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Development and Empirical Study of an Intelligent Car's Line-Following and Obstacle-Avoiding Control System Based on the STC89C52 Microcontroller

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Abstract: With the development of the electronics industry, intelligent small vehicles not only have been widely used in industrial intelligence, but also the products used in smart homes are increasingly favored by people. This group's design is an intelligent small vehicle based on STC89C52. It uses an infrared sensor module for tracking and an ultrasonic sensor module for obstacle avoidance, and transmits the measured data to the embedded microcontroller. The single-chip microcontroller processes the data and gives responses to control the operation of the motor to achieve the functions of tracking and obstacle avoidance. This automatic tracking and obstacle avoidance intelligent small vehicle uses the STC89C52 single-chip microcontroller as the microprocessor, adopts the TCRT5000 infrared sensor module for infrared tracking, adopts the HC-SR04 ultrasonic sensor module for ultrasonic obstacle avoidance, uses the L298N motor driver board and two DC speed motors to form the motor drive module, and uses four South Power batteries to form the power circu. This automatic tracking and obstacle avoidance intelligent small vehicle uses the STC89C52 single-chip microcontroller as the microprocessor, adopts the TCRT5000 infrared sensor module for infrared tracking, adopts the HC-SR04 ultrasonic sensor module for ultrasonic obstacle avoidance, uses the L298N motor driver board and two DC speed motors to form the motor drive module, and uses four South Power batteries to form the power circuit. Through experiments, the intelligent car can successfully follow black lines and avoid obstacles within a 20cm range, achieving the expected design goals.

Keywords: Intelligent Vehicle, STC89C52, Infrared Tracking, Infrared Obstacle Avoidance.

1. Introduction

With the rapid advancement of industrial automation and artificial intelligence technologies, intelligent mobile platforms capable of autonomous navigation and obstacle avoidance demonstrate significant application potential in warehousing logistics, home services, and specialized environmental monitoring. This study addresses the construction of a precise tracking and dynamic obstacle avoidance system for intelligent vehicles navigating complex paths, aiming to resolve autonomous mobility challenges through a low-cost embedded solution. Previous studies have predominantly focused on single-sensor applications or algorithm simulations in ideal laboratory environments, often exhibiting insufficient robustness when handling actual terrain variations and complex logic switching. The innovation of this section lies in proposing a fusion solution combining redundant detection from multiple infrared sensors with ultrasonic scanning for distance measurement. The algorithmic logic was validated through Proteus equivalent simulation, effectively shortening the transition cycle from theory to physical implementation. The overall research approach begins with hardware selection and PCB circuit design for the STC89C52 microcontroller minimal system, establishing a PWM-controlled motor drive system. Subsequently, a software architecture comprising a main loop and functional submodules is constructed. Control programs undergo pre-verification through Proteus simulation, followed by modular debugging and optimization on the physical platform to address practical engineering challenges such as unstable path-following on right-angle turns and missing obstacle avoidance decision logic[1].

The system uses an STC89C52 microcontroller for control. The L298N module drives four DC gear motors, while TCRT5000 infrared sensors enable line tracking by detecting black/white surfaces and outputting corresponding high/low levels. Obstacle detection is handled by an HC-SR04 ultrasonic module, which calculates distance using sound wave echo timing. Software follows a modular structure with main, tracking, and obstacle avoidance routines. The tracking algorithm adjusts wheel speeds based on four infrared sensors' inputs to maintain course. Obstacle avoidance triggers at 20cm, using servo scanning to find a clear path. Proteus simulations verified control logic using switch-based sensor simulation. Physical testing improved obstacle avoidance from simple stops to active detours, and resolved sharp-turn stalling through sensor placement optimizations, enhancing complex terrain performance[2].

2. Hardware Circuit Design

2.1. Hardware Selection

STC89C52 chip
L298N motor driver module
DC3-6V DC gear motor
TCRT5000 infrared tracking module
HC-SR04 ultrasonic obstacle avoidance module
12V lithium battery with model GS53003S45.

2.2. Hardware Function Design

The functions realized by the project of our group are as follows:

Tracking Function

The smart car features line tracking and obstacle avoidance

capabilities.

In tracking mode, four infrared sensors convert ground surface colors into digital signals (black line: high level, white surface: low level) and send them to the microcontroller. The system controls the motors based on sensor input: the car moves straight when both middle sensors detect the black line; it makes a sharp left turn if only the two left sensors detect the line (indicating a significant right deviation), and a slight left adjustment if only the left-middle sensor detects the line, with opposite actions for left deviations.

For obstacle avoidance, an ultrasonic module emits a 40kHz signal after a ≥10μs trigger pulse. Distance is calculated from the echo pulse width (Distance = high-level time × 340m/s ÷ 2), with a measurement cycle ≥60ms to avoid signal interference.

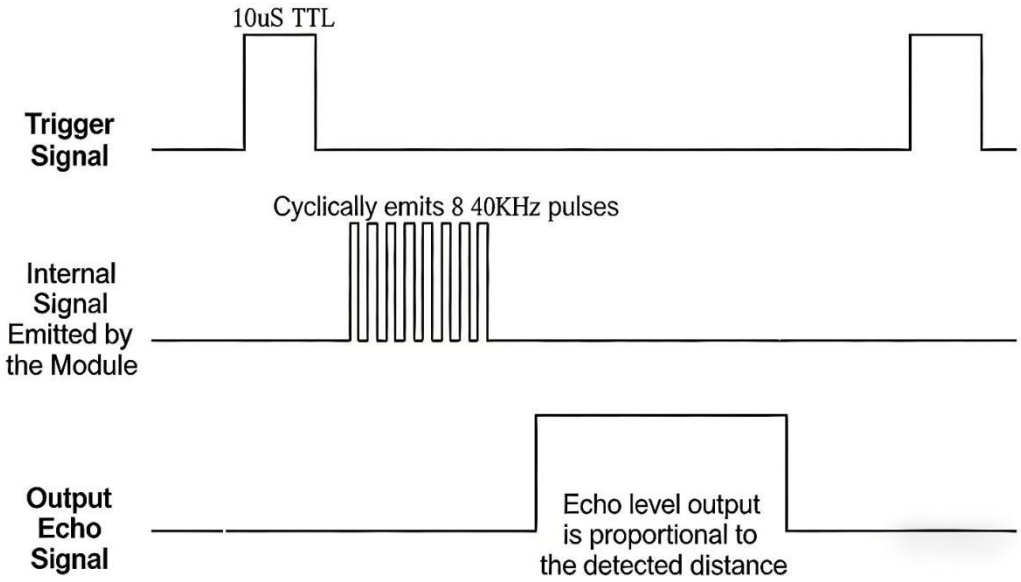


Figure 1 Ultrasonic Timing Diagram

After starting the car, the car travels straight normally. Ultrasonic ranging is triggered by the trigger signal. The ultrasonic sensor above the car continuously transmits signals, and the time interval from transmitting the signal to receiving the response signal is detected at the same time.

If the distance of the obstacle detected by the ultrasonic wave is beyond the set value (20cm) or no obstacle is detected, the car is in a normal driving state and no adjustment is needed. If the distance of the obstacle detected by the ultrasonic wave is less than the set value (20cm), the obstacle avoidance action is executed. A steering gear is connected below the ultrasonic module. When an obstacle is detected directly in front, the steering gear will rotate 45 degrees to the left and then 45 degrees to the right in turn to detect which of the left and right sides has no obstacle. Then the car turns to the side without obstacles and returns to the black track after avoiding the obstacle.

By flipping the level, the switching between the infrared tracking and ultrasonic obstacle avoidance functions of the intelligent car is completed in the code, realizing the control function of the functional modules of the intelligent car.

2.3. System Hardware Connection

As shown in the figure below, Figure 2 is the system circuit diagram. Pin headers H1 and H2 are led out from the single-chip microcomputer. When the P0 port is used as a general-purpose I/O port, a pull-up resistor needs to be added. The resistance value is generally 10K, so we choose to connect a 10K resistor network. H3 and H4 are used to increase the interfaces of VCC and GND. P30/RXD and P30/TXD are the input and output ends of the single-chip microcomputer, which are led out to the pin H12 to prepare for the subsequent program burning.

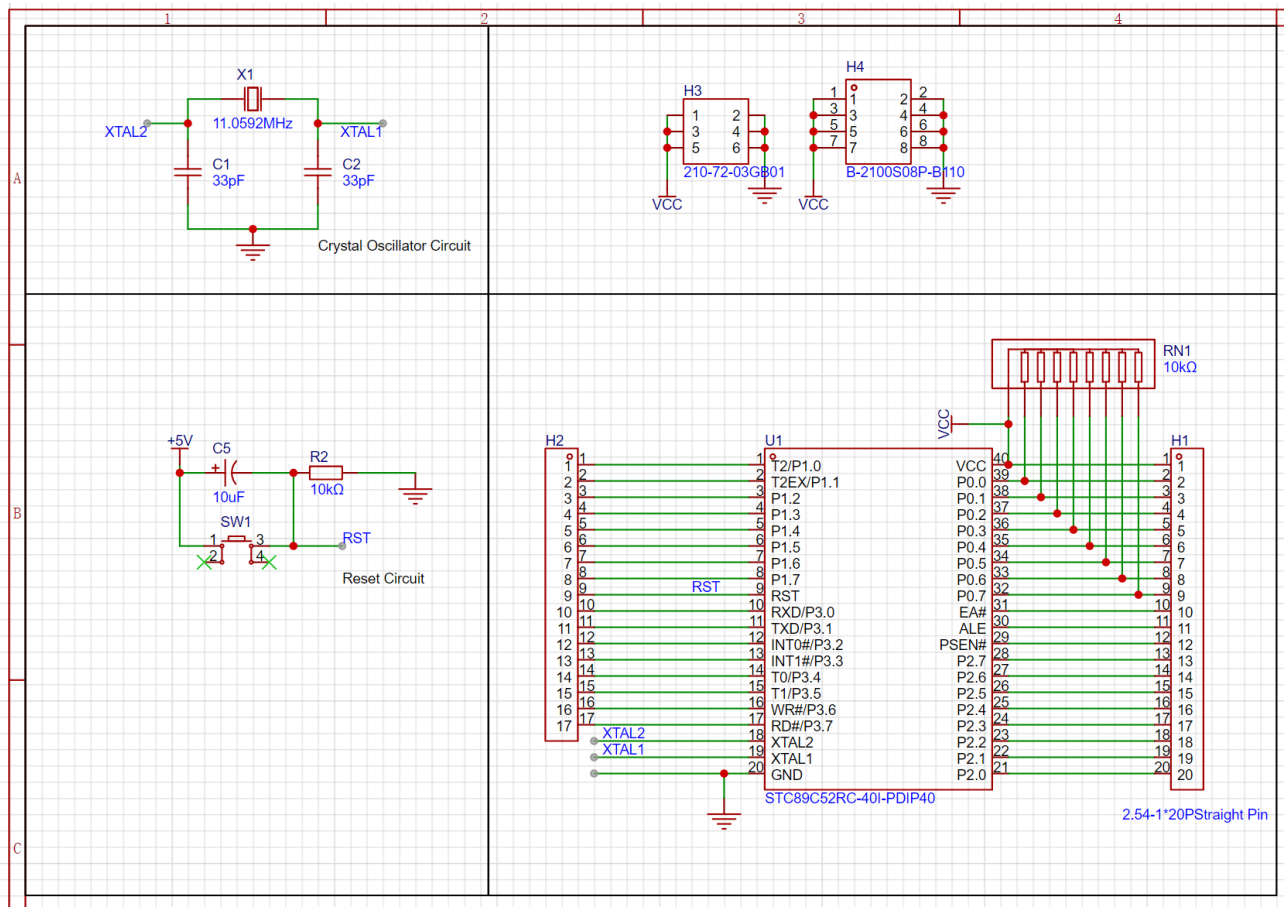


Figure 2 System Circuit

XTAL1 and XTAL2 are connected to a clock circuit with a crystal oscillator of 11.059MHZ.

4 infrared tracking modules: left outer is connected to P2.7, left middle to P2.6, right middle to P2.5, and right outer to P2.4. 4 driver modules: left front is connected to P0.7, right front to P0.2, left rear to P3.7, and right rear to P3.2. 4 wheels: left front wheel is connected to P0.5 and P0.6, right front wheel to P0.3 and P0.4, left rear wheel to P3.5 and P3.6, and right rear wheel to P3.3 and P3.4. Ultrasonic transmitting port is P2.1, and ultrasonic receiving port is P2.2. The key is connected to P1.0.

In the PCB, the P10-P15 I/O ports of the single-chip microcomputer are respectively connected to the logic control signal terminals ENB, IN4, IN3, IN2, IN1, and ENA of the L298N motor driver module. The operating states of the left and right motors are controlled by assigning values to ENA, ENB, IN4, IN3, IN2, and IN1 (see the following truth table for details). The 5V and GND of the L298N motor driver module are connected to the power output in the PCB to supply power to the module. OUT2 and OUT1 of the L298N motor driver module are respectively connected to the positive and negative poles of the left motor, and OUT4 and OUT3 are respectively connected to the positive and negative poles of the right motor.

This driver board can drive two DC motors. The enable terminals ENA and ENB are effective when they are at high level. The control mode and the state table of the DC motor are shown in the following table. Among them, high level is represented by 1, low level by 0, and x represents any state. Truth Table of Motor Driver Module is shown in table 1.

Table 1 Truth Table of Motor Driver Module

ENA	IN1	IN2	Left Motor State	ENB	IN3	IN4	Right Motor State
0	x	x	Stop	0	x	x	Stop
1	0	0	Stop	1	0	0	Stop
1	1	0	Forward rotation	1	1	0	Reverse rotation
1	0	1	Reverse rotation	1	0	1	Forward rotation
1	1	1	Stop	1	1	1	Stop

2.4. Minimum System of Single-Chip Microcomputer

2.4.1. STC89C52 Chip

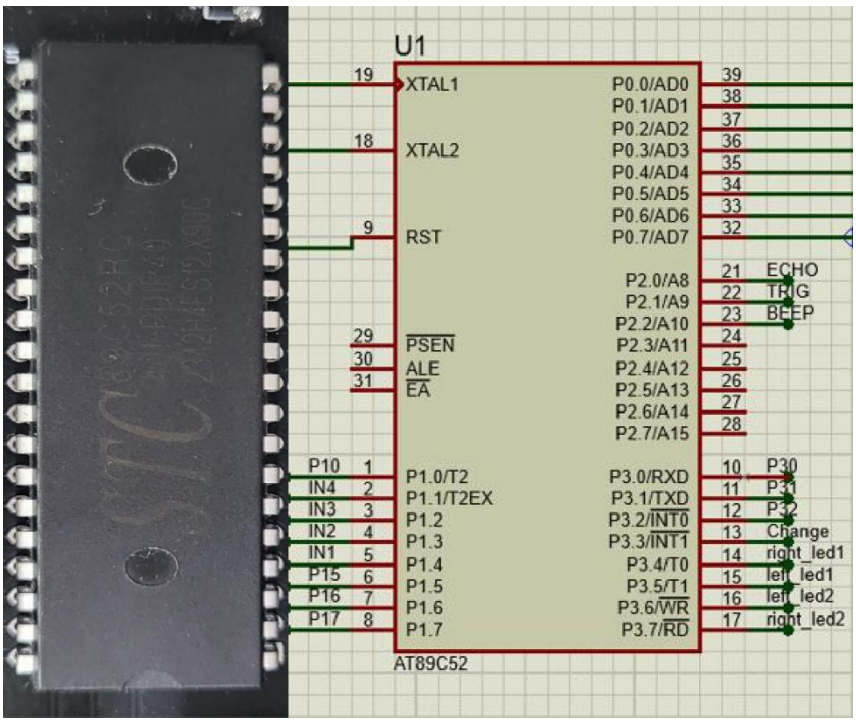


Figure 3 STC89C52 Microcontroller Hardware and Simulation

As shown in Figure 3, it is the physical object and simulation diagram of the STC89C52 single-chip microcomputer used by us. STC89C52 is a low-power, high-performance CMOS 8-bit microcontroller with 8K in-system programmable Flash memory. On a single chip, it has a smart 8-bit CPU and in-system programmable Flash, making STC89C52 a highly flexible and cost-effective solution for many embedded control applications. It has the following standard functions: 8k bytes of Flash, 512 bytes of RAM, 32 I/O lines, watchdog timer, built-in 4KB EEPROM, MAX810 reset circuit, three 16-bit timers/counters, a 6-vector 2-level interrupt structure, and a full-duplex serial port. In addition, STC89C52 can be reduced to 0Hz static logic operation and supports two software-selectable power-saving modes. In idle mode, the CPU stops working, allowing RAM, timers/counters, serial ports, and interrupts to continue working. In power-down protection mode, the RAM content is saved, the oscillator is frozen, and all work of the single-chip microcomputer stops until the next interrupt or hardware reset. The maximum operating frequency is 35Mhz, and 6T/12T is optional. Compared with atmel, STC89C52RC single-chip microcomputer: 8K bytes of program storage space, 512 bytes of data storage space, built-in 4K bytes of EEPROM storage space, which can be directly downloaded using a serial port; AT89S52 single-chip microcomputer: 8K bytes of program storage space, 256 bytes of data storage space, no built-in EEPROM storage space.

2.4.2. Clock Circuit

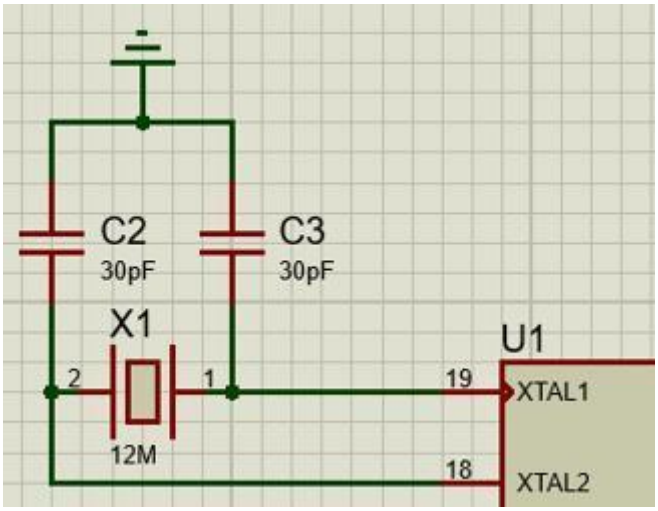


Figure 4 Clock Crystal Oscillator Circuit and Simulation Diagram

Figure 4 shows the clock oscillator circuit, which uses a crystal oscillator and two matching capacitors. This circuit generates the essential clock signal that synchronizes all operations of the microcontroller, ensuring stable system performance.

2.4.3. High-Level Reset Circuit

The power-on reset circuit uses an RC network to generate a reset pulse. Upon power-up, the capacitor holds the RST pin high to reset the microcontroller. As the capacitor charges through the resistor, the voltage on RST drops to a low level

after about 0.5 seconds, allowing the microcontroller to begin normal operation.

2.4.4. CH340 Downloader

CH340 is a USB bus conversion chip that can convert a USB interface into a serial port or a parallel port. It provides commonly used MODEM handshake signals for expanding asynchronous serial ports for computers or directly upgrading ordinary serial port devices to the USB bus. It can not only be used on PC systems but also in embedded Linux systems. The corresponding driver source code is available in the Linux kernel version, which is easy for transplantation and development.

The pins used are as follows:

Positive power supply VCC; Ground terminal GND; TXD serial data output; RXD serial data input.

2.5. L298N Motor Driver Board

The motor drive uses the L298N chip, a dual H-bridge driver that can control two DC motors. The IN1~IN4 pins control the motor direction, while the ENA/ENB pins accept PWM signals for speed regulation. Its internal H-bridge uses power transistors as switches operating in saturation and cutoff modes, enabling efficient PWM-based speed control with a wide range, high overload capacity, and rapid start/stop/reversal capabilities.

2.6. TCRT5000 Infrared Tracking Module

Introduction to TCRT5000 Function

The infrared emitting diode of the sensor continuously emits infrared rays. When the emitted infrared rays are not reflected back or the reflected intensity is not strong enough, the infrared receiving tube is always in the off state. At this time, the output terminal of the module is at a high level, and the indicator diode is always off. When the detected object appears within the detection range, the infrared rays are reflected back with sufficient intensity, and the infrared receiving tube is saturated. At this time, the output terminal of the module is at a low level, and the indicator diode is lit.

Two infrared pairs of tubes are used, which are respectively placed on both sides of the front track of the car body. The steering of the car is controlled according to the situation that the two photoelectric switches receive the white line and the black line to adjust the direction of the car. Tests show that as long as the positions of the two photoelectric switches are reasonably installed, the tracking function can be well realized.

2.7. Ultrasonic Module

The HC-SR04 ultrasonic module is a commonly used ultrasonic ranging module, which is widely used in object distance measurement and obstacle avoidance applications. It consists of an ultrasonic transmitter and a receiver, and can measure the distance between the object and the module in a non-contact manner. The working principle of the HC-SR04 module is to measure the distance by using the propagation time of ultrasonic waves. First, a short pulse signal is sent to the ultrasonic transmitter through the control pin, and the transmitter will emit a beam of ultrasonic waves. Then, the receiver starts to receive the echo and converts the received signal into an electrical signal. The distance between the object and the module can be calculated by measuring the time difference between transmission and reception.

The HC-SR04 ultrasonic ranging module can provide non-contact distance sensing function from 2cm to 400cm, with a ranging accuracy of up to 3mm. The module includes an ultrasonic transmitter, a receiver, and a control circuit. The distance of the obstacle can be obtained by the time interval from sending the signal to receiving the response signal, using the formula: Distance = Time * Speed of sound (340m/s)/2.

The main characteristics of the HC-SR04 ultrasonic module include:

(1) Easy to use: The HC-SR04 module has a simple interface, and usually only needs to provide power supply and connect a few pins to operate.

(2) Wide ranging range: It can perform non-contact ranging within the range of 2cm to 400cm.

(3) High precision: The HC-SR04 module has high measurement accuracy, usually up to ±3mm error.

(4) Fast response: The transmission and reception of ultrasonic pulses are very fast, so the module's measurement of the target distance is almost instantaneous.

(5) Low cost: HC-SR04 is an economical and practical sensor module, so it is widely used in various DIY and embedded systems.

2.8. DC3-6V DC Gear Motor

Operating at 3-6V, the DC gear motor incorporates a gearbox to lower output speed while increasing torque. Controlled by an L298N driver’s H-bridge and PWM signals, it manages direction and speed. This compact, high-torque solution is widely used in toys, robotics, and small mechanisms where precise motion control is needed.

3. Software Design

3.1. Main Program Flow Chart

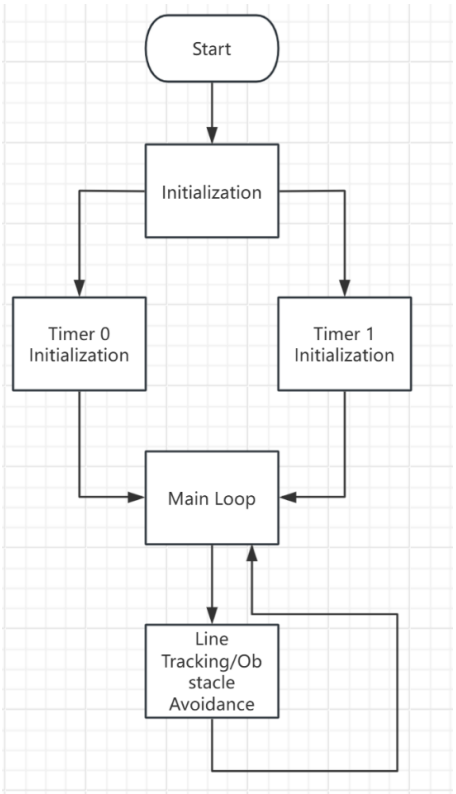


Figure 5 Flow Chart of the Main Program of the Intelligent Tracking and Obstacle Avoidance Car

Figure 5 presents the main program flowchart for the intelligent tracking and obstacle-avoidance vehicle. This flowchart details the system's logical sequence, beginning with hardware initialization and entering the main loop. It then executes corresponding subroutines based on functional switching (infrared tracking or ultrasonic obstacle avoidance), thereby achieving the vehicle's tracking and obstacle-avoidance capabilities.

3.2. Tracking Program Flow Chart

The tracking program starts with hardware initialization and then enters the main loop. The car enters a straight-line driving state and first detects the states of the infrared tracking sensors D1, D2, D3, and D4. If no black line is detected, it keeps moving straight. If both D1 and D2 detect the black line, it first stops, the right motor rotates forward, and the left motor rotates backward to realize in-place left turn. If D2 detects the black line but D3 does not, the speed of the right motor is increased to turn left slightly. If both D3 and D4 detect the black line, it first stops, the left motor rotates forward, and the right motor rotates backward to realize in-place right turn. If D3 detects the black line but D2 does not, the speed of the left motor is increased to turn right slightly. Then the program returns to the main loop to continuously monitor the state of the infrared tracking module. Through the processing of the above different situations, the stable tracking of the car on the track and the effective response under abnormal conditions are realized.

3.3. Obstacle Avoidance Program Flow Chart

The car is equipped with an ultrasonic sensor. The distance can be obtained by the time interval from sending the signal to receiving the response signal, using the formula: Distance = Time * Speed of sound (340m/s)/2.

When there is no obstacle or the obstacle distance is greater than 20CM, the car drives normally. When the obstacle distance is less than 20CM, the obstacle avoidance action is executed. A steering gear is connected below the ultrasonic module. When an obstacle is detected directly in front, the steering gear will rotate 45 degrees to the left and then 45 degrees to the right in turn to detect which of the left and right sides has no obstacle. Then the car turns to the side without obstacles, returns to the black track after avoiding the obstacle, and continuously corrects the track by turning to ensure that the car does not hit the obstacle and drives normally.

4. Simulation Circuit Design

4.1. Simulation Circuit Diagram

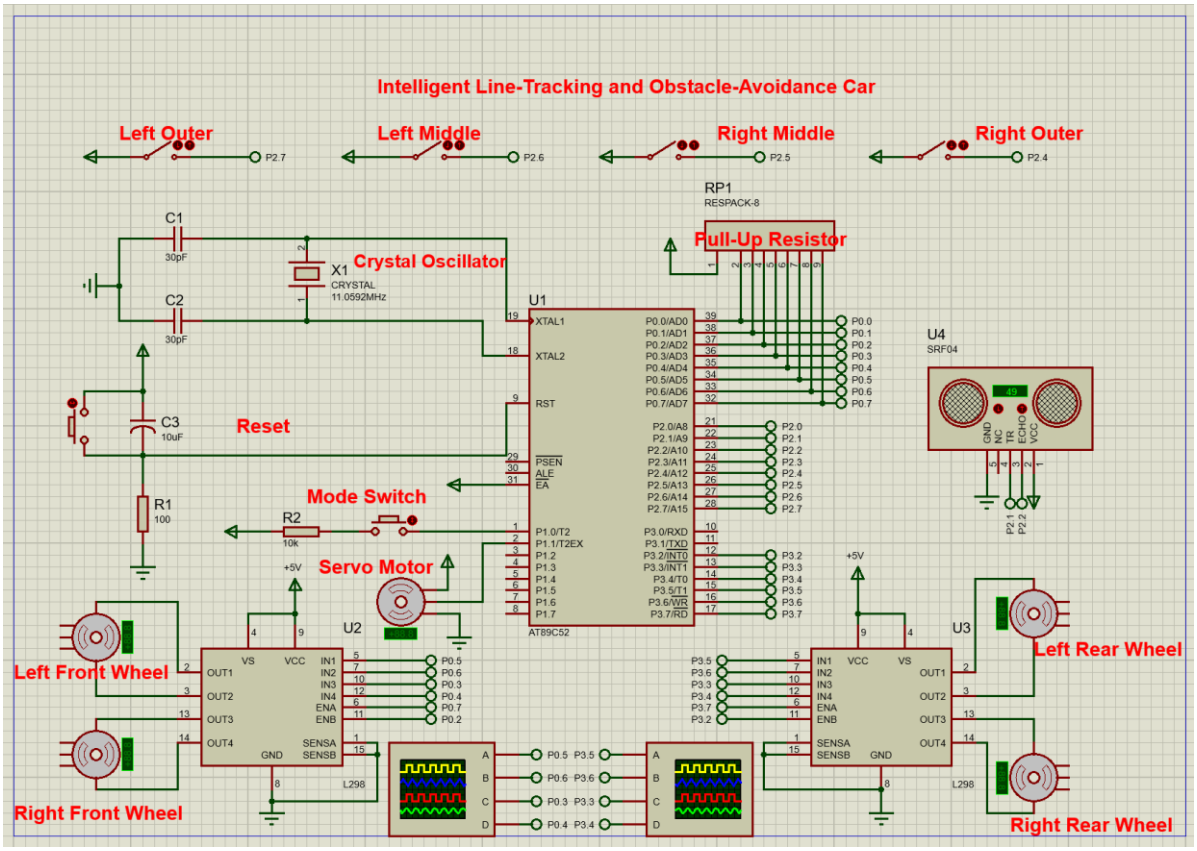


Figure 6 Simulation Circuit Diagram

Figure 6 presents the simulation circuit diagram of the intelligent car's line - following and obstacle - avoiding system designed in Proteus. The circuit incorporates a power - on reset circuit for system initialization. A function key is set to switch the function of the main control module: when the key is disconnected, the system works in the infrared tracking module; when the key is closed, it works in the ultrasonic obstacle avoidance module. The speed of the control motor is realized by changing the duty cycle. For the infrared tracking module, it detects external information and outputs a low level when receiving reflected light (white ground) and a high level when not receiving reflected light (black track line). In the actual simulation process, since the infrared tracking sensor was not found in the Proteus component library, an alternative method was used to equivalently replace the input and output quantities of the sensor. Two switches were employed to simulate the output values of the left and right infrared sensors respectively. When the white ground is detected, the infrared sensor receives the reflected light and outputs a low level, and the switch (set to ground) is in the on state to give a low level. When the black track line is detected, the infrared sensor does not receive the reflected light and outputs a high level, and the switch is disconnected at this time. The ultrasonic module is used to obtain whether there is an obstacle in front, form feedback to the main control module, and the main control module sends corresponding instructions to the motor drive module to adjust the operation of the left and right motors, thereby realizing the left turn, right turn, forward, and stop actions of the car, and thus realizing the tracking and obstacle avoidance functions of the car.

4.2. Analysis of Simulation Principle

The simulation circuit designed by our group: the reset circuit adopts power-on reset; the function key is set to switch the function of the main control module. When the key is disconnected, it is in the infrared tracking working module. When the key is closed, it is in the ultrasonic obstacle avoidance working module to realize function conversion; the speed of the control motor is realized by changing the duty cycle. Different speeds can be switched in the two working states of tracking and obstacle avoidance, and straight-line driving, turning, and other actions are realized by changing the steering of the left and right wheels; the infrared tracking module detects external information, outputs a low level when receiving reflected light, and outputs a high level when not receiving reflected light. The left and right sensors continuously detect; the ultrasonic module is used to obtain whether there is an obstacle in front, form feedback to the main control module, and the main control module sends corresponding instructions to the motor drive module to adjust the operation of the left and right motors, thereby realizing the left turn, right turn, forward, and stop actions of the car, and thus realizing the tracking and obstacle avoidance functions of the car.

During the actual simulation process, our group did not find the infrared tracking sensor in the proteus component library, so we could only use an alternative method to equivalently replace the input and output quantities of the sensor. Two switches were used to simulate the output values of the left and right infrared sensors respectively. When the white ground is detected, the infrared sensor receives the reflected light and outputs a low level. Since the switch is set to ground, the switch is in the on state to give a low level. When the black track line is detected, the infrared sensor does not receive the reflected light and outputs a high level, and the switch is disconnected at this time. The car travels on the black track without adjustment.

4.3. Design Analysis

4.3.1. Tracking

After starting the car, first detect the states of the infrared tracking sensors L1 and L2. If L1 detects the black line but L2 does not, the speed of the right motor is increased. If L2 detects the black line but L1 does not, the speed of the left motor is increased. If neither L1 nor L2 detects the black line, the car moves straight. Then the program returns to the main loop to continuously monitor the state of the infrared tracking module. Through the processing of the above different situations, the stable tracking of the car on the track and the effective response under abnormal conditions are realized.

4.3.2. Obstacle Avoidance

After starting the car, the car travels straight normally. Ultrasonic ranging is triggered by the trigger signal. The ultrasonic sensor above the car continuously transmits signals, and the time interval from transmitting the signal to receiving the response signal is detected at the same time. The distance can be calculated according to the formula: Distance = Time * Speed of sound (340m/s)/2. If the distance is beyond the set value (20CM), the car is in a normal driving state and no adjustment is needed. If the distance is less than the set value (20CM), the car will adjust the track to find a direction without obstacles for normal driving.

5. Physical Debugging Link

5.1. Obstacle Avoidance Debugging

In fact, our car cannot realize the obstacle avoidance function. When the distance from the obstacle is less than 20cm, the car will stop suddenly and the buzzer will sound.

The core reason why our obstacle avoidance function can only achieve the step of "emergency stop and alarm" is that the control logic is too simple. The current program logic of our group for handling obstacle avoidance is basically: if the distance < 20cm, stop all wheels and turn on the buzzer. It lacks the key steps of "decision-making" and "executing detour".

In addition, the hardware dependence is single. We mainly rely on an ultrasonic module facing forward. It can only detect whether there is an obstacle directly in front and the distance, but cannot judge the size and shape of the obstacle, let alone detect the situation on the left and right sides. The information provided by this single sensor is not enough to support the car to make an intelligent decision of "which way to detour".

The most important reason is the lack of time and debugging: due to the large amount of time spent on hardware and PCB prototyping in the early stage, the time left for the in-depth development and debugging of the obstacle avoidance strategy is very tight. We can only realize a most basic minimum guarantee function to prevent collision and damage.

But finally, after intensive debugging the night before the defense, we successfully realized the function of right-angle turning, and we also successfully realized that after the ultrasonic wave detects an obstacle and stops suddenly, it can independently choose the side without obstacles to detour and return to the normal track. The debugging task was successfully completed.

5.2. Tracking Debugging

The car can realize the tracking function, but there is a relatively serious problem: when turning, our car can only make a large turn, that is, a turn with a small amplitude, and the car cannot make a right-angle turn. The important reason for these two situations is that when the car makes a sharp turn or a right-angle turn, the infrared tracking module cannot detect the black line, which will cause the car to stop suddenly.

To address this pain point of "sudden stop at corners", our group discussed and conceived the following solutions at that time. Although they could not all be implemented and verified due to time and condition constraints, the ideas were clear:

5.2.1. Increase the Number of Infrared Sensors

Upgrade the two-channel infrared module to four-channel. The core is to add additional infrared probes at the outermost edges of both sides of the module. The working principle is that when the car makes a sharp turn, the car body will tilt greatly. The outermost probe on the outer side of the turning direction, due to its more outward position and detection angle may be more inclined to the front side, has a greater chance to "glimpse" or timely "capture" the black line after the turn. In this way, even if the inner probe temporarily loses the black line, the outer probe can provide a signal that "the line is still there", and the program can continue to issue a turn command to avoid misjudgment and stop. The reason for not implementing it is that it is necessary to redesign the sensor bracket or PCB board, add sensors and corresponding I/O ports, and modify the program to adapt to more signal inputs. This was a plan that we thought had a lot of changes and did not do due to time constraints.

5.2.2. Optimize the Installation Position and Angle of Sensors

Without increasing the number of sensors, try to adjust the installation position of the existing infrared modules or slightly tilt the two outermost probes. Let the outermost probes cover a wider front side area. Inclined installation can increase its detection "horizontal scanning range", so that when turning, it is more likely to detect the upcoming black line track in advance. A major difficulty for us to implement is that it is necessary to repeatedly experiment to find the best angle and position. The effect may not be as obvious as adding probes, but the changes are relatively small.

6. Conclusions

This research systematically completed the hardware development, programming, simulation verification, and physical debugging of the intelligent vehicle's line-following obstacle avoidance system. By integrating microcontroller control technology, infrared sensing technology, and ultrasonic ranging algorithms, the vehicle achieved stable navigation along preset trajectories and intelligent obstacle avoidance. Key technical challenges overcome include sensor signal processing, precise PWM motor speed control, and hardware-software integration in physical environments. Current limitations include sensitivity to lighting variations, resulting in unstable infrared tracking on dark or highly reflective surfaces, and the limited detection range of a single ultrasonic sensor, which may create blind spots for complexly shaped obstacles. Future research will focus on integrating multi-source sensor fusion technology, combining visual recognition with LiDAR, to enhance the vehicle's autonomous navigation and collaborative operation capabilities across all weather conditions and terrains.

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