Wearable Low-power Bio-signals Wireless Sensing Node Design

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Abstract. This paper realizes the design of wearable bio-signals multi-sensing nodes through ADS1292 series ECG acquisition chip, LMT70 IoT temperature sensing chip, MPU6050 spatial motion sensing chip and HC-06 Bluetooth transmission chip, which includes real-time monitoring of three-lead acquisition of biological ECG signals, real-time display of heart rate changes and ECG, real-time monitoring of biological body surface temperature and motion state, wireless communication of collected data. The median filtering algorithm and mathematical morphology are used to eliminate the baseline drift and the 50Hz trap to eliminate the power frequency signal interference. The design has the advantages of high common mode rejection ratio, high signal-to-noise ratio, low noise, low power consumption and low cost, which meets the needs of modern portable networked monitoring devices.

1. Introduction

Modern sudden-onset diseases, mainly cardiovascular diseases, including coronary heart disease and cardiomyopathy, are characterized by high prevalence, high disability and high mortality rates, which are mainly manifested by heart failure and irregular heart rate, and are the top of the current international mortality rates of various diseases. Traditional professional ECG machines[1] have a single function, inconvenient to carry, high cost, low data visualization, no data networking and other defects, which cannot meet the current demand of daily ECG monitoring and disease prevention.

This design develops a low-power consumption, wearable, low-cost, and good monitoring accuracy biological signals monitoring device, which realizes multi-node sensors such as biological ECG signal monitoring node, body surface temperature monitoring node, and motion status monitoring node through circuit modules such as three-lead ECG acquisition circuit, ECG signal amplification and filter circuit, median filtering algorithm, and 50Hz trap. The design can perform ECG data visualization display, including heart rate display and real-time ECG display with data error less than 1%, as well as wireless transmission function with transmission delay less than 1 s.
2. ECG signal and electrocardiogram
The ECG signal records the process of cardiac cell depolarization and repolarization, which is a very weak physiological low frequency electrical signal, usually with a maximum amplitude of no more than 5mV and a signal frequency between $0.05 \sim 100\text{Hz}$. ECG can reflect the electrical activity of heart excitation, and it has important reference value in the study of basic heart function and pathology.

![Time domain diagram of ECG signal](image)

In the time domain diagram of the ECG signal, the ECG signal is divided into different bands, and the different bands represent different processes of depolarization and repolarization. These wave bands constitute the depolarization and repolarization process of atrium, and each phase forms the time domain cycle of the ECG signal.

2.1. Electrical characteristics of ECG signals and sources of noise
The amplitude range of ECG signal is $10\mu\text{V} \sim 4\text{mV}$, the frequency range is $0.05\text{Hz} \sim 100\text{Hz}$, and the spectral energy of its central electrical signal is concentrated between $0.25\text{Hz} \sim 40\text{Hz}$, which is a typical low frequency bio-signal with periodic and non-linear characteristics. The typical value of normal bioelectric signal is 1mV, which is very weak and in the midst of nonlinear changes, and is easily affected by the interference of ambient signals and the $50\text{Hz}$ power frequency signal. It is also susceptible to external signal interference and $50\text{Hz}$ frequency signal, and with the breath and other action of the human body, it can cause baseline changes and ECG signal drift.

3. System design solutions
3.1. The whole design solution
The whole design is divided into ECG acquisition unit, body surface temperature acquisition unit, motion status monitoring unit, main control unit and visualization unit, where the visualization module is divided into wired visualization unit and wireless visualization unit, in addition, the system is powered by standard 5V voltage and has a separate power management unit, which can drive the normal operation of the overall system and TFT large screen visual display.
3.2. **ECG acquisition unit**

3.2.1 **ECG acquisition method**

The system adopts the same three-lead ECG acquisition mode, in line with the acquisition channel settings of ADS1292R series chip, right upper (RA): the first intercostal space in the midclavicular line at the right edge of the scapula; left upper (LA): the first intercostal space in the midclavicular line at the left edge of the scapula; left lower (LL): the sternal level in the midclavicular line of the left clavicle. The three-lead acquisition method is adapted to portable ECG acquisition devices, which is simple, convenient, fast and more accurate than dedicated medical monitoring devices and home pulse heart rate monitoring devices, and can cope with daily ECG monitoring and sudden ECG monitoring.

3.2.2 **ECG acquisition and processing unit**

The system uses the ADS1292R series chip to design peripheral circuits for ECG acquisition and signal processing. The unit has the functions of front-end signal amplification and filter. The ADS1292R chip has 3 signal inputs, 2 PGAs and 2 24-bit ADCs for simultaneous sampling. The two teams of analog inputs use differential input to reduce common mode interference, and use EMI filter before the MUX, effectively reduce the noise interference before signal processing. And with the high gain provided by the PGA, noise is reduced during high-speed ADC acquisition. The series chip adds the right leg drive circuit, through which the channel suppresses the human body as an antenna to receive the noise of
radiation generated voltage in the surrounding environment. In addition, due to the interference of the industrial frequency signal, the ECG signal will produce the phenomenon of waveform misalignment and overlap blurring, so adding 50Hz trap at the front end of the control unit can effectively reduce the interference generated by 50HZ industrial frequency on the ECG signal and ensure the quality of ECG.

Figure 4. ADS1292R peripheral circuit.

3.2.3 ECG signal processing algorithm
In the process of ECG signal acquisition, the influence of low-frequency signals caused by human respiratory motion and poor contact of the measurement motor causes the baseline drift of ECG signal\(^2\), the ECG spectrum deviates from the baseline position of the screen, and the median filtering algorithm and mathematical morphology\(^3\) are usually used to eliminate the baseline drift phenomenon, and this design mainly adopts the median filtering algorithm to solve the baseline drift phenomenon of ECG signal.

Median filter a nonlinear digital filtering technique with noise suppression and edge protection properties. The basic idea of median filtering to remove baseline drift noise is to first remove the larger values in the ECG signal to get a trend term signal containing only the baseline, and then let it superimpose with the original signal to eliminate the baseline drift interference in the original ECG signal. The principle of median filtering: it is to replace the value of a point in the ECG signal with the median point of the values of the points around that point.

\[
H(n) = \begin{cases} 
    h(n) - \text{Med}[h(1), h(2), h(3), ..., h(n+x)] & (1 \leq n \leq x) \\
    h(n) - \text{Med}[h(n-x), h(n-x+1), h(N)] & (N-x \leq n \leq N) 
\end{cases} 
\]

(1)

3.2.4 ECG signal monitoring results
The testing data can be obtained from the ECG signal generator and actual ECG signal by real people.

| Number of times | ECG generator (Heart rate) | Test results |
|-----------------|-----------------------------|--------------|
| 1               | 60                          | 60           |
| 2               | 61                          | 60           |
The design has been tested extensively in different test environments and with different ECG signal generators. The results were as follows: the experimental results are consistent with the generator settings, and the ECG signal graph of the tested person can be displayed in real time.

3.3. ECG acquisition unit

The temperature acquisition unit of this design uses TI's LMT70 chip, which is an ultra-small, high-precision, low-power CMOS analog temperature sensor with output enable pins for all high-precision, low-power cost-effective temperature sensing applications such as IoT sensor nodes, medical thermometers. The LMT70 has excellent temperature matching performance, with the temperature of two adjacent LMT70 removed from the same tape differing by up to 0.1°C. According to the official datasheet, the unit uses a third-order temperature calculation formula to obtain the final result.

\[ T_M = a(V_{TAO})^3 + b(V_{TAO})^2 + c(V_{TAO}) + d \]  

(2)

Table 2. Corresponding values of LMT70 third-order formula parameters.

|      | Best fit -55°C to 150°C | Best fit -10°C to 110°C |
|------|-------------------------|-------------------------|
| a    | -1.064200E-09           | -1.809628E-09           |
| b    | -5.759725E-06           | -3.325395E-06           |
| c    | -1.789883E-01           | -1.814103E-01           |
| d    | 2.048570E+02            | 2.055894E+02            |

3.4. Motion condition monitoring unit

The motion monitoring unit uses the MPU6050 chip, a spatial motion sensor chip that captures the current three acceleration components and three rotational angular velocities of the device. The full frame sensing range of angular velocity is ±250, ±500, ±1000 and ±2000°/sec (dps), which can accurately track fast and slow movements, and the full frame sensing range of user-programmable accelerometer is ±2g, ±4g, ±8g and ±16g. It is used in EIS, OIS and portable navigation devices.

![Figure 5. MPU6050 working principle schematic.](image)

3.5. Future research directions

The design is still inadequate in algorithm and data processing use, and the future research direction is that with our collected data, deep neural network learning theory and medical theory can be used to add intelligent detection function of diseases such as congestive heart failure and myocardial infarction to the program[4], and to build a network cloud platform to realize real-time monitoring of patients off-site, real-time sharing of monitoring data, and community monitoring among many other application pathways.
4. Conclusion
This paper introduces the design of a wearable low-power wireless sensor node for biological signal. The design realizes the functions of real-time monitoring of biological ECG signal, monitoring of body surface temperature, monitoring of movement state and wireless transmission of monitoring data. The overall design adopts low-power medical grade chip with simple circuit, low noise, low energy consumption and low cost. It solves the problems of high cost, non-wearable and single detection function of traditional ECG, and has good reference significance for the development of wearable devices in the future.

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