ECE 445 Project Proposal

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An autonomous pool cleaner

#Team 24

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1. Introduction

1.1 Problem

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.

1.2 Solution

Our solution 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 brushes and filters 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.

1.3 High-Level Requirements

- The battery of the device needs to have a large capacity to provide enough power to ensure normal work in a swimming pool of at least 500 square meters.
- The pool cleaner can follow programmed routes and are able to cover the entire pool.
- The pool cleaner runs continuously in one cleaning and is able to hold approximately 500 grams of dirt and litter.

2. Design

2.1 Physical Diagram

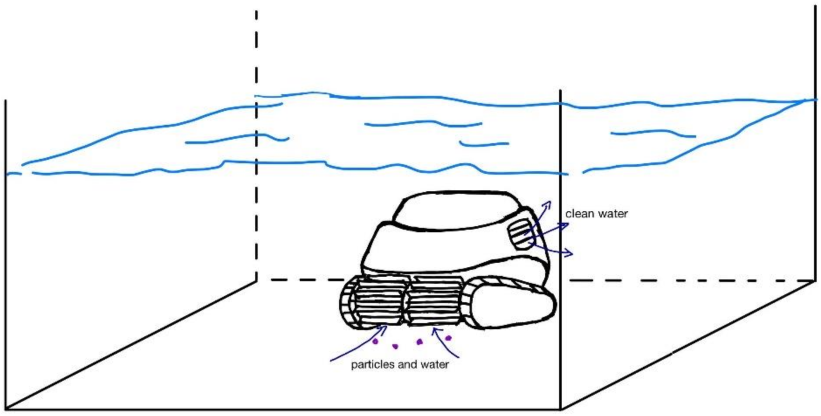

Figure 1

2.2 Block Diagram

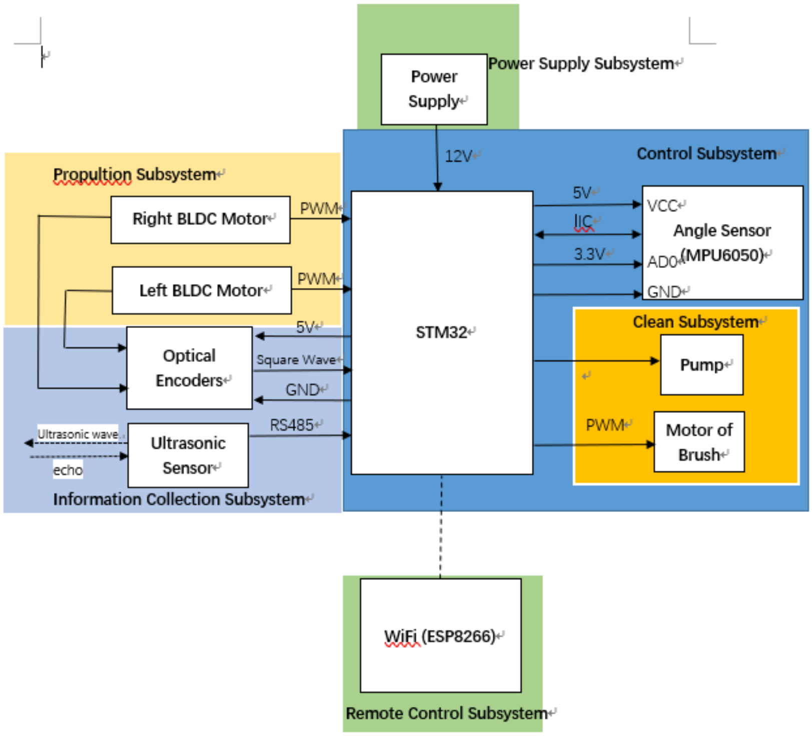

Figure 2

2.3 Subsystem

2.3.1 Power Supply Subsystem

Description:
It contains rechargeable batteries that offer power to STM32, motors, pumps and ultrasonic sensors.

Requirement:
12V Batteries

2.3.2 Cleaning Subsystem

Description:
The process of water purification is through the brush to sweep the pool's garbage to the bottom of the cleaner, the pump will pump the water and garbage from the bottom suction port to the inside of the cleaner, the water pumped up through the internal filter and then discharged from the body's outlet, the impurities in the water will be left in the body by the filter, so as to achieve the effect of water purification.

Requirement:
The brush to have a certain breadth of coverage and the bristles need a certain degree of hardness to concentrate the garbage. The maximum head of the water pump should be slightly larger than the body, and has a large power to be able to suck up the impurities in the water. In addition to filtering visible impurities in the water, the filter should also have the function of purifying harmful particles in the water to achieve a more thorough water purification.

2.3.3 Propulsion Subsystem

Description:
Propulsion subsystem contains wheels, tracks and motors, responsible for achieving the basic walking function of the cleaner.

Requirement:
The wheels, in addition to allowing the cleaner to achieve basic movement functions, also need to ensure that there is a large enough friction with the bottom of the pool that it will not slip during travel. The motor needs to provide enough power to power the pump and the wheels to work. According to our design of the weight and of the cleaner, the output power of the motor should be above 40w.

2.3.4 Body Design Subsystem

Description:
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.

Requirement:

The body design of the cleaner focuses on the design of the shell. the shape and material of the shell need to be able to resist the pressure of the bottom of the deep water of the pool, to ensure the work of the cleaner. At the same time, the shape of the shell needs to minimize the resistance of the cleaner in the underwater movement, saving battery energy. The most important point is that the design and material of the shell should be completely waterproof to protect the internal circuitry and chips. At the same time, it should be noted that in order to ensure that the cleaner has been walking against the bottom of the pool, will not float during the work, we need to increase the overall counterweight of the cleaner whose weight should be roughly 5kg.

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2.3.6 Information Collection Subsystem

Description:

Use ultrasonic underwater sensors to enable the robot to walk underwater along walls, steer etc. The robot moves around the pool’s edge starting from a certain position. Use this to create the pool's contour information L,W.

Requirement:

We use two ultrasonic sensors to detect the distance between the wall and the cleaner. The ultrasound probe emits ultrasound, which propagates through the water, encounters the target, and is reflected back to the ultrasound probe. The distance between the probe and the measured target can be calculated by D=C*T/2 and transmitted to the STM32 in hexadecimal form. The following is the data of the sensor we will first try with.

frequency	Voltage supply	Measuring distance	Blind spot	-3db angle	angle
300KHZ	12V	7.50 m	0.30 m	10°	23°

Table 1

Here is how to keep the cleaner a distance L from the wall. Assume the cleaner goes clockwise.

In the beginning, let both wheels of the cleaner walk at the same duty cycle, ensuring that the ultrasonic sensor is perpendicular to the cleaner's direction of travel and that the vertical distance from the wall is slightly greater than L. The angle between the cleaner and the wall is smaller than θ/2. Allow the cleaner to move at a high speed. At the same time, the ultrasonic sensor starts to operate. The emission angle of the ultrasonic sensor is θ. If the angle between the central axis of the beam and the wall-normal is large, the ultrasound reflected cannot be received, or the error is large, so the angle between the central axis of the beam and the wall-normal should be controlled within θ/2.[1] Since the ultrasonic sensor position is fixed on the cleaner, the ultrasonic sensor's rotation angle equals to the cleaner's rotation angle. In order for the car not to lose control, we require the drift angle of the cleaner α with respect to the wall is also less than θ/2. Then we can get

$$\alpha = \frac{(\omega_1 - \omega_2)rt}{2\pi l} \times 360° < \frac{\theta}{2}$$

Due to the small difference in speed between the two wheels, the drift angle when the cleaner first passes through the plane at a distance L from the wall is less than θ/2, and then the cleaner can walk close to the wall through the proximity wall-following algorithm. If the speed difference between the two wheels is determined, the smaller the drift angle at the first pass of L, the straighter the cleaner will go; conversely, the trajectory will be smoother, but the cleaner may lose control.

We also need to analyze the limit positions to avoid collision. The car body is considered to be rectangular. In differential steering, the body is moving in a circle around an axis. If the car collides with a wall, the collision site must be the two top corners of the front of the body, as shown in the picture.

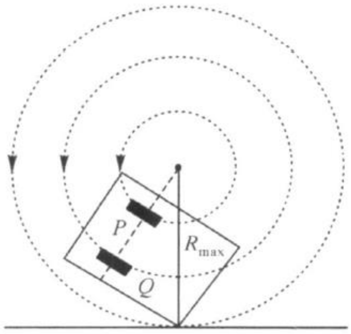

Figure 3

The front of the car is also equipped with an ultrasonic sensor, which requires the car to turn 90° to the right when the distance of the car from the wall is less than the set value.

After the cleaner has walked around the pool wall, the data from the MPU6050, the optical encoder and the ultrasonic sensor measure the map contours L and W and input the information to the STM32.

Tolerance Analysis:

The wall-following algorithm is only possible if the pool is a rectangle and the walls are flat. If the pool is irregular, a more advanced algorithm is required to implement the traversal.

2.3.7 Control Subsystem

Description:
Control Subsystem consists of a MPU6050, which is to detect the angle of the cleaner; a STM32 board that is used to receive the signal from MPU6050, ESP8266, Photoelectric sensors, and Ultrasonic sensors. And STM32 will send different PWM waves to control motors.

Requirement:
MPU6050:
It will output the angle of the cleaner to STM32. We can use the angle in PID control and make the cleaner turn to certain angles.
Incremental pid control algorithm:
u(k) = $Kp \cdot \Delta e(k) + Ki \cdot e(k) + Kd \cdot [\Delta e(k) - \Delta e(k-1)]$
$\Delta e(k)$ will be calculated by the desired angle $\theta 1$ and the current angle $\theta 2$.
$\Delta e(k)$= $\theta 1 - \theta 2$.
u(k) will be added to PWM waves to control the motor and make the cleaner turn to a certain angle.
To control the cleaner go straight, we need to make the right motor and left motor run in same speed. With signals from right and left photoelectric sensor, we can get the speed difference. And by using the speed difference as $\Delta e(k)$, the cleaner can go straight.
Optical encoder:
Optical encoders are used to accurately measure the displacement of a robot as it travels. The optical encoder is a sensor that converts the angular displacement into an electrical pulse signal by photoelectric conversion. The code disc is engraved with equally spaced radiating light-transmitting slits and rotates coaxially with the motor. The diode emits light, which is absorbed by the light-sensitive detector through the equally-spaced slits and the signal is processed to output three sets of square wave pulses. The incremental optical encoder outputs A and B pulses with a 90° difference so that the direction of rotation can be easily determined. At the same time, it outputs a marker signal Z for each rotation of the code disc. The Incremental optical encoder is easy to implement, with a long average mechanical life of tens of thousands of hours or more. It also has high resolution, high resistance to interference, long distances of signal transmission and high reliability.
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

$$\Delta S = \frac{\pi D N}{n}$$

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

$$\Delta S = \frac{\Delta S_l + \Delta S_r}{2}$$

$$\Delta\theta = \frac{\Delta S_r - \Delta S_l}{B}$$

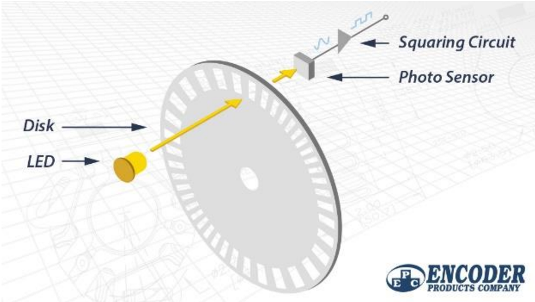

Figure 4

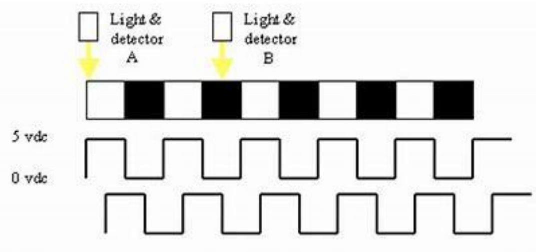

Figure 5

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

$$x_k = x_{k-1} + \frac{\Delta S_{k-1}}{\Delta\theta_{k-1}}(sin(\theta_{k-1} + \Delta\theta_{k-1}) - \sin\theta_{k-1})$$

$$y_k = y_{k-1} + \frac{\Delta S_{k-1}}{\Delta\theta_{k-1}}(\cos\theta_{k-1} - cos(\theta_{k-1} + \Delta\theta_{k-1}))$$

$$\theta_k = \theta_{k-1} + \Delta\theta_{k-1}$$

2.3.8 Route Design Subsystem

Description:

Inner helical trajectory. The spiral trajectory can help to reduce the overall cleaning time required, which can help to improve the robot's performance and reduce energy consumption.

Requirement:

Commonly used strategies in traversal path planning include random turn strategy (a), roundabout S-type strategy (b), and inner spiral strategy (c). The first strategy is extremely inefficient. The second S-type strategy is simple to control, the path is regular, and the direction can be corrected multiple times according to the wall.

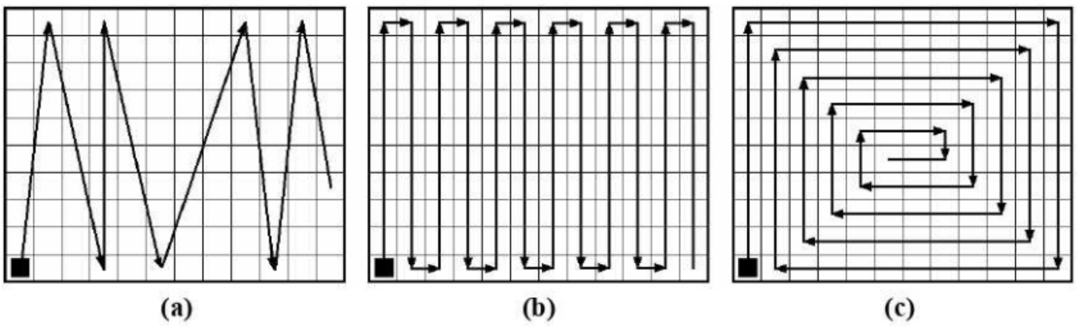

Figure 6

The third strategy, Inner helical trajectory refers to the spiral path taken by a pool cleaning robot during its cleaning process. This method of cleaning has several advantages over other methods, such as reducing the overall cleaning time required, which in turn improves the performance of the robot and reduces energy consumption. More importantly, since the cost of turning is relatively high, this strategy can make as few turns as possible. Due to the limitation of not being able to turn in place, we will further move back and forth to supplement the positions that have not been swept. By following a spiral path, the robot is able to cover the entire pool area systematically and efficiently, without missing any spots. Additionally, this trajectory allows the robot to clean in a way that minimizes unnecessary movement and energy, Resulting in a more cost-effective and environmentally friendly cleaning solution.

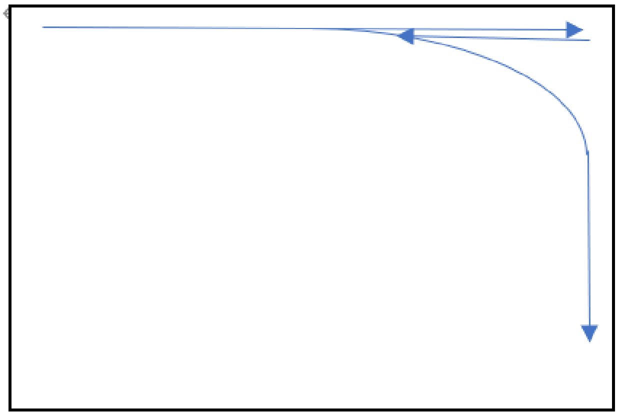

Figure 7

We'll choose this path for the basic function of a pool cleaner. If it is necessary to adapt to more complex environmental conditions in the future, such as irregular swimming pools, obstacles in the swimming pool, etc., we have prepared more solutions. First, use the Grid Map to estimate the absolute position of the pool cleaner, and approximate the environmental information, with a grid no larger than the cleaning width as the smallest unit of the Grid Map. Second, use the A* algorithm, a heuristic search algorithm, for intelligent path search, avoiding obstacles and adapting to complex environments.

Tolerance Analysis:

Swimming pool cleaners are generally designed to clean the entire surface of the pool. However, there is always a risk that the cleaner may miss certain areas or corners due to its design or limitations in its technology. This could result in some debris or dirt being left behind, which could lead to a buildup over time and potential hygiene issues. To verify the effectiveness of a pool cleaner in reaching all areas, it is recommended to conduct an external camera tracking test while the cleaner is operating in a dry pool environment. By continuously monitoring the cleaner's movements and coverage, it can be determined whether it is successfully cleaning all areas or if there are any blind spots. This type of testing can help to identify any potential issues and ensure that the cleaner is operating at optimal performance to maintain a clean and safe swimming pool.

2.3.9 Communication Subsystem

Description:
In this particular system, the STM32 microcontroller communicates with an Android app through an ESP8266 WiFi module. The main function of the Communication Subsystem is to remotely control the startup and emergency stop of the pool cleaning robot, avoiding the need for underwater operation and reducing safety concerns. Additionally, it can also be used to remotely pause and resume the operation of the pool cleaner.

Requirement:
ESP8266 WiFi module: ESP8266 provides a wireless communication interface for the system, allowing the pool cleaner to communicate with external devices such as the Android app. The ESP8266 WiFi module is responsible for establishing a wireless connection with the Android app, and then transmitting the data to the app over the WiFi network. The WiFi module can be powered by either 3.3V or 5V and its configuration is achieved using AT commands. The module can be connected to the microcontroller by inserting it into the reserved interface on the development board.

STM32 microcontroller: It is responsible for processing and formatting the data to be transmitted, and then sending it to the ESP8266 WiFi module through a serial interface.

An Android Cell Phone: Install an APP to connect with ESP8266 WiFi module, design at least 2 buttons to control the startup and emergency stop of the pool cleaner.

3. Ethics and Safety

IEEE Code of Ethics require us to put the safety, health and welfare of the public first [2], 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 [3], we will ensure that the pool data collected by cleaner will not be leaked and will not violate the rights of users.

Reference

[1]Y. Ando, T. Tsubouchi, and S. Yuta, “A Reactive Wall Following Algorithm and Its Behavior of an Autonomous Mobile Robot with Sonar Ring,” Journal of Robotics and Mechatronics, vol. 8, no. 1, pp. 33–39, Feb. 1996, doi: https://doi.org/10.20965/jrm.1996.p0033.

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

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