AN AUTONOMOUS POOL CLEANER

By

Hanwei Yu

Jiayu Zhang

Tianle Li

Wenbo Ye

Final Report for ECE 445, Senior Design, Spring 2023

TA: Cai Tielong

22 May 2022

Project No. 24

Abstract

Our project is to build an autonomous underwater pool cleaning machine that can clean up the bottom of the pool without/with minimum human intervention. The traditional way of cleaning pools requires a lot of manpower and is time-consuming and labor-intensive, but our pool cleaner can rely on algorithms to cover the entire area of the pool, saving a lot of time. The design of the cleaner includes: control system, information collection system, power system, propulsion system, body system, cleaning system, communication system and route design system. After verification, our design meets the requirements and objectives of the project, and each system can be combined with each others successfully to enable the cleaner to perform the desired functions.

Keywords: pool cleaner, waterproof, autonomous

Contents

1. Introduction

1.1 Objective

Regular pool maintenance and cleaning is essential for maintaining good pool hygiene, but traditional manual cleaning methods can be time-consuming and labor-intensive. With the increasing demand for pool usage due to improved lifestyles, there is a need for more efficient and effective pool cleaning solutions to keep pools clean with minimal intervention. Moreover, traditional methods of pool cleaning not only require extensive physical labor but also result in the excessive use of water resources, making it an environmental concern.

Our goal is to create an autonomous pool cleaner that can efficiently clean pools with minimal human intervention. The cleaner is a waterproof machine that contains sensors to detect obstacles and avoid collisions, wheels to navigate around the pool, and a brush to collect debris and particles from the pool water. In addition, it is equipped with batteries that provide power and a remote-control system that allows the machine to be started and stopped from the ground. This autonomous pool cleaner is a highly efficient and effective underwater cleaning device that can save time, effort, and water resources. It can plan an optimal cleaning path and navigate around the pool with ease.

1.2 Background

There are many companies providing pool cleaner, including Zodiac, Hayward, Pentair, Dolphin, and Maytronics. And these companies offer different kinds of pool cleaners, including manual cleaner and autonomous pool cleaners with or without wire.

The price range for a manual pool cleaner is around 200 dollars, and the price for autonomous pool cleaner with or without wire for large pool is around 1400 dollars. And our wireless autonomous pool cleaner will have the price of 600 dollars. It is more convenient than manual pool cleaner and also much cheaper than the autonomous pool cleaner in the market, which could make up for the lack of wall-climbing ability. The The cost of our pool cleaner is about 300 dollars, and the payment of our group is about 9000 dollars, which means that after selling 30 cleaners, the cost will be covered, and we are going to make profit. Overall, our pool cleaner has a high possibility to success.

1.3 Visual Aid

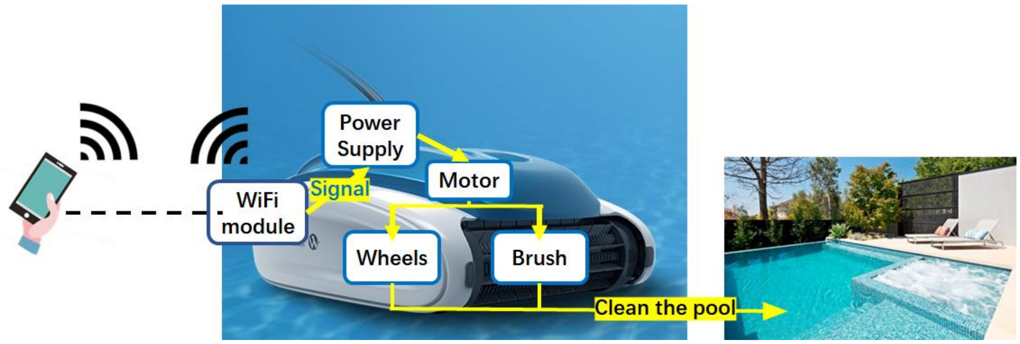


Fig. 1. Visual aid

1.4 High-level Requirements

1. The whole device need to be well waterproof to a long-time underwater work goal.

2. The pool cleaner can follow programmed routes and are able to cover the entire pool.

3. The battery of the device needs to have a large capacity to provide enough power to ensure normal work in a pool.

4. The pool cleaner runs continuously in one cleaning and is able to hold approximately 100 grams of dirt and litter.

2 Design

The hardware structure of the autonomous pool cleaner consists Power Supply Subsystem, Propulsion Subsystem, Information Collection Subsystem, Control Subsystem, Clean Subsystem, and Remote Control Subsystem. Power Supply Subsystem is used to provide different voltages. Propulsion Subsystem is used to control motors. Information Collection Subsystem is used to collect the location of the cleaner. Control Subsystem is used to control the turning angle of the cleaner. Clean Subsystem is used to control pump and the motors of brushes to work. And the Remote Control Subsystem allows people to control the cleaner remotely by their phones.

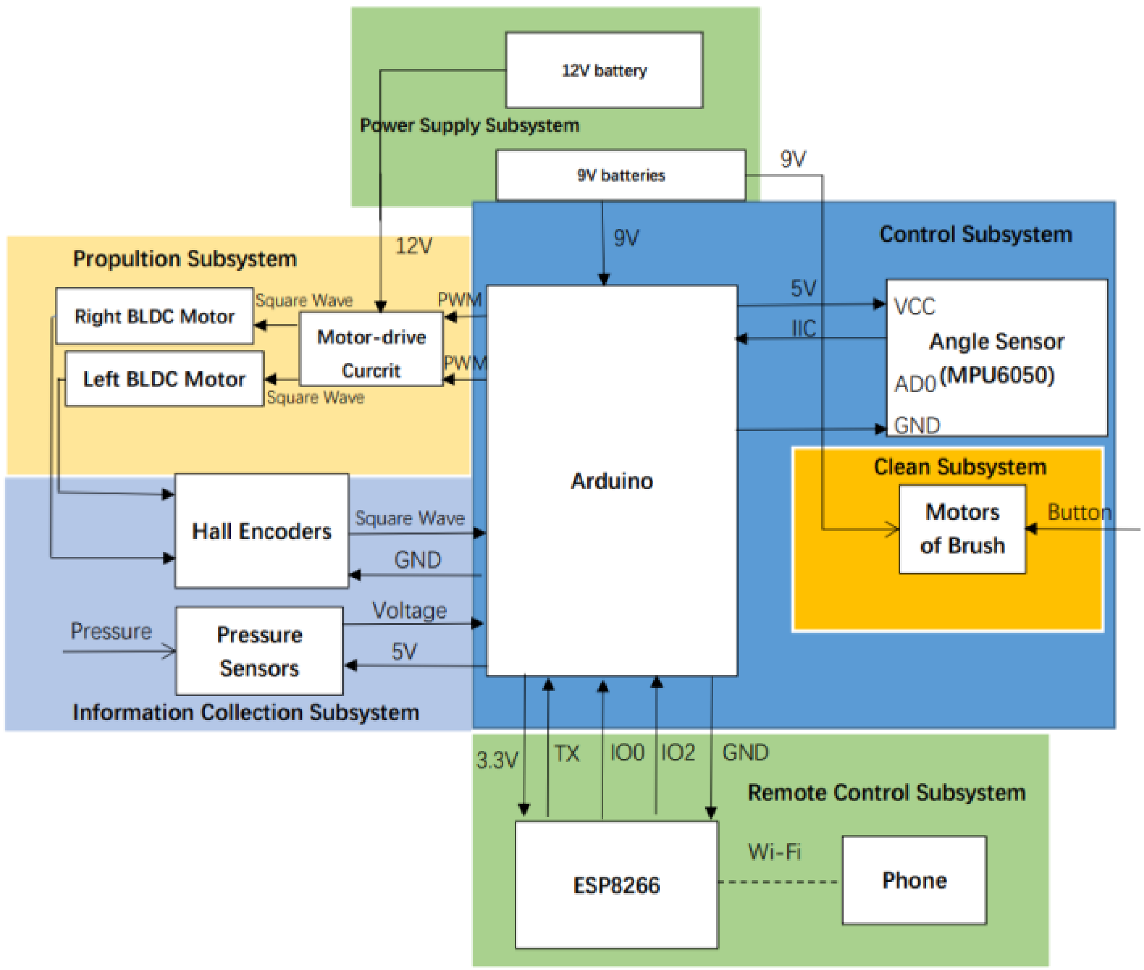
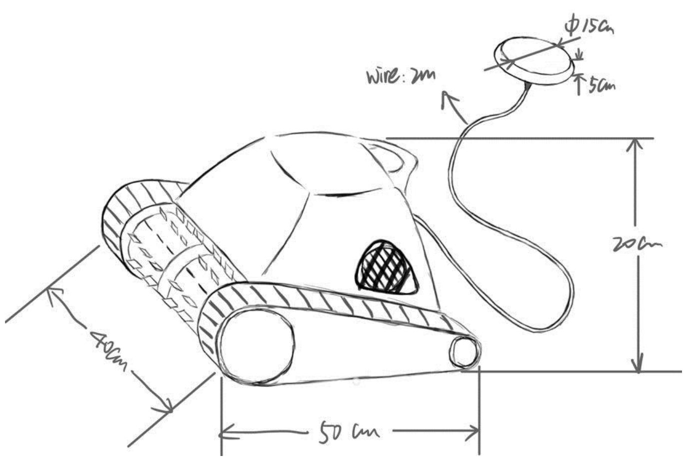


Fig. 2. Block Diagram

Figure 4 and 5 shows the original mechanical design of the cleaner. The cleaner's body consists of two main parts, one at the bottom of the pool for cleaning and moving; the other floating on the water surface, carrying the power system and the main circuits and chips. The two are connected by wires, and the power supply of the lower circuit and components is realized by the upper part and wires. Meanwhile, the upper part carries a Wi-Fi module for remote control with cell phone connection.



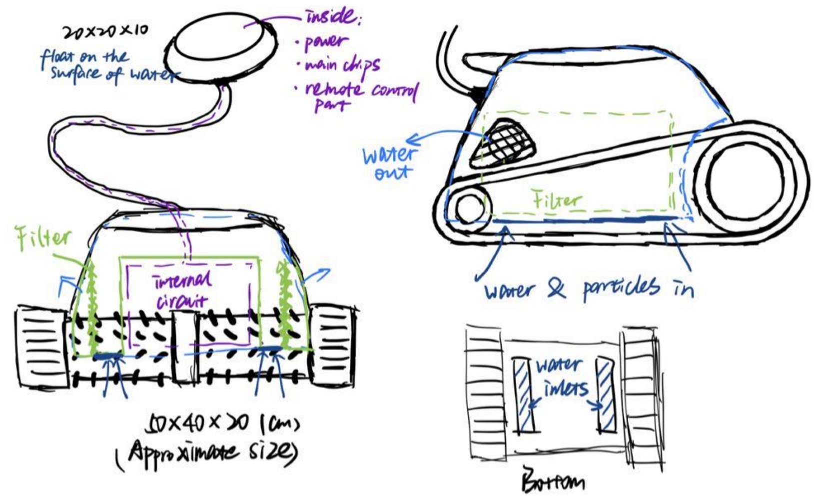


Fig. 4. Original physical design sketch **Fig. 5. Original structure sketch**

Figure 6 shows the new design of the cleaner which still has two main parts. The debris and particles will be swept into the container by the rolling brush with no limit of the size of objects. There is no more need for water pump and filter.

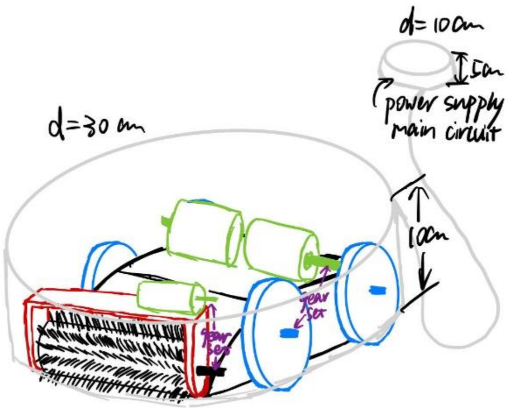


Fig. 6. New physical design sketch

According to the knowledge of fluid mechanics, shown as Figure 5, under the conditions of original suction design, if the distance between the bottom of the cart and the pool is too large, then unless the power of the pump is large, it will not be able to suck up small particles of objects; if the distance is small, then larger objects can only be pushed away and not cleaned.

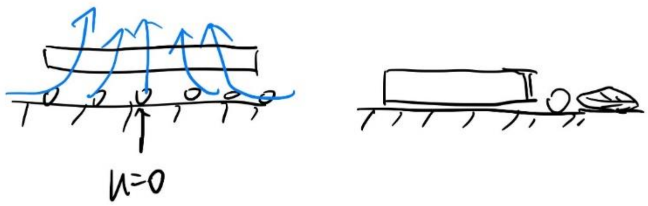


Fig. 7. Schematic diagram of the suction

For the final design, I changed the four-wheel drive to two-wheel drive and added one universal wheel at back. The floating part was also cancelled and changed into a waterproof box which is fixed on the cleaner.

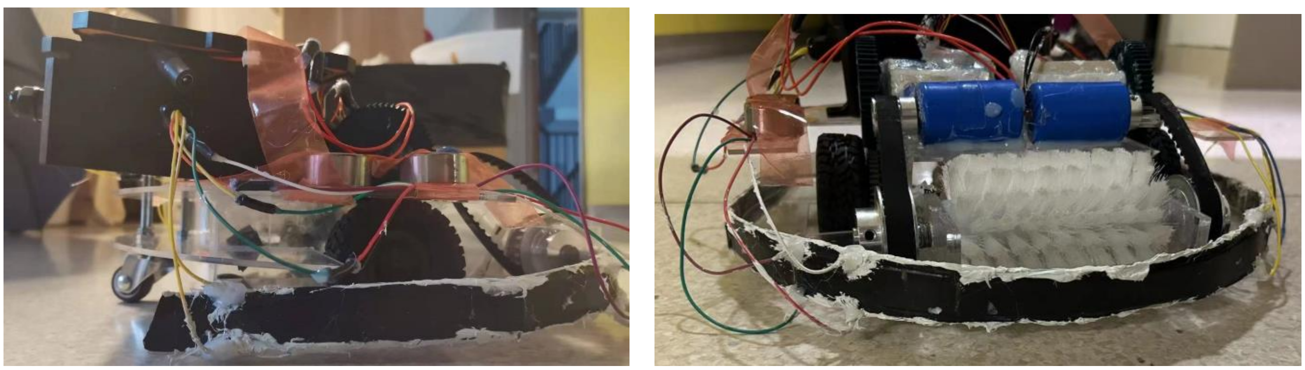


Fig. 8. Side view and front view of the final design

The circuit schematic and PCB layout are shown as follows. They contain all the main components if the whole system. The PCB is 4.535 in times 3.875 in.

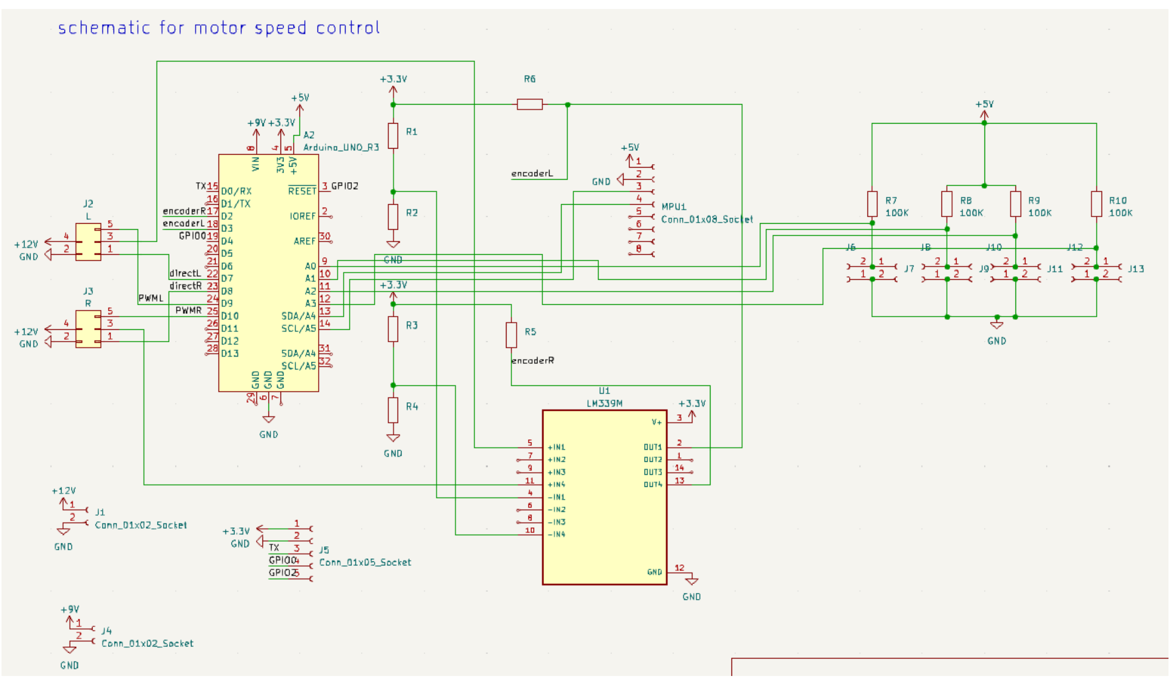


Fig. 9. schematic

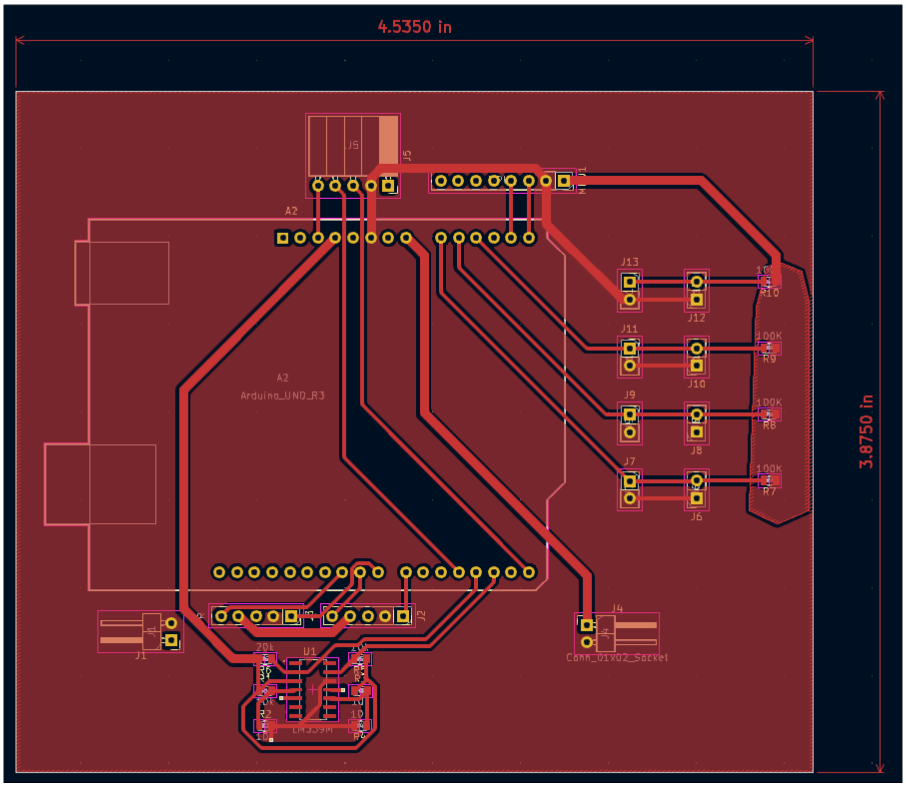


Fig. 10. PCB layout

2.1 Control system

The control system mainly controls the cleaner's movement when cleaning in the pool. Through this system, the cleaner can control the motors' speed, walk in a straight line and turn to certain angle that is desired.

2.1.1 Angle Sensor

MPU 6050 is the angle sensor that could output the angular speed. And I use integration to get the angle.

MPU 6050 has zero offset, so I calculate the mean of 2000 angular speed, and minus it to get rid of zero offset. And I let it wait 5 seconds before measure in case that the cleaner might move at the beginning of the progress.

```
delay(5000);
for(times=0; times<2000; times++)
{
  accelgyro.getMotion6(&ax, &ay, &az, &gx, &gy, &gz);
  Zzero_offset=Zzero_offset+gz;
  delay(1);
}
```

Fig. 11. Zero offset

Because there are some noises even when MPU 6050 does not move, so I filter the angular speed less than 30.

```
accelgyro.getMotion6(&ax, &ay, &az, &gx, &gy, &gz);

gx=gx-Xzero_offset;
gy=gy-Yzero_offset;
gz=gz-Zzero_offset;


if (gx < 6 && gx>-6)
    gx=0;
if (gy < 6 && gy>-6)
    gy=0;
if (gz < 30 && gz>-30)
    gz=0;

nowR = millis();
timeChangeR = nowR - lastR;
lastR = nowR;
agx += gx * pi*timeChangeR/1000.0/65.5/180/2;
agy += gy *pi* timeChangeR/1000.0/65.5/180/2;
agz += gz *pi* timeChangeR/1000.0/65.5/180/2;
```

Fig. 12. Integration and filter

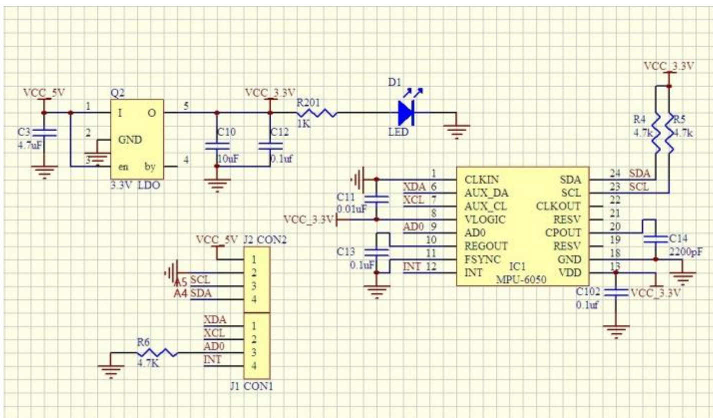


Fig. 13. MPU 6050 Circuit

2.1.2 Motor control

The motor speed is controlled by changing the duty cycle of the PWM wave, with a frequency of 20KHz and an amplitude of 3.3V-5V. The default frequency of the output signal of the Arduino is 490Hz, so the frequency of the PWM is changed by changing the Timer1 and controlling the Output Compare pins OC1A (PB1, Arduino Pin 9) and OC1B (PB2, Arduino Pin 10). The following equations shows the calculations for the desired Top value and Output Compare values.

- $$f_{desired} = \frac{system\_clock}{prescaler*(1+Top)} = 20kHz \qquad (1)$$
- $$Top = \frac{system\_clock}{prescaler*f_{desired}} - 1 = \frac{16*10^6}{1*20*10^3} - 1 = 799 \text{ with prescaler=1} \qquad (2)$$
- $$OCR1A = 800 * (1 - duty\ cycle_{left}) \text{ (reverse control)} \qquad (3)$$
- $$OCR1B = 800 * (1 - duty\ cycle_{right}) \qquad (4)$$

2.1.3 PID control

To make the cleaner walk in a straight line and turn to certain angles, I need the help of PID controls. The following figures shows the choice of Kp, Ki, and Kd if both controls.

Walk in a straight line: Kp=50, Ki=0.001, Kd=10.

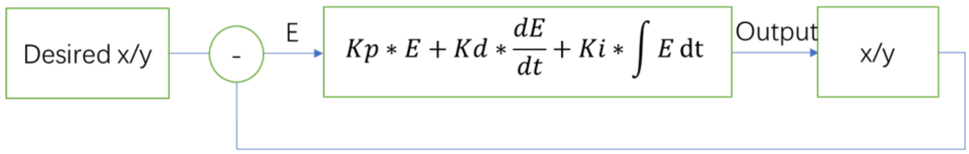


Fig.14. PID control for x/y

Turn 90°: Kp=5000, Ki=0.001, Kd=10

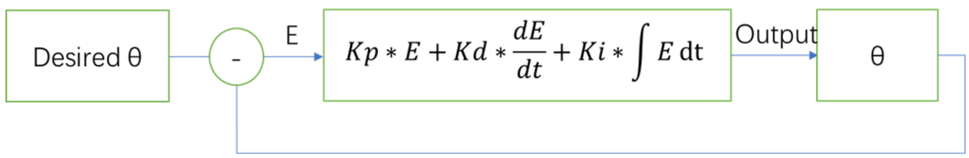


Fig. 15. PID control for θ

2.2 Information collection system

The control system mainly collects the cleaner's location and speed information.

2.2.1 Speed/location recording

We used Hall encoders, which were self-contained in the motors, to record the cleaner's transient speed. output 18 square waves each revolution. Since the speed reduction ratio of the motor is 500, it totally outputs 9000 square waves each revolution. Every short time (about 100 ms), I use interrupt pins on Arduino (Pin 2 and Pin 3) to record the transient speed of each wheel. I accumulate the speed to get an approximation of the cleaner's position in x and y direction.

If the diameter of the cleaner's active wheel is D, the number of slits is n, and the number of pulses read from the light detector A/B in time Δt is N, then the distance ΔS travelled by the trolley in Δt is

$$\Delta S = \pi DN/n \tag{5}$$

The distances travelled by the left and right active wheels in time Δt are ΔS_l and ΔS_r, respectively, and the distance between the two active wheels is B, then the distance of travel ΔS and the angle of rotation Δθ in Δt are

$$\Delta S = (\Delta S_l + \Delta S_r)/2 \tag{6}$$

$$\Delta\theta = (\Delta S_r - \Delta S_l)/B \tag{7}$$

After measuring the cleaner's motion data using sensors, the cleaner's motion model can be described in a two-dimensional coordinate system. Assuming that the robot's location at moment k-1 is (x_{k-1}, y_{k-1}), then the robot's locus at moment k is

$$x_k = x_{(k-1)} + \left(\Delta S_{(k-1)}\right)/\left(\Delta\theta_{(k-1)}\right)\left(\sin\left(\theta_{(k-1)} + \Delta\theta_{(k-1)}\right) - \sin\theta_{(k-1)}\right) \tag{8}$$

$$\theta_k = \theta_{(k-1)} + \Delta\theta_{(k-1)} \tag{9}$$

$$y_k = y_{(k-1)} + \left(\Delta S_{(k-1)}\right)/\left(\Delta\theta_{(k-1)}\right)\left(-\cos\left(\theta_{(k-1)} + \Delta\theta_{(k-1)}\right) + \cos\theta_{(k-1)}\right) \tag{10}$$

2.2.2 Pressure Sensor

I surround the cleaner with bendable pressure sensor to detect if it is touched. The pressure sensor is in the black tape around the cleaner, when it is touched, it will send voltage signals to arduino.

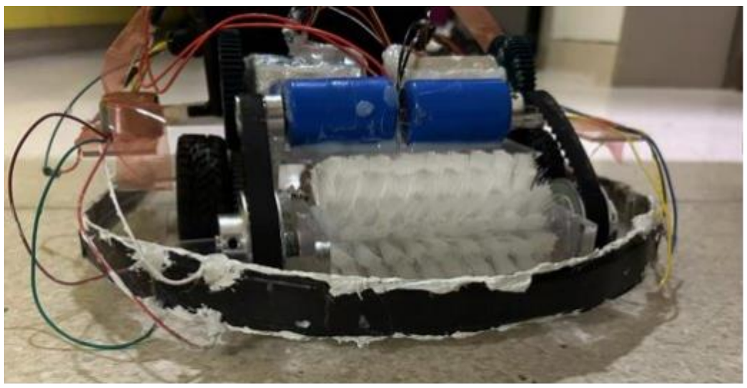


Fig.16. Pressure Sensor

The pressure sensor's resistance will decrease when it is pressed. I serial connect them with 100kΩ resistors, and use 5V from arduino to provide voltage. And I measure the voltage on the pressure sensor by port A0, A1, A2, A3 on arduino. When the sensor is pressed, the voltage measured decreases.

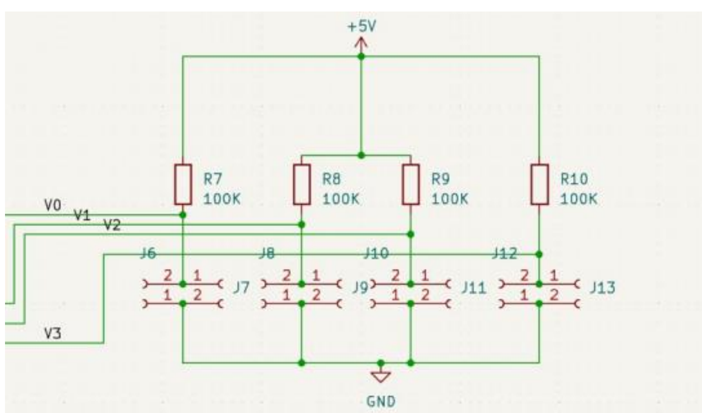


Fig.17. Circuit for Pressure Sensor

2.3 Communication system

In this subsystem, the design of a Wi-Fi module based on the ESP8266-01S chip, which will be used to remotely control a pool cleaner. The aim is to connect the module to a smartphone application and to an Arduino, which will control the pool cleaner. The CH340C chip will be used for testing purposes. The ESP chip receives the signals from the cellphone and then the Arduino board receives signals from the chip.

2.3.1 ESP8266-01S Chip

The ESP8266-01S module is a low-cost Wi-Fi chip, which can connect to a variety of networks. It was programmed using the Arduino IDE platforms. The module comes with a built-in antenna and supports a range of communication protocols. The supporting voltage of the chip is 3.3V.

Table 1 ESP8266-01S Chip Parameters

Power Consumption	Effective Range	Connection Speed	Max Throughput
around 70mA in active mode and less than 200uA in sleep mode	up to 50m indoors and up to 100m outdoors, depending on environmental factors	up to 72 Mbps	up to 16 Mbps

The module comes equipped with both UART and SPI interfaces. UART is the default interface used for communication between the ESP8266-01S and external devices such as the CH340C USB-to-serial converter, while SPI can be used as an alternative interface for certain applications.

2.3.2 CH340C Chip

The CH340C chip is a USB to serial converter chip commonly used in microcontroller programming and debugging. It allows for communication between a computer and other electronic devices that use serial communication protocols, such as the ESP8266 WiFi module.

```
  IPAddress localIP = WiFi.softAPIP();
  Serial.print("SoftAP IP address: ");
  Serial.println(localIP);

  pinMode(1, OUTPUT); //Mode
  pinMode(0, OUTPUT); //Start or Stop
  pinMode(2, OUTPUT); //Turn Right

  server.begin();
  Serial.println("Server started");

}

void loop() {

  if(State1){ //Mode
    digitalWrite(1, HIGH);
  }else{
    digitalWrite(1, LOW);
  }

  if(State2){ //Start or Stop
    digitalWrite(0, HIGH);
  }else{
    digitalWrite(0, LOW);
  }

  if(State3){ //Turn Right
    digitalWrite(2, HIGH);
  }else{
    digitalWrite(2, LOW);
    delay(500);
    digitalWrite(2, HIGH);
    State3 = true;
```

```
WiFiClient client = server.available();

if (client) {
  Serial.println("New client connected");
  String request = client.readStringUntil('\r
  Serial.println(request);
  client.flush();

  if (request.indexOf("/LED=M") != -1) {

    if(State1){State1 = false;}
    else{State1 = true;}

  } else if (request.indexOf("/LED=R") != -1)
    State1 = true;
    if(State2){
      State2 = false;
    }else{State2 = true;}

  if (request.indexOf("/LED=T") != -1) {
    State3 = false;
  }


  client.println("HTTP/1.1 200 OK");
  client.println("Content-Type: text/html");
  client.println();


  client.println("<html>");
  client.println("<head>");
  client.println("<meta name='viewport' conte
  client.println("<style>");
  //client.println("body {text-align: center;
```

Fig.18. CH340C Connected with ESP8266

Fig.19. Three Buttons on the Webpage

2.3.3 Cellphone Webpage and Interaction

Some programming was did on the ESP8266 Chip (Wi-Fi Module) through the CH340C, and the module was made into hotspot mode, so that our cellphone could successfully connect to the Wi-Fi Network of the chip, and then a webpage will be opened where the cleaner can be controlled to start and emergency stop.

The website address is the IP address of the network. The webpage consists of three buttons and some basic introductions of our course and the function of the page itself. The users should be informed the usage and find it easy and comfortable to use.

There are two mode selections, controlled by the first button. The first one is Automatic Cleaning Mode, in which the cleaner automatically finds its way and cleans the pool. However, Manual Control Mode makes us manually control the cleaner. In this mode, the cleaner will turn right exactly 90 degrees if we press the third button. The second button controls the cleaner to start or stop. When it is stop, the screen shows start. When it is stop, the screen shows stop. Every time we press start button, the default mode will be automatic.

2.4 Route Design System

Route Design Algorithm contains four part: gothrough1, gothrough2, gothrough3, and gothrough4. And it also contains the mode changing of the cleaner. When Wifi Module send Mode=1 signal, the cleaner will change mode from autonomous to ESP8266-01S Chip manual.

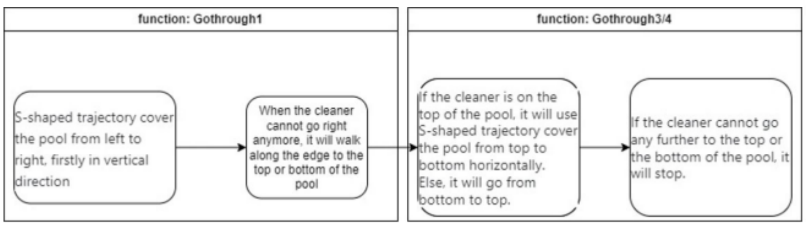


Fig. 19. Route Design Algroithm

```
void loop()//traversal
{
  // Serial.println("start looping!");
   Serial.println(agz);
  // Serial.println(x); //沿x方向走，theta是0
  // Serial.println(y);
  // Serial.print("time");
  // Serial.println(timemid-timein);
   calculate();
  if(digitalRead(START)==LOW){
    Mode=1;
  }
  if(Mode==1){
    if(digitalRead(0)==LOW){
      spinaround(agz+pi/2);
      calculate();
    }
  }
  else if(Mode==0){
    Serial.println(agz);
    if(turn==0){
      gothrough1();
    }
    if(turn==1){
      gothrough2();
    }
    if(turn==2 && direction1==1){
      gothrough3();
    }
    if(turn==2 && direction1==-1){
      gothrough4();
    }
    else{
      OCR1A=799;
      OCR1B=799;
      }

  }
```

Fig. 20. Route Design Algroithm

Gothrough1 is the step that the cleaner S-shaped trajectory cover the pool from left to right in vertical direction. This step can cover the left and right sides of the barrier.

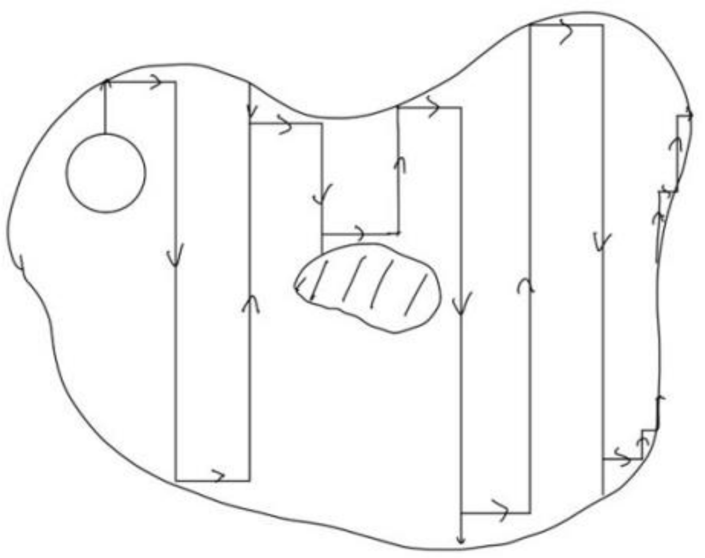


Fig. 21. Gothruogh1

Gothrough2 is the step to turn to horizontal direction.

Gothrough3 is the step when the cleaner is at the bottom of the pool and is going to cover the pool from bottom to top. This step can cover the up and down sides of the barrier.

Gothrough4 is the step when the cleaner is at the top of the pool and is going to cover the pool from top to bottom. This step can cover the up and down sides of the barrier.

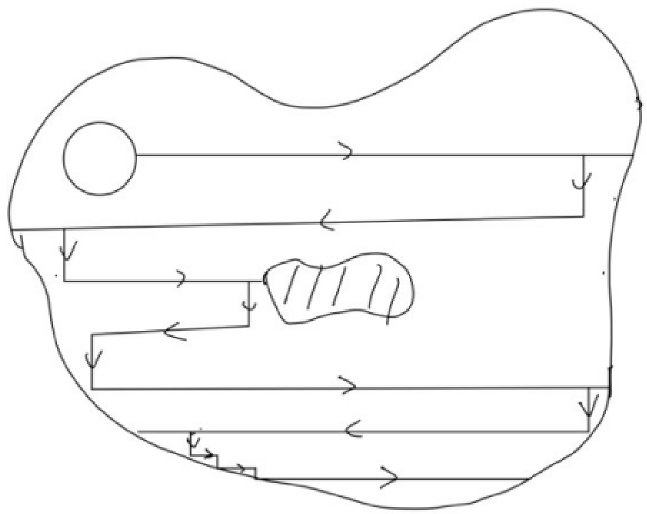


Fig. 22. Gothruogh4

And after these steps, the cleaner will stop cleaning. Because all the directions of the barrier is cleaned, the whole pool is covered.

The detailed algorithms for gothrough1, gothrough3, and gothrough4 are similar. I will take gothrough1 as an example. The cleaner first go straight in pid control in direction x (up), when it touches the wall, it will go back for 15 cm, and then it turns right and go 30 cm. After that, it will go straight in direction -x (down), then it will repeat the steps until it cannot go any further in direction right.

But there are situations where the cleaner cannot go right for 30 cm and touches the wall in the middle of it. Then the cleaner will first go in the direction opposite to the direction before it is touched (up or

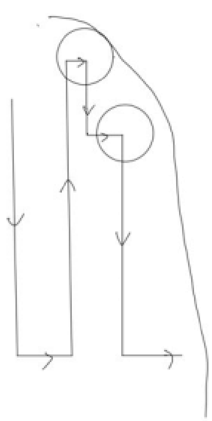


Fig. 23. Cannot go right

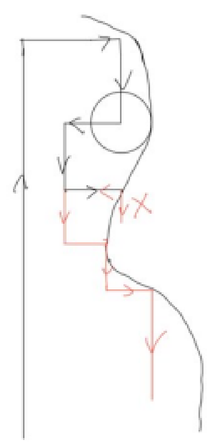


Fig. 24. Cannot go right and down

down), go for 15 cm, and then try to go right. But there are situations where the cleaner can neither go right nor go up or down. Then the cleaner will firstly go left, then go down, if down side not allowed, go left again, then go down. After go down 15 cm, the cleaner will go right again, try to continue to reach 30 cm. Time of the cleaner trying to go right for 30 cm is recorded. And if the cleaner cannot go right for 30 cm after 140s, I assume it reached the rightmost place of the pool, and the step will turn to gothrough2. At this point, the cleaner should either at the top or the bottom of the pool. Because every time it cannot go right, it will go up or down, and after 140s accumulation, it will be at the top or the bottom of the pool.

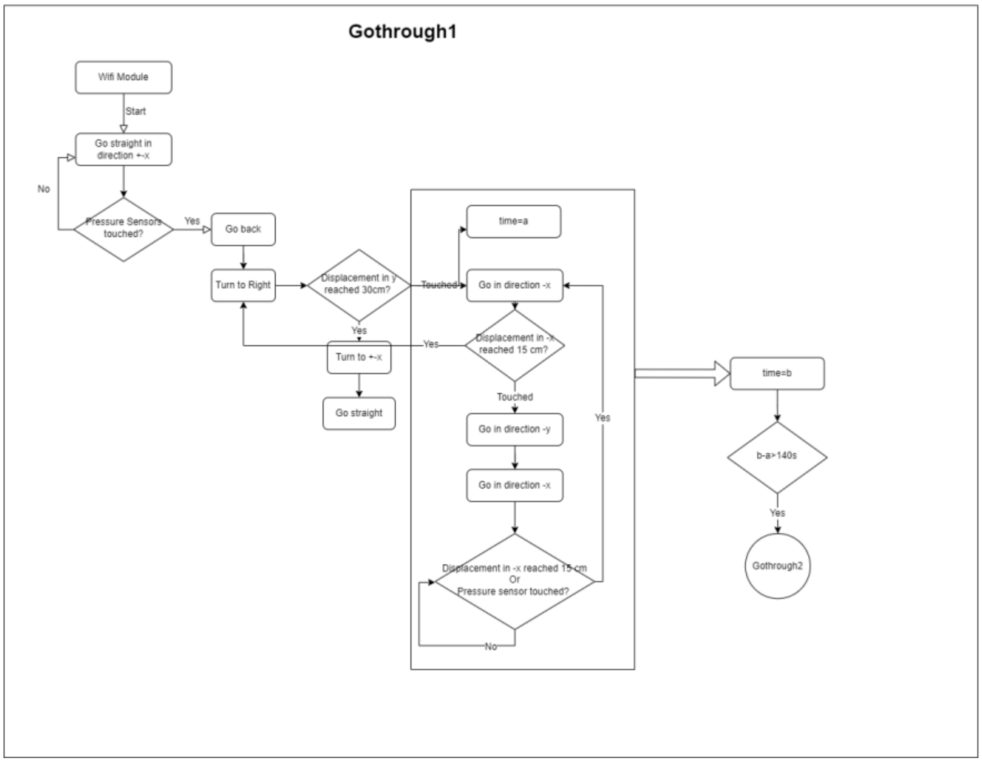


Fig. 25. Gothrough1

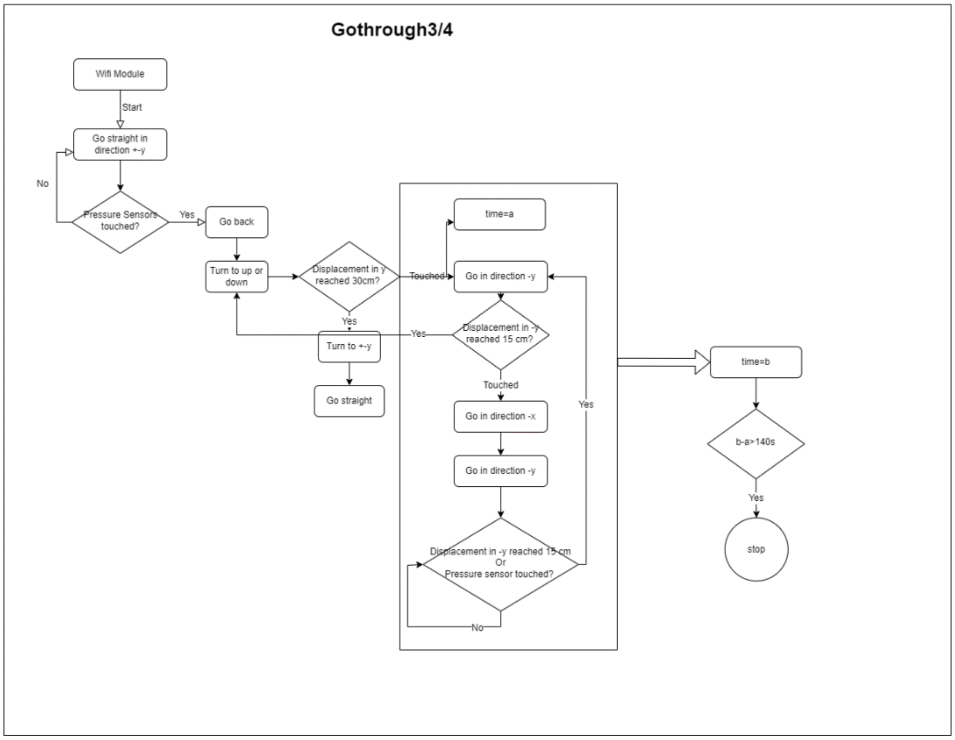


Fig. 26. Gothrough3/4

2.5 Propulsion subsystem

The propulsion subsystem contains wheels, motors and gears responsible for achieving the basic walking function of the cleaner.

2.5.1 Motor

The motor needs to provide enough power to ensure the proper functioning of the wheels. The weight of the cleaner is 2.5kg. The coefficient of friction at the bottom of a standard pool is at least 0.5. The diameter of the wheel is 67mm.

The torque each wheel needed to overcome friction:

$$\tau = F \cdot r = \frac{\mu F_N}{2} r = \frac{\mu m g}{2} r = \frac{0.5 \times 2.5 \times 9.81}{2} \times \frac{67 \times 10^{-3}}{2} = 0.21 Nm \qquad (11)$$

The output of each motor equals to $3kg \cdot cm = 3 * 9.81 * 0.01 Nm = 0.29 Nm$. Considering the gear efficiency of 90%, the torque is still enough.

2.5.2 Wheels

The wheels are driven by motors and are used to achieve the basic action functions of the cleaner. Wheels made of harder material and with greater friction coefficient are chosen to prevent slipping. One more universal wheel is needed to keep balance.

Diameter 67mm　　Thickness 25mm

Fig. 27. Type of wheels

2.5.3 Gears

Considering the space for the collector, the gears are necessary. I used 1:1 gear ratio of two-gears (56 teeth) set to reduce transmission loss and the difficulty to limit the position of gears.

2.6 Cleaning System

The cleaning method is changed from suction to sweep, thus only a brush and two motors, two pairs of synchronous wheels and belt set and a collector for particles are need. Filter and water pump are canceled.

2.6.1 Brush

The length of the brush is 100mm, the diameter is 70mm and the length of bristles is 20mm. The bristles are stiff enough to sweep up particles like coins.

2.6.2 Motors and synchronous wheels and belt

They are used to drive the motor. The motor is waterproofed itself. The gear ratio of the synchronous wheels is 2:5 to prevent brushes from spinning too fast.

2.6.3 Collector

The collector is made of acrylic boards so that users can clearly see what are cleaned by the robot. A ramp is added to the bottom of the collector to facilitate the collection of objects. The collector is slightly wider than the brush, and the edges are kept at a distance from the brush to prevent it from getting stuck.

2.7 Body System

The body system is the overall mechanical design, including the shell and base of the cleaner as well as the internal parts and structural design.

2.7.1 Material

The device is basically made of acrylic boards because of the time limitation due to our change of design. At the same time, the acrylic plates are lighter to ensure that the motor can drive the whole device.

2.7.2 Waterproof

Waterproofing is a critical point for our project since it is the premise that the other functions of the cleaner work properly. For the motors I designed a shell for waterproofing and to fix its position. It has a rubber seal output axis of motor. We filled the inside space with waterproof glue and reinforced outer surface with it as well considering the properties of 3D printing product. The gaps are covered with waterproof tape to further guarantee waterproofing.

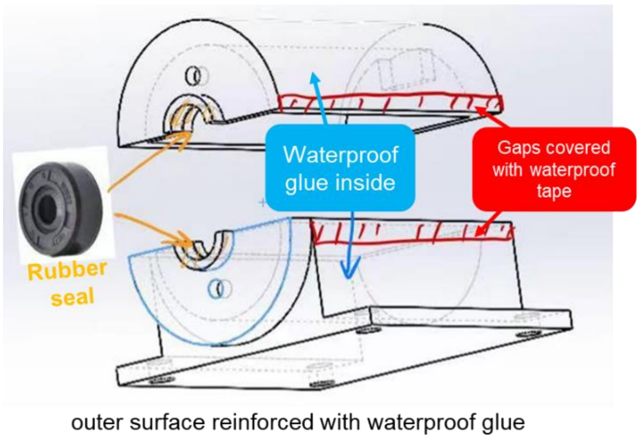


Fig. 28. Waterproofing of motor

For Pressure sensors I used taps and glue to achieve waterproofing and a waterproof box for circuit and batteries.

Fig. 29. Waterproofing of pressure sensor and circuits

3. Design Verification

3.1 Control system

Because the control system and the information collection system are interlinked, only if both systems function correctly, the cleaner can follow the planned route, and can be represented in the video or image.

3.1.1 Straight forward

Fig. 30. the figure shows that the vehicle can walk in a straight line

3.1.1 Turning

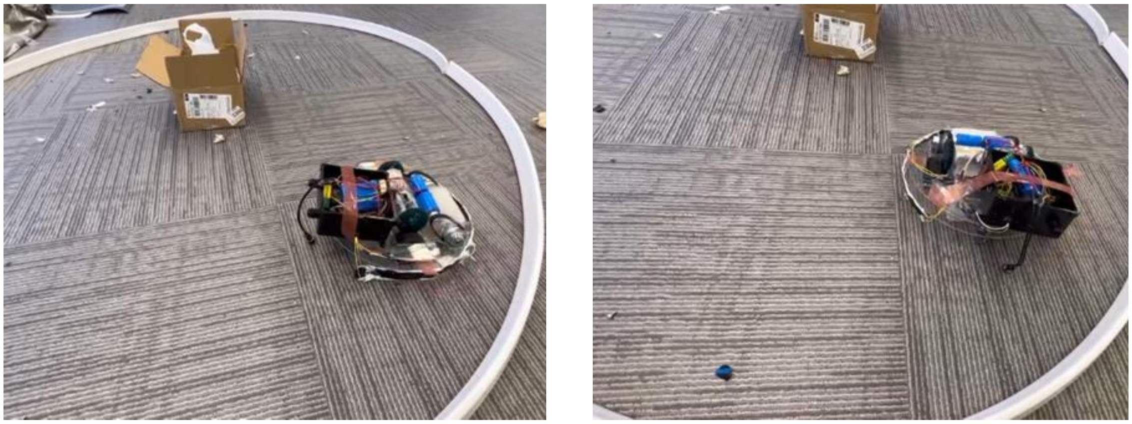
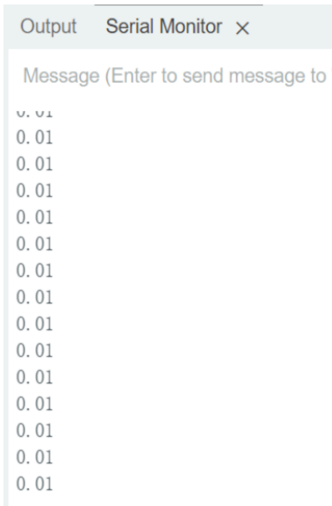
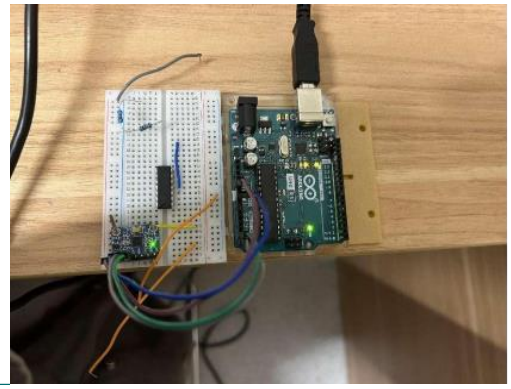


Fig. 31. the figure shows that the vehicle can turn 90°

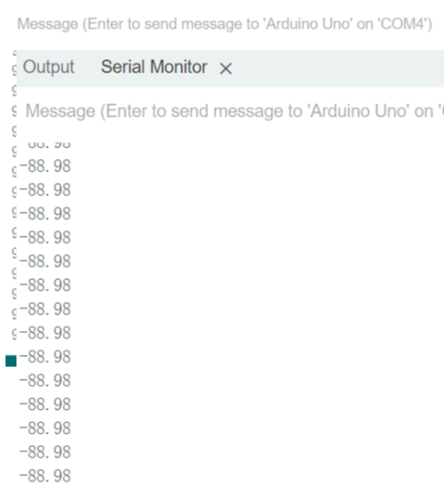
3.1.2 Angle Sensor

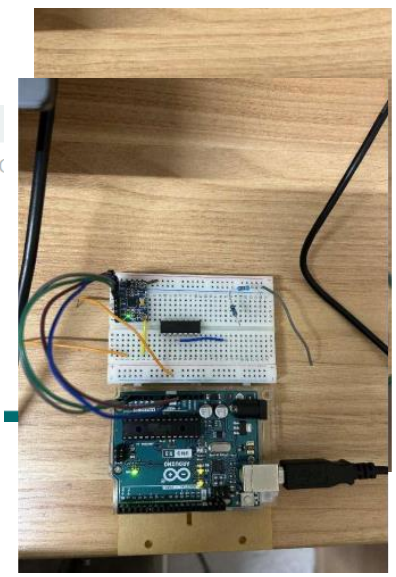
The board is at first horizontal to the desk edge, and the tested degree is 0.01.





When the board turn 90 degrees counterclockwise, the tested degree is 90.42. The error is 0.42/90=0.467%, it is in 1%.

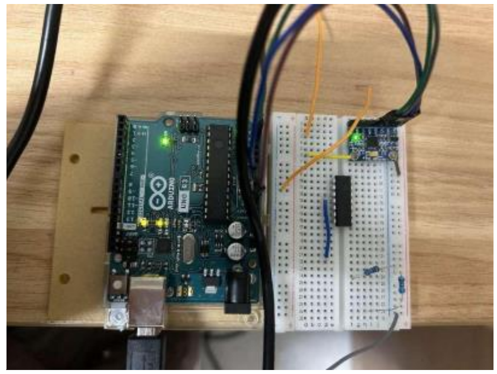




When the board turn 90 degrees clockwise, the tested degree is -88.98. The error is 1.02/90=1.13%.

When the board turn 180 degrees clockwise, the tested degree is -179.21. The error is 0.79/180=0.439%, it is in 1%.


Output
Serial Monitor
Message (Enter to send message to 'Arduir
-179. 21
-179. 21
-179. 21
-179. 21
-179. 21
-179. 21
-179. 21
-179. 21
-179. 21
-179. 21
-179. 21
-179. 21
-179. 21
-179. 21



4. Costs

4.1 Parts

Table 2 Parts Costs

Part	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
MPU 6050	1.38	1.38	1.38
Pressure Sensor	3.43	20.6	20.6
Synchronous wheels (10 teeth)	0.79	1.58	1.58
Synchronous wheels (25 teeth)	1.64	3.28	3.28
belts	0.54	1.08	1.08
Waterproof motors	4.13	8.26	8.26
wheels	0.88	1.76	1.76
Universal wheel	0.70	0.70	0.70
brush	4.98	4.98	4.98
Waterproof glue	3.53	3.53	3.53
Waterproof tape	1.40	1.40	1.40
Rubber axial seal	0.50	1.0	1.0
Shaft (D5mm L5mm)	0.046	0.092	0.092
Shaft (D8mm L5mm)	0.18	0.72	0.72
Motor of wheel	5.57	11.14	11.14
Arduino	20.7	20.7	20.7
Wi-Fi Module (ESP8266-01S)	1.5	4.5	4.5
Electronic Component Box	1.0	1.0	1.0
USB to Serial Chip (CH340C)	2.0	2.0	2.0
Waterproof and anti-slip floor mat	10.0	20.0	20.0
Waterproof switch	3.143	3.143	3.143
Insulation potting adhesive	0.486	0.486	0.486
Insulation tape	1.7143	1.7143	1.7143
Total	**/**	**114.0453**	**114.0453**

4.2 Labor

The salary for every person is $30/hour, and everyone works 10 hours per week. It takes us 8 weeks to finish the design. We have four members in the group, so the total cost for labor is 30*10*8*4=9600$.

5. Conclusion

5.1 Accomplishments

Through the course of this project, we successfully designed and built a pool cleaner that automatically cleans up the whole bottom of the pool without or with minimal human intervention.

The functions of wireless transmission include: the startup, movement, and stopping of the cleaner are controlled by a smartphone through a Wi-fi module. When the user pressed “start/stop” on the phone, the cleaner automatically traversals the pool bottom and sweeps in the dirt and trash. The process can be stopped by pressing “start/stop” on the phone again. The user can also choose another mode on the phone to manually control the movement of the cleaner.

The control system uses a combination of Hall encoders, algorithms, and PID control to enable the vehicle to go straight and steer in place.

The information collection system uses a combination of MPU 6050, algorithms, and the control system to allow the vehicle to navigate through the environment and reach every part of the pool bottom.

For the motion subsystem, when working underwater, the gear transmission is not stuck, and the tire does not skid. The overall velocity accords with the theoretical calculation. For the cleaning subsystem, objects less than 3mm in height can be collected, and there is no distinction as to the hardness of objects.

We also made the underwater cleaner completely waterproof. Waterproofing works mainly on: motors, pressure sensors, wires and circuits. To test if the cleaner is waterproof, we place the cleaner underwater and pour a lot of water on it. When we turn it on, the cleaner is not damaged.

5.2 Uncertainties

There are several challenges and uncertainties that may affect the functions of the cleaner.

It is not precise enough to record the location of the cleaner using one phase Hall encoder. The error comes from the fact that when the cleaner is backed up or turned (one wheel is backed up), according to the program setting, the information collection system calculates the displacement of the section where the wheel is slowing down (still moving forward) as negative, thus making the calculated coordinates different from the actual coordinates. However, since the coordinates are only used to control the cleaner in a straight line, this error has little effect on the cleaner navigating through the pool.

Acrylic material strength is low, resulting in the component limit will be affected by gravity, and the device itself is easy to be damaged. The scope of the robot's actual cleaning is limited and it can't deal with objects in the corners. At the same time, many metal parts of the device are exposed to water, which is easy to rust, affecting the use of the equipment.

5.3 Ethical considerations

IEEE Code of Ethics require us to put the safety, health and welfare of the public first [1], and we will ensure that cleaner is designed with safety and environmental sustainability in mind. We need to ensure that the components of the cleaner can operate for long periods of time under a certain water pressure and must completely prevent dust or water vapor from entering the control module and circuitry to prevent operational failures and safety issues from leakage and rechargeable battery leaks. Therefore, strict enforcement of IP68 guidelines through the use of waterproof coatings and the design of a tight waterproof structure is necessary for the safe operation of the cleaner.

ACM Code of Ethics 1.6 mentioned privacy [2], we will ensure that the pool data and location information collected by cleaner will not be leaked and will not violate the rights of users.

5.4 Future work

A very simple and easy-to-implement improvement plan is to add a power switch and a total control signal to the device so the user can start the brushes and the motors at the same time.

Since the performance of Arduino is too low, it is not very suitable for running complex programs. It is recommended to change it to FPGA or other microcontrollers to prevent the code from becoming too complicated or the microcontroller from consuming too much power when adding new functions.

As to structure, first is to replace the acrylic sheet with a material with higher structural strength. At the same time, further optimization the structural design is necessary which includes control the center of gravity in the middle of the cleaner to prevent it from leaning forward or leaning back and increase the scope of the sweep.

References

[1] Ieee.org, “IEEE code of Ethics,” IEEE. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 08-Mar 2023].

[2] “ACM Code of Ethics and Professional Conduct ,” [Online]. Available: https://www.acm.org/code-of-ethics[Accessed: 08-Mar 2023].

Appendix A

Requirement and Verification Table

Table 1 System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Requirement a. Pid control should control the cleaner to turn to certain angle in 10s, and the pression should be in 1°. b. Pid control should let the cleaner maintain a certain angle after turning.	1. Verification a. Draw a straight line on the floor and let the machine parallel to it. And let the cleaner turn 60°. Then measure the actual angle it turns. If the angle is between 59° and 61°, it success. b. Use a long ruler to see if the cleaner goes straight.	Y
2. Requirement a. The cleaner should be waterproof.	2. Verification a. Place the cleaner underwater and turn it on. Pour a lot of water on it, and see if it is damaged.	Y

Schedule

Table 2 Schedule

Week	Jiayu Zhang	Tianle Li	Wenbo Ye	Hanwei Yu
3/13/2023	Select proper MPU 6050, MPU 6050 implementation on arduino	Confirm the design of information collection system, buy some elements for experiment. Learn arduino.	Became familiar with the Arduino platform and C++, learned how to use the Wi-Fi module to implement remote control	Refer to the existing pool cleaning robots on the market to determine the approximate size and structure of our cleaner.
3/20/2023	Finish and order version 2 PCBs MPU 6050 output and control the turning angle of a car with pid control.	Purchase elements such as ultrasonic sensors, stepper motor, and optical encoder. Write basic functions on arduino to enable the motor to spin, measure	Purchase an ESP8266-01S and its connector CH340C. Consider the path planning that may need to be used for more complicated environments such as irregular pools or	Complete sketch design. Searched and compared components such as DC motors, pumps, tracks, filter. Start modeling of the cleaner.

		distance, and avoid obstacles.	encountering obstacles.	
3/27/2023	Design and test the circuits that output 3.3V/5V/9V/12V. Design motor-drive circuits.	Connect the ultrasonic sensor with the stepper motor. Complete the wall following algorithm.	Learn the AT instruction set and do some basic programming for ESP8266 module; planned to connect a cellphone to the WIFI network of the chip, and then the phone will receive a webpage where the cleaner can be controlled	Update sketch design. Determine the specific type of elements including DC motor, wheels and filter. Solve the waterproof problem of the main circuit. Complete the modeling of some components.
4/3/2023	Work on information collection subsystem.	Try to record the position and angle of the cleaner through the optical encoder. Refine the information collection system.	Develop a webpage or smart mobile application to connect to ESP8266-01S Wi-Fi modules.	Determined the internal structure. Solve the waterproof problem of the motor underwater. Keep on modeling.
4/10/2023	Work on PCB design.	Further improve the cleaner's performance to make it walk more precisely.	Use network protocols to enable communication between mobile phones and Wi-Fi modules	Refine and optimize modeling. Start 3D printing of components.
4/17/2023	Test the whole system.	PCB design.	Connect the ESP 8266-01S to the Arduino motherboard and achieve mobile phone control over the start and stop of the cleaner	Complete the modeling and print the shell. Test the waterproof performance and structural strength of the body.
4/24/2023	Test the PCB board and assemble the whole cleaner.	Choose a reasonable method for conducting environment testing. Conduct environment testing	Further optimize the cleaner's performance in more complicated environments	Assembling the cleaner. Optimize the waterproof treatment.
5/1/20	Test the whole cleaner.	Test the whole cleaner. Prepare for final demo.	Test the whole cleaner. Prepare for final.	Test the cleaner. Prepare for demo and fianl report.