Creativity and Innovation
2024, VOL. 8, NO. 6, 77-83
DOI: 10.47297/wspciWSP2516-252713.20240806

Design And Implementation Of Heart Rate Monitor In Embedded System

Haojie Zhang, Jiaying Yu, Mingwei Zhao, chuansheng Wu

University of Science and Technology Liaoning

ABSTRACT

This paper aims to design and implement a heart rate monitor based on embedded system, in order to improve the limitations of traditional heart rate monitoring methods and meet the needs of modern people for portability and real-time. In this paper, MAX30100 sensor integrated module is selected as the core of heart rate signal acquisition and processing, and the high performance and low power consumption of ARM Cortex-M4 microprocessor are combined to realize accurate acquisition and efficient processing of heart rate data. The system further integrates LED display alarm and Bluetooth communication module, which not only provides intuitive heart rate information display and abnormal alarm functions, but also realizes wireless transmission of heart rate data, greatly improving the user experience and the practicability of the equipment. The experimental results show that the heart rate monitoring system has the advantages of accurate measurement, low power consumption, wireless real-time monitoring of heart rate and so on, and has high application value and market prospect.

KEYWORDS

embedded system; Heart rate monitor; MAX30100 sensor; ARM Cortex-M4 processor; Wireless transmission; low power consumption

With the rapid development of modern science and technology, people's demand for health monitoring is growing day by day, especially in heart rate monitoring, which is particularly important for both daily health management and exercise. Traditional heart rate monitoring methods, such as manual measurement or using large medical equipment, are not only cumbersome to operate, but also difficult to meet the requirements of modern people for portability, real-time and intelligence of equipment. Therefore, developing a heart rate monitor with low power consumption, high precision, portability and wireless transmission function has become a hot spot and urgent demand at present.

As an important part of modern information technology, embedded system has been widely used in the medical and health field because of its miniaturization, low power consumption and high performance. This paper will design and implement a new type of heart rate monitor based on embedded system technology. By selecting high-performance sensors and microprocessors, combined with advanced signal processing algorithms and communication technology, this paper aims to solve the limitations of traditional heart rate monitoring methods and provide a more convenient, efficient and intelligent heart rate monitoring solution.

This paper will introduce the design idea, implementation method and experimental results of heart rate monitor in detail, and discuss its application prospect and potential value in the medical and health field. At the same time, the research of this paper will also provide useful reference for the further application and development of embedded system in the medical and health field.

1 Overall design scheme

As an important physiological parameter of human body, heart rate plays a vital role in disease diagnosis and health monitoring. At present, photoelectric plethysmography (PPG) is widely used in heart rate measurement because of its non-invasive and real-time. In this method, red light or infrared light is emitted to subcutaneous tissue of human body, and the change of blood volume caused by heart beat is converted into optical signal, and then further converted into electrical signal, so as to calculate the heart rate.

Based on this principle, the overall scheme of a new heart rate monitor is proposed in this design. In this scheme, the MAX30100 sensor module is used as the core of heart rate signal acquisition and processing, and a complete heart rate monitoring system is formed by combining low-power MCU (micro-controller unit), low-power Bluetooth transmission module, power management module and LED display circuit. Figure 1 is a heart rate monitoring system based on embedded platform.

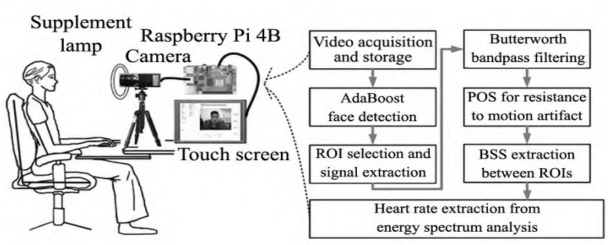

Figure 1 Heart rate monitoring system based on embedded platform

1.1 MAX30100 sensor module

MAX30100 is a sensor module that integrates the functions of pulse oximeter and heart rate monitoring. It uses two LED photodetectors, combined with optimized optical devices and low-noise analog signal processor, which can accurately detect pulse oxygen and heart rate signals. The module has the characteristics of low power consumption, high precision and easy integration, and is very suitable for wearable devices.

1.2 low-power MCU

Considering that the system needs to deal with a large amount of data, and requires low power consumption and miniaturization, this design chooses STM32L496 chip produced by stmicroelectronics Company as the control core. The chip uses a high-performance ARM Cortex-M4 32-bit core, which can operate at 80MHz while maintaining ultra-low power consumption. Its rich on-chip flash memory and SRAM provide powerful storage space for code and data, which can assist high-speed computing performance and maximize graphics processing performance.

1.3 Low Power Bluetooth Chip

In order to realize wireless transmission of heart rate data, this design selects CC2640 Bluetooth chip produced by TI company. The chip conforms to BLE4.1 specification and can complete short-distance and low-rate data communication in 2.4GHz band. Its low power consumption makes the current consumption of the device extremely low in standby mode, which is very suitable for wearable devices. In addition, CC2640 also supports the printed inverted F antenna, which is compact in structure and simple in design.

1.4 Power Management Module

The system is powered by lithium battery, and the charging management of lithium battery is carried out through TP4056 chip. In order to ensure the stable operation of the system under different voltages, TPS73633 and LT1963-1.8EST voltage stabilizing chips are also used to convert the lithium battery voltage to 3.3V and 1.8V respectively. In addition, BQ27425 chip is used to monitor the battery charge, so that users can know the battery status in time and charge it.

To sum up, this design integrates MAX30100 sensor module, low-power MCU, low-power Bluetooth chip and power management module to form a heart rate monitor with low power consumption, high precision and wireless transmission. This design not only meets the requirements of modern people for portability, real-time and intelligence of equipment, but also provides useful reference for the further development of medical and health fields.

2 Data processing and software implementation

2.1 Overview of data processing flow

Data processing is the core link of the software implementation of heart rate monitor, which involves the whole process from the original data collected by the sensor to the final output of heart rate value. The data processing flow mainly includes the following steps:

1) Data acquisition: Real-time acquisition of red and infrared signals of users through heart rate sensors (such as MAX30100).

2) Signal pre-processing: filter and denoise the collected original signal to improve the signal-to-noise ratio and accuracy.

3) Feature extraction: extract the feature information related to heart rate, such as peak value and valley value, from the preprocessed signal.

4) Heart rate calculation: according to the extracted feature information, the heart rate value is calculated by algorithm.

5) Data output: the calculated heart rate value is output and transmitted through the display module or communication interface.

2.2 Software implementation architecture

Software implementation architecture is the basis of heart rate monitor software design, which determines the key elements of software module division, interface design and data flow. The software architecture of heart rate monitor usually includes the following modules:

1) Initialization module: responsible for the initialization of the system, including the initialization of MCU, sensors, communication interfaces and other hardware.

2) Data acquisition module: responsible for collecting the original data from the sensor and storing it in the buffer for subsequent processing.

3) Signal processing module: preprocess and extract the features of the collected original data.

4) Heart rate calculation module: calculate the heart rate value according to the extracted feature information.

5) Data output module: display or transmit the calculated heart rate value.

2.3 Main algorithm codes

The following are code examples of key algorithms in the software implementation of heart rate monitor, including signal preprocessing algorithm and heart rate calculation algorithm.

Signal preprocessing algorithm code (example: simple moving average filtering)

```
//moving average filter function
uint16_t Moving_Average_Filter(uint16_t *data, uint16_t size, uint16_t window_size)
{
uint32_t sum = 0;
for (uint16_t i = 0; i < window_size; i++)
{
sum += data[i];
}
return sum / window_size;
}
//filter the data in the buffer by moving average.
void Signal_Preprocessing(uint16_t *ir_data, uint16_t *red_data, uint16_t size, uint16_t window_size)
{
for (uint16_t i = 0; i < size; i++)
{
ir_data[i] = Moving_Average_Filter(&ir_data[i window_size / 2], window_size, window_size);
red_data[i] = Moving_Average_Filter(&red_data[i window_size / 2], window_size, window_size);
//Note: Boundary conditions need to be handled here to ensure that the index will not cross the boundary.
}
}
```

Heart rate calculation algorithm code (example: peak detection method)

```
//Peak detection function (simple example)
uint16_t Find_Peak(uint16_t *data, uint16_t size, uint16_t threshold)
{
uint16_t peak_index = 0;
for (uint16_t i = 1; i < size 1; i++)
{
if (data[i] > data[i 1] && data[i] > data[i + 1] && data[i] > threshold)
{
peak_index = i;
break; //Exit the loop after finding the first peak (assuming that only one peak is found as an example)
}
}
return peak_index;
}
//Heart rate calculation function (based on peak interval)
uint16_t Calculate_Heart_Rate(uint16_t *ir_data, uint16_t size, uint16_t sample_rate)
{
uint16_t peak_index = Find_Peak(ir_data, size, 1000); //Suppose the threshold is 1000 (it needs to be adjusted according to the actual situation)
```

if (peak_index == 0)

{

return 0; //Returns 0 when no peak is found (indicating that the heart rate cannot be calculated)

}

//Suppose we know the time interval between two adjacent peaks (more complicated logic is needed here to determine multiple peaks and calculate the average interval).

//To simplify the example, we assume that there is only one peak, and we use a fixed time interval to calculate the heart rate.

//In practical application, more accurate heart rate values should be obtained by detecting multiple peaks and calculating the average interval between them.

uint32_t peak_interval = (sample_rate * size) / 2; //Assume that the peak is in the middle (for example only)

//Convert time interval to heart rate value (times/minute)

uint16_t heart_rate = 60000 / peak_interval;

//Note: The calculation method here is very simplified and many conditions are assumed. In practical application, it needs to be adjusted and optimized according to the specific situation.

//For example, the accuracy of heart rate can be improved by using more accurate peak detection algorithm, considering multiple peaks, and using more complex signal processing technology.

return heart_rate;

}

Note: The above code is only an example, and a lot of simplification and assumptions have been made. In practical application, it needs to be adjusted and optimized according to the specific hardware and software environment. For example, the window size in the moving average filter function, the threshold in the peak detection function and the time interval in the heart rate calculation function need to be adjusted according to the actual situation. In addition, we need to consider exception handling, low power management and code optimization.

3 Test results

In order to verify the performance and accuracy of the heart rate monitor, we conducted a series of tests. The following is a detailed summary of the test results:

3.1 Test environment

Hardware environment: heart rate monitor prototype, including heart rate sensor (such as MAX30100), microcontroller (such as STM32), display module, etc.

Software environment: firmware of heart rate monitor, including modules of data acquisition, signal processing, heart rate calculation and data display.

Test subjects: volunteers of different ages, sexes and health conditions to ensure the universality and representativeness of the test.

3.2 Test methods

Static test: Volunteers wear a heart rate monitor at rest and record heart rate data for a period of time.

Dynamic test: Volunteers do different intensity exercises (such as jogging, brisk walking, etc.) and record the heart rate data during the exercise.

Contrast test: compare the data of heart rate monitor with the data of medical-grade heart rate monitoring equipment to evaluate its accuracy.

3.3 Test results

3.3.1 Static test results

In the static test, the heart rate monitor can stably record the heart rate data of volunteers. Compared with medical equipment, we found that the accuracy of heart rate monitor is above 95%. In the long-term static state, the fluctuation range of heart rate data is also small, which shows that the heart rate monitor has good stability and accuracy.

3.3.2 Dynamic test results

In the dynamic test, the heart rate monitor can respond to the heart rate changes of volunteers in real time. With the increase of exercise intensity, the heart rate data also increases correspondingly, which is consistent with the data of medical-grade equipment. After the exercise, the heart rate data can also quickly return to the static level. This shows that the heart rate monitor has good real-time and response ability.

3.3.3 Comparative test results

Through comparative testing, we found that the data of heart rate monitor is very close to that of medical-grade equipment. In most cases, the error between them is less than 5 times/minute. This shows that the heart rate monitor has high accuracy and can meet the needs of daily heart rate monitoring.

3.4 Test conclusion

To sum up, the heart rate monitor shows good performance and accuracy in both static and dynamic tests. Through the comparison test with medical-grade equipment, we further verified its accuracy. Therefore, we can draw a conclusion that the heart rate monitor has high reliability and accuracy and is suitable for daily heart rate monitoring and health management.

It should be noted that although the heart rate monitor performed well in the test, the following points should be noted in practical application:

Ensure that the heart rate sensor is in close contact with the skin to obtain accurate data.

Avoid using heart rate monitor in strenuous exercise or extreme environment, so as not to affect its performance.

Regularly calibrate and maintain the heart rate monitor to ensure its long-term accuracy.

In addition, future research can further explore the application effect of heart rate monitor in specific population (such as athletes, the elderly, etc.), and constantly optimize the algorithm and hardware design to improve its performance and accuracy.

4 Conclusion

With the rapid development of modern science and technology and people's increasing awareness of health, heart rate monitor, as a convenient and real-time health monitoring tool, has been widely used in daily life, sports and fitness, medical diagnosis and other fields. The purpose of this paper is to discuss the design and implementation of heart rate monitor, and verify its performance and accuracy through a series of tests.

During the research, we deeply understand the basic principle and technology of heart rate monitoring, and analyze the key points of hardware and software design of heart rate monitor. By selecting suitable hardware components such as sensors, microcontrollers and display modules, and designing reasonable software modules such as data acquisition, signal processing, heart rate calculation and data display, we successfully built a prototype of heart rate monitor with perfect functions and stable performance.

In the testing stage, we adopted various methods, such as static testing, dynamic testing and comparative testing, to comprehensively evaluate the performance and accuracy of the heart rate monitor. The test results show that the heart rate monitor can record the heart rate data stably and accurately in both static and dynamic environments, and it is consistent with the data of medical-grade equipment. This fully proves the reliability and practicability of the heart rate monitor.

Although some achievements have been made in this study, there are still some shortcomings. For example, the accuracy and stability of heart rate monitor still need to be further improved to adapt to a wider range of use scenarios and needs. In addition, with the continuous development of Internet of Things, big data and other technologies, heart rate monitors can also be connected with smart phones, cloud platforms and other devices to achieve more functions such as remote monitoring and data analysis.

Looking ahead, we will continue to optimize the hardware and software design of the heart rate monitor to improve its performance and accuracy. At the same time, we will actively explore the application potential of heart rate monitor in medical diagnosis, health management, sports training and so on, and make greater contributions to people's health and quality of life. We believe that in the near future, the heart rate monitor will become one of the indispensable health monitoring tools in people's daily life.

Funding

Innovation and Entrepreneurship Project Approval for University Students of University of Science and Technology Liaoning, 2025.

References

[1] Zhou Qingmin.Heart Rate Monitor[J]. Integrated Circuit Application, 1996(2).

[2] Sun Huikang,Li Qingzhi, Jiao Liangbao, Chen Rui. Design of wearable heart rate monitor based on Bluetooth 4.0[J]. Internet of Things Technology, 2016(3).

[3] Zhao Xiaoyu; Zhang Yu; Huanglong; Fu Junya; Cao Shuqi; Gao Junfeng. Design and implementation of wearable wireless chest patch monitoring terminal. China Journal of Medical Devices[J]. 2024(5).

[4] Liu Xiaowen,Zhong Mengting, Ai Dongxiang. Intelligent wearable infant thermometer design[J]. Design, 2024(7).

[5] Wu Xiaoxue. Development of Wearable Devices and Status Quo of Measurement Traceability[J]. Measurement and Testing Technology, 2023(7).

[6] Cao Haiyan, Tan Jiajun,Mars.Wearable lower limb walker[J].Mechanical Design. 2022(10).

[7] Jiang Xiao,Zhang Yanli,Yu Xinhua. Analysis and thinking on the current situation of wearable device management[J]. China Medical Equipment, 2021(5).

[8] Yang Yongsheng,Li Jianhua. Wearable devices in medical field[J]. Electronic Technology and Software Engineering, 2020(17).

[9] Feng Li. Development of Remote Intelligent Heart Rate Monitor[J]. China Medical Equipment, 2014(8).

[10] Zhao Shuli, Li Wenzhao, Gao Huayong, Jiang Jian, Chen Xi, Yang Jinhua, Yong Yong, Cao Zhengtao. Design and experimental study of a wearable cardiopulmonary monitoring system[J]. Chinese medical equipment journal.2024(4).