Multifunctional intelligent line-following robot

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Abstract. This paper introduces an intelligent robot with the functions of automatic line patrol, positioning and parking, real-time ranging, color recognition and object block transmission. The H bridge drive motor is controlled by Arduino as MCU, so that the intelligent car can realize the functions of forward, backward and steering. The circuit test, hardware debugging, PCB drawing, code improvement and overall structure design in the design process are described in the article. The conclusion is that the robot can realize normal line patrol, parking, ranging, color recognition and block delivery.

Keywords: Line-following, Arduino, Color-recognition, robot design, real-time display.

1. Introduction

Intelligent robots have been put into use in many fields and can perform tasks well. Amazon let customers in California and Texas test Prime Air drone deliveries with the developed delivery system. According to University of Wales Research Group, D. I. Jones' research group has developed a visually guided drone for relevant power line inspection. The aim of this project is to create line patrol robots that can be guided by 30mm-wide black tape on the floor for navigation. While walking the patrol line, the distance already moved needs to be displayed on the trolley and, after stopping at the end of the guide line, the robot can transport the mission object to the target area according to the color. This paper introduces the structure and function realization of intelligent robot under this background.

2. Structure Design and Parameter Calculation

2.1 Robot Hardware Block Diagram

The hardware block diagram of the smart cart is shown in Figure 1 and consists of a total of one Arduino Uno motherboard, eight modules, and two power supplies.

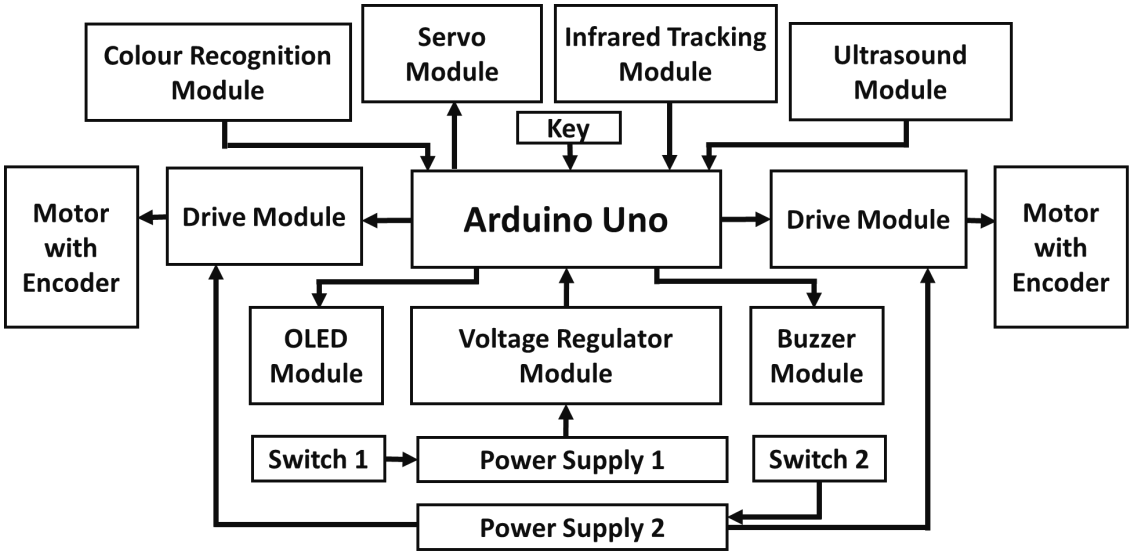


Figure 1. Hardware block diagram

2.2 Structure of Robot

The overall assembly structure of the trolley is as follows:

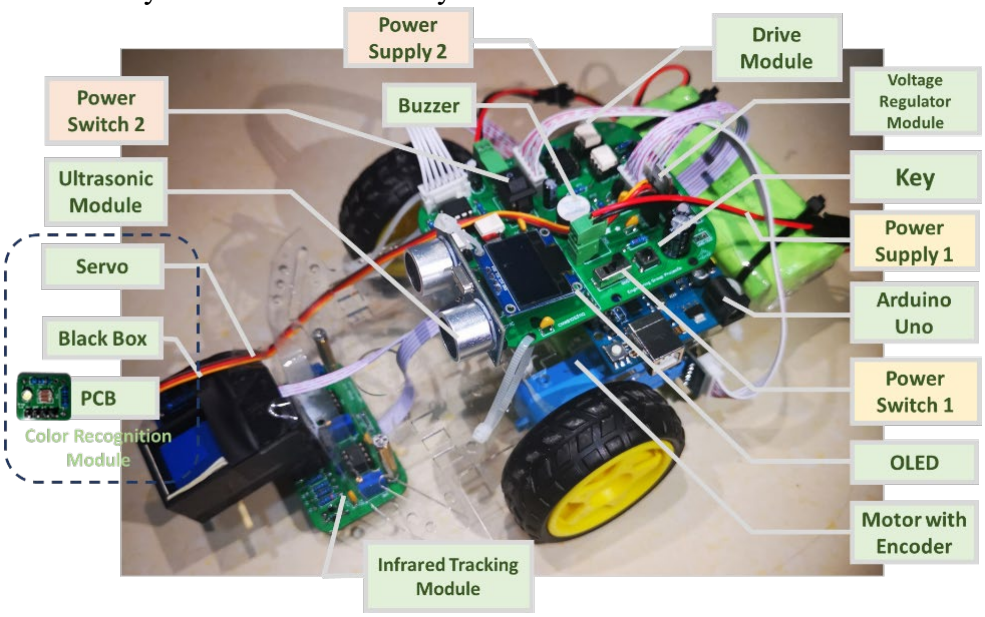


Figure 2. Structure of Robot

After the assembly of the car, the power supply of the car and the start of the program can be controlled by switches and buttons. First, turn on the power switch 1 to supply power to the Arduino and most modules, then turn on the power switch 2 to supply power to the drive circuit, and then control the start of the program by pressing buttons.

2.3 Module, Circuit Design and Calculation

2.3.1 Driving Circuit Design

The robot is equipped with a motor with an encoder, and the drive circuit is designed by photoelectric coupling chip 4N33 and driver chip L9110H.

An optical coupler is a component that uses light energy to connect two different circuits or transfer energy from one circuit to another. The two circuits are completely electrically isolated from each other and there is no electrical connection between them. The robot adopts photoelectric coupling chip 4N33, which is composed of diode and triode. When light is applied to the base of a phototransistor, it conducts the electric current. Moreover, 4N33 uses two transistors, and when the infrared light falls on the base of one transistor, it will conduct the other transistor.

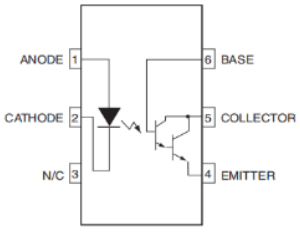


Figure 3. 4N33 Chip pin diagram

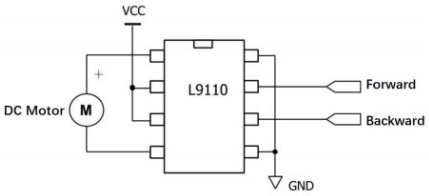


Figure 4. L9100h Chip pin diagram

As shown in Figure 3 and 4, when the PWM signal is input to pin 1 of the optocoupler chip, the current passes through and the diode emits light, then the transistor turns on. The current directly enters the ground from the transistor instead of L9110H motor drive chip. When pin 1 is not input with PWM signal, diode does not turn on, and transistor does not turn on. The current generated by VCC flows into input port of L9110H.

Therefore, the PWM signal output by MCU is negatively correlated with the signal input into L9110H chip. In addition, when one output end of the optocoupler connected to the two input ends of the motor driver chip outputs PWM signal and the other outputs high voltage, at the low PWM signal and high voltage, the motor driver chip can control input IA, IB to control the output OA, OB, thus drive the motor to work properly.

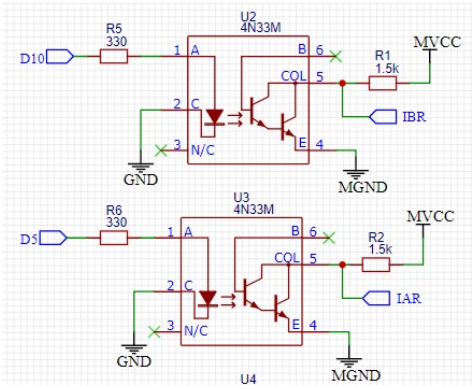


Figure 5. Photoelectric coupling chip interface

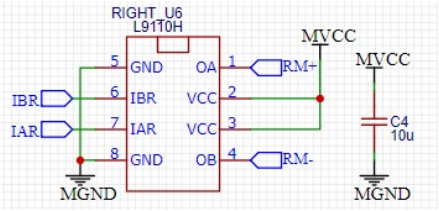


Figure 6. Motor drive circuit

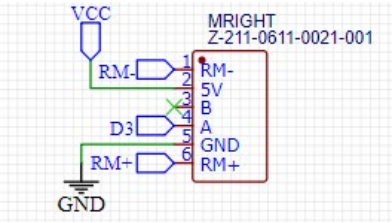


Figure 7. Motor-encoder interface

L9110 chip has a large current drive ability. In the typical application circuit L9110, two signals for optical isolation PWM signal will be input respectively, representing the motor positive and negative power, DC motor directly connected to the motor drive chip. When the continuous forward current of pin 4 at the output end of the photoelectric coupling chip, namely the emitter, is 80mA, the reverse voltage is 3V and the continuous collector current is 150mA. And at 25°C, when IF is 10mA, the typical input forward voltage VF is 1.2V. Therefore, according to Ohm's law, the resistance value of port 1 of the photoelectric coupling chip used in this design is 330Ω, and they can control the current remains at about 10mA, which is within the range of acceptable current. And according to the ohm meter measurement, The L9110H chip has an internal resistance of about $5.8k\Omega$. Therefore, when using the 7.6V battery as the power supply, choose the resistance of $1.5k\Omega$ at pin 5. The L9110H can divide the voltage of 6V, which meets the requirements.

Use the function that analogWrite(pin, value) to output PWM, the range of the value is from 0 to 255.

2.3.2 Buzzer Design

Because the working current of the buzzer is generally relatively large, so it is best not to use the I/O port of the single chip microcomputer to drive the buzzer directly, so when designing the buzzer circuit, the amplifier circuit is selected to drive the buzzer, and the transistor is used to amplify the current. When NPN triode is used to control the buzzer, the buzzer drive circuit includes the following parts: triode, buzzer, current limiting resistor, pull-down resistor and power filter capacitors.

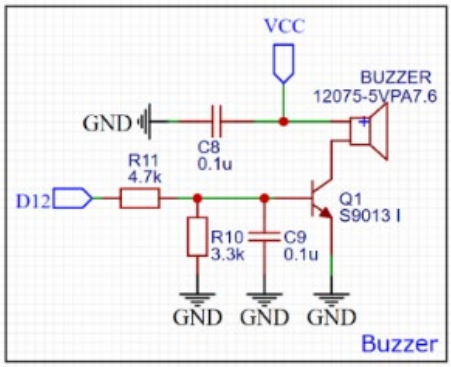


Figure 8. Buzzer circuit

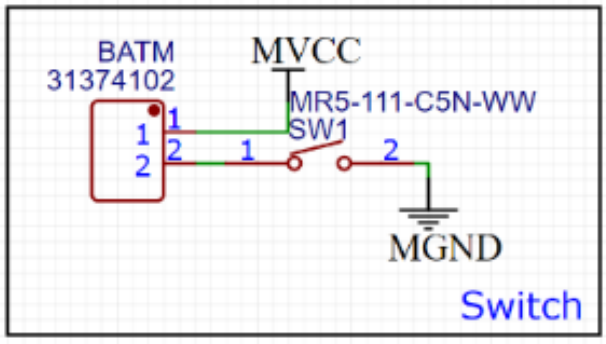


Figure 9. Switching circuit

Capacitors can effectively filter interference signals in strong interference environment, avoid buzzer change sound accidentally, filter high frequency power clutter. For an active buzzer, write a digital high level and the buzzer will turn on. Write a digital low level and the buzzer will turn off.

Improvements can also be made to provide continuity by adding continuity diode D1. Otherwise, there may be a reverse induced electromotive force at both ends of the buzzer, resulting in spikes of tens of volts, which may damage the driving transistor and interfere with other parts of the entire circuit system.

2.3.3 Switch and Key Design

For the toggle switch, choose the ship switch and toggle switch to control the power supply on and off. The ship switch is selected to control the motor drive with the circuit and control motor power supply on and off, while the toggle switch is selected to control the power input of the 5V-voltage-regulator-output circuit.

The ship switch is normally connected to control the power supply of the motor and the driving circuit. Pins 1, 5 of the toggle switch are fixed pin. Pin 3 is not connected and pin 1, 2 are connected to control the on and off of the circuit, that is the switch is opened or closed through the on-off relationship between 1, 2 and 2, 3.

The size of the selected keys is 6*6*4.3. When the key is not pressed, the value read by Arduino is 0 (low level). When the key is pressed, the value read by Arduino is 1 (high level). Use this condition to write a judgment statement to trigger subsequent functions. Use this condition to write a judgment statement to trigger subsequent functions.

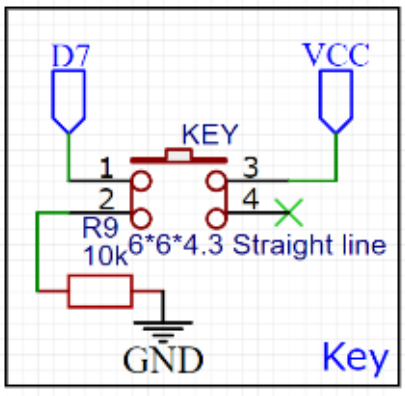


Figure 10. Circuit schematic

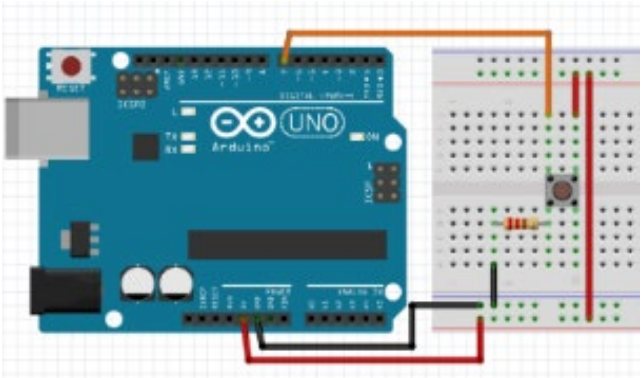


Figure 11. Circuit simulation diagram

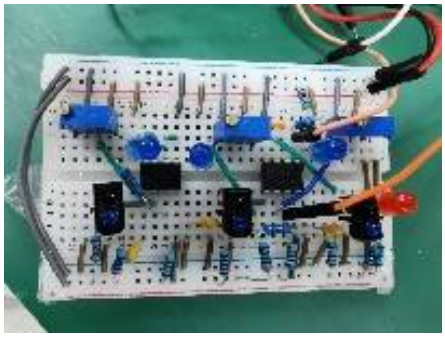


Figure 12. Breadboard circuit for TCRT5000

2.3.4 Infrared Tracking Module Design

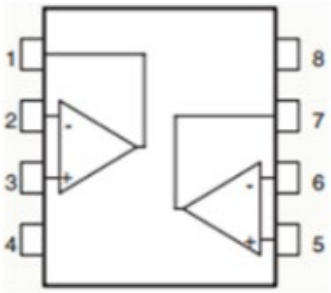
1)TCRT5000 Component

The TCRT5000 consists of an infrared transmitter tube (black, CE terminal) combined with an infrared receiver tube (blue, AK terminal). It uses the shading or reflection of the infrared beam by an object to output different voltages and operates at 3.3V to 5V. (TCRT5000, Internal structure, Infrared tracking module circuit

The supplied regulated voltage Vcc = 5V is known, the required resistor resistance can be derived from Ohm's theorem and the current parameters.

Table 1. Resistance value selection

Parameter	Max Value (mA)	Calculation Min Resistance (Ω)	Selected Resistance(Ω)
Forward Current I_F	60	83	300
Collector Current I_C	100	50	10 k



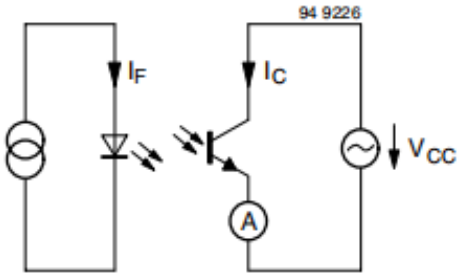


Figure 13. Test circuit **Figure 14.** LM393

2)LM393 Component

The LM393 consists of two independent voltage comparators (Figure 11) with a detuned voltage of no more than 2.0mV. To reduce interference inputs, all unused pins of the comparator should be grounded. When the car sweeps to the black line, the output of the comparator goes high; when it sweeps to the white line (i.e. the obstacle) the output goes low and the blue indicator lights up. The module detection distance is 2 ~ 30cm, and detection distance can be adjusted by potentiometer, clockwise adjustment potentiometer, detection distance increases. The uncertain signal is clamped at a high level by a resistor through a 10kΩ pull-up resistor, which also acts as a current limiter.

Table 2. Infrared tracking module tracking conditions

Data	Data	Data	Status	Target PWM_Left_S	Target PWM_Right_S	Target PWM_Left_A	Target PWM_Right_A
0	1	0	Straight	25	25	15	15
0	0	1	Right_angle	25	11	15	-14
1	0	0	Left_angle	11	25	-14	15
0	1	1	Right_little	25	15	15	-14
1	1	0	Left_little	15	25	-14	-15

In this project, we use three infrared tubes to realize the tracking function, the principle of line patrol and a tracking service robot similar. During tracking, the module will output the number 0 or 1, so there are 23=8 conditions. According to the requirement of the project, we will only use 6 of them, as shown in Table 1. The output signals of the tractor sensors from the left to the right side of the trolley are A(0) to A(2) respectively. We give a specific expected PWM value for a specific situation and output it after PID parameter adjustment to achieve the correct tracking effect.

Since the speeds of the left and right motors under the same voltage and the same PWM are inconsistent, it is necessary to adjust the PWM output to the motor in real time to ensure that the left and right wheel speeds meet expectations. Based on the characteristics that the intelligent line patrol car needs to change the speed quickly, we choose the position-based PD control. The algorithm logic of PD control is proportional control term plus differential control term plus friction compensation. The two friction compensations of the left and right wheels are 70 and 54, respectively. Proportional Control: K_p×error=K_p×(target-current). Kp is 16 in the initial step-start stage, 16 in the S-bend stage, and 10 in the obtuse angle and right-angle turning stages. Derivative Contro:l K_d×(error-last_error). Kd is 0 at the beginning of the step-start stage, Kd is 6 in the S-curve stage, and Kd is 15 in the obtuse angle and right-angle turning stages.

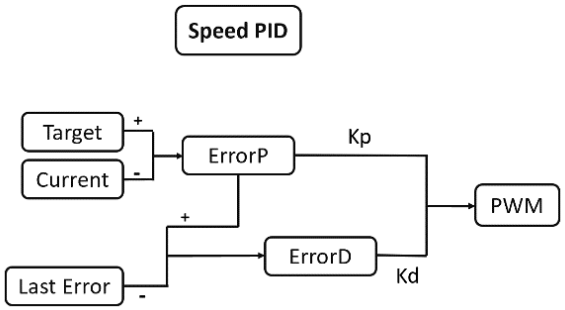


Figure 15. PID flow chart

2.3.5 Voltage regulator circuit design

In regulator circuit, choose 7805 as regulator chip, 7805 three-terminal regulator IC internal circuit has protection function, which makes its performance is very stable. The maximum input voltage is 35V, the output voltage is fixed 5V voltage, the maximum output current can reach 1.5A.

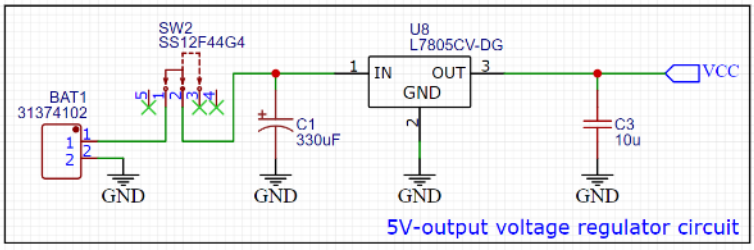


Figure 16. Voltage regulator circuit module

8V and 7.8V batteries are used as the power supply for output, and filter capacitors are added at the input and output ends to connect the voltage regulator circuit.

2.3.6 OLED Display Module Design

To calculate the distance traveled by the car before terminal zone, we get a proportional coefficient k, and multiply by the number of pulses in the whole process to get length of guide line, and display it on OLED.

We use external interrupts to calculate the number of pulses generated by the rotation of hall encoders. When wheel starts to rotate, the hall encoder will continuously generate pulses, set the external interrupt to high level trigger to get the total number of pulses. Let the car go through a specific distance to get the average total number of pulses of the left and right wheels, divide the distance by total number of pulses to get k.

```
// Calculate the length of guideline
count=(counter_left+counter_right)/2;
distance = count*0.000376773;
```

Figure 17. Code of distance measure



Figure 18. Experimental results of pulse number

Specific distance: $x = 340(cm)$
The average pulses (we measured ten sets of data and averaged them): $n = 9024.6$
Proportional coefficient $k = x/n \approx 0.000376773(m)$
Overall pulses: N
The length of the guide line $L = k \times N = 0.000376773 \times N\ (m)$
In order to display the value on OLED, we can call the library of "Adafruit_ssd1306syp".

```
display.setTextSize(2);     // Text size setting
display.setCursor(0,0);     // Set the starting point of the display
display.print("distance:"); // Print string "distance:"
display.setCursor(0,30);
display.print(distance);
display.setCursor(70,30);
display.print("m");
display.update();          // Show data on the display
display.clear();           // Clear the screen
```

Figure 19. Code for distance display

Above code can set the display position, set the font size, and clear the screen (experiments show that the OLED must clear the screen, otherwise the display screen will be stuck with the superposition of display data).

2.3.7 Ultrasonic Parking Module Design

Using the HC-SR04 to detect the distance between the car and the wall, set a critical value that will crash with the wall, and when the distance is less than the detection value, the brake will be used. The principle of parking is similar to that of an obstacle avoidance robot . The working principle of ultrasonic sensor is to emit sound waves, and then use the received signals and sound speed to calculate the distance from obstacles.

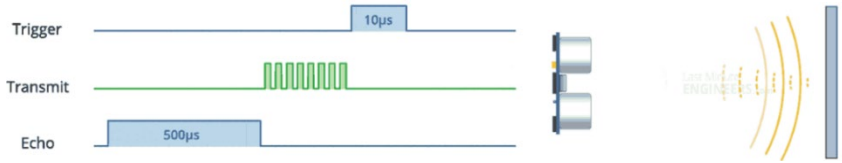


Figure 20. Schematic diagram

The module needs to input a high-power square wave of at least 10us to the trigger pin, and then the module will automatically transmit 8 40KHz sound waves, and the echo pin will change to high level. When the return signal is received by the module, the echo pin end becomes low level. High level duration is the time from the emission to the return of ultrasonic wave. Distance from car and wall can be calculated by formula:

$$distance(cm) = \frac{High\ level\ time(us) \times 340 \times 100}{10^6 \times 2} \approx \frac{High\ level\ time(us)}{58}$$

The pulsein() function, which can be used to detect the pulse width of high and low levels of pin output.

The range of the critical value needs to be specifically debugged after the car is assembled, because the vehicle speed is constantly changing, and quality of the test car built with bread board is different from that built with PCB, which will lead to different inertia. The commissioning results show that setting the critical value of 20cm can not only ensure that the vehicle stops in the terminal zone, but also will not crash with the wall.

2.3.8 Color Recognition Module Design

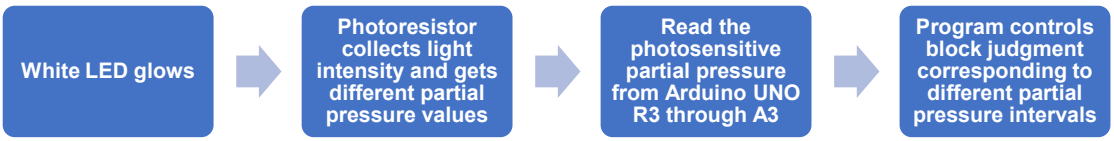


Figure 21. Flow chart of color recognition scheme

The resistance value of the photoresistor in the dark environment is very large, more than 20 kiloohms. The resistance of the photoresistor under the illumination of white light is relatively small, about 1 kiloohm. In order to make the photoresistor voltage divider value most sensitive to opaque blocks of different colors, a resistor with a resistance value of 1 kiloohm was selected in series with the photoresistor to divide the voltage.

The power supply is provided by the 5V output of the voltage regulator module, connect the end of the resistor away from photoresistor. One end of the photoresistor away from the voltage dividing resistor is grounded, the other end is connected to the A3 of Arduino. The details are shown in the Figure 19 and 20.

MCU collected the average value of reflected light intensity ten times through the A3 port.

The maximum voltage that 3MM white hair white LED light (L0008) can withstand is 2.8V~3V. For safety reasons, we added a 10 ohms protection resistor to prevent the LED from burning out. The end of the protection resistor away from the white LED is connected to D4 of the Arduino. The end of the white LED away from the protection resistor is grounded. The specific circuit diagram is as follows. setcolor() subfunction to keep the white LED on.

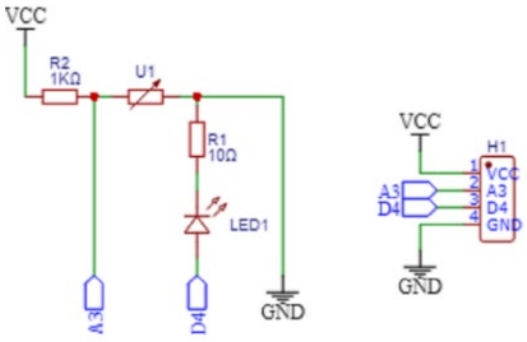


Figure 22. Circuit schematic



Figure 23. PCB

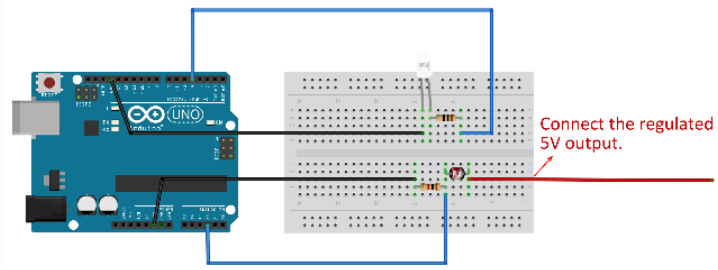


Figure 24. Circuit connection diagram

2.3.9 Block-throwing

Place the 3D image notch in the lower right corner facing forward on the front end of the car. In the drop block area, the block will drop from the 2.2cm*2.2cm square area on the lower surface of 3D image above. The upper surface of the box half where the PCB is glued will be sealed. Before reaching the throwing area, the servo blocks the block. When reaching the throwing area, control the steering gear to stop blocking the door. The all-black design of box can ensure color recognition environment is not disturbed by external light.

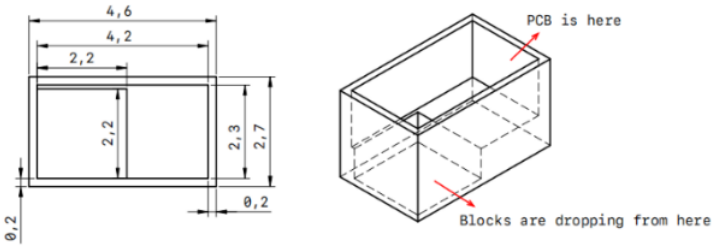


Figure 25. Design sketch of all black box (secret room)

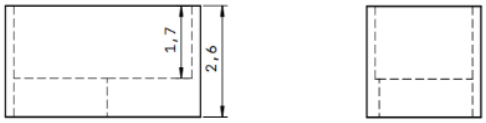


Figure 26. Servo

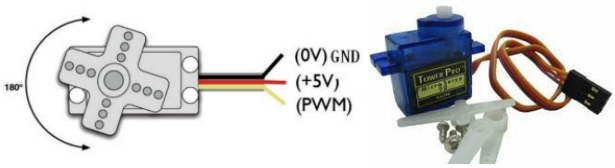


Figure 27. Servo pin connection diagram

As described in black box section, after car enters throwing area, servo will rotate 80°, no longer blocking the block, and allowing the block to fall freely. The following is pin connection diagram of the servo. PWM will be connected to D13 of Arduino, 0V is grounded, and +5V is provided by output of voltage regulator module.

Because the library for driving the servo will use the same timer as PWM, so PWM cannot output. Therefore, subfunction of servodo() is used. The frequency of this pulse function is 50Hz, which can convert angle into a pulse value, give servo a high level, then delay pulse value, and give servo a low level to drive.

3. Programming

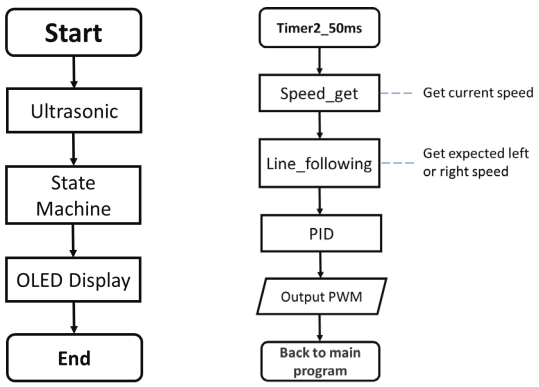


Figure 28. Main loop and timing interrupt flowchart

When designing the code, we only put state machine function, ultrasonic sensor and OLED display distance code in main loop. External interrupts are used to measure number of output pulses of hall encoder. Given a desired speed, a timing interrupt function is defined to measure speed of the car. This speed is taken as current speed and debugged with PID algorithm. The output value is given to the motor as PWM to make car run in an ideal state. When placing object to target zone, the car will use the RGB value obtained in advance to judge direction at the crossroad, use the servo to control the block, input a high level to motor to make car retreat, and then the buzzer rings for 1s, all tasks are finished.

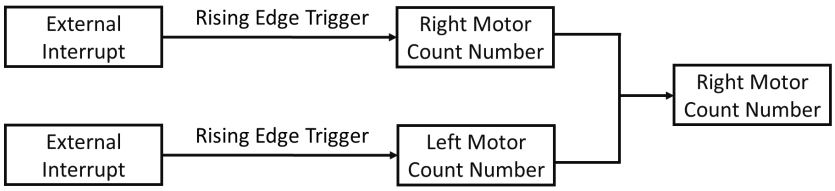


Figure 29. Measuring distance flow chart

At first, the team planned to use PID control but changed the scheme because integral control always accumulates. The speed often failed to reach the target value, which was later found to be due to the lack of friction compensation or the positive throttle limit being too small.

Secondly, speed often exceeded target value due to a misinterpretation of friction compensation as overcoming dynamic friction rather than static friction. The friction compensation value should therefore be slightly less than minimum PWM value that will allow wheel to travel slowly in a straight line after a hand push.

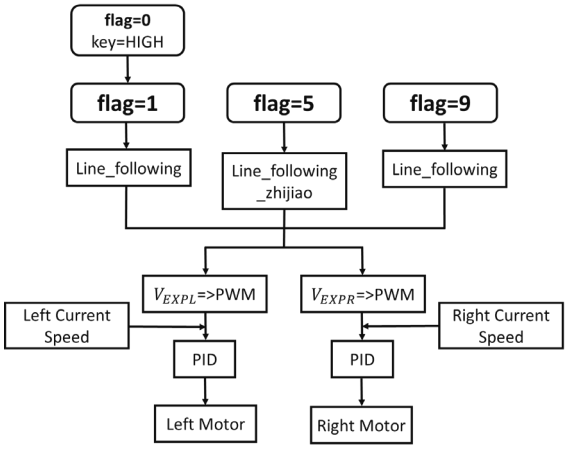


Figure 30. Line following flow chart with PID

Thirdly we found that the deviation could not be adjusted. This was because the reverse throttle limiter was set too small or the Kp value was too small and the response was not fast enough. Because the Kd value is too small to remove the vibration of the car, it oscillates a lot when the car is traveling in a straight line. When the car is traveling along an S-curve, it sometimes drifts off the tracking track when turning because the differential between the left and right wheels is not set enough to complete the turn when turning. When taking obtuse and right-angled corners, we found that the differential that previously applied to S-curves no longer applied to the second half, and that we needed to increase the differential between the left and right wheels. For this reason, we wrote a new line following the function after the first half.

In addition, in the test on the full run, later on, we found that the car would run off the road when it first started. In this respect, we wrote a small part for the start of the acceleration in the garage where there was no tracking at the beginning, as a step-by-step.

4. Result and Conclusion

The intelligent robot designed in the project can complete following tasks: Patrol line movement, walking precisely and quickly along a guide line made up of black tape. Parking in the terminal area, identifying the parking line and stopping in time. Distance display, to show precisely the length of the guide line that has been walked. Recognition of the mission object colour and drop-off, colour recognition and route selection according to the placed object after parking, drop-off of the object to the target colour area.

Compared with visual tracking patrol robot is simpler. However, there are still some shortcomings to be tested and improved, such as the optimization of the USE of PID algorithm, function encapsulation and logic simplification, etc., which will be discussed and improved in the future.

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