

Design and Implementation of an Ultrasonic-Based Vehicle Distance Monitoring System

Guifang Meng

Suzhou Vocational Institute of Industrial Technology, Suzhou 215104, China
00146@siit.edu.cn

Abstract: To address the frequent traffic accidents caused by incorrect distance judgment during driving, this paper designs and implements an ultrasonic-based vehicle distance monitoring system. The system takes the STM32F103C8T6 single-chip microcomputer as the control core, integrating the HC-SR04 ultrasonic ranging module, DS18B20 temperature sensor, OLED display module, acousto-optic alarm module and independent key module to build a complete vehicle distance monitoring and early warning system. The DS18B20 collects ambient temperature data to perform temperature compensation for ultrasonic ranging, improving ranging accuracy; the HC-SR04 real-time monitors the distance between the vehicle and obstacles ahead, and triggers acousto-optic graded alarms of different frequencies combined with the safe distance threshold preset by the user through keys; the OLED display synchronously presents temperature values, real-time distance and threshold parameters to achieve data visualization. Test results show that the system has small ranging error, fast response and accurate alarm logic. With low hardware cost and convenient deployment, it can effectively assist drivers in maintaining a safe distance, reduce the risk of traffic accidents, and has good practical value and promotion prospect.

Keywords: STM32 Single-Chip Microcomputer, Ultrasonic Ranging, Vehicle Distance Monitoring, Temperature Compensation.

1. Introduction

At present, the number of motor vehicles in China continues to rise, and the road traffic safety situation is becoming increasingly severe. Rear-end collisions and other vehicle accidents occur frequently, among which accidents caused by drivers' failure to accurately maintain a safe following distance account for a consistently high proportion. In scenarios such as high-speed driving, adverse weather conditions including rain, snow and fog, or night driving, drivers' visual judgment is easily disturbed, making it difficult to perceive changes in vehicle distance accurately and in real time, and the delayed reaction further amplifies the accident risk. Traditional vehicle distance monitoring relies on the driver's subjective judgment and lacks scientific and effective objective monitoring and early warning means. Although the radar- and camera-based distance monitoring systems equipped on existing high-end vehicles offer excellent performance, they are costly and technically complex, making them difficult to popularize in low- and mid-end vehicles and the existing vehicle fleet. Therefore, developing a low-cost, high-precision and easy-to-promote vehicle distance monitoring system has become an urgent need to address the pain points of traffic safety. Ultrasonic sensing technology features low cost, strong anti-interference capability and accurate short-range measurement, which fits the scenario requirements of vehicle distance monitoring. The STM32 single-chip microcomputer, characterized by efficient computation, rich interfaces and high cost performance, can accomplish core tasks such as sensor data processing and functional control. Meanwhile, ambient temperature affects the propagation speed of ultrasonic waves and causes ranging errors, so a temperature compensation mechanism is required to optimize the accuracy, which provides a clear technical direction for the system design [1-10].

This study improves the engineering application scheme of

ultrasonic ranging in vehicle distance monitoring. The temperature compensation technology is adopted to solve the accuracy problem caused by environmental interference, providing a technical reference for the design of similar sensing systems. A cooperative control architecture of the STM32 single-chip microcomputer and multiple modules (sensors, display and alarm) is constructed, which enriches the practical experience of embedded technology in the field of automotive assisted driving. The system achieves high-precision vehicle distance monitoring at low cost; with a simple hardware structure and convenient deployment, it can be widely adapted to various vehicles and lowers the threshold for popularizing traffic safety equipment. Through graded audible and visual alarms and real-time data display, the system provides drivers with intuitive warnings, extends the available reaction time, effectively reduces the occurrence of accidents and safeguards the safety of drivers and passengers. It also supports user-defined safe distance thresholds to adapt to different road conditions and driving habits, thereby improving practicality. In addition, the system lays a foundation for subsequent expansion of functions such as multi-sensor fusion and networked communication, and has important practical value for promoting the development of low-cost intelligent driving assistance technology.

Scholars at home and abroad have carried out extensive research on the application of ultrasonic ranging technology in vehicle distance monitoring and related fields, yielding rich results. Abroad, Chang S, in Principles and Applications of Ultrasonic Waves Based on Single-chip Microcontroller, conducted an in-depth study on the combined application of ultrasonic technology and single-chip microcomputers, verified the high efficiency of single-chip microcomputers in ultrasonic signal processing, and provided core technical support for embedded vehicle distance monitoring systems. Sun X and Xinyu S, in Design of ACC Adaptive Cruise System Based on Ultrasonic Ranging and Internet of Vehicles,

integrated ultrasonic ranging with Internet of Vehicles technology to design an adaptive cruise control system, realizing dynamic monitoring and adjustment of vehicle distance and improving the intelligence level of the system. Ying C et al., in Ultrasonic Range Finder for Vehicle Collision Avoidance System, designed an ultrasonic range finder for vehicle collision avoidance scenarios and improved the ranging stability in complex environments by optimizing the sensing algorithm [8-13].

Domestic research focuses more on engineering applications and accuracy optimization. Zhang Yunqiang et al., in Design of Ultrasonic Ranging and OLED Display System Based on STM32 Single-Chip Microcontroller, constructed an integrated system of an STM32 single-chip microcomputer and an OLED display, realizing real-time visualization of ranging data. Tao Feifan, in Design of Ultrasonic Ranging System Based on Temperature and Humidity Compensation, focused on solving the influence of ambient temperature and humidity on ranging accuracy and controlled the error within a reasonable range through a compensation algorithm. Jiang Zhiwei et al., in Design of Combined Laser and Ultrasonic Ranging Based on STM32, adopted a multi-sensor fusion scheme, further improving the anti-interference capability and measurement range of the ranging system. In addition, scholars such as Guo Chengmao, Yan Yuchan and Li Xiuquan designed STM32-based ultrasonic ranging systems for specific scenarios such as forklift alarms and vehicle assisted driving, verifying the adaptability of this technology in different traffic scenarios [11-16].

Overall, the basic integration of ultrasonic and embedded technologies has been achieved at home and abroad, but existing research still has room for improvement in terms of low-cost popularization and adaptability to complex road conditions. Some high-end schemes are costly, while the accuracy and stability of low-cost systems need to be further optimized, which provides the improvement direction for this study. Finally, system testing and verification are carried out. A hardware test platform is built, and soldering and assembly, program burning and device connection are completed. Comprehensive tests are conducted on parameter setting, ranging accuracy, temperature compensation effect and the graded alarm function to ensure the stable and reliable operation of the system.

2. Hardware System Design

The system adopts a modular architecture design of "control core + functional modules". With the STM32F103C8T6 single-chip microcomputer as the control center, it integrates multiple functional modules to realize the whole-process functions of vehicle distance monitoring, data processing, interactive control and early warning. Each module performs its own duties and works cooperatively to ensure the stable and efficient operation of the system.

The control core is the minimum system of the STM32F103C8T6 single-chip microcomputer, which includes basic units such as the power supply interface, reset circuit and crystal oscillator circuit. It is responsible for receiving input signals from each functional module, performing data computation and logic judgment, and sending control instructions to the output modules; it is the data processing and control core of the system.

At the functional module level, the temperature detection module adopts the DS18B20 sensor to collect ambient

temperature data in real time and transmit them to the main control unit, providing the basis for temperature compensation of ultrasonic ranging. The ultrasonic ranging module transmits and receives ultrasonic signals through the HC-SR04 sensor to obtain real-time distance data between the vehicle and obstacles ahead. The independent key module provides three function keys, allowing the user to switch the display interface and adjust the minimum safe distance. The OLED display module uses a 0.96-inch screen to present the temperature value, the current distance value and the preset minimum distance in real time, realizing data visualization. The audible and visual alarm module consists of an LED and a buzzer, and executes graded alarms according to the instructions of the main control unit. The power supply module provides stable power through a DC005 DC power socket to ensure the normal operation of all modules.

All modules are electrically connected to the minimum system of the single-chip microcomputer through pins, forming a closed-loop architecture of "data acquisition - processing - output - feedback", which ensures timely signal transmission and accurate control logic. The STM32F103C8T6 single-chip microcomputer is the core control unit of this system. It belongs to the STM32F1 series of STMicroelectronics and adopts the ARM Cortex-M3 core. Featuring high performance, low power consumption and high cost performance, it fully meets the control requirements of the vehicle distance monitoring system. The maximum main frequency of this microcomputer reaches 72 MHz, and it provides 64 KB of flash memory and 20 KB of static random access memory (SRAM). The sufficient storage resources can meet the computational requirements of system program storage, data caching and coordinated control of multiple modules.

In terms of hardware interfaces, the STM32F103C8T6 provides abundant I/O pins and supports multiple communication protocols such as GPIO, UART, SPI and I2C, which can flexibly realize circuit connection and data interaction with the HC-SR04 ultrasonic sensor, DS18B20 temperature sensor, OLED display module, audible and visual alarm module and independent key module. Its built-in peripherals such as timers and ADC converters provide hardware support for data acquisition timing and signal processing, improving the accuracy and response speed of data acquisition.

The microcomputer adopts the LQFP48 package, which is compact in size and convenient for layout and soldering on the system circuit board, adapting to the installation requirements of vehicle-mounted scenarios. Meanwhile, its wide operating voltage range and strong anti-interference capability enable it to withstand the complex electromagnetic interference and voltage fluctuations of the vehicle-mounted environment, ensuring stable operation of the system. The physical device is shown in Fig. 1.



Figure 1. Physical picture of the STM32F103C8T6 microcontroller

The minimum system of the single-chip microcomputer is the foundation for the stable operation of the STM32F103C8T6. It consists of the power supply circuit, crystal oscillator circuit, reset circuit and the core microcomputer. All parts work cooperatively to provide stable power supply, clock and reset functions for the system, ensuring the normal operation of the main control unit. The power supply circuit adopts a DC005 DC power socket as the power supply interface. After the external DC power is connected, the input voltage is converted into a stable 3.3 V voltage through a voltage regulator circuit to provide working power for the microcomputer and peripheral modules. Filter capacitors are designed to suppress voltage fluctuation and improve power supply stability. The crystal oscillator circuit includes a main crystal oscillator and a backup crystal oscillator: the main crystal oscillator adopts an 8 MHz passive crystal, which forms a high-frequency oscillation circuit together with 20 pF capacitors to provide the clock signal for the 72 MHz main frequency of the microcomputer; the backup crystal oscillator uses a 32.768 kHz crystal for clock timing in low-power scenarios, ensuring the timing accuracy of the system. The reset circuit adopts a key-reset design, which controls the level change of the reset pin through an external key to realize automatic power-on reset and manual reset functions, facilitating program debugging and system fault recovery. The module circuit design strictly follows the pin definitions and electrical characteristics of the STM32F103C8T6, accurately connecting the power supply, crystal oscillator, reset and other circuits to the corresponding pins of the microcomputer to form a complete minimum system loop. The circuit layout fully considers electromagnetic compatibility to reduce signal interference and ensure stable signal transmission of each part of the circuit.

The temperature detection module of this system adopts the DS18B20 digital temperature sensor. The sensor adopts a single-bus interface design with a simple hardware structure; only one I/O line is needed to communicate with the microcomputer, and no additional analog signal conversion circuit is required, which simplifies the system wiring. Its measuring temperature range is -55°C to $+125^{\circ}\text{C}$, and the measurement accuracy can reach $\pm 0.5^{\circ}\text{C}$. It can accurately collect the vehicle-mounted ambient temperature and provide reliable temperature compensation data for ultrasonic ranging. The sensor features low power consumption and strong anti-interference capability, adapting to the use requirements of the complex vehicle-mounted environment. The temperature detection module is shown in Fig. 2.



Figure 2. Physical picture of the DS18B20 temperature sensor

In terms of circuit design, the VCC pin of the DS18B20 is connected to the 3.3 V power supply, the GND pin is grounded, and the I/O pin is connected to the PB14 pin of the STM32F103C8T6 through a 10 K pull-up resistor, forming a complete data transmission loop and ensuring stable transmission of temperature signals. The wiring schematic diagram is shown in Fig. 3.

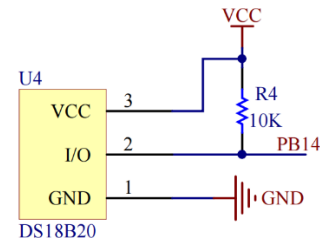


Figure 3. Wiring schematic diagram of the temperature detection module

The ultrasonic ranging module of this system adopts the HC-SR04 sensor, which is a low-cost, high-precision short-range ranging device. Its core consists of a transmitting end, a receiving end and a control circuit, featuring a wide ranging range, fast response and strong anti-interference capability. Its ranging range is 2 cm to 400 cm, and the measurement accuracy can reach ± 0.3 cm, which can meet the requirements of short-range vehicle distance monitoring in vehicle-mounted scenarios. When working, the sensor transmits a 40 kHz ultrasonic signal, which is reflected by the obstacle and then received by the receiving end; the distance is calculated according to the propagation time of the signal. No complex signal processing is required, which adapts to the real-time monitoring requirements of the system. The physical device is shown in Fig. 4.



Figure 4. Physical picture of the HC-SR04 ultrasonic ranging sensor

In terms of circuit design, the VCC pin of the HC-SR04 is connected to the 5 V power supply to ensure the normal operation of the sensor; the GND pin is grounded to achieve common grounding of the circuit; the TRIG pin (trigger end) is connected to the PB12 pin of the STM32F103C8T6, and the microcomputer sends a trigger signal to control the ultrasonic emission; the ECHO pin (receiving end) is connected to the PB13 pin to feed the reflected signal back to the microcomputer for distance calculation. The wiring of each pin is simple and standardized, ensuring stable signal transmission and guaranteeing ranging accuracy. The wiring schematic diagram is shown in Fig. 5.

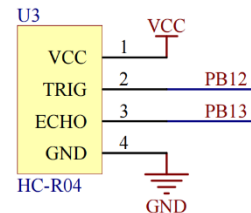


Figure 5. Wiring schematic diagram of the ultrasonic ranging module

This system selects a 0.96-inch OLED display as the display module. The display adopts the I2C communication protocol and features self-luminescence, low power consumption, fast response and high contrast. It can clearly display data without a backlight, adapting to the low-power requirements of vehicle-mounted scenarios. Its display resolution is 128×64 , and it can simultaneously present

multiple sets of data such as the temperature value, real-time distance value and preset minimum distance. The interface is intuitive and easy to read, and the display is compact and easy to install without occupying too much vehicle-mounted space. The physical device is shown in Fig. 6.

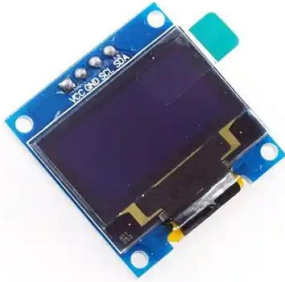


Figure 6. Physical picture of the OLED display

In terms of circuit design, the VCC pin of the OLED display is connected to the 3.3 V power supply, the GND pin is grounded, the SCL pin is connected to the PB6 pin of the STM32F103C8T6, and the SDA pin is connected to the PB5 pin. Data interaction with the microcomputer is realized through the I2C bus, with stable transmission and simple wiring. The wiring schematic diagram is shown in Fig. 7.

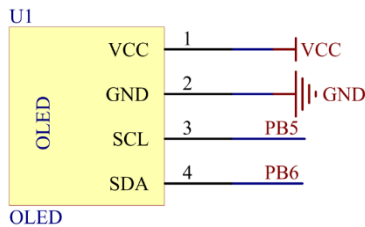


Figure 7. Wiring schematic diagram of the OLED display module

The audible and visual alarm module of this system consists of an LED and a buzzer, and its core function is to issue graded warnings according to the vehicle distance status. The LED provides intuitive visual prompts, while the buzzer emits audio alarms; the two work cooperatively to ensure that the driver perceives risks quickly. The module has a simple hardware structure, low power consumption and rapid response, adapting to the real-time warning requirements of vehicle-mounted scenarios. It can switch the alarm frequency in different distance intervals to realize gradient warning. The physical devices are shown in Fig. 8.



Figure 8. Physical pictures of the LED and the buzzer

The module is driven by a transistor. The VCC pin is connected to the 3.3 V power supply, the GND pin is grounded, and the control end is connected to the corresponding I/O pin of the STM32F103C8T6. The microcomputer outputs high and low levels to control the start/stop of the module and the alarm frequency. A current-limiting resistor is connected in series in the circuit to protect the components, ensuring stable operation of the module and accurate signal transmission. The wiring schematic diagram is shown in Fig. 9.

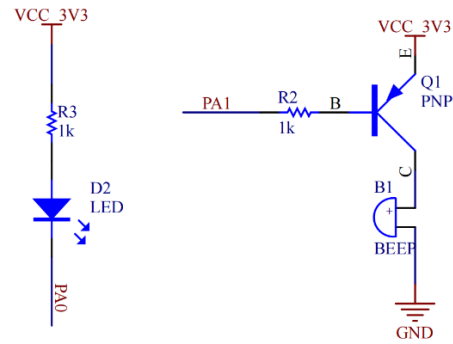


Figure 9. Wiring schematic diagram of the audible and visual alarm module

The independent key module of this system adopts three tactile keys, which are defined as the mode switching key (K1), the value increasing key (K2) and the value decreasing key (K3), respectively. Tactile keys are characterized by sensitive operation, simple structure and low cost. They conduct when pressed and disconnect when released, enabling accurate human-computer interaction and adapting to the user's need to customize the minimum safe distance. The keys are compact and easy to install, and can be flexibly arranged on the system panel for convenient operation by the driver. The physical devices are shown in Fig. 10.



Figure 10. Physical picture of the independent keys

One end of each of the three keys is connected to the PB7, PB8 and PB9 pins of the STM32F103C8T6, respectively, and the other ends are commonly grounded. The microcomputer identifies key operations by detecting the level changes of the pins. The circuit requires no additional driving components, has simple wiring, and can respond to key instructions quickly, ensuring efficient and convenient parameter setting. The wiring schematic diagram is shown in Fig. 11.

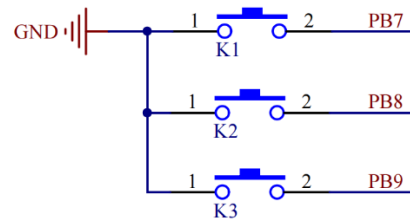


Figure 11. Wiring schematic diagram of the independent key module

3. System Software Design and Test

The programming environment used in this design is Keil5. Compared with other software programming environments, Keil5 is more lightweight and faster, with simpler operation, and is deeply favored by embedded software developers. Keil5 supports a variety of chips, including 51 single-chip microcomputers, STM32, HC32, NXP, etc. The generated HEX files can be directly burned into the microcomputer through a programmer, which is very convenient. In addition, Keil5 provides three compilation modes: single-file

compilation, partial compilation and full compilation, giving developers more choices; the compilation results are displayed at the bottom of the interface for developers to locate errors. In the main program, each module is initialized first, and then the program enters the while main loop. In the main loop, the program first enters the first function, the key function, which detects whether a key is pressed through key scanning, switches the mode through the keys, and sets the minimum distance. Then it enters the second function, the monitoring function, which detects the current temperature value through the temperature detection module and obtains the distance value through the ultrasonic module. Next, it enters the third function, the display function, which displays different interfaces according to different display mode flags: Interface 0 displays the monitored temperature value, distance value and minimum distance; Interface 1 displays the setting of the minimum distance. Finally, it enters the fourth function, the processing function: if the distance is less than half of the minimum value, the audible and visual alarm frequency is 100 ms; otherwise, if the distance is less than the minimum value, the alarm frequency is 300 ms; if the distance is greater than the minimum value, the audible and visual alarm is turned off. When a value changes, the measured values are sent.

The test environment setup is carried out around three core links: hardware, software and device connection, ensuring that all modules work cooperatively and providing a stable foundation for system function verification. The soldering and assembly of all components were completed according to the system schematic diagram. First, the STM32F103C8T6 microcomputer was soldered onto the core circuit board, and the DC005 power socket, reset key and crystal oscillator circuit were connected in sequence to form the minimum system. Subsequently, the corresponding interfaces of the HC-SR04 ultrasonic sensor, DS18B20 temperature sensor, 0.96-inch OLED display, audible and visual alarm module and independent key module were soldered respectively, ensuring accurate pin connection without cold solder joints or short circuits. After assembly, a hardware power-on pre-check was carried out to confirm that the power supply of each module was normal and there was no abnormal heating. The physical picture of the system hardware is shown in Fig. 12.

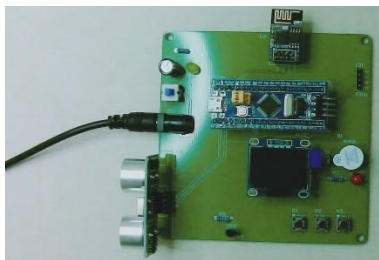


Figure 12. Physical picture of the system hardware

The Keil5 development environment was set up, and the STM32F1 series chip support package and related driver libraries were installed. The system program code, including the main program, drivers of each module and logic control code, was imported. Errors were eliminated through syntax checking and full compilation, and a HEX-format burning file was generated. The USB-TTL programmer was connected to the download port of the microcomputer, the burning software parameters were configured, the generated HEX file was selected, and the program burning was completed. At the same time, normal serial communication was ensured, laying a foundation for subsequent data debugging. The DC power adapter was connected to the DC005 socket to provide stable

power supply for the system. The microcomputer was connected to the computer through a serial cable to monitor the program running status and data output. The wiring between each functional module and the microcomputer was checked for firmness, ensuring that the ultrasonic sensor and temperature sensor were installed without occlusion, and that the keys and display were arranged for convenient operation and observation. Finally, a complete test hardware platform was formed to ensure the smooth progress of subsequent functional tests. After the power button was pressed, the system was powered on and started running. After initialization, the OLED display showed the current ambient temperature, distance and minimum distance.

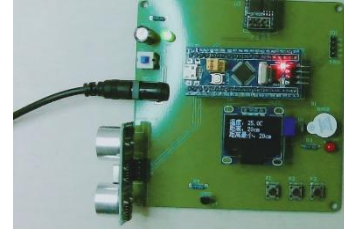


Figure 13. Initial screen of the system

After power-on initialization, the system enters the main monitoring interface by default, and the OLED screen displays the real-time temperature, current distance and the initial minimum distance (20 cm). During the test, pressing the K1 key switches the system to the parameter setting interface, where the screen displays "Set Minimum Distance" and the current threshold, and the value blinks to indicate that it is editable. Pressing the K2 key increases the minimum distance in steps of 1 cm, while pressing the K3 key decreases the value in steps of 1 cm, and the range can be flexibly adapted to different road conditions. After repeated key operations, it was verified that the value adjustment responded sensitively without lag, and the interface switching was smooth. After the parameter setting was completed, pressing K1 again returned to the monitoring interface, and the new threshold was saved and took effect. The test screen is shown in Fig. 14.

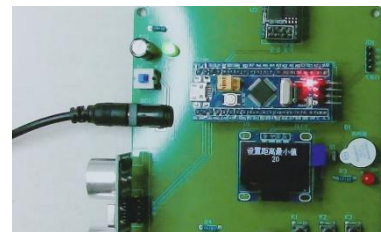


Figure 14. Parameter setting interface

A graded test was carried out based on the set minimum distance (20 cm): when the obstacle was placed 15 cm from the sensor (i.e., within the interval of 1/2 to 1 times the minimum value), the system collected distance data in real time and displayed them on the OLED screen, and at the same time triggered the audible and visual alarm with a stable frequency of 300 ms per cycle, providing a moderate warning intensity. When the obstacle was moved to 7 cm (less than 1/2 of the minimum value), the ranging data were updated in real time, and the alarm frequency increased to 100 ms per cycle, strengthening the risk warning through high-frequency alerts. When the obstacle was beyond 20 cm, the alarm function was turned off, and the on-screen data continued to refresh stably. The tests verified that the ultrasonic ranging features high accuracy and rapid response, and that the graded alarm logic

is accurate, meeting the design requirements. The test screens are shown in Fig. 15 and Fig. 16.

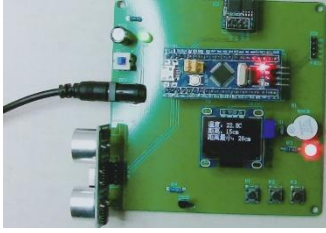


Figure 15. Ultrasonic ranging function test 1

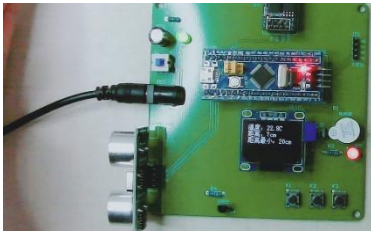


Figure 16. Ultrasonic ranging function test 2

4. Conclusion

This study successfully designed and implemented an ultrasonic-based vehicle distance monitoring system. With the STM32F103C8T6 single-chip microcomputer as the core, a complete architecture of "sensor acquisition - main control processing - interactive display - graded early warning" was constructed. The system integrates hardware modules such as the HC-SR04 ultrasonic sensor and the DS18B20 temperature sensor, and corrects environmental interference through a temperature compensation algorithm, improving the ranging accuracy. Independent keys are designed to realize user-defined safe distance thresholds, and an OLED display is used to present key data in real time. The audible and visual alarm module triggers graded warnings according to the vehicle distance, meeting diversified use requirements. Tests have verified that the system features accurate ranging and rapid response, can accurately switch the alarm frequency in different distance intervals, and offers convenient parameter setting and stable, reliable operation. The overall scheme has the advantages of low cost, high cost performance and easy deployment. It effectively solves the pain points that traditional vehicle distance monitoring relies on subjective judgment and high-end systems are difficult to popularize, provides a practical technical solution for improving driving safety, and fully achieves the preset research objectives.

References

- [1] Chang, S. (2025). Principles and applications of ultrasonic waves based on single-chip microcontroller. *Education Reform and Development*, 7(6), 236–243.
- [2] Zhang, Y. Q., Li, Z. C., Zeng, F. G., et al. (2025). Design of ultrasonic ranging and OLED display system based on STM32 single-chip microcontroller. *Electronic Technology*, 54(01), 1–3. (in Chinese)
- [3] Tao, F. F. (2024). Design of ultrasonic ranging system based on temperature and humidity compensation. *Electronics Production*, 32(16), 83–85+79. (in Chinese)
- [4] Xu, H., & He, Y. G. (2024). Design of a car-following driving system based on STM32. *Modern Information Technology*, 8(10), 194–198. (in Chinese)
- [5] Wang, B. J. (2024). Design of an ultrasonic ranging system based on STM32 microcontroller and LabVIEW. *Mechanical and Electrical Information*, (04), 32–35+39. (in Chinese)
- [6] Zhong, J. H., & Tao, Y. T. (2023). Ultrasonic rangefinder based on STM32. *Internet of Things Technologies*, 13(09), 32–35. (in Chinese)
- [7] Guo, C. M., & Yang, Z. Z. (2022). Design of a forklift alarm system based on ultrasonic ranging. *Electronic Test*, 36(21), 26–28. (in Chinese)
- [8] Yan, Y. C. (2022). Ultrasonic ranging system based on STM32 single-chip microcontroller. *Internal Combustion Engine & Parts*, (17), 76–78. (in Chinese)
- [9] Xing, D. Y. (2022). Design and implementation of an ultrasonic radar early warning system. *Scientific and Technological Innovation*, (10), 185–188. (in Chinese)
- [10] Jiang, Z. W., Liu, P. P., Yang, Y., et al. (2021). Design of combined laser and ultrasonic ranging based on STM32. *Computer Technology and Development*, 31(07), 171–175. (in Chinese)
- [11] Sun, X., & Xinyu, S. (2020). Design of ACC adaptive cruise system based on ultrasonic ranging and internet of vehicles. *Journal of Physics: Conference Series*, 1650(2), 022029.
- [12] Zhang, A. D. (2020). Design and implementation of an ultrasonic ranging system based on STM32 single-chip microcontroller. *Journal of Tongling Vocational & Technical College*, 19(03), 51–53+58. (in Chinese)
- [13] Ji, S. F., Lei, R. Y., & Wang, Q. (2020). Design of an ultrasonic ranging system based on STM32 and LabVIEW. *Journal of Hunan Post and Telecommunication College*, 19(01), 29–31. (in Chinese)
- [14] Liu, J. W. (2019). Design of an ultrasonic ranging intelligent robot control system based on STM32. *Electronic Components and Information Technology*, 3(10), 45–48. (in Chinese)
- [15] Zhang, B. B. (2019). Design of a multi-channel ultrasonic ranging system based on STM32. *Electronics Production*, (19), 84–85+92. (in Chinese)
- [16] Li, X. Q., Liu, J., Hei, C., et al. (2018). Design of an ultrasonic precise ranging system based on STM32. *Journal of Yangtze University (Natural Science Edition)*, 15(17), 29–32+5. (in Chinese)