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Algal treatment system based on ultrasonic vibration principle and water nest principle for mechanical ships

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Abstract: With the development of automatic control technology, machine control has gradually replaced the complex and cumbersome manual control mode. Given the current situation in the aquaculture industry where high-temperature weather leads to algae overgrowth, damaging lake ecology, depleting oxygen in the water, and causing a large number of aquatic organisms to die, there is a need for the design of a mechanical ship for algae treatment. The device is designed with an underwater variable diameter telescopic rotary blade combined with ultrasonic vibration, a screw slide table structure, a new crank rocker structure, and a variety of sensors. The device also incorporates OPENCV's visual recognition system to achieve automatic harvesting of algae. This integration significantly enhances the efficiency of algae removal.

1. Research objective

1.1 Research background of works

With the development of society, people's living standards continue to improve, and industry develops rapidly, which brings a series of environmental problems. The General Office of the Central Committee of the Communist Party of China and the General Office of the State Council issued the "Guiding Opinions on the Establishment of a System of Natural Protected Areas with National Parks as the Main Body", proposing important protection of the park environment. With the warming of the global climate, in some parks and scenic spots, due to the increase in temperature in summer and autumn, algae will bloom in the water, occupying most of the water area of one to two meters underwater, and the reproduction of a large number of algae will produce a large number of harmful substances, causing environmental pollution and reducing a series of problems of biodiversity. Therefore, there is a high need for algae treatment in the lake. Figure 1 below shows the algae bloom in the lake in the park.

Figure 1: Algae bloom in a park lake

For current algae treatments, the following three methods are mainly adopted in Table 1:

Table 1: Current methods of algal treatment

treatment	vintage	drawbacks
Manual processing	Strong operability, more extensive processing	The processing efficiency is low, the security is low, and the time is long
Chemical treatment	High processing efficiency	Great pollution
Pure mechanical treatment	High processing efficiency and high security	The processing precision is low

As shown in Table 1, compared with the three existing algae treatment methods, pure mechanical treatment has a stronger application, higher efficiency, and better comprehensive performance, but its processing accuracy is not high, and algae treatment is not complete enough, and it needs to be improved and upgraded in some aspects to achieve a better treatment effect. [1]

Therefore, compared with manual processing, the design of the device has the advantages of automation, intelligence, higher efficiency, and lower cost; Compared with chemical treatment, the main use of mechanical principle, less harm to the water environment; Compared with pure mechanical processing, the principle of ultrasonic vibration and a series of optimization of the mechanical structure for its application environment are adopted, which has a wider working range, higher accuracy and processing completeness, and intelligent processing is also realized. It has good application potential. Figure 2 below shows the current purely mechanical processing device.

Figure 2: Currently purely mechanical handling devices

1.2 Significance of Works Research

In recent years, with the strengthening of environmental protection, the state attaches more importance to the protection of wetland parks, and with the proliferation of algae, the ecological environment on the lake has caused great damage, and absorbed a large amount of oxygen in the water, resulting in the death of aquatic organisms such as fish and shrimp. The design of an algae removal

device can greatly improve the water environment and reduce unnecessary harm.

A kind of water algae treatment device based on the ultrasonic vibration principle and OpenCV vision library is designed to realize automatic and efficient algae removal. Given the environment where most algae are long and grow 1-2 meters underwater, the underwater algae are treated by a multistage transmission device. The principle of ultrasonic vibration and the structure of variable-diameter rotary blades are used in algae removal. Design a screw sliding table structure and crank rocker new structure to achieve extrusion dehydration and dumping, improve work efficiency; Use a variety of sensors and visual recognition to improve the stability of work. Therefore, the device has a wide range of application prospects. Figure 3 below shows water pollution caused by algae.

1) Given the problem of algae blooms in aquaculture farms and lakes, recycling and treatment of algae in water is the main direction.

2) The device has a variety of sensors, machine vision recognition technology, and positioning technology, and can also carry out some water surface detection and transportation tasks.

Figure 3: Map of water pollution caused by algae

2. Research Content

2.1 Design scheme

1) Overall design solution

The algae removal mechanical device based on OpenCV mainly adopts a variety of modular structured design ideas, the device can be divided into an ultrasonic vibration cutting processing module, collection and movement module, dehydration molding module, dumping storage module, sensor control module, visual identification and detection module, to achieve efficient work of the device.

The main control of the device is STM32F407 to realize the overall control of the device, using the principle of ultrasonic vibration and the principle of water adsorption, combined with a variety of complex mechanical structures and sensors to realize the overall feasibility of the device. The ultrasonic vibration cutting module was used to cut and crush the algae. The collecting and moving module is used to collect the crushed algae from the water and move it to the surface of the device for a series of subsequent processing. The collected algae can be dehydrated and extruded into pieces by a dehydration-forming module. The dumping storage module is used to carry and store algae.

In the sensor and visual recognition module, Raspberry PI is used to build an OpenCV visual library to process and analyze the images collected and recognized by the depth camera. OpenCV is a cross-platform computer vision and machine learning software library that runs under the Raspberry PI system and uses the Python language for programming.

In the process of algae harvesting, Raspberry PI, camera, and OpenCV were used to identify the contours and coordinates of algae, and the processing results and coordinates were sent to STM32F407 through a serial port for harvesting and processing in the control harvesting device. Figure 4 below

shows the overall design flowchart.

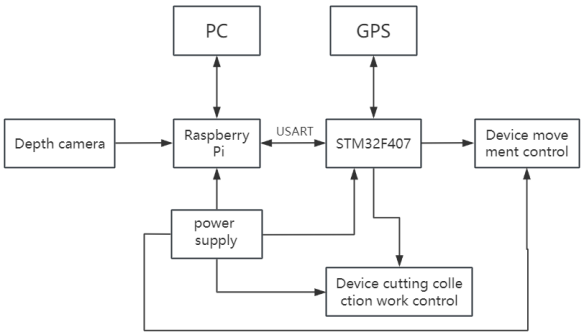

Figure 4: Overall design flowchart

2) Overall design solution for the structure of the device

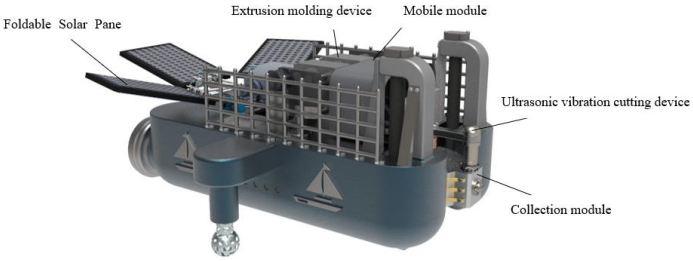

Figure 5: Overall shape of the product

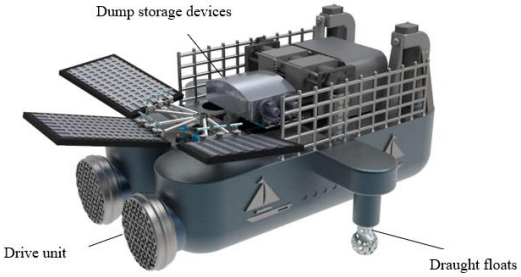

Figure 6: Overall shape of the product

The algae removal mechanical device mainly adopts a variety of modular structured design ideas, the device can be divided into an ultrasonic vibration cutting processing module, collection and movement module, dewatering molding module, dumping storage module, sensor control module, visual identification detection module, etc., to achieve efficient work of the device. Figure 5 and Figure 6 above are the overall schematic diagram of the device.

The device starts to work, transmits the target position to the device controller, and the device plans the path of the water surface through the GPS positioning system to achieve accurate position movement. Through the visual recognition module, the distribution of algae is identified by the camera, the image is generated and transmitted to the host computer to realize man-machine control; At the same time, the variable diameter telescopic blade starts the high-speed rotary cutting and ultrasonic vibration cutting work. There is a water level sensor at the bottom of the device to realize real-time detection of the bearing capacity of the device to ensure safety; The retractable bucket in the water moves up and down to collect algae, and the two modules work simultaneously; The telescopic bucket is returned to the device, the infrared ranging sensor sends out a signal, the transmission device is opened, and the algae is transported; At the end of its transmission, the screw slide began to rotate and

compress, and the algae was extruded and dehydrated. The whole formed algae is dumped, collected, and stored by the crank and rocker structure, and the speed and torque of the motor are controlled by the detection of the pressure sensor to ensure the smooth operation of the whole device. In the process of movement, the ultrasonic obstacle avoidance sensor can realize the effective avoidance of obstacles, and the navigation system can realize the return and discharge. Figure 7 below is the overall working flowchart, Figure 8 is the solar panel diagram.

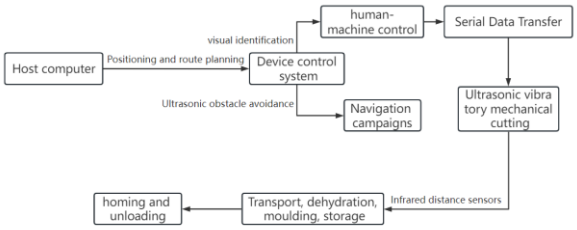

Figure 7: The working flowchart of the whole device

Figure 8: Retractable solar panel

1) Ultrasonic Vibration Cutting Processing Module

The module is mainly divided into two cutting parts. One part utilizes a multistage transmission telescopic rotary reducer blade, while the other part employs the ultrasonic vibration principle to achieve cutting.

Most algae grow when the visual sensor recognizes the algae in the water. The telescopic rotary reducer blade part receives the signal and starts to work. The telescopic rod stretches to a position one to two meters underwater. The internal motor rotates at high speed, causing the blade radius to increase during rotation. Consequently, the rotating diameter gradually expands, increasing the cutting range of the blade. To facilitate the cutting treatment of algae within the area, allowing for better absorption and chopping of subsequent algae. Figure 9 and Figure 10 below show the structural diagrams of the module.

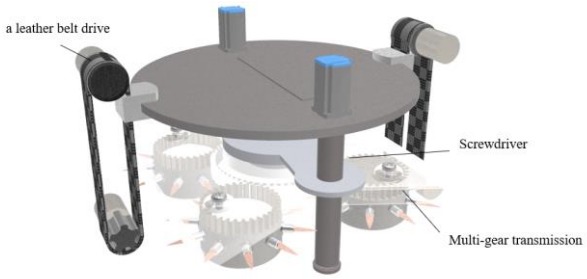

Figure 9: Multistage drive

Figure 10: Telescopic rotary reducer cutting machine

Ultrasonic vibration is used to cut algae by combining the principles of water nest adsorption and Seabin. A cutting blade driven by ultrasonic power is placed in the collection bucket, causing it to vibrate at high frequency and high speed. In the work, the ultrasonic generator will produce high-frequency alternating current, through the transducer to produce the same frequency of high-speed vibration, while the amplitude of the blade increases with the help of the amplitude transformer, to be able to cut algae, improving the cutting efficiency of the device; At the same time, the effect of thinning algae is realized under the cyclic high-speed frequency cutting. Figure 11 below is an ultrasonic vibration-cutting device.[2]

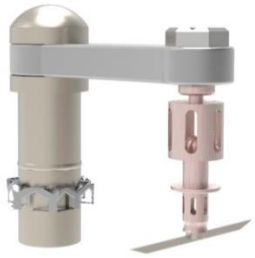

Figure 11: Ultrasonic vibration cutting device

3) Collection of mobile modules

This part is mainly used for collecting and transporting the algae after cutting. The collection section is upgraded on the traditional Seabin principle, utilizing the water nest principle to achieve a more enhanced - and effective attraction. At the same time, the solar panel on the top of the device is used to absorb solar energy to ensure the all-weather working efficiency of the device.

When the cutting device stops working, the collection device receives the signal and starts to work. By expanding the collection bucket up and down, it vibrates up and down on the water surface to produce a low water surface water nest. Meanwhile, combined with the principle of Seabin, the water pump is used to further absorb water at the bottom of the collection bucket to produce negative pressure adsorption. The strong suction allows the surrounding algae to be further adsorbed in the collection bucket. Figure 12 below is a screw telescopic collection device.

Figure 12: Screw telescopic collector

The power source of the adsorption module is the water pump, and the lithium battery dual-core 98/128AH pump is used as the pump of the device. The power of the pump is 100W and has the performance characteristics of low noise, high power, and high endurance. The 100W power pumping pump combined with the water nest principle can efficiently complete the absorption of algae, and at the same time, the impact on underwater fish and other underwater organisms is small. The characteristics of high battery life and high power can ensure that the pump can achieve an all-weather operation and provide a lot of time for solar energy storage. Compared with other types of pumps, the pump has the advantages of low power and high endurance.

When the collection bucket collects the algae movement to the device on the water surface, the infrared sensor detects that the collection bucket is reset, transmits the signal to the main controller, the opening of the cylinder wall is opened, and the algae in the bucket is transported and moved by the mobile algae rod, motor and conveyor belt, and then the follow-up work is carried out in the subsequent work module. Figure 13 below is a moving algae rod, and Figure 14 is a conveyor device.

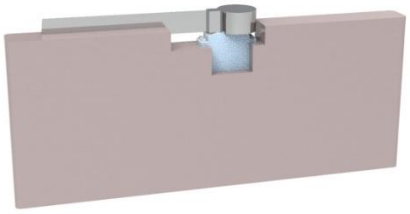

Figure 13: Mobile Algae Pole

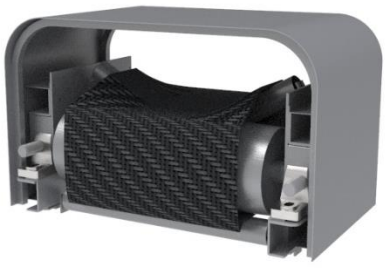

Figure 14: Transmission mechanism

At the same time, when the infrared sensor detects that the collection bucket is back on the device, its counter counts the value, at this time, the STM32 control system module receives the signal, the buzzer sounds, and carries out the next part of the work.

4) Dehydration moulding module

The module is used to achieve the effect of extrusion dewatering the collected algae.

The design of this part adopts a screw-sliding table structure, and the extrusion block adopts a meshing contact structure. The two extrusion blocks can move and extrude together on the sliding table by using different driving motors to drive the rotation of the screw. At the same time, the meshing contact structure is adopted on the extrusion fast to carry out a good extrusion dewatering molding of the internal algae, which can fully realize the effect of dewatering the algae. The plane of the extrusion block adopts a regular square structure so that the algae residue forms a block structure in the extrusion device to achieve a molding effect, which is convenient for subsequent handling, moving, and recycling. Figure 15 below shows a dewatering compression block device.

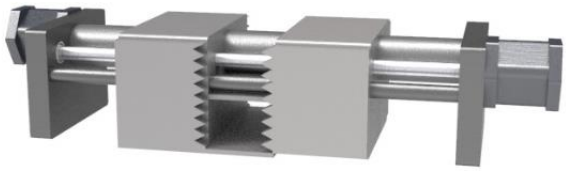

Figure 15: Dewatering and compression block device

5) Dump storage module

The device module is mainly used to dump and store the extruded algae.

This part uses the structure of the crank slide rod to realize the inclined rotation of the bottom plane of the barrel. First, the motor drives the turntable to rotate at a certain speed, and the turntable is connected with another crank through a slide rod so that the bottom of the barrel fixed on its surface can rotate in a certain Angle direction, and at the same time, the heating and drying of the blower can realize the dumping of the internal algae. Figure 16 below is a crank rocker tipping device.

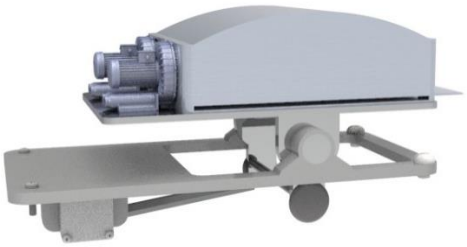

Figure 16: Crank rocker tipping device

After dumping, the algae pieces are moved to the storage device by sliding rail and arranged neatly in a certain space, which can effectively reduce the space occupation.

The structural motion diagram of the tipping device is shown in Figure 17 below:

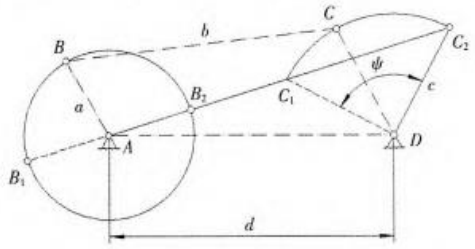

Figure 17: Crank rocker structure sketch

6) Control module

The module uses the combination of a variety of sensors and a visual recognition system to convey the corresponding signal to the control system, and the control system sends corresponding instructions

to each module in turn to drive the work, to achieve the smooth operation of the entire device.

The module mainly includes an ultrasonic obstacle avoidance sensor, water level sensor, infrared distance sensor, pressure sensor, OPENCV visual recognition system, and STM32 control board system. Figure 18 below shows the STM32 control board and its schematic.[3]

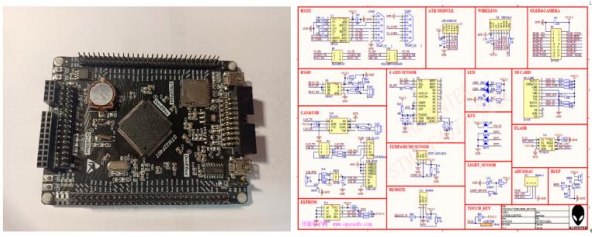

Figure 18: STM32 control board and its schematic

7) Identification system module

The visual recognition system is equipped with underwater and water waterproof cameras to detect algae above and below the water surface, generate images, and then compare the Raspberry PI with the original algae images, and identify the level of similarity according to the color and shape of the recognized objects. If the similarity is very high, you can start driving other modules to work. If the similarity is low, the image position data will be transmitted to the human-computer interaction page of the upper computer, and the operator on the ground can choose whether to control the device for algae removal through the identification of the image. Figure 19 below is a visual identification device.

Figure 19: Visual identification device

Sonar image recognition system aims to enhance the accuracy of visual recognition during navigation. It utilizes synthetic aperture sonar to continuously transmit and receive sonar signals for underwater target detection. Detection sonar detects the shape of underwater objects based on the backscattering principle of incident sound waves and can provide acoustic imaging of the shape of objects. The image is denoised by the median filter in the spatial domain, and then the algae is analyzed to determine the image, and then the subsequent processing is controlled.

8) Visual recognition processing section

For algae recognition, Raspberry PI is used to build an OpenCV library for image processing. OpenCV provides a large number of computer vision, image processing, and machine learning algorithms, which can process various operations of images and videos. [4]

Firstly, the algae image is collected by depth camera and then processed by OpenCV on Raspberry PI. Through color space conversion, the image is converted from BGR color space to HSV color space by the cv2.cvtColor function, to facilitate better color processing. Define the threshold range of green algae in HSV color space, then create a mask, and use white pixels to represent green algae. Finally, the cv2.findContours function is used to find all the contours in the mask, that is, the algal contours in the image.

For determining the position of algae, the boundary box of the outline is first obtained through

cv2.boundingRect, and this boundary box is drawn on the image. The moment of the outline is calculated using the cv2.moments function, and then the center point (centroid) of the outline is calculated. Finally, the coordinates of the centroid are determined to represent the position of the algae. Figure 20 below is an Algae location identification map.

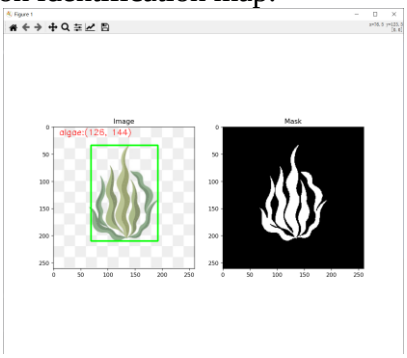

Figure 20: Algae location identification map

2.2 Feasibility analysis

1) Device feasibility analysis

For the part of the device, the device adopts the principle of ultrasonic vibration coupled with mechanical cutting. The frequency of an ultrasonic wave is greater than 16000Hz, which makes the blade vibrate fast enough to make the algae be crushed and cut.

For the rotating device, the selection of the motor needs to be calculated and judged.

$$J_L = J_W + J_D \tag{1}$$

$$T_f = \frac{D}{2ni} * Wg \tag{2}$$

formula, J_L is the total moment of inertia, The unit is Kg·m^2;
J_W is the moment of inertia of the load, The unit is Kg·m^2;
J_D is pulley moment of inertia, The unit is Kg·m^2;
T_f is Travelling torque, The unit is N·M;
D is synchronous belt pulley diameter, The unit is m;
n is synchronous belt efficiency, Unitless;
W is load quality, The unit is Kg;
g is gravitational acceleration, The unit is N/Kg;
I is reduction ratio, Unitless。

From the above formula, it can be seen that the deceleration ratio is 10, the diameter is 0.05m, and the efficiency is 0.95. Taking other known parameters into account, the moving torque can be calculated to be 1.05N·M, which meets the prescribed safety value and ensures work efficiency.

For the structure of the crank rocker, due to the structural design, its maximum swing foot can be controlled at 90 °, and when the swing Angle is too large, its corresponding transmission Angle will be reduced, which is not conducive to its work of algae dumping.

To achieve a good drive, crank length and rocker drive need to meet a series of relationships.

$$\Phi = 2\arcsin(\frac{a}{c}) \tag{3}$$

$$a^2 + d^2 = b^2 + c^2 \tag{4}$$

formula, a is Crank length, The unit is cm;
b is a pole, The unit is cm;

c is rocker length, The unit is cm;

d is rack length, The unit is cm;

Φ is rocker swing, The unit is.

The length of the crank a is 60cm, the length of the frame is 200cm, and the swing Angle is 90 °. The length of b and c can be calculated, and the design of the structural frame of the whole crank rocker can be realized according to the data.

2) Ultrasonic Vibration Cutting Analysis

The cutting principle of ultrasonic vibration is a special cutting technology that makes the tool vibrate at a high speed along the cutting direction at a frequency of 20-40KHz, which can achieve a fine-cutting treatment.

At the same time, ultrasonic vibration cutting technology can be divided into two aspects:

On the one hand, in one-dimensional ultrasonic vibration cutting, the tip vibration direction is parallel to the direction of cutting speed, and the cutting speed is less than the vibration speed of the blade, resulting in the periodic separation of the blade and the cutting material, which can effectively reduce the cutting force, improve the fineness of cutting and the life of the blade.

On the other hand, in elliptical ultrasonic vibration cutting, the reverse effect of the friction force between the front tool surface of elliptical ultrasonic vibration cutting and the object to be cut makes the cutting depth resistance decrease to 1/10 of one-dimensional ultrasonic vibration cutting and 1/50 of ordinary cutting, which can effectively improve the stability of vibration.

At the same time, to meet the cutting efficiency, by vertically changing the vibration direction and the amplitude rod to increase the amplitude, the cutting speed needs to meet:

$$v = 2\Pi f A \tag{5}$$

formula, *v* is cutting speed, The unit is m/min;

f is vibration frequency, The unit is kHz;

A is amplification, The unit is mm;

According to the formula, when the vibration frequency reaches 20kHz and the amplitude is about 1mm, the cutting speed can reach 125.6m/min, which is greater than 75m/min, and the purpose of efficient cutting can be realized. Figure 21 below is a comparison of different vibratory cutting methods.

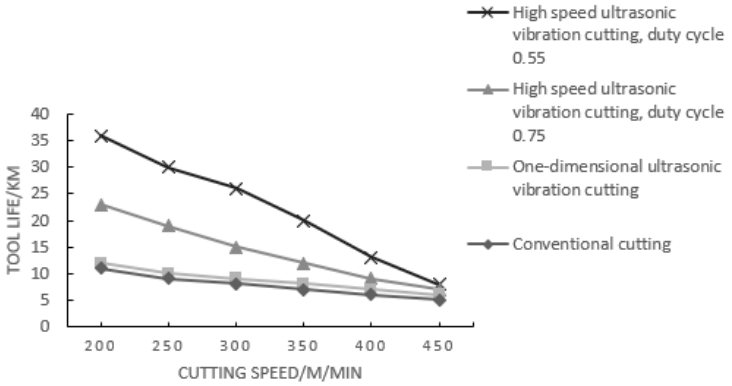

Figure 21: Comparison chart of different vibratory cutting methods

3) Visual identity analysis

The overall intelligent control of the device requires a good identification process, and for algae in the water, a good identification system is needed to ensure the normal operation of its subsequent devices.

The device uses OpenCV based visual recognition system to identify the contours of aquatic

organisms, thus generating images, comparing algal maps, judging whether it is algae, and then deciding whether to proceed to the next step. [5]The initial code demonstration and experimental phenomena are performed by using Jupyter. Figure 22 below shows the code and phenomenon diagram of algae identification.

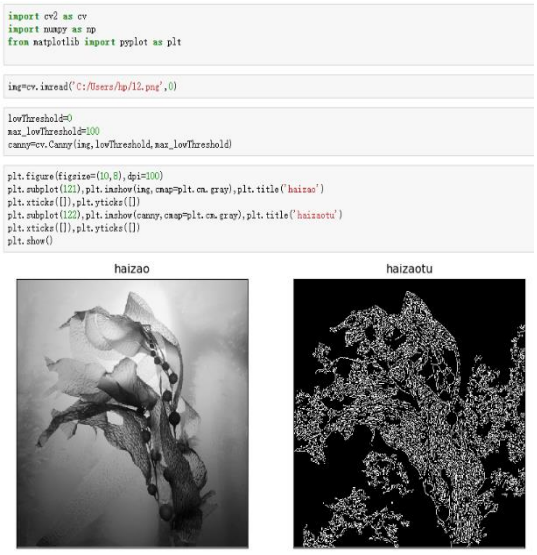

Figure 22: Codes and phenomenon diagrams for algae identification

4) Intelligent control analysis

When the device is powered on in the working state, the voltage and current rise to the working environment. When the visual recognition system recognizes the algae, it passes a signal to the STM32 control board to run the working code, and the buzzer rings for 2 seconds to indicate the operation mode. The normal operation of each device is realized through the signal transmission of each part of STM32 and the delay control.

The ultrasonic obstacle avoidance sensor module is used to control the stopping and obstacle avoidance of the device. When it works with the visual recognition system to detect the endpoint, the sensor is used to detect the obstacle avoidance to realize the top of the device. Its main parameters are shown in Table 2:

Table 2: Parameter list of the sensor

parametric	
Detection distance	2mm-30cm
operating voltage	3.3-5v
sizes	3.1cm*1.5cm
output method	Digital Signal Output

The sensor has the advantages of small size, convenient control, high detection accuracy, and wide application range, and can be well applied to the operation of the device to achieve a high stability. Its circuit connection diagram is shown in Figure 23:

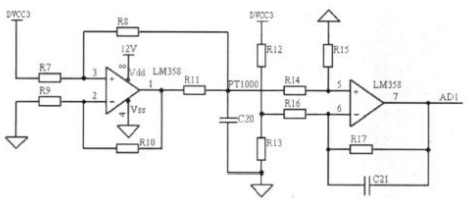

Figure 23: Sensor Circuit Connection Diagram

3. Domestic and foreign research status and development trends

At present, many methods of removing algae have been studied by domestic and foreign scholars, but no safe, efficient, and cheap treatment technology has been formed. At the same time, at home and abroad, algae removal technology is mainly studied in the pre-treatment of algae, enhanced coagulation, air flotation, and micro-flocculation.

At present, the methods of removing algae are mainly physical methods, chemical methods, and biological methods. The physical method is mainly artificial mechanical fishing, which consumes a lot of manpower and financial resources, has low efficiency, and is not suitable for large-scale treatment. The chemical method will pollute the water environment and is not a good choice. Biological treatment has a long operation period, slow effect, and has certain defects in technology, which is not suitable for extensive treatment of algae. Figure 24 below shows the current algae removal method:

Figure 24: Current algae removal methods

In recent years, with the rapid development of artificial intelligence and the power industry, researchers at home and abroad are actively moving towards electrochemical methods and automated intelligent algae removal technology. Although electrochemical treatment has high energy consumption, high cost, difficult intelligent treatment, and high technical requirements, it provides a good direction and application prospect for the subsequent development of algae removal.

4. Innovation

4.1 Application Innovation

The ultrasonic vibration cutting technology is applied to the treatment of algae in water, which realizes a fast and wide range of cutting and improves the working efficiency of the whole device.

4.2 Combination and innovation

1) Principle combination

The principle of Seabin is combined with the principle of water nest to achieve a greater suction force, which can fully promote the absorption of algae after cutting;

2) Combine with technique

The device combines ultrasonic vibration technology, infrared sensor, ultrasonic sensor, water level sensor, Raspberry PI, and STM32 MCU to realize intelligent treatment of algae and improve the processing efficiency of the device.

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