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# DESIGN OF A MICROCONTROLLER-BASED SMART BLIND CANE

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**Abstract:** Individuals with visual impairment encounter substantial difficulties in navigating daily activities due to their inability to perceive their immediate surroundings, particularly during pedestrian crossings at intersections. To address these mobility constraints, this research proposes the development of an intelligent assistive cane incorporating a single-chip microcontroller system. The cane uses a modular design, mainly integrating an STM32F103C8T6 minimum system module, an ultrasonic ranging module, an OpenARTmini vision sensor module, and a voice synthesis module. The intelligent guide cane integrates an ultrasonic ranging module with a visual sensor module, enabling the recognition of traffic light signals and traffic signs while achieving three-dimensional environmental perception. This design overcomes the limitations of ecological sensing imposed by traditional single-sensor systems. Additionally, it incorporates a composite feedback mode consisting of buzzer alarms, vibration feedback, and speech synthesis, which facilitates differentiated information transmission tailored to diverse scenario requirements. By meeting the daily needs of blind individuals through context-specific information delivery, the system enhances their independent mobility and promotes social participation.
**Keywords:** Blind mobility assistance; Smart navigation cane; Modular design; STM32F103C8T6 minimum system

## 1 INTRODUCTION

According to the World Health Organization (WHO), visual impairment is one of the most common problems affecting approximately one sixth of the world's population [1]. There are approximately 40 million to 45 million blind people globally, and the number of blind people is still on the rise each year. One of the most crucial senses in human existence is sight [2]. However, visually impaired people have this handicap. They face numerous difficulties in their daily lives, among which the problem of getting around is particularly challenging.

Scholars such as Sharma T and Nalwa T designed a smart cane equipped with infrared and ultrasonic sensors, which can effectively detect obstacles [3]. Pariti J, Tibdewal V, and other scholars developed a smart mobile cane that notifies users through different parts of the hand to convey obstacle-related information [4]. Aravinth T S created a WiFi- and Bluetooth-based smart cane, optimizing its usage methods to enhance accessibility for blind individuals [5]. Soares J M S, Guerra C S D, and other scholars designed an electronic laser-assisted smart cane capable of identifying obstacles at the user's head height, which holds significant importance for the development of environmental perception technology in smart guide canes [6]. Tang J, Sun M, and other scholars developed a visual odometry-assisted cane that directly detects obstacles and attracts the attention of surrounding people, providing multiple layers of protection for the visually impaired [7]. Scholars, including Abu-Abdoun D I and Alsyouf I, innovatively designed a GPS-enabled cane by integrating the specific needs of blind individuals, further facilitating their daily mobility [8]. These research findings provide valuable references for the design of the smart blind cane proposed in this paper. Nevertheless, existing smart blind canes demonstrate limitations in environmental perception: they depend exclusively on a single sensor, exhibit inadequate modular integration, and fail to recognize traffic light colors or issue corresponding alerts when visually impaired individuals encounter traffic lights during their mobility.

This paper uses the STM32F103C8T6 as the main control chip, integrating multiple modules to achieve low-cost dual-mode detection of obstacles and traffic lights. By combining a three-level alarm mechanism with preset interaction parameters, it breaks through the limitations of traditional devices in complex intersection scenarios and enhances the safety of blind individuals when traveling.

## 2 OVERALL SYSTEM DESIGN

### 2.1 Design Scheme

The blind guidance system is composed of multiple modules, including a power supply circuit, STM32F103C8T6 minimum system module, HC-SR04 ultrasonic ranging module, OpenART mini vision sensor module, SYN6288 Chinese speech synthesis module, buzzer and vibration motor module, as well as an OLED display module.. This intelligent white cane design prioritizes safe mobility for the visually impaired as its central objective, focusing on two core functionalities: obstacle distance detection and traffic light color recognition at intersections. Through differentiated communication protocols coordinating with the STM32F103C8T6 microcontroller, these modules collectively form an integrated guidance system that combines environmental perception, signal processing, and multimodal interaction. This architecture ensures comprehensive functional integration and stable system operation, as shown in Figure 1.

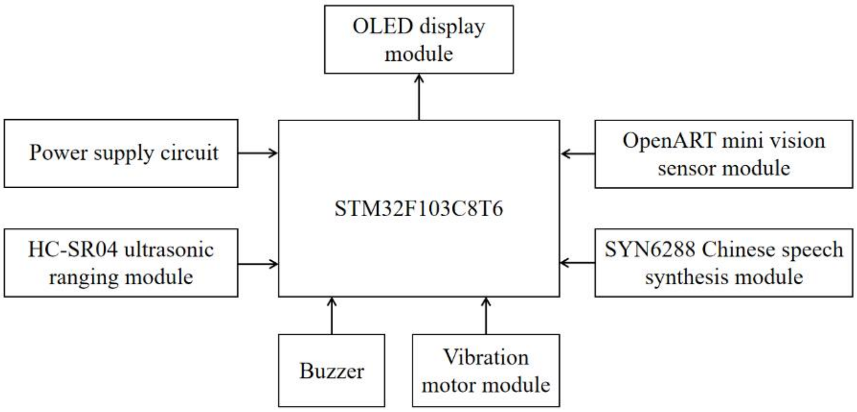


**Figure 1** Overall Framework Diagram of the System

### 2.2 System Hardware Design

#### *2.2.1 Main control chip*

The design employs the STM32F103C8T6 microcontroller as the central control unit. It has strong computing capabilities and abundant interfaces, which can meet the requirements of the Intelligent Blind Stick and facilitate the efficient control of each module. The STM32F103C8T6 has a total of five pins connected to the positive pole of the power supply and four ground pins, which supply power to different internal modules respectively. It can control modules such as HC-SR04, SYN6288, and OpenART mini in real time. For HC-SR04, the specific pins of the single-chip microcomputer output control signals for distance measurement. For example, PA0 provides a trigger signal to Trig, and PA1 receives the Echo signal, and the distance is calculated through a formula. For SYN6288, the single-chip microcomputer sends commands and text through the UART interface, sets the baud rate, etc., and the synthesized voice of the module is amplified and played. For OpenART mini, the single-chip microcomputer transmits data through asynchronous serial communication. The module is programmed with OPENMV IDE and the PYTHON language. It collects images of traffic lights, makes judgments, and then informs the single-chip microcomputer of the color situation through the serial port. Then the system reminds the user by controlling the voice module, as shown in Figure 2.


**Figure 2** STM32F103C8T6 Chip

#### *2.2.2 Ultrasonic ranging module*

The HC-SR04 ultrasonic ranging module is an important part of the Intelligent Blind Stick. It is designed to accurately measure the distance between the blind stick and the obstacles in front. With excellent performance, its range covers a wide interval from as close as 2 centimeters to as far as 400 centimeters, and within this range, its ranging accuracy can reach an amazing 3 millimeters. The module is ingeniously constructed, consisting of three parts: an ultrasonic transmitter, a receiver, and a control circuit. Each part undertakes a crucial task, jointly ensuring the accuracy and stability of ranging. In the intelligent blind guidance cane, this module is connected to the microcontroller, responsible for emitting and receiving ultrasonic waves, and transmits the measured data to the microcontroller for processing, as shown in Figure 3.


**Figure 3** HC-SR04 Ultrasonic Ranging Module

### *2.2.3 SYN6288 Chinese speech synthesis module*

The human-machine interaction system operates through the SYN6288 Chinese speech synthesis driver software. It is a speech synthesis module that is used to play Chinese speech, and can support words synthesized using English letters [9]. This driver communicates with the microcontroller via asynchronous serial interfaces, processing text encoded in GB2312, GBK, and Unicode standards. Universal Asynchronous Receiver Transmitter is a serial communication protocol that helps in communicating data between devices [10]. This module also has abundant control functions, such as synthesis, stop, pause, continue, and baud rate adjustment. Through speech synthesis algorithms, it converts text into natural, intelligible audio output, achieving real-time text-to-speech conversion. The full-duplex communication module connects to the main chip through TXD and RXD pins. When receiving command frames from the main controller, it processes structured data packets containing frame headers, data length indicators, command codes, text content, and XOR checksums. For instance, commands like "Front red light, do not advance" trigger corresponding voice alerts through internal processing. Based on visual sensor input regarding traffic light status, the system activates specific voice prompts: "Red or yellow light ahead, stop" or "Green light ahead, proceed." The module supports parameter adjustments, including volume levels, speech rate modulation, and background music integration, ensuring optimized auditory reception of traffic signals for visually impaired users. This implementation demonstrates dynamic audio feedback driven by environmental sensing and standardized communication protocols, as shown in Figure 4.


**Figure 4** SYN6288 Chinese Speech Synthesis Module

### *2.2.4 OpenART mini vision sensor module*

The OpenART mini vision sensor module employs the high-performance MIMXRT1064 processor and integrates the OpenMV machine vision library. It supports data storage via Type-C interface or SD card, while its built-in image sensor captures 240×320 resolution images. By defining the value ranges for the L, a, and b components corresponding to red, yellow, and green colors in the Lab color space, the module achieves accurate identification of traffic light color zones. Operating continuously at intersections, the module transmits recognition results through a serial port at a 115200 baud rate to the microcontroller. This provides critical input for the SNT6288 speech synthesis module to determine traffic signal states. This innovation effectively resolves the critical challenge of blind individuals being unable to discern traffic lights at crossings. The system converts visual recognition outcomes into audible voice commands, enabling safe and precise navigation through intersections. This technological advancement significantly enhances the adaptive capabilities of visually impaired individuals to surrounding traffic conditions during independent travel, as shown in Figure 5.

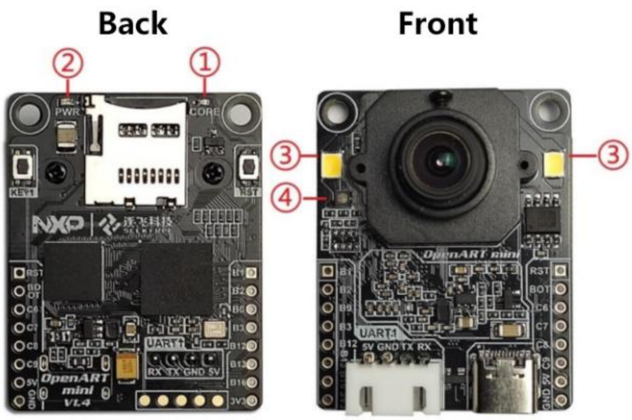


**Figure 5** Indicator Lights of the OpenART mini Intelligent Vision Sensor Module

### *2.2.5 OLED display module*

The OLED display module features a 0.96-inch monochromatic screen with 128 × 64 resolution, utilizing the I2C communication protocol to interface with the microcontroller. Driven by the SSD1306 controller chip, it supports 256-level brightness adjustment and operates as a self-emissive device requiring no backlight, making it ideal for low-power applications. In this system, font generation software converts ultrasonic ranging results and traffic light status data into character codes for real-time visualization. This provides graphical feedback for visually impaired users, such as dynamically updated obstacle distance measurements. Combined with voice prompts and vibration alerts, it establishes a multimodal feedback mechanism to enhance environmental perception. The display's visual supplementation proves particularly effective in quiet environments, offering complementary data through graphical cues. Additional configurability includes volume, speech rate, and background music adjustments to facilitate auditory reception of traffic signals. This integration of visual and auditory modalities enhances the system's practical applicability, as shown in Figure 6.

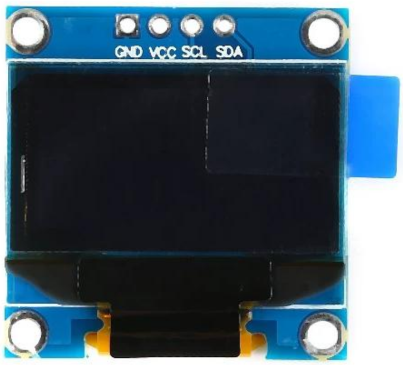


**Figure 6** Overall Framework Diagram of the System

## 2.3 System Software Design

The system program is developed using the C language within the Keil 5 MDK integrated development environment. Its functional architecture comprises multiple core modules, with the main program module serving as the control hub. This hub assumes critical responsibilities, including system initialization configuration, task timing scheduling, and resource coordination and management. Another key component is the HC-SR04 ultrasonic ranging module subroutine, which operates based on the principle of ultrasonic ranging. It transmits ultrasonic waves, receives reflected waves from the surrounding environment to detect road conditions, and identifies the presence of obstacles. When an object is detected within a 50cm range, the system triggers corresponding voice prompts according to the current environmental status, thereby establishing a closed control loop from environmental perception to information feedback. Additionally, the software includes the OpenART mini visual sensor subroutine, which is capable of detecting traffic lights. Upon detecting a red or yellow light, the system invokes the SYN6288 Chinese voice synthesis subroutine to provide prompts such as "Red/yellow light ahead, do not proceed." When a green light is detected, it prompts "Green light ahead, proceed." The software also features an OLED display subroutine, which shows prompt information such as distance and time on the OLED screen, enabling users to easily monitor the current environment and system status. Furthermore, the vibration and buzzer control subroutines deliver dual tactile and auditory alerts, ensuring users effectively receive system notifications. Finally, the software can rapidly generate target code, which is concise and understandable, facilitating maintenance and future upgrades.

# 3 RESULT

## 3.1 Distance Measurement Test

This study conducted obstacle detection accuracy tests on the intelligent navigation cane using four standard distances, with the test results shown in Table 1.

**Table 1** Precision Test of HC-SR04 Ultrasonic Ranging Module

| Distance (cm) | Accuracy rate |
|---|---|
| 25 | 98% |
| 50 | 97% |
| 75 | 93% |
| 100 | 91% |

The results indicate that the system achieves over 95% accuracy in short-distance obstacle detection, with minor deviations observed as distance increases. These deviations are primarily attributed to ultrasonic signal attenuation at longer ranges. Within the 100 cm operational range, assisted obstacle avoidance can be effectively achieved, demonstrating compliance with the design specifications. The observed performance degradation beyond proximity aligns with inherent physical limitations of ultrasonic wave propagation, particularly energy dissipation effects over extended distances.

## 3.2 Traffic Light Recognition Test

This study evaluated the recognition performance of the OpenART mini module for three traffic light colors under a standardized testing distance of 30 cm, with experimental outcomes shown in Table 2.

**Table 2** Recognition Accuracy Table

| Colour | Accuracy rate |
|---|---|
| Red light | 90% |
| Yellow light | 93% |
| Green light | 96% |

The experimental results demonstrate that the green light recognition achieved the highest accuracy rate, followed by yellow and red lights. The study attributes this performance hierarchy to green light's superior distinctiveness in the Lab color space compared to other colors, coupled with the module's stable recognition of high-luminance colors. Red light detection showed relative susceptibility to ambient light interference due to lower brightness levels, potentially leading to threshold misjudgments. While red light recognition accuracy remained above 90% despite illumination challenges, and yellow light exhibited intermediate performance, the system's overall capability meets the operational requirements for traffic signal identification in close-range scenarios as specified for navigation cane applications.

# 4 CONCLUSIONS AND OUTLOOKS

The intelligent cane system distinguishes itself from existing commercial alternatives by integrating ultrasonic distance sensors, vision sensors, and voice synthesizers, enabling enhanced environmental exploration, obstacle avoidance, and traffic light recognition for visually impaired users. Through optimized hardware circuit design and refined software logic architecture, this system demonstrates robust adaptability to complex environments while minimizing system crashes during operation, thereby improving travel safety.

However, this system still has some shortcomings, including a relatively limited visual recognition range and non-expandable hardware components in the main control module. In the future, improving the algorithm could enable it to operate better under varying light conditions, thereby further enhancing the adaptability of the intelligent cane system.

# COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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