Design and Implementation of an Intelligent Bluetooth Wristband System

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Abstract

With the popularization of smart wearable devices and the increasing demand for health monitoring, portable smart wristbands have become important tools for personal health management. This paper designs a Bluetooth-enabled smart wristband system based on a microcontroller unit. Taking the microcontroller as the core control unit, the system integrates a heart rate and blood oxygen detection module, an MPU6050 attitude sensor, a DS1302 clock module, and a Bluetooth communication module, together with a buzzer alarm unit and a key operation unit. The system can realize step counting and calorie consumption calculation through the MPU6050 sensor, collect human physiological parameters in real time via the heart rate and blood oxygen module, and accurately display the system time through the DS1302 module. Meanwhile, it supports Bluetooth wireless communication to realize data interaction and remote control with mobile terminals. The keys are used for local function switching, and the buzzer provides an alarm for abnormal data. Featuring small size, low power consumption and comprehensive functions, the system can meet the needs of daily health monitoring and time management.

Keywords

STM32 microcontroller, Bluetooth smart bracelet, heart rate and blood oxygen monitoring.

1. Introduction

As the concept of health management becomes increasingly rooted in people's minds and the pursuit of a high-quality life continues to rise, portable smart wearable devices have quietly integrated into every aspect of the public's daily life, evolving into indispensable companions for tracking personal health conditions and exercise status. Different from traditional wearable products that only have single functions, modern smart wearable devices stand out with their unique advantages: on the one hand, they feature high sensitivity in real-time vital sign monitoring, which can accurately capture subtle changes in the human body; on the other hand, they boast user-friendly interactive design, allowing users to operate and obtain data easily without complicated steps. Whether it is the first ray of sunshine breaking through the window in the morning, the tiny device on people's wrists is silently working, recording every beat of the heart, every breath of the body, and even the subtle changes in blood oxygen saturation; in the evening, when people take a walk in the park, jog on the trail, or do fitness exercises in the community, this small wrist-worn device can accurately capture every running track, every step of the stride, and even the posture changes during exercise, providing users with intuitive and detailed exercise data[1-5].

With the continuous upgrading of consumer demand and the rapid development of electronic information technology, the core market demand for smart wristbands has long been far beyond the initial simple timekeeping function. In the early stage of the development of smart wristbands, most products only focused on basic functions such as time display and simple step

counting, which could not meet the in-depth needs of users for personal health management. However, in recent years, as people's awareness of health management has gradually increased, users' demand for smart wristbands has shifted to the in-depth collection of multi-dimensional health data, intelligent analysis of data, and seamless intelligent interconnection with other devices. Users are no longer satisfied with just obtaining superficial digital data such as step count and heart rate; instead, they expect to deeply interpret the health status of the body through these data, perceive subtle changes in physical condition in a timely manner, and then adjust their living habits and exercise plans to achieve a more scientific and healthy lifestyle. At the same time, users also put forward higher requirements for the portability, battery life, and cost of smart wristbands—they hope to have a device that is small in size, easy to carry, low in power consumption, and affordable, which can realize comprehensive health monitoring without bringing too much burden to daily life. Therefore, a high-performance, low-cost, and user-friendly smart wristband solution with comprehensive functions has become an urgent gap to be filled in the current market[6-8].

In response to the above market demands and user needs, this paper designs a Bluetooth intelligent wristband system based on a microcontroller, which is like a portable personal health butler, providing users with all-round and intimate health management services. The system takes the high-performance, low-power microcontroller as the core control unit, and ingeniously integrates multiple functional modules to form a complete and efficient intelligent monitoring system. Specifically, it includes a high-precision heart rate and blood oxygen detection module, which can continuously and stably collect the user's heart rate and blood oxygen saturation data in real time, and timely identify abnormal physical signs; an MPU6050 attitude sensor with high sensitivity, which can accurately capture the user's movement posture, step frequency, and movement amplitude, so as to realize accurate step counting and scientific calculation of calorie consumption; a DS1302 clock module with high precision, which can provide stable and accurate system time display, facilitating users to grasp the time at any time while monitoring their health; and a Bluetooth communication module with stable performance, which can realize seamless wireless connection with mobile phone terminals[2-7].

In the actual use process, the system shows excellent performance and humanized design: when the user starts to move, the MPU6050 attitude sensor will immediately start working, silently counting every solid step, recording the movement distance and movement time, and intelligently calculating the calorie consumption according to the user's basic information and movement intensity, just like a silent coach, providing scientific reference for the user's exercise plan. After the exercise, the user can easily view the detailed exercise data through the mobile phone APP connected via Bluetooth, including step count, calorie consumption, movement duration, and other information, so as to clearly understand their own exercise effect. In terms of health monitoring, the heart rate and blood oxygen detection module works continuously, and once abnormal data such as too high or too low heart rate and blood oxygen saturation are detected, the built-in buzzer alarm unit will immediately issue a prompt sound to remind the user to pay attention to their physical condition and take corresponding measures in time. In addition, the system is equipped with a key operation unit, which is convenient for users to switch between different functions locally, such as switching between time display, heart rate monitoring, and step counting interfaces, without relying on the mobile phone terminal, further improving the convenience of use[6-9].

Overall, this Bluetooth intelligent wristband system has the characteristics of small size, low power consumption, comprehensive functions, simple operation, and low cost. It effectively solves the problems of single function, high cost, and inconvenient use of some existing smart wristbands in the market, and can fully meet the needs of the public for daily health monitoring, exercise data statistics, and time management. It is hoped that through the design and implementation of this system, a lightweight and low-cost daily health management solution

can be provided for users, enabling everyone to easily grasp their own health code, monitor their physical condition in real time, and build a solid health barrier in the fast-paced modern life, so as to better promote the popularization and development of smart health management.

2. Hardware System Design

The STM32 microcontroller is a 32-bit microcontroller based on the ARM Cortex-M series core launched by STMicroelectronics (ST). Its core principle lies in integrating the Central Processing Unit (CPU), Flash memory, Random Access Memory (RAM), and various peripheral interfaces (such as UART, I2C, SPI) onto a single chip. By executing pre-programmed programs, it achieves data operation, logic control, and interaction with external devices. Featuring high performance, low power consumption, and high integration, it has become the mainstream core device for embedded development. According to their functions, its pins can be divided into power supply pins (providing 3.3V core power), GPIO (General-Purpose Input/Output) pins (flexibly configurable for input/output modes to realize signal interaction with peripherals such as sensors and buttons), reset pins, clock pins, and communication pins. Different models (such as STM32F103) offer pin counts ranging from 36 to 144, accommodating hardware designs of varying complexities. The STM32 minimum system is the fundamental circuit ensuring the independent operation of the microcontroller, mainly consisting of three parts: a power supply circuit (converting 5V to stable 3.3V power), a reset circuit (realizing system power-on reset or manual reset), and a crystal oscillator circuit (providing a clock reference via an 8MHz/12MHz crystal). Some models require configuration of BOOT pins (determining program startup modes). As the core foundation for building application systems such as smart wristbands, the minimum system ensures that the microcontroller completes instruction execution and basic operation.

The MAX30102 heart rate and blood oxygen module implements heart rate and blood oxygen detection based on Photoplethysmography (PPG) technology. Its core principle is to emit red and infrared light through the skin, capture periodic changes in light reflection intensity at the receiving end, and convert these changes into blood oxygen saturation and heart rate values. Integrating an optical sensor and a low-noise amplifier, the module supports I2C communication, features extremely low power consumption, and incorporates a built-in ambient light suppression algorithm to reduce interference from external light. Its compact size meets the portability requirements of the wristband. After being processed by the microcontroller, the collected data can be displayed in real time or transmitted via Bluetooth, making it a core component of the wristband's physiological monitoring. The MPU6050 integrates a 3-axis accelerometer and a 3-axis gyroscope, serving as the core module for realizing step count and calorie calculation of the wristband. The accelerometer captures acceleration changes during limb movement, converts them into steps through algorithms, and estimates calorie consumption combined with parameters such as the user's weight. The gyroscope senses angular velocity and compensates for motion errors to improve the accuracy of step count statistics. Equipped with a built-in Digital Motion Processor (DMP), the module reduces the computational load of the microcontroller, supports I2C communication, and features low power consumption and small size. It perfectly adapts to the wearable design of the wristband and can stably collect posture and motion data. The DS1302 is a low-power Real-Time Clock (RTC) chip specifically designed for the time management of wristbands. It can accurately record time dimensions such as seconds, minutes, hours, days, weeks, months, and years, and includes an automatic leap year compensation function. It interacts with the microcontroller through synchronous serial communication, has a built-in trickle charging circuit, and can maintain timekeeping when powered off via an external button battery, ensuring that system time is not lost. In the wristband, this module provides a time reference

for data such as step counts and heart rates, and can also display the system time in real time. With simple wiring and extremely low power consumption, it meets the battery life requirements of wearable devices. The OLED module adopts self-luminous technology, eliminating the need for a backlight. Featuring low power consumption and high contrast, it is the core display component of the wristband. Commonly with a 128×64 resolution, it supports I2C/SPI communication and can clearly display data such as heart rate, blood oxygen, step count, and system time. It responds quickly and operates stably at low voltages. The module's small size allows direct connection to the GPIO pins of the microcontroller, adapting to the miniaturized design of the wristband, realizing local data visualization, enabling users to intuitively view various monitoring results, and enhancing the interactive experience.

The HC series Bluetooth modules (such as HC-05/HC-06) are based on the Bluetooth 2.0/4.0 protocol and communicate with the microcontroller via the UART serial port, serving as the core of the linkage between the wristband and mobile phones. Small in size and low in power consumption, the modules can wirelessly transmit data such as heart rate, blood oxygen, and step counts collected by the wristband to mobile terminals, and can also receive control commands from mobile phones (such as time calibration and alarm threshold setting). With a communication distance of up to 10 meters, no complex configuration is required, and point-to-point transmission is stable. Adapting to the portability of the wristband, it realizes the core functions of data interaction and remote control.

The small passive buzzer module commonly used in wristbands is driven to sound by pulse signals output from the GPIO pins of the microcontroller. Its core functions are abnormal reminder and operation feedback. When heart rate and blood oxygen values exceed set thresholds, the buzzer triggers an alarm. The module only needs to be connected in series with a current-limiting resistor to link with the microcontroller, featuring extremely low power consumption and small size. It fully adapts to the wearable design of the wristband and serves as an auxiliary core module to ensure usage safety and optimize the interactive experience.

3. System software design

The main program of this system is developed based on the STM32 microcontroller adopting the modular programming idea. Its core logic consists of three main processes: initialization, cyclic acquisition and processing, and interactive feedback, ensuring the stable and efficient operation of the system. After the program starts, global initialization is executed first: configure the system clock and interrupt priority, complete the initialization of GPIO ports and I2C/SPI/UART communication protocols, perform parameter configuration and self-inspection on modules such as heart rate and blood oxygen, attitude sensor, clock, Bluetooth, OLED, and buzzer, and load the system time reference and default parameters of health thresholds.

In the main loop stage, multi-task scheduling is executed according to priority: first, real-time collect heart rate and blood oxygen, MPU6050 attitude data, and DS1302 time information through the corresponding communication interfaces; second, perform algorithmic processing on the collected data, parse the attitude data into steps and convert them into calories, and verify the validity of heart rate and blood oxygen data; then scan key commands to realize interactive operations such as display interface switching and threshold setting, and trigger the buzzer alarm if abnormal physiological data is detected; finally, synchronously display the processed time, steps, and physiological data on the OLED module, and transmit the data to the mobile terminal through the Bluetooth module. The program embeds low-power management logic, which controls the module to enter sleep mode during idle periods, balancing functional integrity and the wristband's battery life requirements.

The heart rate and blood oxygen subprogram is responsible for data collection and parsing of the heart rate and blood oxygen module. After the program starts, it first initializes

communication, configures core parameters such as the module's sampling rate and gain, and then cyclically reads the photoelectric signal values of red light and infrared light. Environmental noise is eliminated through sliding window filtering, pulse wave peaks are extracted, and the time interval between adjacent peaks is calculated to obtain the real-time heart rate; combined with the red/infrared light absorption ratio, blood oxygen saturation is converted through a calibration algorithm. If the data exceeds the preset threshold, the subprogram triggers the buzzer alarm flag, and at the same time encapsulates the valid data into a structure for the main program to call and transmit to the OLED or Bluetooth module.

The attitude detection subprogram is designed for the attitude sensor. During the initialization phase, it configures the range of the accelerometer and gyroscope, and enables the built-in data processing function to reduce the computing load of the main controller. The subprogram cyclically reads the three-axis acceleration data, identifies effective gait through threshold judgment and peak detection algorithms, accumulates steps, and then converts them into calories combined with preset parameters such as weight and step length. At the same time, it reads gyroscope data to compensate for motion errors and correct the accuracy of step counting. The subprogram regularly writes step and calorie data into the shared buffer for the main program to call, and controls the module to enter low-power mode during idle periods to reduce the wristband's energy consumption.

The OLED display subprogram is responsible for the visual output of various data. During initialization, it configures the SPI/I2C communication protocol and completes basic settings such as screen clearing and display area division. The subprogram receives display commands issued by the main program, parses data frames such as heart rate and blood oxygen, steps and calories, and system time, converts numbers and characters into dot matrix drive signals according to the preset interface layout, and refreshes the display content in divided areas. It supports interface switching logic triggered by keys, which can quickly switch between different data display pages, and the refresh frequency is set to 1Hz, balancing display fluency and power consumption control.

The Bluetooth subprogram realizes wireless data interaction between the microcontroller and the mobile phone. During the initialization phase, it configures the serial port baud rate and completes the setting of the Bluetooth module's pairing mode and communication protocol. The subprogram adopts an interrupt-triggered mode. After receiving the health data frame encapsulated by the main program, it adds a check bit and sends it to the Bluetooth module through the serial port to realize data upload; at the same time, it monitors the serial port data of the Bluetooth module, parses the control commands issued by the mobile phone (such as time calibration and threshold modification), writes the command parameters into global variables, and feeds them back to the main program to execute corresponding operations.

4. Conclusion

This study designs and implements a Bluetooth intelligent wristband system based on the STM32 microcontroller, with convenient health monitoring and interaction as the core objectives. Adopting the modular design concept, the hardware and software architectures are constructed to fully meet the daily health management and exercise tracking requirements. At the hardware level, the STM32 microcontroller serves as the core, integrating key components such as the heart rate and blood oxygen sensor, attitude sensor, clock module, and Bluetooth module, together with the OLED display and buzzer alarm unit. This design realizes the full-link functionality of data collection, wireless transmission, visual display, and abnormal reminder. Meanwhile, the selection of modules prioritizes low power consumption and portability, ensuring compatibility with the characteristics of wearable devices. At the software level, the main program and various functional subprograms are developed based on the modular

programming idea. The operational logic, including initialization, data collection, processing, and interactive feedback, is established. Multi-task scheduling is implemented to guarantee data real-time performance and system stability, while a low-power management strategy is embedded to extend battery life. Through physical welding and program burning verification, the system accurately completes heart rate and blood oxygen monitoring, step count and calorie calculation, and realizes wireless data interaction with mobile phones via Bluetooth, along with real-time local display. All modules cooperate stably. In summary, the system exhibits comprehensive functions, reliable operation, and controllable costs, effectively meeting the daily health management needs of the general public. In future work, data accuracy can be further improved by optimizing algorithms, and additional functions such as sleep monitoring can be expanded to enhance the system's practicality and market adaptability.

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