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Design and Implementation of an Intelligent Ultrasonic System based on 51 Microcontroller

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ABSTRACT

With the rapid development of microelectronics and intelligent technology, microcontroller units (MCUs) are increasingly applied in various fields. This paper proposes the design and implementation of an intelligent ultrasonic system based on a 51 microcontroller, integrating ultrasonic sensors, an LCD display, and a 51 MCU to achieve real-time distance measurement, data display, and intelligent control functions. The system utilizes a CD4069 ultrasonic sensor to transmit and receive ultrasonic waves, measuring the distance between the sensor and an object by calculating the time difference between transmission and reception. The measured distance data is processed and displayed on an LCD screen in real-time. Furthermore, the system features intelligent control capabilities, automatically adjusting and controlling devices based on the measured data, thereby enhancing the system's level of intelligence. The intelligent ultrasonic system based on the 51 microcontroller offers advantages such as low cost, high precision, and strong versatility. It can be widely used in various fields, including intelligent robots, obstacle avoidance systems, and automatic parking systems. The design and implementation of this system not only demonstrate innovative applications of ultrasonic ranging technology but also provide valuable references for the extensive application of microcontroller units in intelligent technology fields.

KEYWORDS

51 Microcontroller; Intelligent Ultrasonic; Real-Time Distance Measurement; LCD Display; Intelligent Control.

1. INTRODUCTION

With the rapid development of microelectronics and intelligent technology, microcontroller units (MCUs) are increasingly applied in various fields. Among these applications, ultrasonic ranging technology shows broad prospects in fields such as intelligent robots, obstacle avoidance systems, and automatic parking systems[1]. However, traditional ultrasonic ranging systems face challenges such as high costs, low accuracy, and poor versatility, failing to meet the demands of intelligent applications. Therefore, designing a low-cost, high-accuracy, and versatile intelligent ultrasonic system has become a current research focus and challenge.

To address this issue, this paper proposes the design and implementation of an intelligent ultrasonic system based on a 51 microcontroller. The system integrates ultrasonic sensors, an LCD display, and the 51 MCU to achieve real-time distance measurement, data display, and intelligent control functions[2-3]. Specifically, the system employs a CD4069 ultrasonic sensor to transmit and receive ultrasonic waves, measuring the distance between the sensor and an object by calculating the time difference between transmission and reception. The measured distance data is processed and displayed on an LCD screen in real-time. Additionally, the system features intelligent control capabilities, allowing it to automatically adjust and control equipment based on the measurement data, thus enhancing its level of intelligence.

The intelligent ultrasonic system based on the 51 microcontroller offers advantages such as low cost, high accuracy, and strong versatility, making it suitable for various applications, including intelligent robots, obstacle avoidance systems, and automatic parking systems[4-5]. The design and implementation of this system not only demonstrate innovative applications of ultrasonic ranging technology but also provide valuable references for the widespread application of microcontrollers in intelligent technology fields.

2. HARDWARE DESIGN

The hardware design is the foundation of the entire intelligent ultrasonic system, determining its performance and stability[6]. The proposed intelligent ultrasonic system consists of the following main components: the 51 microcontroller, ultrasonic sensor, LCD display, power module, and control circuitry. Each part is designed to achieve the system's real-time distance measurement, data display, and intelligent control functions. The hardware physical diagram is shown in Figure 1 below.

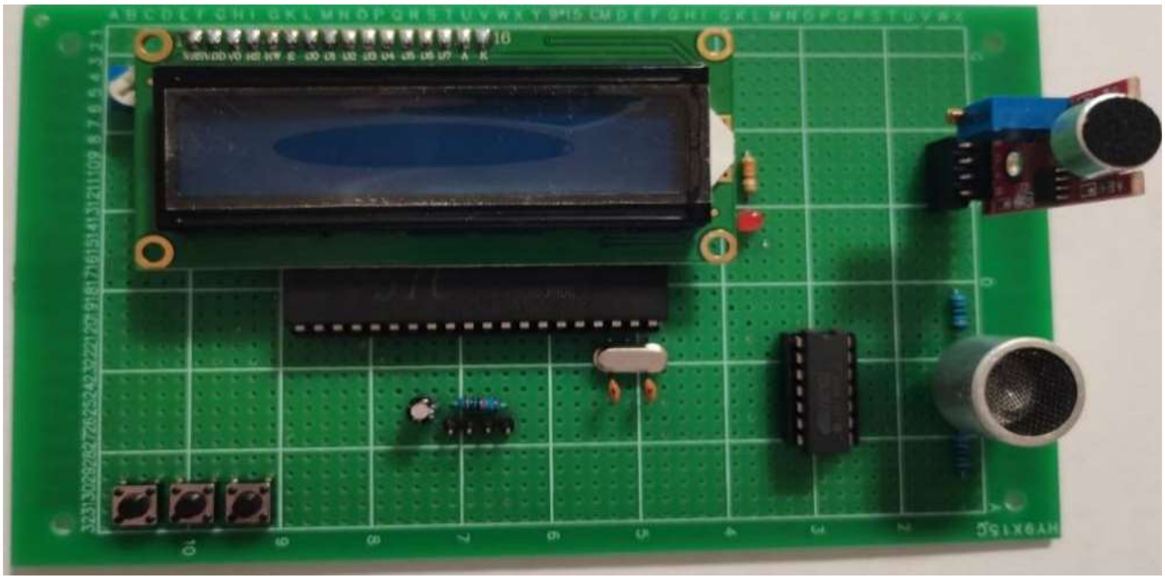

Figure 1. The hardware physical diagram

2.1. 51 Microcontroller

The 51 microcontroller serves as the core control unit of the entire system, responsible for coordinating and managing the collection and processing of sensor data, data storage and display, and the output of control signals[7]. This paper utilizes the STC89C52 microcontroller, which features high performance, low power consumption, and ease of programming, meeting the system's requirements for real-time performance and reliability.

2.2. Ultrasonic Sensor

The system employs the HC-SR04 ultrasonic sensor, known for its high measurement accuracy, fast response speed, and ease of use. This sensor measures the distance between the sensor and the object by emitting and receiving ultrasonic waves and calculating the time difference between emission and reception. To improve measurement accuracy, the system incorporates both hardware and software filtering and calibration.

2.3. LCD Display

An LCD1602 display is used to show the measured distance data in real-time. It connects to the 51 microcontroller via the I2C bus and features clear display, low power consumption, and easy programmability. The LCD display provides users with real-time information about the distance to objects in the environment, ensuring system visibility and usability.

2.4. Power Module

The power module supplies stable working voltage to the entire system[8]. The system requires a 5V DC power source and uses a voltage regulation circuit to ensure the proper operation of all components. High-efficiency voltage regulation chips are preferred to enhance system stability and energy efficiency.

2.5. Control Circuitry

The control circuitry executes the system's intelligent control functions, automatically adjusting and controlling equipment operation based on the measured distance data. This section includes relay modules, motor driver modules, etc., and different actuators can be added as needed to achieve diversified control. The system outputs control signals through the 51 microcontroller to drive the corresponding modules to execute operations.

2.6. Communication Module (Optional)

To achieve more advanced functions, such as remote monitoring and data transmission, the system can include an ESP8266 Wi-Fi module or other communication modules. This module transmits the sensor data over the internet to a remote server or smartphone application, realizing intelligent and networked control.

By designing and integrating the above components, the proposed intelligent ultrasonic system based on the 51 microcontroller can achieve low-cost, high-accuracy, and multifunctional real-time distance measurement and control, making it suitable for various intelligent application scenarios.

3. SOFTWARE DESIGN

The software design is crucial for ensuring the intelligent ultrasonic system's effective operation and performance. This section introduces the system's software architecture, including the main program, sensor data acquisition, data processing, display management, and intelligent control logic.

3.1. Overview of the Software Architecture

The software architecture involves various functional modules that work together to achieve real-time distance measurement, data display, and intelligent control. The primary components include the main control program, sensor handling module, data processing module, display module, and control logic module.

3.2. Main Control Program

The main control program initializes the system, manages the overall workflow, and coordinates the various modules. It begins with the initialization of the microcontroller, sensor modules, and peripherals:

```
#include <REGX51.H>
void main() {
    // Initialize system
    system_init();

    while (1) {
        // Acquire Sensor Data
        acquire_sensor_data();

        // Process Data
        process_data();

        // Update Display
        update_display();

        // Execute Control Logic
        execute_control_logic();
    }
}
```

3.3. Sensor Data Acquisition

The sensor handling module is responsible for triggering the ultrasonic sensor, measuring the echo time, and converting it into distance data. The HC-SR04 sensor is used to measure the distance:

```
void acquire_sensor_data() {
    trigger_ultrasonic_sensor();

    unsigned int echo_time = measure_echo_time();

    unsigned int distance = calculate_distance(echo_time);

    store_distance(distance);
}
```

}

3.4. Data Processing

The data processing module filters and calibrates the raw distance data to ensure accuracy and reliability. This module will also include any necessary error-checking algorithms:

```
void process_data() {
    unsigned int raw_distance = get_stored_distance();

    unsigned int filtered_distance = filter_data(raw_distance);

    calibrated_distance = calibrate_data(filtered_distance);
}
```

3.5. Display Management

The display module updates the LCD with the latest distance measurements. This module handles the communication with the LCD1602 display and formats the data for display:

```
void update_display() {
    clear_lcd();

    unsigned int display_distance = calibrated_distance;

    display_on_lcd(display_distance);
}
```

3.6. Intelligent Control Logic

The control logic module uses the processed distance data to make decisions and control connected devices (e.g., activating motors or triggering alarms). The system can dynamically adjust its operation based on real-time measurements:

```
void execute_control_logic() {
    unsigned int current_distance = calibrated_distance;

    if (current_distance < THRESHOLD) {
        activate_control_device();
    } else {
        deactivate_control_device();
    }
}
```

Flowchart of Software Operation

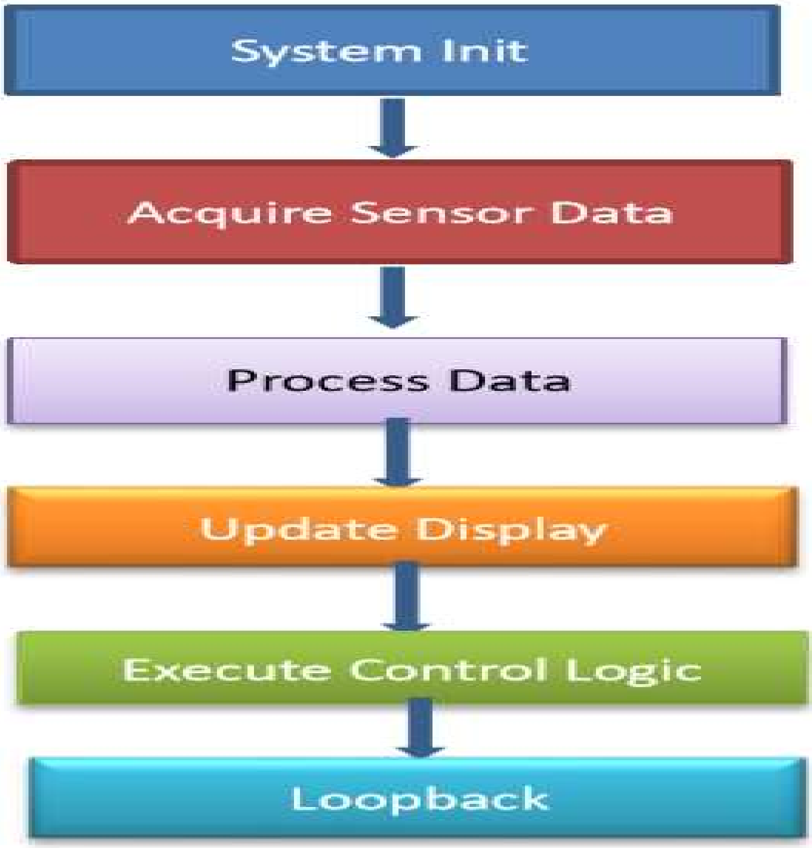

Figure 2. Flowchart of Software Operation

By following this detailed software design framework, the intelligent ultrasonic system based on the 51 microcontroller can effectively achieve real-time distance measurement, accurate data processing, clear data display, and intelligent control. This approach ensures that the system is both reliable and adaptable, providing a robust platform for various intelligent applications.

4. SYSTEM TESTING

System testing is critical to ensure the functionality, reliability, and performance of the intelligent ultrasonic system. This section outlines the testing procedures for verifying key features including mode selection, time setting, ultrasonic activation, and control logic.

4.1. Functional Testing

Functional testing verifies that the system performs as expected when different modes are selected and adjusted using buttons S1, S2, and S3.

4.1.1. Mode Selection and Adjustment

The system includes multiple modes controlled by S1, S2, and S3:

MOD0 (Ultrasonic Control Mode): Activated by sound detection or pressing S2. The CD4069 oscillator generates a 25kHz ultrasonic signal. It can also be manually triggered or scheduled.

MOD1 to MOD3 (Time Adjustment Modes):

MOD1: S2 increases hours, S3 decreases hours.

MOD2: S2 increases minutes, S3 decreases minutes.

MOD3: S2 increases seconds, S3 decreases seconds.

MOD4 to MOD6 (Start Time Adjustment): Set the start time for the CD4069 operation.

MOD7 (End Time Adjustment): Set the end time for the CD4069 operation.

Test Setup: Burn the code onto the circuit board.

Procedure:

Use S1 to switch between modes.

Adjust time settings using S2 and S3 in MOD1 to MOD3.

Set start and end times using MOD4 to MOD7.

Expected Results: The system should correctly switch modes and adjust times based on button inputs.

4.2. Time Period Setting and Ultrasonic Activation

Test the system’s response to time period settings:

Test Setup: Initialize the system and set working time periods using the LCD display.

Procedure:

Ensure the current time falls within the set period.

Verify that the ultrasonic emitter activates and the indicator LED lights up (shown in Figure 3).

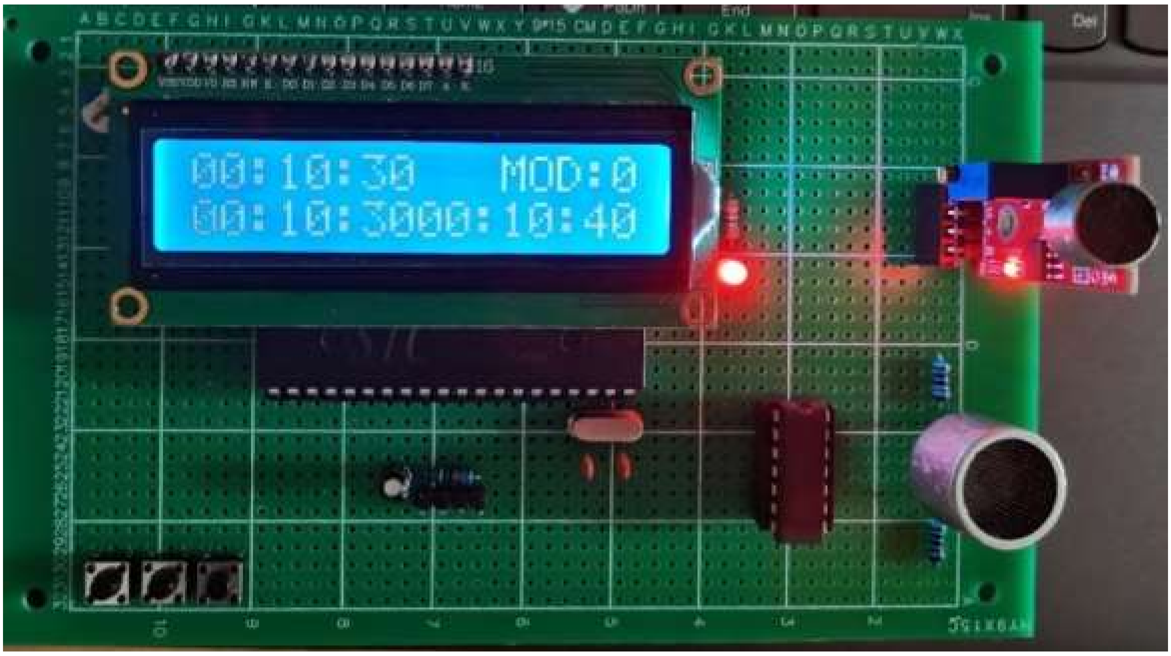

Figure 3. Setting time periods for activating ultrasonic waves

Expected Results: The ultrasonic emitter should activate and the indicator LED should light up when the current time is within the set period.

4.3. Sound Signal and Manual Trigger Testing

Test the system’s response to sound signals and manual triggers:

Test Setup: Initialize the system without a specific time period.

Procedure:

Detect a sound signal or press S2 to manually trigger the ultrasonic emitter.

Verify that the ultrasonic emitter activates and the indicator LED lights up (shown in Figure 4).

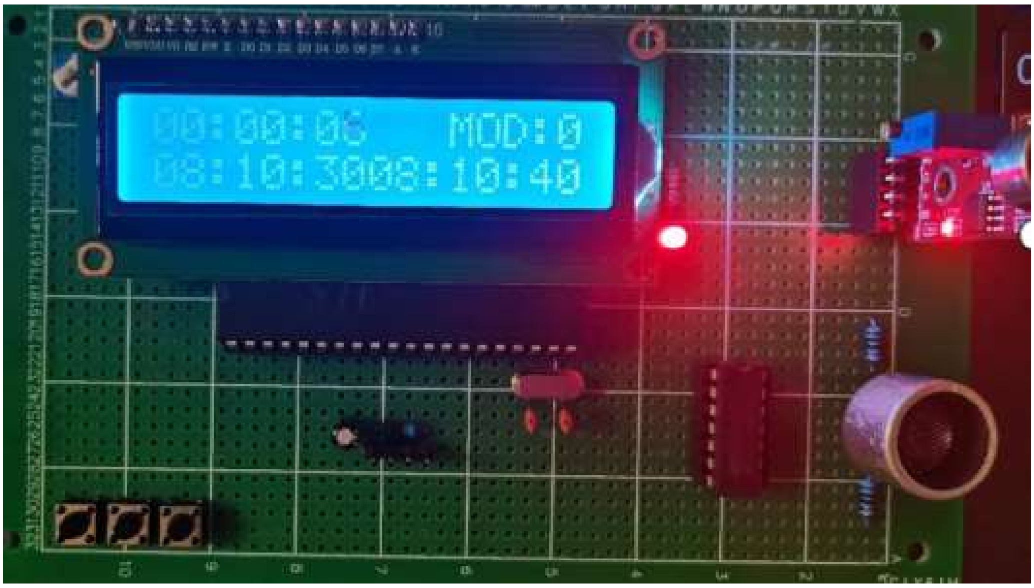

Figure 4. shows the ultrasonic indicator light turning on when button S2 is pressed.

Press S3 to stop the ultrasonic emitter and verify that the indicator LED turns off (shown in Figure 5).

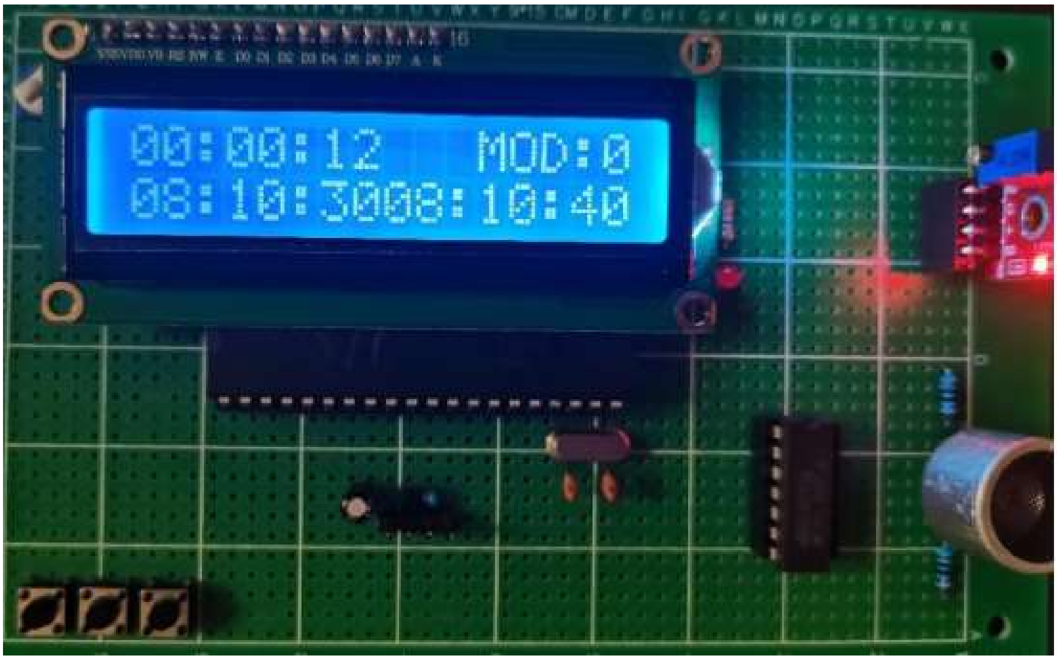

Figure 5. shows the S3 ultrasonic indicator light turning off when pressed

Expected Results: The system should correctly activate and deactivate the ultrasonic emitter based on sound signals or button presses, with the indicator LED reflecting the state.

4.4. Integration Testing

Integration testing ensures that all components work together seamlessly:

Test Setup: Assemble the entire system including the 51 microcontroller, ultrasonic sensors, LCD display, control devices, and sound sensor.

Procedure:

Run the main program with real-time distance measurements and mode functions.

Simulate varying operational scenarios by manipulating inputs and observing the response.

Confirm that the ultrasonic emitter, data processing, display output, and control logic operate cohesively.

Expected Results: The assembled system should function smoothly, providing real-time distance measurements, accurate data display, seamless mode transitions, and responsive control.

By following these testing procedures, the intelligent ultrasonic system based on the 51 microcontroller can be validated for accuracy, reliability, and performance, ensuring it meets the requirements for various intelligent applications.

5. CONCLUSION

The intelligent ultrasonic system based on the 51 microcontroller successfully demonstrated precision, versatility, and user-friendly operation through thorough design and testing. The integration of the HC-SR04 ultrasonic sensor, LCD1602 display, and control circuits enabled accurate real-time distance measurement, adaptive mode selection, and efficient control mechanisms. Functional tests verified that the system responded correctly to time settings and external triggers, seamlessly integrating all components to ensure reliable performance. This project achieved its goals, providing a robust, low-cost solution suitable for diverse applications such as intelligent robots and obstacle avoidance systems, thus laying a strong foundation for further advancements in intelligent system design.

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