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Design and Implementation of an Intelligent Cane System Based on STM32

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Abstract

Targeting the safety needs of elderly people in the context of population aging, this study presents the design of an intelligent cane system based on the STM32F103C8T6 microcontroller. The system integrates functions including heart rate monitoring, fall detection, obstacle detection, GPS positioning, ambient light sensing with auto-illumination, and wireless communication. Through the collaborative work of multi-sensor fusion and the STM32 microcontroller, it realizes real-time monitoring and safety protection of elderly people's movement status.

Keywords

Intelligent cane; STM32; Sensor fusion; Elderly monitoring; Fall detection.

1. Introduction

United Nations statistics predict that the global population of people aged 60 and above will increase to 2 billion by 2050. In China, the proportion of the population aged 60 and above rose from 7.62% to 18.70% between 1982 and 2020, and the proportion of those aged 65 and above surged from 4.91% to 13.50%. The intensification of population aging has amplified safety needs for mobility-impaired individuals. Traditional canes provide only supporting functions and cannot meet intelligent requirements for health monitoring and environmental perception. By integrating sensor technology and IoT technology, intelligent canes significantly enhance elderly people's safety and independence.

The intelligent cane system designed in this study integrates health monitoring, environmental perception, and emergency alarm functions, delivering the following capabilities:

Real-time heart rate and blood oxygen monitoring and abnormal alarm

Fall detection and automatic alarm based on acceleration sensors

Ultrasonic obstacle detection and avoidance reminder

GPS positioning and remote trajectory tracking

Light-adaptive lighting and manual emergency lighting

Mobile APP data synchronization and remote monitoring

2. Overall System Design

2.1. Functional Requirement Analysis

The core functions of the system are designed around a three-layer architecture of "safety monitoring--environmental perception--emergency response":

Health Monitoring Layer: The MAX30102 sensor enables real-time monitoring of heart rate and blood oxygen saturation. After processing by the STM32, data is transmitted to the APP, and sound /light alarms are triggered in case of abnormalities.

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Environmental Perception Layer: The ADXL345 acceleration sensor is used to detect attitude changes, the HC-SR04 ultrasonic module identifies front obstacles, and the light sensor realizes automatic control of illumination.

Emergency Response Layer: Integrated with GPS positioning, WiFi communication, and buzzer/vibration modules, supporting automatic fall alarm, manual emergency call, and APP remote monitoring.

2.2. System Architecture Design

The system utilizes STM32F103C8T6 as the main control chip, and the hardware architecture is shown in Fig. 1. Each sensor module communicates with the microcontroller through interfaces such as I2C and USART. After processing, data is uploaded to the APP through the WiFi module and real-time displayed on the OLED screen.

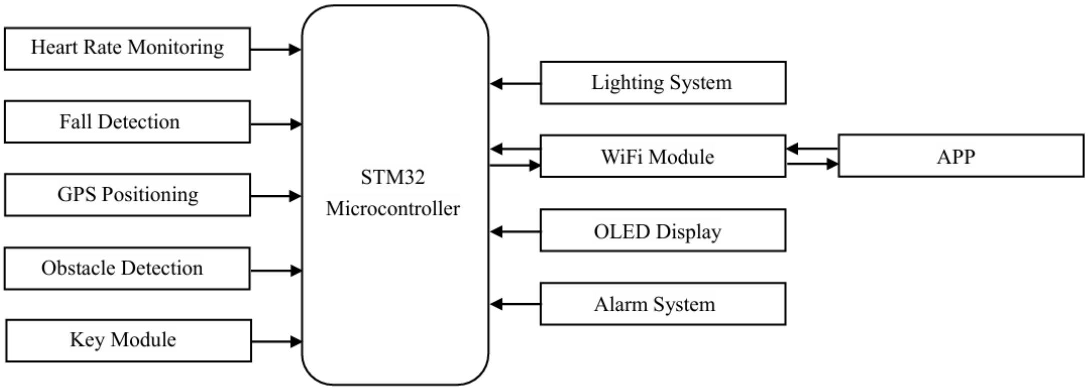

Fig. 1 System Block Diagram

The composition of system hardware modules is shown in Table 1.

Table 1 Composition of System Hardware Modules

Module Type	Core Component	Communication Interface	Function Description
Main Control Module	STM32F103C8T6	-	Data processing and system control
Health Monitoring	MAX30102	I2C	Heart rate/blood oxygen detection
Posture Detection	ADXL345	I2C	Fall detection
Environmental Perception	HC-SR04	GPIO	Obstacle ranging
Positioning Module	ATGM336H-5N	USART	GPS/BDS positioning
Human-Computer Interaction	OLED display	SPI	Status display
Alarm Module	Buzzer	GPIO	Sound-light/vibration alarm
Communication Module	ESP8266	USART	WiFi data transmission

3. Hardware Design and Implementation

3.1. Main Control Module Design

The STM32F103C8T6 microcontroller is selected, based on the ARM Cortex-M3 core, with a main frequency of 72MHz, integrated with 64KB Flash, 20KB SRAM, and rich peripheral interfaces (3 USARTs, 2 I2Cs, 3 SPIs), meeting the requirements of low power consumption and multi-sensor communication. The physical diagram of STM32F103C8T6 minimum board is shown in Fig. 2. The minimum system includes:

Crystal Oscillator Circuit: A 32.768kHz crystal is connected to PC14/PC15 pins, with 20pF load capacitors to stabilize oscillation.

Reset Circuit: A 10kΩ pull-up resistor and 105nF capacitor form an RC reset network, and the NRST pin is connected to the reset button.

Power Management: The 5V is converted to 3.3V power supply through the AMS1117-3.3 chip.

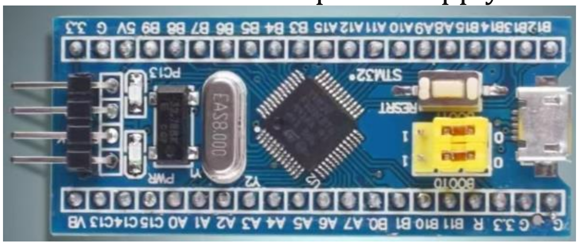

Fig. 2 The physical diagram of STM32F103C8T6 minimum board

Pin Diagram of STM32F103C8T6 Minimum System Board is shown in Fig.3.

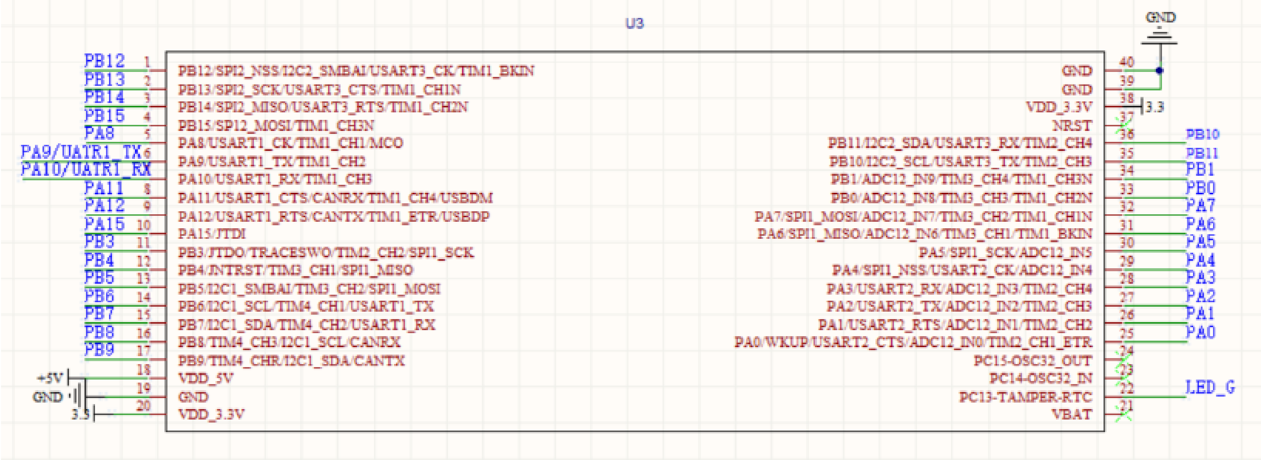

Fig.3 Pin Diagram of STM32F103C8T6 Minimum System Board

3.2. Health Monitoring Module

The MAX30102 sensor is used for heart rate and blood oxygen monitoring. Based on the photoplethysmography (PPG) technology, it calculates heart rate and blood oxygen saturation by emitting light signals through red (660nm) and infrared (940nm) LEDs and receiving reflected light by a photodetector. The module communicates with the STM32 through the I2C interface (SCL connected to PB9, SDA connected to PB8), and the INT pin (PB7) is used for interrupt-triggered data reading. Heart Rate Module Circuit Diagram is shown in Fig.4.

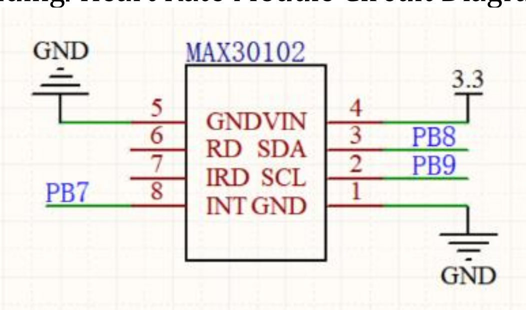

Fig.4 Heart Rate Module Circuit Diagram

3.3. Fall Detection Module

The ADXL345 three-axis acceleration sensor is selected, with a resolution of 13 bits, which can detect acceleration changes of ±16g. The X/Y/Z axis acceleration data is read through the I2C

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interface (SCL connected to PB6, SDA connected to PB5), and the fall state is determined by the threshold detection algorithm: when the acceleration change rate of any axis exceeds 8g and lasts for more than 200ms, it is determined as a fall. The module has a built-in 32-level FIFO buffer to reduce data reading frequency. Acceleration Detection Circuit Diagram is shown in Fig.5.

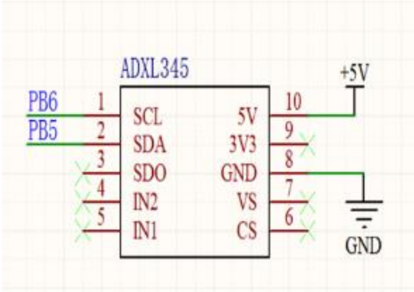

Fig.5 Acceleration Detection Circuit Diagram

3.4. Obstacle Detection Module

The HC-SR04 ultrasonic module is used, with a ranging range of 2-450cm and a precision of 3mm. It is controlled by GPIO pins: the Trig pin (PB12) sends a 10μs high level to trigger ranging, and the Echo pin (PB13) receives the echo signal. The distance is calculated according to the pulse width (distance = high level time × sound speed / 2). The system sets a warning distance of 500cm, and when the distance is less than this value, the buzzer and vibration alarm are triggered. Ultrasonic Sensor Circuit Diagram is shown in Fig.6.

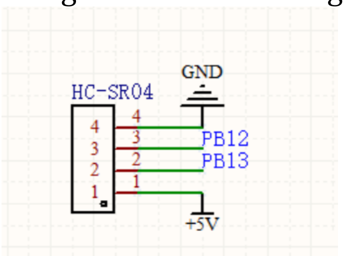

Fig.6 Ultrasonic Sensor Circuit Diagram

3.5. Positioning and Communication Module

The ATGM336H-5N module is used for GPS positioning, supporting dual-system positioning of GPS/BDS, with a positioning accuracy of ≤10m. It outputs NMEA-0183 format data through the USART interface (RX connected to PA3), and parses out latitude and longitude, speed and other information. GPS Module Circuit Diagram is shown in Fig.7.

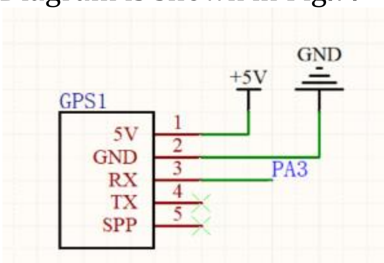

Fig.7 GPS Module Circuit Diagram

The ESP8266 module is selected for WiFi communication, which communicates with the STM32 through USART (URXD connected to PB10, UTXD connected to PB11), supporting AP/STA modes to realize data upload to the cloud server. WiFi Module Circuit Diagram is shown in Fig.8.

ISSN: 1813-4890

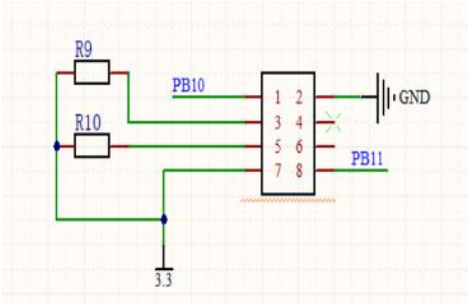

Fig.8 WiFi Module Circuit Diagram

3.6. OLED display Module

The display part uses a 0.96-inch OLED display (SSD1306 driver), which displays heart rate, blood oxygen, distance, positioning and other information through the SPI interface (SCLK connected to PA5, MOSI connected to PA7, CS connected to PA4). OLED Circuit Diagram is shown in Fig.9.

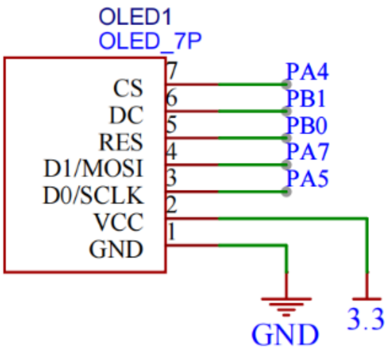

Fig.9 OLED Circuit Diagram

4. Software Design and Implementation

4.1. System Software Architecture

The software adopts a modular design, developed based on the STM32 HAL library, mainly including:

Driver layer: Driver programs for each sensor (I2C/USART communication)

Function layer: Data processing algorithms (heart rate calculation, fall detection, distance calculation)

Application layer: Main program loop, key response, display control, communication protocol

4.2. Main Program Design

The main program flow is shown in Fig. 10. The initialization includes:

System clock configuration (72MHz)

GPIO/peripheral clock enable

Sensor initialization (MAX30102/ADXL345/HC-SR04)

WiFi module networking (connect to the specified SSID)

In the main loop, sensor data is updated every 3 seconds, and the processing logic includes:

Reading and filtering heart rate/blood oxygen data

Acceleration data collection and fall judgment

Ultrasonic ranging and obstacle alarm

GPS data parsing and position update

APP communication data packaging and sending

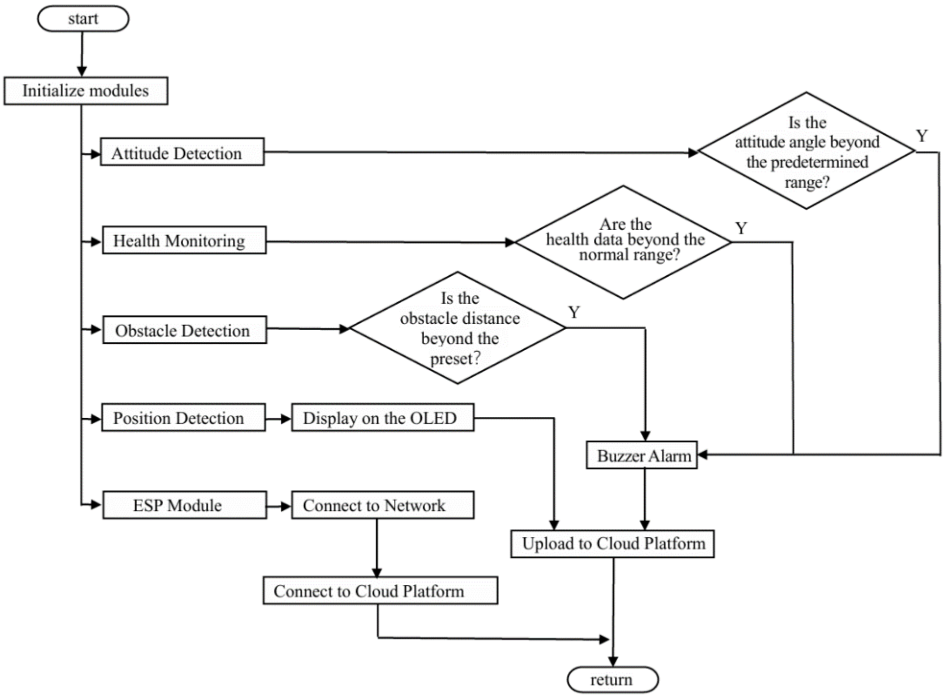

Fig. 10 Main Program Flowchart

5. Conclusion and Prospect

5.1. Research Conclusion

This study designs and implements an intelligent cane system based on STM32, integrating multi-sensor fusion and wireless communication technologies, with the following innovations:

Adopting a three-layer architecture of "health monitoring--environmental perception--emergency response" to achieve all-round protection of elderly people's movement safety.

Integrating PPG technology and acceleration sensing to improve the accuracy of heart rate monitoring and fall detection.

Integrating GPS and WiFi communication to realize integrated positioning tracking and remote monitoring.

5.2. Future Prospects

Algorithm optimization: Introduce deep learning algorithms (such as LSTM neural networks) to process acceleration data and reduce the false alarm rate in complex scenarios.

Hardware upgrade: Use low-power Bluetooth 5.0 instead of WiFi to extend battery life; integrate barometric pressure sensors to achieve floor recognition.

Function expansion: Docking with smart city systems to realize public place emergency calls and rescue resource scheduling.

User experience optimization: Optimize the cane's shape design, use lightweight materials and ergonomic grips to improve wearing comfort.

This study provides a technical reference for the development of intelligent auxiliary devices for the elderly. In the follow-up, the system performance will be further improved to promote industrial application.

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