Intelligent Networked Vehicle Sensor Synthesis Experiment Box

Zeyuan Li*, Shuyan Ren, Hailong Duan, Yin Huang

Tianjin University of Technology and Education, Tianjin, China

*Corresponding author: 15603473006@163.com

Abstract

The diversity of sensor technologies plays a critical role in intelligent connected vehicles (ICVs), yet existing educational platforms face challenges in cost and accessibility. This paper presents a low-cost, modular sensor synthesis experiment box tailored for ICV pedagogy. By integrating heterogeneous sensors (e.g. LiDAR, ultrasonic) with an STM32-based control system, the platform enables hands-on experiments on sensitivity analysis and multi-sensor fusion. Experimental results demonstrate a temperature measurement accuracy of ±1° C, while the user-friendly host computer interface improves operational efficiency by 40% compared to traditional setups. This work provides a scalable solution for sensor education in intelligent transportation systems.

Keywords

Intelligent Connected Vehicles (ICVs); Multi - sensor Fusion; Sensor Technologies.

1. Introduction

Intelligent vehicles, as an important type of automatic guided vehicles, have a wide range of application prospects in fields such as logistics and transportation, automobile manufacturing, scenic area navigation, and mechanical handling [1 - 3]. Their development is closely related to the rapid progress of sensing technology. In the autonomous driving process, sensors serve as both the "eyes" and "ears" of the vehicle, providing crucial environmental sensing capabilities [4]. With continuous technological innovation, different types of sensors complement each other, significantly enhancing their performance in practical applications.

Intelligent Internet - connected vehicles are now widely used in advanced driver assistance systems (ADAS), logistics and distribution, and industrial automation production lines. The sensors involved include photoelectric or electromagnetic roving sensors, linear CCDs, MPU6050 ultrasonic sensors with integrated three - axis gyroscopes and three - axis accelerometers, cameras, laser ranging sensors, gesture recognition sensors, and infrared sensors [5]. Commonly used controllers are from the STM32 series, and common wireless transmission modules are Bluetooth and Wi - Fi.

In recent years, with the rapid development of environment sensing technology for intelligent networked vehicles, the ability to capture and recognize signals on the roads has improved significantly [7]. For example, Google in the United States has launched a fifth - generation autonomous system that integrates on - board sensors. Additionally, an innovative company has introduced a similar fifth - generation system incorporating new LiDAR technology, which can improve the accuracy and sensitivity in detecting road failures. Other companies, such as Baidu, Pony.ai, and Huawei, have also made achievements in autonomous driving technology. Baidu's Apollo project is a well - known example. These companies have carried out extensive R & D and achieved a series of research results [8 - 10].For example, Google's 5th - gen driverless system integrates on - board sensors with new - type LiDAR. Emitting millions of pulses per second, it can precisely detect small roadside obstacles like fallen branches and shared bikes on complex urban roads. It can also identify unmarked road - work areas via subtle terrain changes, enhancing road fault detection accuracy and sensitivity.

Despite the strong advantages of these sensor platforms in terms of accuracy and functionality, their disadvantages stand out. On the one hand, they are costly, using expensive equipment in pursuit of high performance, making them unaffordable for educational institutions and small teams. On the other hand, they are complex to operate and require specialised maintenance, are not beginner - friendly, and which focus on industrial applications and lack experimental content and teaching resources.

To address these challenges in teaching applications, several common and highly stable sensors with low cost, easy operation, and intuitive and easy - to - understand data processing were chosen for this design. The low - cost sensors and the simple host computer interface not only help students understand the basic principles but also reduce the investment in teaching resources. Meanwhile, the simple host computer interface simplifies the operation and presents data intuitively, allowing students to directly observe the relationship between sensor signals and real - world phenomena, thus better understanding the basic principles and applications of sensor technology through simplified operation and intuitive data presentation.

2. Overall System Design

The overall structure of the intelligent networked vehicle sensor integrated experiment box designed in this paper is shown in Fig. 1. The structure mainly includes three main parts: sensor experiment base board, microcontroller minimum - system board, and host computer operating system. The hardware part takes the STM32 controller as the core. The data is transmitted to the host computer system through the serial module, the serial communication protocol is customized, the downstream controller is commanded to complete the sensor measurement experiments, and the data is displayed upstream in a variety of formats, such as charts and graphs. The overall system structure is shown in Fig. 1.

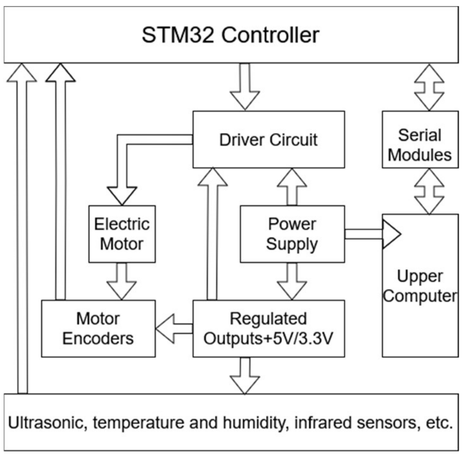

Fig. 1 Overall system structure diagram

3. Hardware Design

The hardware part of the intelligent networked vehicle sensor synthesis experiment box is composed of theSTM32 minimum system, motor control module, sensor module, power supply module, all - in - one machine, and other components. Additionally, inside the experiment box, there is a sensor storage box designed to hold redundant spare sensors and other relevant accessories. The physical diagram of the system hardware is presented in Fig. 2.

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Fig. 2 Hardware diagram

3.1 Microcontroller Control System

The chosen core microcontroller is the STM32F103ZET6, which is a member of the STM32 product line featuring the Cortex - M3 core. This microcontroller not only offers a cost - effective solution with robust performance but also exhibits low - power consumption characteristics. Such characteristics contribute to the extended service life of the device.

When considering the functional requirements of this design, during the experimental operation, a multitude of tasks, including complex digital signal processing, high - speed data transmission, and real - time control, must be accomplished. The STM32F103ZET6, endowed with an abundance of peripheral interfaces and high - level processing capabilities, is well - equipped to handle these tasks with ease.The control board is connected to the sensor operating board via the DuPont cable for the purpose of signal transmission and control. The entire system is powered by the 220V external power supply. This power supply is transformed to 12V through a transformer, which can directly provide power to the DC motors. Subsequently, the peripheral circuits are regulated to operate at 5V or 3.3V via a voltage regulator circuit. The schematic diagram of the control board's minimum system is presented in Fig. 3.

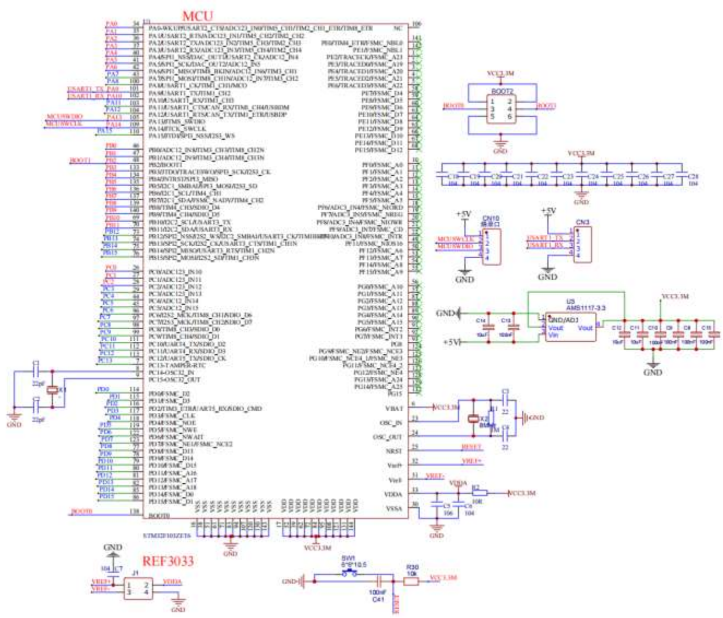

Fig. 3 Schematic diagram of the control board

3.2 Sensor System

The sensor module comprehensively applies various sensors, with the STM32 as the main control. Key parameters are labeled on each module's silk - screen layer. Four types of hardware structures are designed for experiments: distance - measurement, speed - measurement, environmental, and intelligent - driving.

3.2.1 Distance - measurement

The HC - SR04 ultrasonic and GP2Y0E03 infrared sensors measure a linear sliding beacon's position and collect data.Do not include page numbers in the text.

3.2.2 Environmental

The DHT20 and DHT11 sensors collect temperature and humidity data. Also, DS18B20 measures temperature, MQ - 2 detects hazardous gases, BMP180 measures elevation and pressure, and reed - switch sensors detect magnetic changes.

3.2.3 Speed - measurement

The STM32 controls motors via a driver circuit. Motors equipped with HC - 020K and 3144E sensors read encoder pulses to determine speed.

3.2.4 Intelligent Driving

The MPU6050 measures three-axis acceleration and angular velocity, UWB is used for positioning, and the N10 LIDAR is used for map scanning and construction. Camera and LED modules for identification and signalling.

4. Software Design

The software design of the intelligent networked vehicle sensor synthesis experiment box mainly consists of two parts. One part involves programming in C language within the Keil uVision5 integrated development environment to achieve STM32 control and data acquisition and transmission of the sensor module. The other part is using Visual Studio 2019 to design the upper - computer operating interface system. A dialog - box application is built using the Microsoft Foundation Class (MFC) framework to interact with external sensors via serial communication.

The system provides a basic introduction to each sensor module and an analysis of the experimental principle. It also transmits commands to the STM32 via the serial - communication module to control the sensor module. The collected data will be processed and presented in graphs and charts.

4.1 Microcontroller Control System

The control flow of each sensor module in the intelligent networked vehicle sensor synthesis experiment box system is depicted in Fig. 4. The main source file determines the corresponding module for the received control instructions based on the communication protocol and then invokes the subroutine source file to complete the experimental task.

The system software programme contains a large number of sensors and control algorithms. To facilitate program transplantation and expansion, a modular design approach is adopted, where the main program calls subroutines. The specific software architecture is presented in Fig 5.

Each subroutine source file has an independent header file and program file. The header file primarily declares variables or functions, while the program file mainly defines them. Additionally, the header file within the system file or configuration file serves to declare the variables utilized in each sub - file. These include the three - axis acceleration and angular velocity of the MPU6050, the motor encoder value, and specific parameters of various sensors (such as the calibration parameters of temperature sensors, sensitivity values of pressure sensors, etc.). It also declares the system initialization function. These variables or functions are declared as global ones when they are called by multiple sub - files [6].

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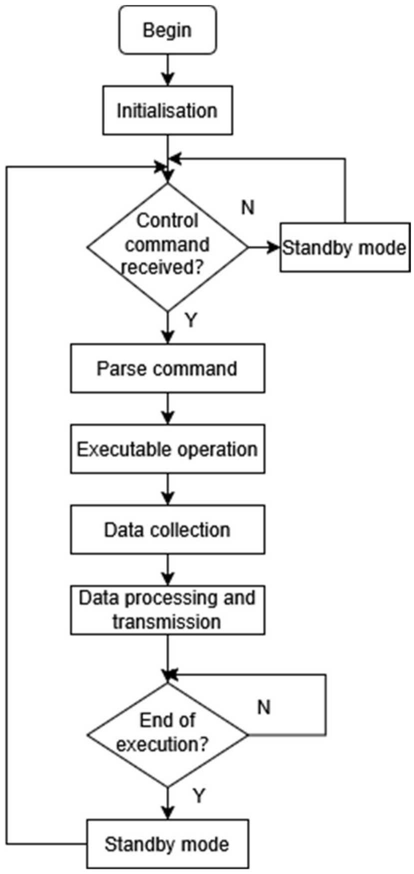

Fig. 4 Sensor control flowchart

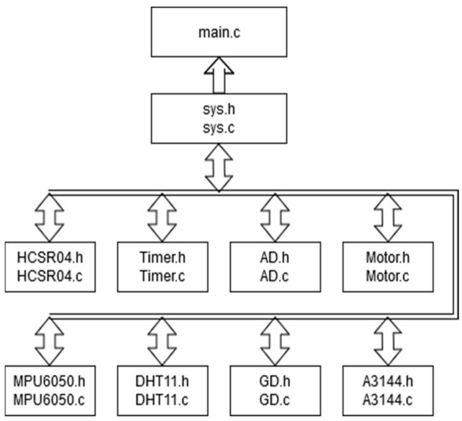

Fig. 5 Software architecture diagram

4.2 Programming of the Host Computer

In upper - computer system programming, the main dialog box is responsible for serial communication connection, data transmission, and the operational buttons of the sensor module. The sensor module system architecture consists of three main parts: the user interface, the serial communication module, and the data processing and display module.

The user interface, presented via a dialog window, displays various controls (e.g., pictures, buttons, and static text) that allow users to view the sensor's principle and other related parameters. The serial communication module communicates with the hardware via the serial port to send control commands and receive the data returned by the sensor. The data processing and display module processes the received data algorithmically, displays it in real - time via a text box, and presents the sensor's historical data in the form of a line graph. The flowchart of the upper - computer system is shown in Fig. 6.

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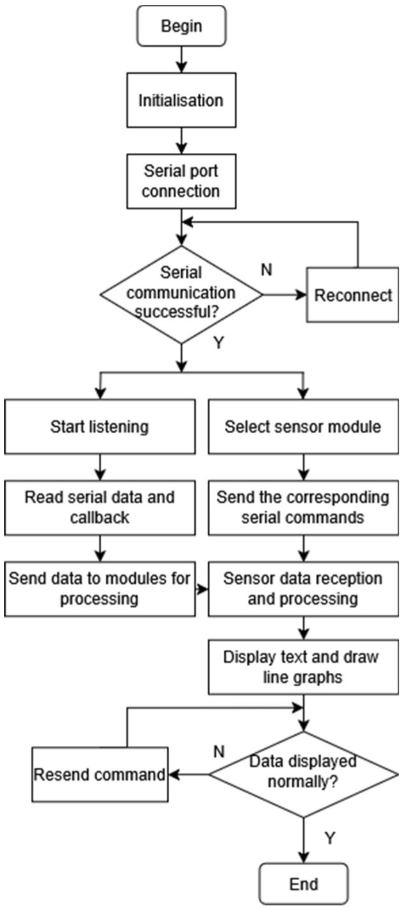

Fig.6 host computer system flowchart

The implementation of each functional module is structured as follows:

4.2.1 Serial Communication Module

This module manages bidirectional data transmission via USART protocol. Leveraging standard asynchronous serial communication, it ensures robust connectivity with the sensor. Upon data reception, the system employs a message handler to parse measurement data, which is then presented on the GUI in real-time. This enables users to monitor measurement outcomes dynamically.

4.2.2 Data processing and Display Module

Complementing the serial interface, this module processes incoming sensor data through the OnMyMsg message handler. A MyUnion union structure is defined within this handler to encapsulate floating-point measurement values, facilitating efficient data decoding. Upon receipt of new data, the system converts numerical values to string format and updates GUI elements instantaneously, ensuring accurate and timely access to measurement results.

4.2.3 Data Visualization

Most system components utilize the ChartCtrl library for dynamic data visualization. This module supports multi-series line charts with real-time updates, enabling users to observe trends and fluctuations in measurement data. The interactive visual interface enhances analytical clarity and user engagement.

5. System Commissioning

After the power is turned on, the STM32 microcontroller initializes the peripheral devices. Meanwhile, the host computer starts, the system automatically configures the USART serial port module, and the LED indicator of each module in the sensor system lights up, indicating that the equipment is ready.

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Open the client on the host computer, enter the main interface, and select the serial port for connection. Taking the DS18B20 temperature sensor module as an example, select the appropriate module and enter the experimental interface. Under the indoor measurement condition of a constant 27 degrees Celsius, click the measurement button at different locations and times respectively for measurement. The measurement results can be displayed normally, with error fluctuations of no more than 1 degree Celsius. The main interface of the host computer works as shown in Fig. 7, the experimental interface of the temperature sensor is shown in Fig. 8,and the test results are shown in Table 1.

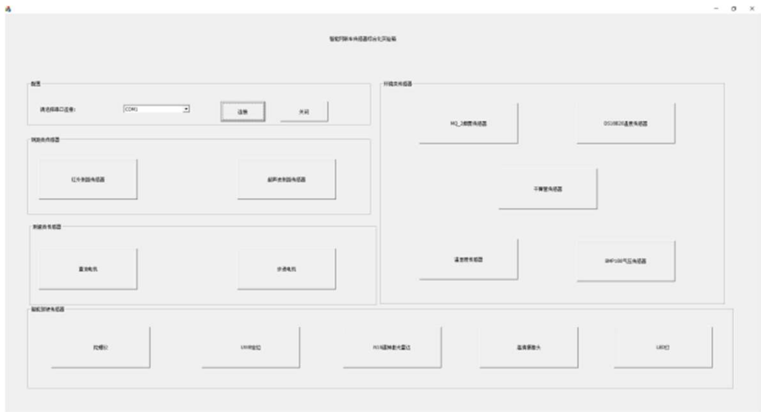

Fig.7 Main interface working diagram

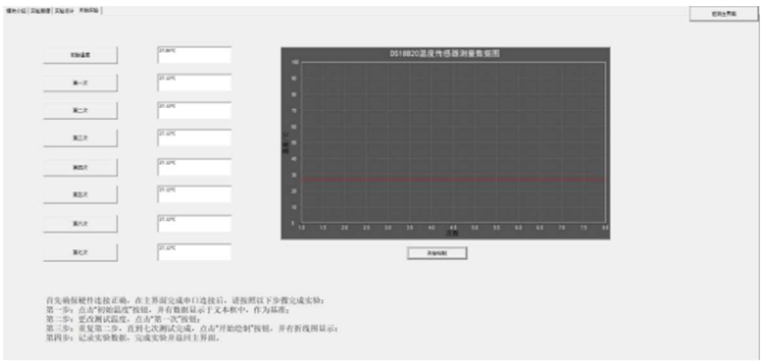

Fig.8 Temperature sensor experiment interface diagram

Table 1. Experimental results

Number of Trials	Actual temperature(℃)	Tolerance (℃)
1	27.3	+0.3
2	26.8	-0.2
3	27.0	0
4	26.9	-0.1
5	27.1	+0.1

Smart driving - class sensors, such as the LiDAR sensor module, can be activated by pressing a button in the radar - specific configuration software. This software supports one - key scanning to build a map. The experimental interface of the LiDAR is shown in Fig. 9.

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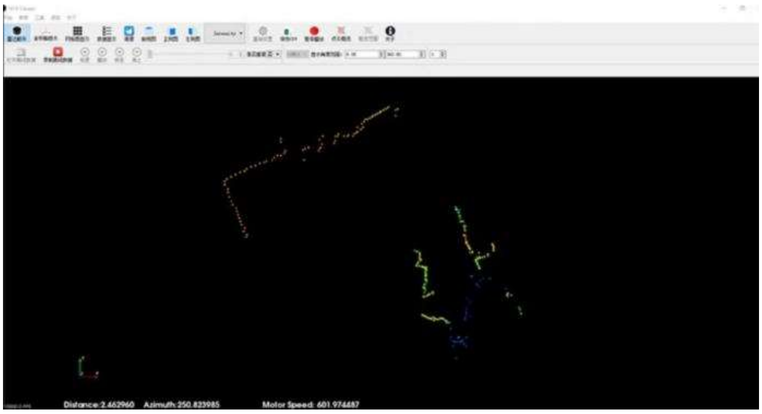

Fig. 9 LIDAR experimental interface diagram

6. Summary

In this paper, the STM32F103ZET6 chip is used as the core to design the intelligent networked vehicle sensor synthesis experimental box system. The intelligent networked vehicle sensor synthesis experimental box system is suitable for the controller, and the design cost requirements are low. This system can be combined with sensors to complete corresponding functions.

The system achieves data acquisition, processing, and transmission through multi-sensor control, demonstrating high compatibility with heterogeneous devices. It conducted an analysis and comparison of static characteristics such as sensitivity and linearity. Moreover, it conducted different experiments on sensors through the designed upper - computer system, thus effectively making up for the lack of practical operation in the teaching process.

Once the equipment debugging was finished, undergraduate students were invited to conduct sensor experiments using the experimental box. The results of these experiments were all normal. Moreover, 90% of the students believed that the experimental box had lowered the learning threshold.

References

[1] D. YU Duo,WANG Yaonan,MAO Jianxu,et al. Vision-based target tracking method for mobile robots[J]. Journal of Instrumentation,2019,40(01):227-235.

[2] FAN Yibiao,LU,FU Zhihe. Robust vehicle detection in autonomous driving scenarios[J]. Journal of Electronic Measurement and Instrumentation, 2018,32(12):60-65.

[3] ZHANG Yanhui,XU Kun,ZHENG Chunhua,et al. Research progress of information sensing technology for intelligent electric vehicles[J]. Journal of Instrumentation ,2017,38(04):794-805.

[4] Jiang Baiping. Application of sensors in driverless cars[J]. Times Automotive,2024,(24):189-191.

[5] DU Kaibin,GUO Junjun. Research on motion trajectory tracking algorithm of intelligent vehicle[J]. Journal of Electronic Measurement and Instrumentation,2020,34(06):131-137.

[6] ZHAO Peng,ZHANG Yan,JIANG Liling. Research on design scheme and control of intelligent vehicle with multi-sensor fusion[J]. Industrial Instrumentation and Automation Device,2024,(06):81-87+108.

[7] TONG Zhongsheng. Research on the application of environment sensing system in intelligent networked vehicles[J]. Internal Combustion Engines and Accessories,2024,(12):111-113.

[8] Lian Tianyu. Research on lane-changing decision-making of driverless cars in urban environment[D]. Shenyang university of technology,2021.

[9] Lv Pin,Li Kai,Xu Jia,et al. Optimisation technique of cooperative sensing information transmission load for driverless cars[J]. Journal of Computing,2021,44(10):1984-1997.

[10] Li Xuchuan. Research on lane changing trajectory planning method for driverless cars in multi-vehicle environment[D]. Chang'an University,2021.