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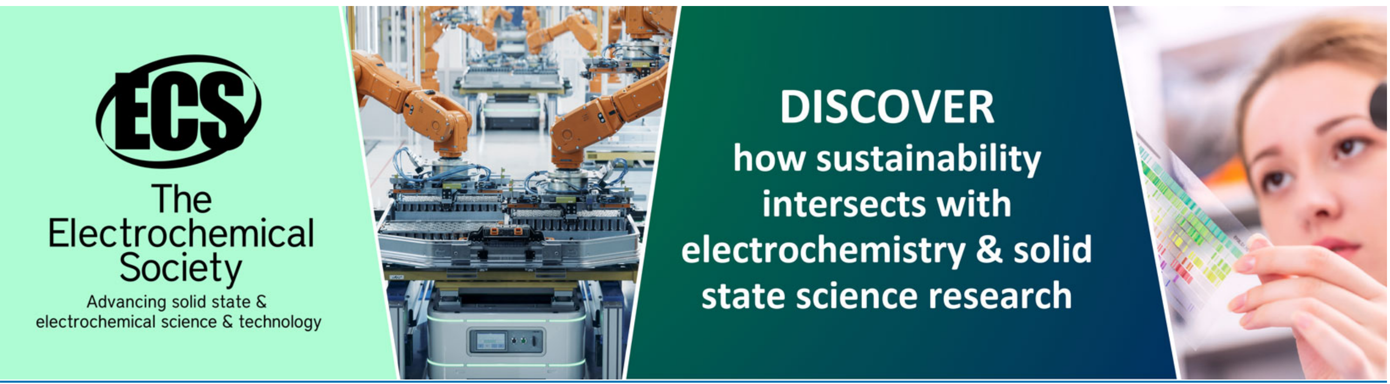

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Wearable respiratory strain monitoring system based on textile-based capacitive strain sensor

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Abstract: Respiratory state analysis based on respiratory strain monitoring plays an increasingly important role in the assessment of the continuous dynamic physiological state of the human body. The proposed respiratory strain monitoring system uses the STM32F411 single-chip microcomputer as the main control chip, combined with the FDC2214 capacitor-to-digital converter, collects the capacitance value of the flexible cloth-based capacitive strain sensor through the IIC method, and sends the collected result to the upper computer for processing and analysis through Bluetooth. The device collects the respiratory strain signal of the chest in three motion states: stationary, walking, and running. Through data acquisition and algorithm processing, it can clearly display the waveform of respiratory strain, and the extraction accuracy of the respiratory rate is ±1rpm. The experimental results show that the system has good stability and accuracy, strong anti-interference ability, and can meet the requirements of continuous dynamic high-precision respiratory rate monitoring.

1. Introduction

During breathing, humans obtain oxygen and emit carbon dioxide to maintain vital vitality. Through monitoring the respiratory signals, we can obtain the changes of human physiological state or psychological state [1]. When it is quiet, the breathing state of normal adults is 12-20 times / min. The abnormal respiration rate is closely related to upper respiratory tract diseases, bronchial and lung diseases, cardiogenic diseases and psychological and emotional abnormalities. At present, real-time respiratory rate monitoring has been widely used in clinical, such as sleep apnea, sudden infant death syndrome and postoperative patients with respiratory tract complications and other clinical diseases. In addition, real-time dynamic breathing rate monitoring is of great significance in the physical and operational training of personnel in special industries such as the military and fire protection.

However, traditional respiration rate monitoring devices have the disadvantages of being difficult to carry and complicated to operate. With the development of science and technology, some new breathing rate measurement technologies have also appeared in recent years, based on methods such as ECG envelope [2], chest impedance [3], image vision [4], and photoelectric volume pulse wave [5]. The purpose of simplifying the use is achieved, but under dynamic conditions, there are generally shortcomings that are susceptible to interference and the accuracy cannot be guaranteed. Due to the advantages of being portable, easy to operate, and low cost, flexible wearable devices provide a direction guide for real-time monitoring of human respiratory state [6,7]. Flexible wearable dynamic breathing measurement can grasp real-time and accurate breathing state parameters such as personal breathing rate, breathing depth and breathing ratio without affecting daily life. Dynamic and precise monitoring also provides more abundant for subsequent diagnosis and analysis Reference information [8,9].

In this paper, a flexible cloth-based capacitive strain sensor is used as the sensing front end, STM32F411 single-chip microcomputer is used as the main control chip, and a flexible cloth-based capacitive strain sensor is used as the sensing front end. TI's low power consumption and low power are mainly used. The cost and high-resolution capacitance-to-digital converter FDC2214 collects capacitance changes, monitors the state of breathing strain [10], and carries out wireless transmission and reception of data to achieve breathing strain in three motion states of stationary, walking, and running Signal acquisition, stable operation of the device and high measurement accuracy.

2. Overall system design

The system is generally divided into a CPU core module, a power module, a capacitance acquisition module and a Bluetooth transmission module. The system uses STM32F411 as the control core, communicates with the capacitance acquisition module through the IIC protocol, performs register setting and data reading, and collects through the UART interface The results are sent to the upper computer through the Bluetooth module. The principle of the wireless respiratory strain monitoring system is shown in Figure 1. In this paper, the cloth-based capacitive strain sensor and the same elastic fabric are used to form a closed breathing detection zone. Because of the good elasticity of the substrate, this structure not only ensures the wearing comfort but also improves the reliability of strain sensing.

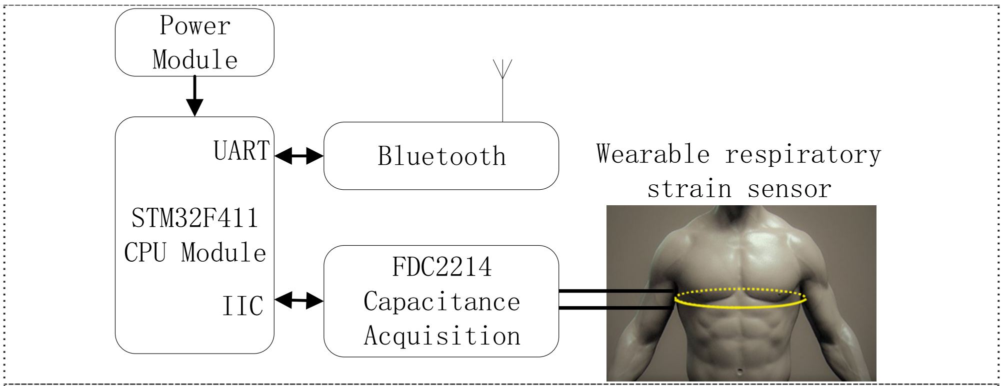

Figure 1. Schematic diagram of wireless respiratory strain monitoring system

3. Selection of main components

3.1. Selection of microprocessor

STM32F411CEU6 belongs to the STM32 Dynamic Efficiency ™ series. This is a high-performance product that provides the best balance between dynamic power consumption (running mode) and processing performance, while integrating a large number of value-added features in a small 3 x 3 mm package. The STM32F411 MCU integrates the Cortex®-M4 core (with floating point unit) and operates at a frequency of 100 MHz, while also achieving excellent low-power performance in run and shutdown modes. The processor has built-in 256KB flash, 128KB SRAM, 12-bit A/D, 11 timers, 3 USART and 5 SPI and other resources.

3.2. Flexible cloth-based capacitive strain sensor

The flexible cloth-based capacitive strain breathing belt developed by Ningbo Material of the Chinese

Academy of Sciences is used. This sensor is formed by a stretchable TPU film sandwiched between two layers of highly conductive materials like a sandwich. The stretching and shrinking deformation of the sensor, the thickness of the dielectric layer and the area of the capacitive electrode plate will change, and the capacitance value of the sensor will also change accordingly. The sensor has an initial capacitance value of 1nF, a deformation range of 0 to 100%, a linearity of 0.998, a sensitivity of 17pF / mm, and a resolution of 0.1%. The actual sensor is shown in Figure 2.

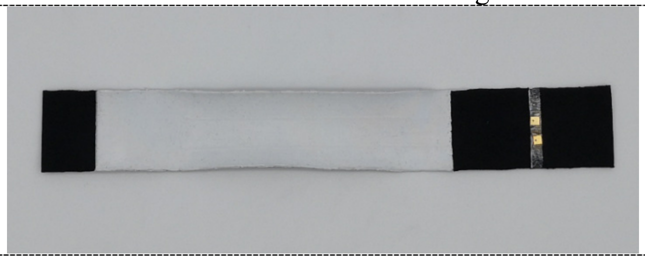

Figure 2. Physical picture of the sensor

3.3. Capacitance-to-digital converter FDC2214

The core part of the capacitance measurement module uses TI's capacitance-to-digital converter FDC2214, which uses an innovative anti-EMI architecture and is a capacitive detection sensor with high resolution, multi-channel, and strong noise resistance [11]. Its working voltage is 3.3 V, with a high-speed I2C interface, and its basic principle is shown in the figure.

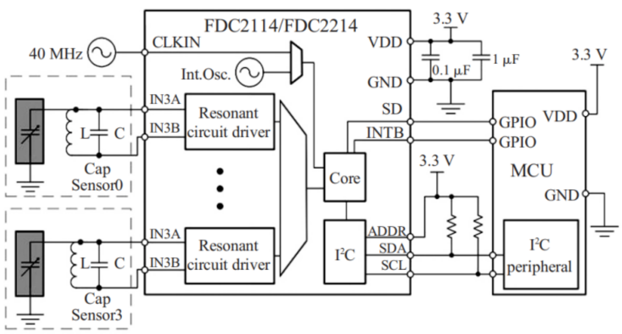

Figure 3. Schematic diagram of capacitance-to-digital converter

When the variable capacitance sensor under test is connected to the LC resonant circuit, it will generate an oscillation frequency fS, which is the core parameter for calculating the size of the capacitor. Another important parameter is the clock reference frequency fREF from the internal clock or external supply. The digital output of each channel is the ratio of fS /fREF.

4. System hardware design

The hardware design principle of the system is shown in Figure 4.

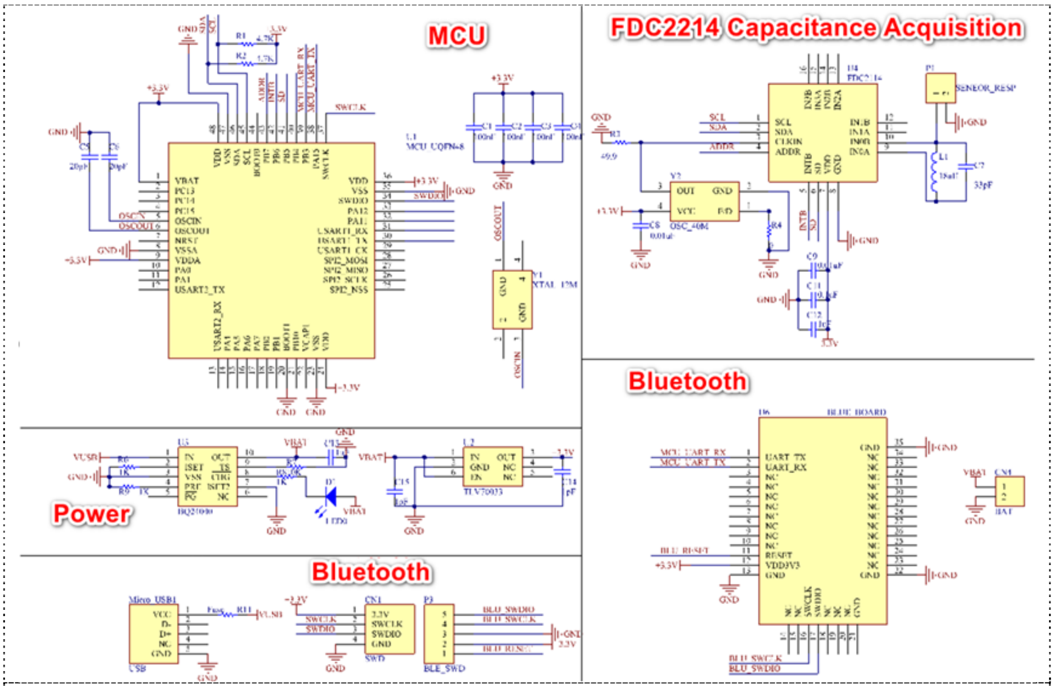

Figure 4. Schematic diagram of system hardware design

4.1. Power module

The system is powered by a 3.7V polymer lithium battery. The 3.3V voltage required by other parts of the system circuit is obtained by using the LDO linear voltage regulator TLV70033. The PCB has an onboard Micro USB interface. The USB power supply is used and the BQ24040 chip is used to implement charge and discharge management.

4.2. Capacitance acquisition module

FDC2214 uses the IIC interface to communicate with the main control STM32F411, and connects the corresponding pins of the SDA, SCL and FDC2214 of the microcontroller through two 4.7K pull-up resistors. 40M external active crystal oscillator (model) input is used here to improve stability. PB5, PB6 and PB7 of the main control microcontroller are connected to the SD, INTB and ADDR pins, respectively, for shutdown mode setting, interrupt signal reception and IIC address select. The digital output of each channel is proportional to the ratio of fS / fREF, and set this value to DAXA. The I2C interface is used to support device configuration and transmit digital DAXA to the STM32 host processor. When the respiration rate is detected, the change process of the capacitance can be obtained by measuring the oscillation frequency of the resonance circuit, and then the breathing-related features can be extracted.

4.3. Bluetooth transparent transmission module

Using the independently developed Bluetooth transparent transmission module, based on Nodic52832 chip, low voltage 3.3V work, using the serial port of STM32F411 to communicate with it [12], the module can realize the transparent transmission of data between the UART serial port and Bluetooth, and can pass AT commands To modify the basic parameters such as baud rate, name, password and working mode of Bluetooth serial communication. The transmission bandwidth of the module is 80kbps, and the power consumption of the RF working state is 15mA.

5. System software design

5.1. FDC2214 setting process

After the FDC is powered on, it enters sleep mode, wakes up the FDC according to the following configuration, and enters a low-power operating mode.

- Chip configuration register 0x0A, enable FDC2214, take internal clock as reference clock, and turn on low power consumption mode.
- Clock divider configuration register 0x14, internal clock divider DIVIDER=2, and set the frequency of the sensor between 0.01MHz and 10MHz. Final reference frequency fREF=fCLK/DIVIDER .
- Channel configuration register 0x1B, enable 0,1channel, and refers to a bandwidth of 1M.
- Sampling rate configuration register 0x08, set the interval to 20ms, that is, the sampling rate is 50Hz.
- Conversion time configuration register 0x10, set the conversion time to 7us.
- The drive current configuration register is 0x1E, and the drive current is 0.264mA.

The flow chart is shown in Figure 5.

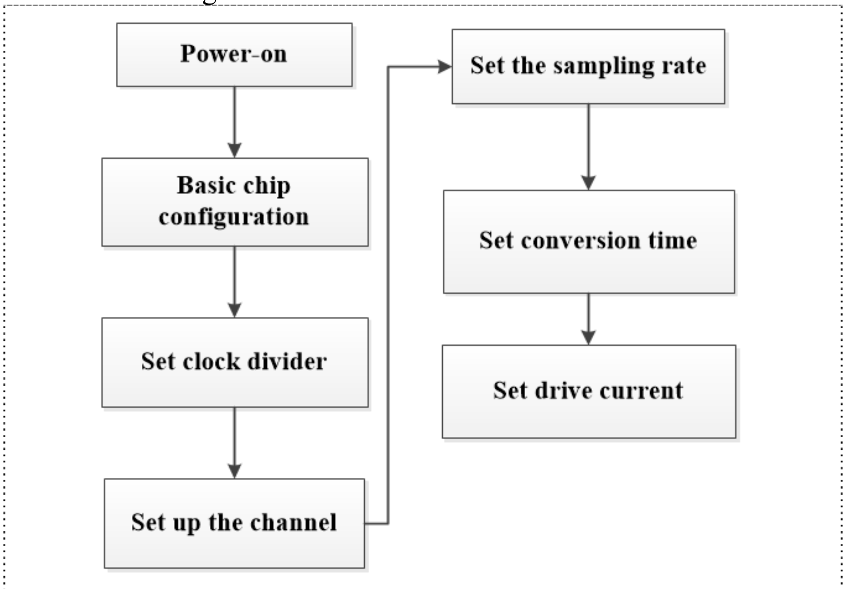

Figure 5. FDC2214 configuration flowchart

5.2. Respiratory strain data processing algorithm

Before extracting the peak point, the signal is first preprocessed, and the data points with a sampling frequency of 50 Hz are sequentially read in, and 1500 points are read each time. Wavelet decomposition and reconstruction are used to preprocess the original signal to remove high-frequency noise and remove baseline drift. Select the wavelet basis function as 'sym4' and the number of decomposition layers is 8 layers. According to the wavelet function frequency decomposition rule, the approximate signal frequency of the 8th layer is zeroed to remove the baseline drift, and the detail coefficients of the 1st, 2nd and 3rd layers are removed High-frequency noise, and then wavelet reconstruction. Three sliding window integrations are performed on the normalized data. The peak value of the de-maniculated data is initially extracted, and the final position and amplitude of the peak value are obtained by double filtering of the amplitude and time domain. Where Fs is the sampling frequency, and V is the interval difference between the peak positions. The calculation formula of respiration rate is as follows:

$$\text{Rrate} = \frac{60 * \text{Fs}}{\text{mean(V)}} \tag{1}$$

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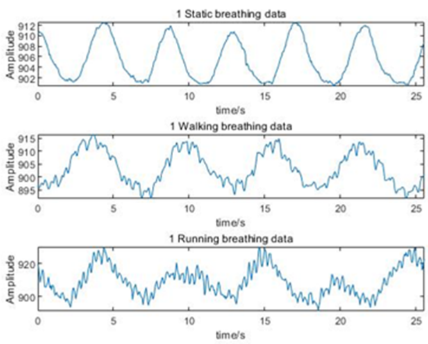
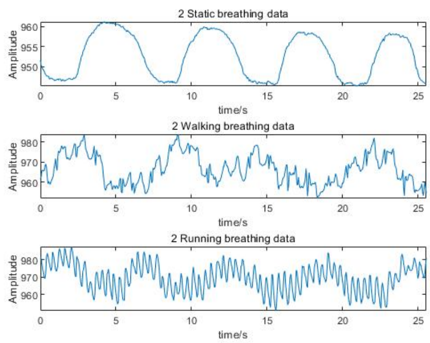
6. Experiments and Results

One volunteer from the project team, a young male, is 173cm tall and weighs 63kg. The sensor is located in the middle of the chest. Figure 6 is the actual picture of this experiment. The breathing strain is collected under the state of sitting, walking, and running. The collected signals are filtered to dry, threshold screening, peak detection and trough detection. Afterwards, the effect of exercise on breathing, so first collect breathing data in static state, followed by walking state, and finally running state. Figure 7 represents the waveform data of the raw breath data in three states, where (a) and (b) respectively represent the first collected breath data and the second collected breath data. The abscissa represents the number of sampling points, and the ordinate represents the amplitude (converted to the capacitance value).

Figure 6. Experimental physical map.



(a) Experiment 1



(b) Experiment 2

Figure 7. The original breathing waveform in three states

In order to further verify the accuracy of respiration rate measurement, a simulation experiment was designed to put the breathing detection belt on a telescopic actuator driven by a stepper motor. The speed and amplitude of the reciprocating motion of the telescopic actuator can be adjusted to keep the amplitude of the reciprocating motion 25mm The reciprocating speed of the actuator is 15 rpm, 20 rpm, 25 rpm, 30 rpm, 40 rpm and 60 rpm. The calculation of respiration rate adopts the method of counting the number of simulated breathing waves within 1 minute. The test values of respiration rate are shown in the table

Table 1. Test values of respiration rate

Nominal value（rpm）	Measured value（rpm）	Error（rpm）
15	14	1
20	19	1

25	25	0
30	30	0
40	40	0
60	59	1

The system error is less than 1rpm, and the test results show that the system has high accuracy and strong practicability.

7. Conclusion

This paper designs a breathing strain detection system based on the capacitance-to-digital converter FDC2214. The flexible cloth-based capacitive strain sensor is used as the sensing front end, and the low-power STM32F411 microcontroller is used as the control core. The hardware and software design is described in detail. The breathing strain acquisition system has the characteristics of high precision, fast response, compact structure and strong anti-interference ability. The final test shows that in the three states of human sit-down, walking and running, the signal-to-noise ratio of the respiratory strain signal is high and the waveform is clear and obvious. The accuracy of respiration rate measurement reaches ± 1rpm, and the subsequent development process further optimizes the data post-processing algorithm, which can reduce the impact of local noise signals on the measurement accuracy. It is very important for the development of wearable respiratory state monitoring products and disease diagnosis based on respiratory characteristic analysis.

Acknowledgments

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