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Respiratory Rate Real-time Monitoring System with FBGs

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Abstract: In order to monitor respiratory rate in real-time and have good portability, a respiratory rate monitoring system based on fiber optic sensing was designed. According to the testing requirements, the overall composition structure of the system was designed, which is divided into fiber optic sensing module and data processing module. The design basis for the system composition was provided, and the fiber optic sensor and processing module were designed based on respiratory characteristics. The fiber optic sensor is encapsulated in a flexible silicone sheet and then fixed onto a T-shirt. The selection of fixed positions is based on the level of respiratory sensitivity. A power module design for portable structures was provided, and a conversion module from sensor data to respiratory rate was built. Ultimately, the monitoring system will be integrated into a portable device. The experiment collected actual human BCG signals with noise interference and completed the inversion calculation of respiratory rate, with an accuracy better than ±1bpm. It verifies the feasibility of this system.

1. Introduction

According to the latest market demand analysis of the cardiovascular drug industry, there are currently about 290 million cardiovascular disease patients in China, with the highest mortality rate. More than 60% of them can provide early warning through abnormal heart and lung parameters before onset, thereby intervening in advance to avoid accidents [1]. Applying fiber optic sensing networks that are small in size, lightweight, flexible to wear, and not affected by electromagnetic interference to real-time monitoring of daily physiological parameters for this population [2-4]. It has significant importance in the field of smart healthcare and intelligent monitoring.

Heart and lung function is an important manifestation of human vital signs, and monitoring of heart and lung parameters is particularly crucial [5-9]. The evaluation of cardiopulmonary function usually uses body temperature and respiratory rate, so it is of great significance to study monitoring systems with high sensitivity, good stability, strong anti-interference ability, and easy wearing.

Common similar products include: firstly, the Jieruitai GT6800 [10] and the Philips IntelliVue MX700 [11], which have the advantage of high accuracy and can detect multiple physiological parameters. The disadvantages are large size and high price. It is only suitable for bedside placement in hospitals or homes. Secondly, Haoluowei TE-5100Y-C [12] is an electrode mount testing device with the advantages of compact structure and easy portability; The disadvantage is that it only detects electrocardiogram data, the electrical connector is disposable, suitable for carrying around, and the monitoring frequency is limited. Thirdly, DidoY2S wristband [13] is a portable monitoring device with the advantages of compact structure, easy portability, and repeatable monitoring; Its disadvantage is that the detection parameters are single, the accuracy is low, and it is suitable for carrying around.

We proposed a fiber optic sensing system that can monitor real-time parameters such as respiratory rate. It has the advantages of good flexibility, high comfort, and portability.

2. System composition

The system composition is shown in Figure 1, which can be divided into two modules: the acquisition module and the data processing and display module. In the acquisition module, by designing the FBG packaging structure and simulating the FBG stress distribution, the focus is on obtaining the optimal FBG sensor parameter design. In the data processing and display module, the algorithm for calculating human physiological parameters is mainly reflected, which is implemented through multi physics field fusion and calibration experiments, and combined with data integration under various testing conditions to form a calibration database.

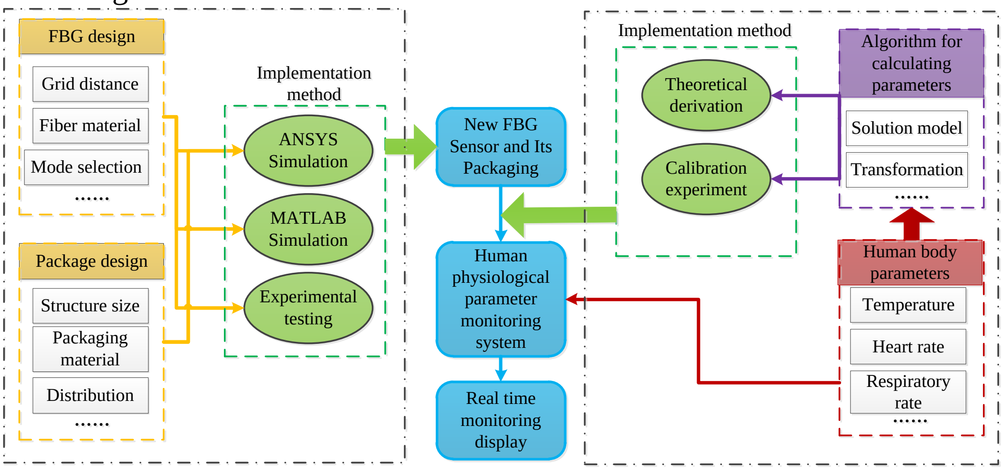


Figure 1 System composition structure block diagram

3. Sensor distribution design

Select an appropriate FBG distribution design based on the testing requirements for respiratory rate. FBG1 and FBG2 are mainly used to measure respiratory signals, while FBG3 is mainly used to measure body temperature. Therefore, three FBGs were designed and installed respectively on the chest, abdomen and lower back. Among them, the left and right symmetrical positions can be considered to take turns to prevent reducing the impact of random errors [14-16].

The signals collected by FBG1 and FBG2 include respiratory and body temperature signals, as well as noise signals. The signals collected by FBG3 mainly include body temperature signals. As shown in Figure 2, the integrated demodulator measures 150mm * 80mm * 20mm. The demodulator module is suspended or tied to the waist side of a T-shirt through fabric, and connected to a mobile app via Bluetooth to achieve the integrated function of "monitoring demodulation data reception", meeting the requirements for real-time measurement of smart wearable devices [17].

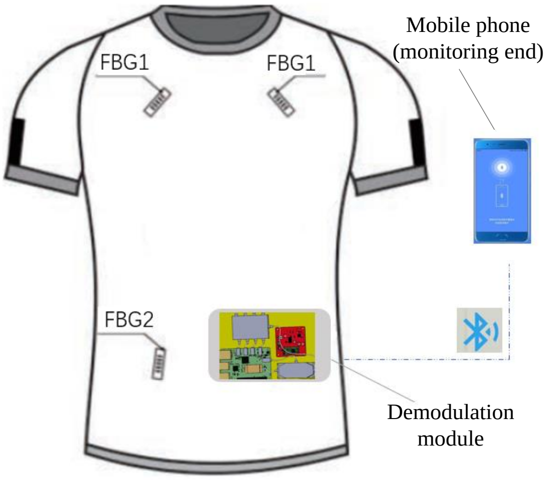


Figure 2 Sensor distribution and demodulation module

4. Structure and implementation of demodulation module

4.1. Structural design

Considering the requirements of miniaturization and convenience, a narrowband light source edge filtering method is adopted to design fiber optic demodulation equipment. Its characteristic is to use a narrowband laser as the light source, which significantly reduces the volume compared to a tunable laser light source. Among them, the light source part is powered by a 7800mAh lithium battery for the demodulator, which is of moderate size and has a long-lasting battery life. After packaging, the demodulator part is in the form of a long strip, and the product structure diagram is shown in Figure 3.

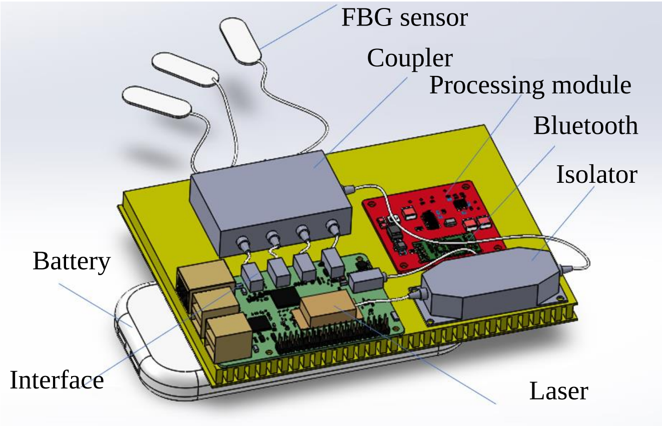


Figure 3 Design of the demodulation module structure

4.2. Circuit implementation

To meet the needs of miniaturization and portability, the power module of the fiber optic demodulator adopts the form of lithium battery power supply. A 7.2V 7800mAh lithium battery is selected to power the demodulator, which is of moderate size and has a long battery life. The power module, as shown in Figure 4, needs to supply power to the laser light source, conversion circuit, and microprocessor. They require voltages of 5V, ±5V, and 3.3V respectively. The power supply generates a 5V DC voltage input through a voltage reducing chip, which is then converted into the required voltage values by a voltage stabilizing power supply chip. The TPS60400 voltage stabilizes the output to -5V, while the ADP151 voltage stabilizes the output to 3.3V.

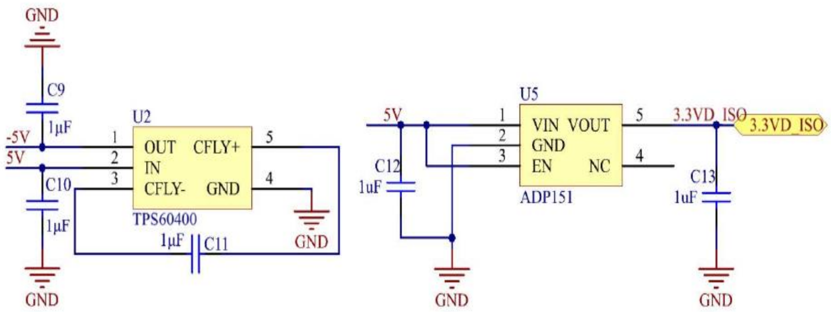


Figure 4 Portable power module

The conversion circuit mainly converts the current signal output by the photodetector into a voltage signal. The input signal of the photodetector is a light signal, and the output signal is a current signal. Only by converting the current signal into a voltage signal can the AD acquisition chip perform acquisition, so a conversion circuit is required. In this circuit, the AD825 chip is used to convert the current signal into a voltage signal. The negative voltage small signal output through AD825 is first amplified by a first stage amplification circuit. The amplifier circuit uses LF353 with a supply voltage of ±5V. The conversion module is shown in Figure 5.

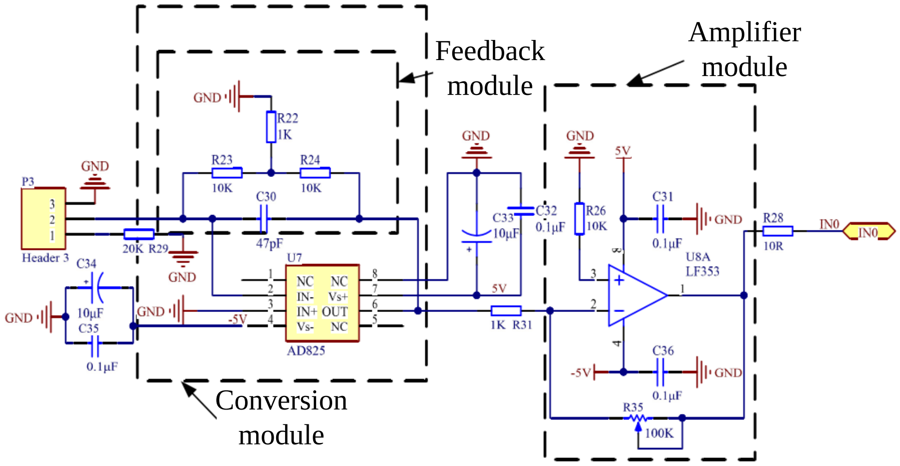
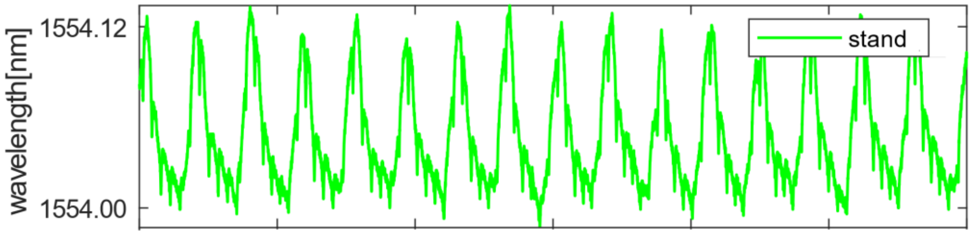


Figure 5 Conversion module

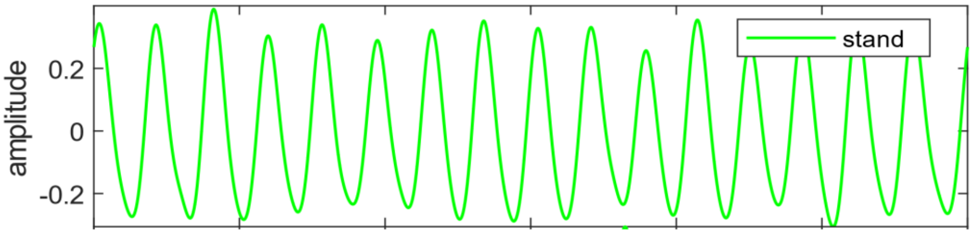
The communication module adopts low-power Bluetooth module CC2541 and corresponding data transmission protocol to achieve communication between the upper computer and the lower computer of the system. It has excellent receiver sensitivity and can operate stably in EDR and BLE modes. It adopts Bluetooth 4.0 protocol and is compatible with any version of Bluetooth. This communication module has very few external components and operates at a frequency of 2.4GHz. The Bluetooth module will exchange data with the external host computer and execute corresponding instructions to control the operation of the FBG demodulator.

5. Respiratory rate test

Due to the experiment simulating rapid breathing, it found that prolonged and excessive deep breathing can cause adverse symptoms such as cerebral hypoxia, dizziness, and blurred vision in the subjects. Therefore, only the respiratory rates under slow breathing and normal breathing were collected during the experiment. The respiratory data is separated from the data detected by FBGs. Figure 6 shows the measured changes in FBG wavelength with different states during respiratory monitoring. Among them, Figure 6 (a) shows the BCG waveform of experimental testing, and Figure 6 (b) shows the respiratory state waveform after separating noise and heartbeat signals.



(a) raw data



(b) demodulated signal

Figure 6 Respiratory rate test data based on fiber optic sensing

The experiment found that when standing, the change in respiratory wavelength is greater, and at the same time, the change in chest cavity is also greater. The breathing wavelength changes in the upright and lying states are similar, smaller than those in the standing state, and the changes in the chest cavity are smaller. The breathing rate is slightly faster when standing, followed by upright sitting, and slowest when lying down. After completing 20 sets of tests, it was found that the respiratory rate inversion results were statistically analyzed. The calculation accuracy of the system is better than ±1bpm.

6. Conclusions

This article proposes a respiratory rate monitoring system based on fiber optic flexible sensing. Aiming at real-time and accurate recognition of respiratory rate, FBG sensor distribution and peripheral circuit module based on FPGA processing control were designed. The completed tasks include:

(1) It designed the overall structure of the system and the packaging design of the sensing module, and constructed the fiber Bragg grating sensing network and its distribution structure. This intelligent sensing fabric can be easily worn and carried by subjects, which is beneficial for the research of wearable health monitoring systems.

(2) We tested the collection and analysis of respiratory signals and obtained BCG signals based on fiber optic sensing. A real-time monitoring system for human physiological parameters based on fiber optic flexible sensing has been proposed.

However, the system still has shortcomings. Considering the diversity of human physiological parameters, in subsequent research, in addition to detecting respiratory rate, other physiological signals such as blood pressure, blood oxygen, body temperature, etc. can also be detected simultaneously.

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