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WIND-SOLAR HYBRID DRIVE-CONTROLLED AUTONOMOUS SHIP FOR EXPLORATION BASED ON RASPDERRY PI

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Abstract: In order to facilitate the monitoring of water area data in various regions, enhance the efficiency of environmental monitoring, and respond to the national goals of carbon peaking and carbon neutrality, this project has developed an intelligent unmanned detection vessel driven by a hybrid of wind and solar power. This project adopts Raspberry PI 4b motherboards. By designing the hull of the unmanned vessel and integrating a remote control system and an intelligent detection system, it is equipped with high-precision GPS positioning to control the unmanned vessel to perform monitoring tasks in specific waters. By using video monitoring and various sensors to collect data, and after analysis, the test information is transmitted in real time to the user's mobile phone APP or computer. The collected monitoring data can be synchronized to the user's terminal device in real time to ensure the timeliness and accuracy of the information. This system has high stability and reliability in actual operation. Meanwhile, the unmanned vessel can generate electricity by using the wind-solar drive module to achieve its endurance. This research has certain reference value.
Keywords: Unmanned vessel; Raspberry Pi; Hybrid power drive; Water quality monitoring

1 INTRODUCTION

Driven by the "dual carbon" goals implemented in our country and the demand for intelligent water area monitoring, unmanned vessels are transforming from "traditional fuel-driven + manual remote control" to "new energy autonomous drive + mission-oriented intelligent operation"[1]. Especially in small and medium-sized water area monitoring scenarios, the requirements for the equipment's endurance, environmental friendliness, and multi-parameter perception capabilities have significantly increased, pushing unmanned vessels to accelerate their iteration towards the "low energy consumption - high collaboration" direction[2,3]. As surface intelligent equipment capable of autonomously completing water area data collection and environmental monitoring, its design needs to take into account the particularities of the operation scenarios - such as the strict requirements for endurance stability and anti-water interference capabilities[4].
Abroad, the United States initiated the research on unmanned ships as early as the 1930s. Its "Spartan Scout" and "X-2" and other equipment were mainly focused on military reconnaissance. Their power systems were mainly powered by diesel or lithium batteries, which had limitations such as limited endurance (single operation < 8 hours) and high carbon emissions[5]. The Japanese Yamaha "UMV-H" and "UMV-O" also expanded to marine exploration, but they relied on a single battery for power supply and had insufficient stability in cloudy or low wind speed environments[6]. In China, the research on unmanned ships driven by policies has achieved breakthroughs (such as the "Zhuhai Cloud" research vessel and the "Jinghai" series), but most of the equipment still relied on traditional power sources or single solar power. They have shortcomings in endurance under complex weather conditions (such as continuous cloudy days)[7].
Based on the current technical status both domestically and internationally, the core competitiveness of unmanned ships is shifting from "function realization" to "energy and environmental compatibility"[8-10]. In response to the shortcomings of the above power system, this project has developed an intelligent detection unmanned ship with a hybrid power system of wind and solar energy. The core innovation mainly lies in three aspects: 1. Energy system: Using monocrystalline silicon solar panels (with a conversion efficiency of 22%) and vertical-axis wind turbines (with a startup wind speed of ≤ 1.8m/s), through an MPPT intelligent controller to achieve coordinated management of wind and solar energy, maintaining 80% rated power output even in cloudy or low-light conditions, which increases the endurance by 50% compared to single solar energy drive; 2. Operation adaptability: Optimizing the streamlined hull (with a resistance coefficient reduced by 15%) and double-layer waterproof structure (IP68 level sealing), adapting to complex water flow environments in small waters such as lakes and rivers; 3. Task-oriented: Centered on water quality monitoring, integrating multi-sensor collaborative sampling and real-time data transmission, achieving "energy autonomy + monitoring autonomy" in a dual closed-loop control[11,12].

2 TOTAL DESIGN SCHEME

This project developed an unmanned ship based on Raspberry Pi, which is a multi-functional unmanned vessel. Various sensors are utilized to obtain water quality information. The high-definition camera module onboard enables real-time monitoring and acquisition of image data. It communicates with the end users through the lightweight MQTT communication protocol for data exchange, and supports remote status inquiries. Additionally, in combination with the accompanying traction device, the unmanned ship can be extended to scenarios such as maritime rescue, garbage cleaning, and the transportation of small supplies by water. Its working process is as follows: After the unmanned ship enters the water area to be tested, it can start the water quality sensor for water quality detection. The test data obtained is processed by Raspberry Pi, and the analysis results are sent to the cloud server through the MQTT protocol. The server parses the results and then transmits them to the user terminal. Users can obtain real-time water quality data through the mobile App at any time, thereby achieving the purpose of monitoring various parameters of water quality. The workflow diagram is shown in Figure 1.

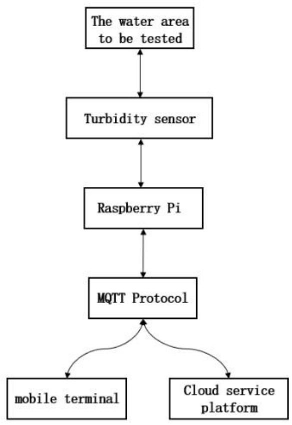

Figure 1 Workflow of the Unmanned Ship

3 HARDWARE DESIGN OF UNMANNED VESSELS

The hardware of the unmanned ship developed in this project is controlled based on the Raspberry Pi development board. It integrates a driving system, a camera module, and modules suitable for monitoring various water quality parameters (such as temperature sensors, turbidity sensors, and pH value sensors, etc.). The hardware architecture design is shown in Figure 2. Each module works collaboratively with the main control board through interfaces to jointly support the monitoring and operation functions of the unmanned ship.

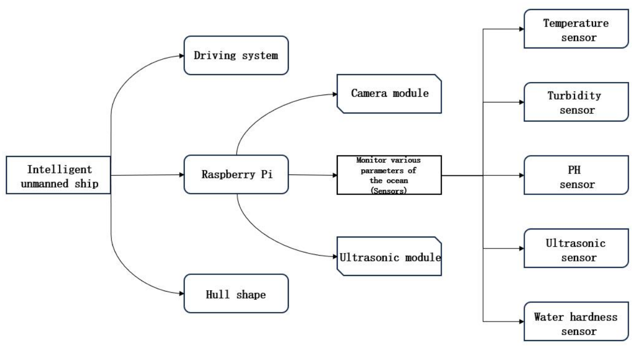

Figure 2 Hardware Architecture Design of Unmanned Ship

According to the overall structure design shown in Figure 3, the operation control process of the unmanned ship is as follows: After the user issues an operation instruction through the mobile phone APP, the Raspberry Pi main control board receives the instructions parsed by the MQTT protocol and immediately transmits control signals to the driving system, causing the motor to operate and achieving the regulation of the navigation status. The Raspberry Pi main control board establishes data interaction with various water quality sensors through expansion interfaces and collects real-time data parameters such as turbidity and pH value. These detection data are preliminarily processed and uploaded through the MQTT protocol, and after completing the analysis of the water quality status, they are pushed to the cloud server, which then sends the data to the mobile phone APP. The camera module is responsible for capturing the images of the water surface and its surroundings; the GPS module acquires the spatial coordinates of the unmanned ship in real time, providing accurate location information for remote control, and at the same time, in conjunction with the camera module, realizes the spatial positioning and image association of the operation scene.

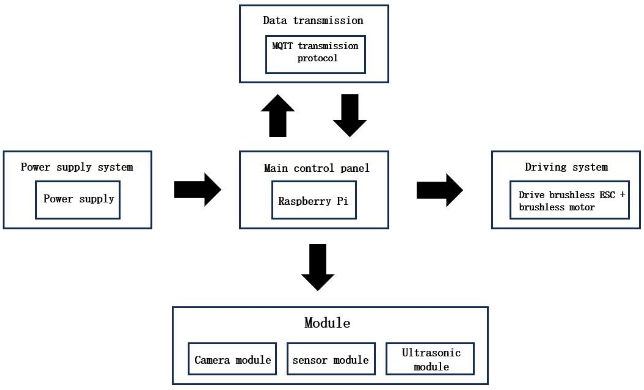

Figure 3 Overall Structure Design of the Unmanned Ship

3.1 GPS Positioning Module

This project uses the GPS module of the Yabo intelligent model ATGM336H-5N. The working process is as follows: Connect the USB interface on the Raspberry Pi motherboard to the Micro interface of the GPS module. Its function is to output navigation data and input interactive commands. The GPS module usually outputs second pulses and is connected to an antenna, and the antenna is installed on the ship deck. According to Figure 3, the GPS module obtains the position information of the unmanned ship, and the Raspberry Pi motherboard acquires the relevant data and processes it. Then, it uploads it to the cloud server via the MQTT protocol. When receiving data, the cloud service platform receives the relevant data and transmits it to the Raspberry Pi motherboard for data processing.

3.2 Data Transmission

The data transmission of this project is implemented using Python on the Raspberry Pi to connect with a regular MQTT server, and it performs message publishing and subscription in dual threads. The unmanned ship uses the paho-mqtt library in Python to complete the communication tasks under the MQTT protocol. MQTT is a lightweight messaging protocol, suitable for situations with limited network bandwidth. By creating an MQTT client on the Raspberry Pi using Python, message publishing and subscription can be achieved.

Based on the operational characteristics of unmanned vessels on open waters, their signal transmission is unobstructed and has a wide coverage area. Their data transmission adopts a hierarchical network scheme: relying on mobile phone 5G/4G hotspots to establish the basic connection, which can support data interaction over medium to long distances on the water surface; at the same time, the Wi-Fi module installed on the Raspberry Pi motherboard has 360° omnidirectional coverage capability, which can provide unified network support for multiple unmanned vessels conducting collaborative operations, improving the efficiency of cluster operations while expanding the monitoring coverage area. Compared to the configuration of LTE modules, using Wi-Fi modules has three advantages: first, the transmission bandwidth is larger, which can meet the real-time transmission of large-capacity data such as high-definition images; second, the power consumption is lower, saving about 20% compared to LTE modules, which helps to reduce the energy consumption of the entire vessel; third, the connection stability is stronger, reducing data packet loss in complex water environment. When the navigation distance of the unmanned vessel exceeds the coverage radius of Wi-Fi, the system automatically switches to the mobile data module to maintain remote communication, ensuring stable data transmission for the unmanned vessel at longer distances or in complex water areas[13].

3.3 Dving System

This project adopts a drive system that uses two electric motors as the propulsion units to precisely control the ship's navigation status. The specific connection method is as follows: Connect the brushless power regulator with a rated current of 30A to the wires of the ROV brushless motor. The pin 12 on the main board is connected to the yellow signal of the power regulator to control the working state of the brushless motor. Finally, the positive pole of the power supply is connected to the red power line of the power regulator, and the negative pole of the power supply and the GND of the main board, as well as the black power line of the power regulator, are connected to provide normal power supply for the brushless motor (Figure 4 Connection diagram of the drive system).

After the control terminal sends the operation instructions, the Raspberry Pi motherboard acquires the relevant information and outputs the PWM signal. By adjusting the PWM pulse width, it controls the motor driver, thereby controlling the rotational speed of the brushless motor. This control system uses the rotational speed difference between the two motors to form the steering torque to complete the course adjustment, ensuring the stability of the ship's movement in complex waters.

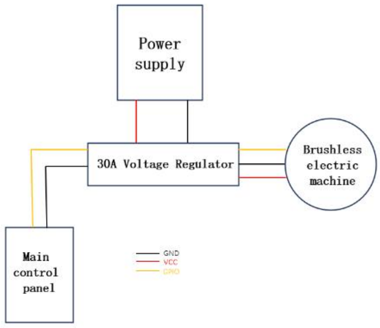

Figure 4 Connection Diagram of the Drive System

3.4 Camera Module

This project uses the camera module from Yabo Intelligent Company. The camera adopts a USB2.0 direct plug-in interface. Connect the USB2.0 interface of the camera to the USB interface of the Raspberry Pi motherboard. Thus, the camera connection is completed.

3.5 Ultrasonic Module

This project uses the HC-SR04 ultrasonic module. The VCC of the ultrasonic module is connected to the 5V pin of the Raspberry Pi motherboard, and the Trig and Echo pins of the ultrasonic module are connected to the GPIO ports of the Raspberry Pi. Finally, the GND of the ultrasonic module is connected to the GND of the Raspberry Pi motherboard. This completes the circuit connection of the ultrasonic module. The HC-SR04 ultrasonic module uses IO triggering for distance measurement. It sends a high-level signal of at least 10us. The module will automatically send 8 40kHz ultrasonic wave pulses and simultaneously start the echo detection mechanism to determine the existence of the reflected signal. When the Raspberry Pi motherboard receives the high-level echo signal from the ultrasonic module, the duration of this high-level pulse corresponds to the round-trip propagation time of the ultrasonic wave from emission to reflection and back to reception. Based on this, the actual distance between the unmanned ship and the target obstacle can be calculated. (Figure 5 The working principle of the ultrasonic module).

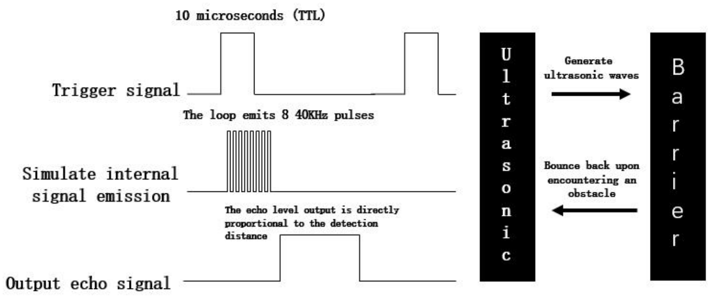

Figure 5 The Working Principle of the Ultrasonic Module

3.6 Sensor Module

To achieve the detection function of the unmanned ship, this project integrates various types of sensors, including the TS-30 turbidity sensor, pH sensor, 18B20 temperature sensor, and TDS sensor, etc. In practical applications, the test sensors can be selected according to actual needs.To achieve the detection function of the unmanned ship, this project integrates various types of sensors, including the TS-30 turbidity sensor, pH sensor, 18B20 temperature sensor, and TDS sensor, etc. The specific process is as follows: Connect the signal pins of the test sensor to the ANALOG IN interface on the Raspberry Pi motherboard, connect the positive power supply to the VCC interface on the main control board, and connect the negative power supply to the GND interface. (Figure 6 Principle structure diagram of the TDS sensor).

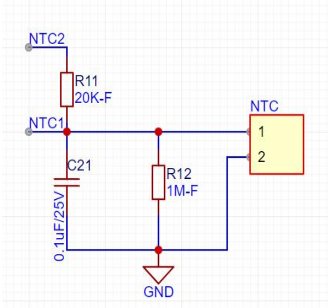

Figure 6 Principle Structure Diagram of the TDS Sensor

According to the actual testing requirements, the sensors can be connected to the Raspberry Pi motherboard. When the sensors collect data and transmit it to the Raspberry Pi motherboard, the motherboard will process the data and send it to the cloud server through the server. Then, users can directly obtain the relevant data information on their mobile phones.

3.7 Power Drive Module

The wind power drive module mainly consists of wind turbines and solar photovoltaic panels. On unmanned ships, waterproof solar photovoltaic panels and small wind turbines are installed. Based on efficient photovoltaic materials and advanced aerodynamics principles, they can start and generate electricity under different light intensities and lower wind speeds. They provide continuous renewable energy input for the power system of unmanned ships. Their surfaces have been specially treated. The solar panels and wind turbines have excellent resistance to seawater corrosion and UV aging, which is sufficient to adapt to harsh sea conditions. The pictures of the wind turbine and the solar panel are shown in Figures 7 and 8.

Figure 7 Small Wind Turbine Generator

Figure 8 Solar Photovoltaic Panel

3.8 Hull Design

To reduce the running resistance of the unmanned ship, the hull design of this project adopts a streamlined shape. In terms of waterproofing, a double-layer waterproof design is used. A waterproof layer is placed inside the hull, and a sealing layer for the cabin is added between the deck and the boat to prevent water from entering the hull. To enhance the visibility of the unmanned ship during operation, the hull is coated in yellow, which makes it easy to quickly determine the location where the unmanned ship is working. At the same time, it is driven by two high-speed motors and two propellers, resulting in lower energy consumption during operation (Figure 9 shows the physical image of the unmanned ship's hull).

Figure 9 Physical Image of the Unmanned Ship's Hull

4 UNMANNED VESSEL CONTROL SOFTWARE

4.1 Terminal Program Design

This project uses the WxBit programming software to design the mobile control terminal App and the control interface. This software can program the control interface according to the actual needs of users, and the program is simple to write. The position detection function of the unmanned boat can obtain the specific position of the unmanned boat and monitor the target environment by using the Baidu Map API. The control interface is shown in Figure 10.

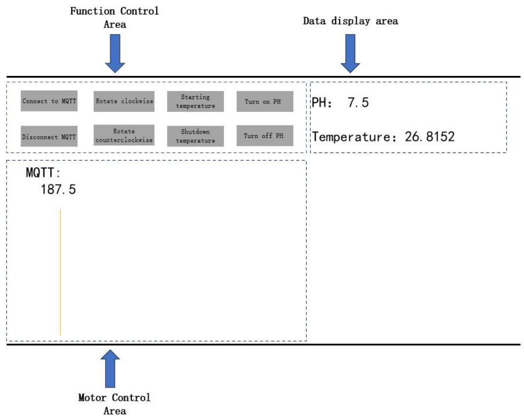

Figure 10 Terminal Application of Unmanned Vessel

4.2 Terminal Control System Design

This project combines software and hardware to design the control system. It uses the user terminal to control the unmanned boat and thereby achieve monitoring. The first step is to connect the Raspberry Pi motherboard to the computer. The second step is that the program can write the software Visual Studio Code onto the motherboard and use the mobile App to control the navigation direction of the unmanned boat. The interface of the APP can obtain detection data through various sensors. The third step is to obtain the corresponding IP through the connection of the Raspberry Pi motherboard, and the user logs into the local network IP on the web page to set the camera. The camera image is displayed through the web page on the computer end. The position of the unmanned boat is obtained by using the GPS positioning module on Baidu Map[14].

5 OPERATION AND DEBUGGING OF UNMANNED VESELS

5.1 Test Preparation

To ensure the safety, reliability and accuracy of the unmanned vessel in practical applications, tests are conducted before its deployment in the actual environment, prior to the laboratory setting: the sealing performance of the hull is tested to verify whether it has the ability to withstand underwater pressure and prevent water vapor penetration; at the same time, the operation performance of the motor is comprehensively inspected to ensure that it can stably output power in the water environment and drive the unmanned vessel to navigate efficiently; for the WiFi module, the stability and smoothness of signal transmission are analyzed to ensure that the unmanned vessel can achieve real-time and accurate data interaction in complex water environments; in addition, various sensor modules also need to undergo strict tests, including attitude sensors, environmental sensors, etc., to test whether they can accurately perceive the surrounding environmental information when working in the water environment, providing a reliable basis for the intelligent decision-making of the unmanned vessel. The power supply voltage of each module is checked to ensure its stability, whether there are errors in the data transmission process, and the accuracy of the sensor measurement results, so as to comprehensively ensure the safety of the unmanned vessel in practical applications.

5.2 Actual Operation test

This project developed an unmanned ship that operates in an autonomous mode and has detailedly recorded its navigation trajectory and yawing conditions. During the actual water area tests, the unmanned ship ran normally. The hull has good sealing performance, ensuring that all modules in the cabin can operate normally. At the same time, the Wi-Fi signal transmission was normal. Even in the sea area, its data could maintain stable transmission, and the terminal equipment could receive various data in real time, ensuring the timeliness and accuracy of information interaction.

Moreover, the unmanned ship has a large-capacity battery and a wind-solar hybrid power generation system, providing energy for its long-term operation. The test results show that the endurance and stability of this unmanned ship are both good**.**

5.3 Test Result

The unmanned vessel successfully followed the preset autonomous route, and the actual route was basically coincident with the preset route. The maximum yaw angle was 2.5°, and the average yaw angle was 0.8°. The navigation time was 12 minutes, which was within the expected time range. The unmanned vessel demonstrated excellent stability and accuracy in the autonomous navigation mode, and the yaw situation was within the acceptable range, verifying its self-sufficient navigation capability.

During the autonomous navigation test of the unmanned ship, the ship demonstrated excellent navigation capabilities. During the test, it was able to accurately follow the preset route and conduct fixed-point sampling without deviating from the course or colliding with obstacles. Its autonomous obstacle avoidance system worked properly, responding promptly when encountering potential obstacles and adjusting the navigation direction to ensure navigation safety. At each sampling point, the speed was adjusted to ensure the accuracy of the samples. During the test, the unmanned ship could maintain a stable navigation state and could promptly sense environmental changes and adjust its operating state. In addition, the navigation efficiency of the unmanned ship also met the expected goals. During the test, it could complete the tasks at a relatively fast speed while maintaining low energy consumption**.** The actual measurement and navigation of the unmanned vessel are shown in Figure 11-12.

Figure 11 Measured Data of the Unmanned Ship

Figure 12 Navigation Map of the Unmanned Ship

6 CONCLUSION

This project develops an intelligent unmanned ship controlled by Raspberry Pi. It has diverse functions, including autonomous navigation, data collection, and the ability to perform complex tasks such as underwater topography mapping and water quality analysis. In terms of power supply, a power system combining wind turbines and solar charging panels was developed. This design aims to utilize the complementarity of wind energy and solar energy to create an efficient, environmentally friendly, and sustainable energy solution. By using a mixed power drive method of wind and solar energy, the unmanned ship can achieve long voyages and ensure stable power supply, enabling it to adapt more flexibly to various environmental conditions[15].

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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