of a wearable SAS detection system. Firstly, the paper introduces each module of the terminal in detail, mainly describes the specific hardware design of flexible fabric electrode, ECG signal conditioning module, microcontroller module, Bluetooth module, etc., explains the circuit schematic diagram in detail and calculates the parameters in detail. Finally, the terminal and host computer algorithm of the system are tested to verify the feasibility of the designed system. The algorithm of wearable terminal and upper computer is verified by experiment. The accuracy of terminal signal acquisition is verified by standard equipment. The system terminal equipment designed in this paper is low cost, small and light, safe and comfortable to wear, can be monitored for a long time and has a high accuracy of diagnosis. It is suitable for daily family monitoring, and solves the problem that a large number of patients with SAS can not get medical treatment in time. The system is also suitable for daily sleep monitoring.

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References
[1] Sharma H, Sharma K K. (2016) An algorithm for sleep apnea detection from single-lead ECG using Hermite basis functions. Computers in Biology & Medicine, 77: 116-117.
[2] Roopa M G, Rajanna K, Mahapatra D r, et al. (2013) Polyvinylidene fluoride film based nasal sensor to monitor human respiration pattern: an initial clinical study. Journal of Clinical Monitoring and Computing, 27(6): 647-657.
[3] Choi S, Jiang Z. (2008) A wearable cardiorespiratory sensor system for analyzing the sleep condition. Expert System with Applications, 35(1-2): 317-329.
[4] Uchida S, Endo T, Suenaga K., et al. (2011) Sleep evaluation by a newly developed PVDF sensor non-contact sheet: a comparison with standard polysomnography and wrist actigraphy. Sleep & Biological Rhythms, 2011, 9(3):178-187.
[5] Huang Y J, Lin B S, Wang H Y, et al. (2013) A wearable bio-potential monitor system with capacitive coupling electrode. Intelligent Information Hiding and Multimedia Signal Processing, 2013 9th International Conference on IEEE, 56-59.
[6] Xiao X, Dong K, He W, et al. (2017) Research Progress of Electrodes in Wearable Electronic Garments. Journal of Clothing Research, 2(01):1-6.
[7] Lu L, Zhang H, Xie G. (2016) Area design and optimization of textile-structure flexible ECG electrodes[J]. Shanghai Textile Science & Technology. 44(03):45-48+53.
[8] Zhang Y. (2019) Design of Wearable Single-lead ECG Monitoring System. North University of China.
[9] Valchinov E, Antoniou A, Rotas K, et al. Valchinov E, Antoniou A, Rotas K, et al. (2014) Wearable ECG system for health and sports monitoring[C]. Wireless Mobile Communication and Healthcare (Mobile health), 2014 EAI 4th International Conference on IEEE: 63-66.
[10] Li Z, Jisen Gao, Haoshan Tian, et al. (2017) Design of smart pill box monitoring system based on EFM32 and GSM*. Transducer and Microsystem Technologies.36(08): 89-91+98.