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Design and Implementation of Autonomous Underwater Vehicle "NEMO III"

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ABSTRACT

In recent years, with the increasing progress of the country in the development and utilization of marine resources, the development of underwater robot technology has become more and more rapid, and a large number of marine exploration tools and means have been developed, especially, the underwater autonomous vehicle (AUV),as a human robot to explore the unknown marine world, which has become a research hotspot in the field of marine environmental development technology. This paper elaborates on the multi-purpose intelligent sensing underwater vehicle developed by the team. The aircraft adopts modular design structure, omnidirectional drive propulsion mode, can be equipped with a variety of sound and light detection instruments, and uses PID and cross-spectral control algorithms. Accurate positional relationship is calculated from the acquired data, and after data fusion, it is output to the control system, and the task path is planned in real time and navigation and driving instructions are issued to realize completely unmanned navigation. For the target object in the underwater environment, combined with the image recognition and feature matching algorithm and the underwater acoustic directional guidance detection method, the effectiveness of the whole system structure applied to the "NEMO III" AUV control is demonstrated.The actual flight test verified that the self-developed "NEMO III" AUV can independently plan the mission path and perceive the target feature information according to the underwater scene environment, and control the aircraft to complete the underwater high-precision operation tasks independently. It has certain autonomous decision-making and intelligence. The ability to control indicates that the technology can be applied to engineering practice.

KEYWORDS

Intelligent perception; Underwater target detection and tracking; Unmanned autonomous guidance; PID; cross-spectral method

1 Introduction

In recent years, with the increasing progress of the country in the development and utilization of marine resources, the development of underwater robot technology has become more and more rapid, and a large number of marine exploration tools and means have been developed, especially underwater autonomous vehicles as a human. Robots exploring the unknown ocean world have received much attention from many countries.

Autonomous Underwater Vehicle (AUV) is an important tool for humans to explore the unknown ocean world. It has great application value in many aspects such as marine environment detection, marine rescue and salvage, underwater security supervision, hydrological parameter monitoring, topography and mapping, etc.[1-2], becoming an advanced ocean country to enter and exit the deep sea and compete for international seabed resources. arms.

In view of this, the team developed a set of "NEMO III" AUV system as a test platform, which can achieve functions such as track navigation control, underwater acoustic guidance positioning, image recognition and tracking, grabbing target objects, and fixed-point placement of props. Accurate underwater positioning accuracy of ±0.02m vertical and ±0.05m horizontal. In this paper, the AUV is elaborated in detail from mechanical structure design, hardware electronic design and system software design.

2 Mechanical structure design

"NEMO III" AUV adopts a frame structure in the overall design of the system. It is made of sheet metal firmware made of aluminum alloy material. The surface is treated with anti-oxidation and hardening to enhance the hardware strength and corrosion resistance. The aircraft is 1.1 meters long, 0.56 meters wide, 0.48 meters high, weighs 37 kilograms, and has a pressure of 100 meters. It is equipped with two cabins on the upper and lower sides. The cabin shells are made of acrylic material and are designed to easily monitor the running state of internal components. The O-ring is sealed between the end of the casing and the groove of the end cover; the end cap is an acrylic plate, and the position of the snap ring and the sealing end is relatively fixed to support the protection; Body testing and epoxy resin sealing treatment, while taking into account the aesthetic and practical. The electronic compartment is located on the upper level, with built-in main control hardware circuit, nested lower camera in the middle of the cabin, external suspension arm; battery compartment is located on the lower layer. It is designed for easy installation and removal.

The entire cabin of the "NEMO III" AUV is placed on a fixed frame with 8 propellers propped around the fixture. The structure is a 6-degree-of-freedom, fully-driven propulsion layout, ie traverse, sway, heave , roll, pitch and yaw, to achieve direct navigation, side shifting, turning and other functions of the aircraft. Among them, two main pushes on the left and right provide the propulsion power of the aircraft; two side pushes before and after, changing the action of the aircraft The attitude and azimuth in the middle; 4 vertices of the apex angle, for the depth control of the dive and the upward movement of the aircraft, driving the guidance of the aircraft, so that the carrier advances toward the target. The externally mounted sensor is connected to the frame by a 3D print. The front view camera has been detachably sealed; the bottom is equipped with a Teledyne Reson TC4013 hydrophone.

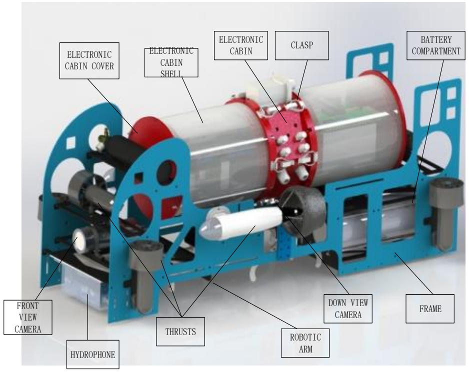

Figure 1 AUV mechanical structure frame diagram

3 Hardware electronic design

The hardware structure system of "NEMO III" AUV can be divided into digital system and power system to reduce the mutual interference between the two signal transmissions. As shown in Figure 2, the left side is the power system and the right side is the digital system. The entire power supply is loaded in the battery compartment, consisting of 24V and 12V four hot-swappable lithium polymer batteries, totaling 25900mAh, which can meet the 6-hour battery life.

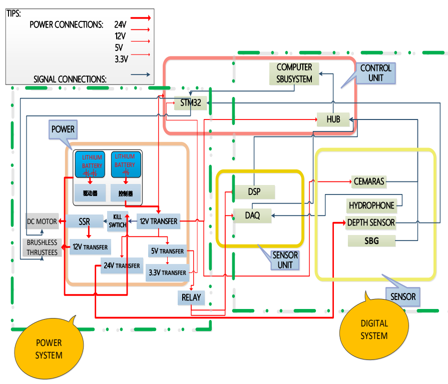

Figure 2 AUV hardware structure diagram

3.1 Digital system

The digital system consists of an industrial computer, an information acquisition device, and a data processing device. The core component of the system is the industrial computer as the upper computer, responsible for formulating and completing the autonomous operation strategy of the aircraft; the information collection device is composed of inertial measurement device SBG, depth sensor, temperature and humidity sensor, hydrophone and camera. The main function is to obtain water under sound and light information. The inertia and depth sensors provide attitude information of the aircraft, while the camera and hydrophone acquire underwater underwater sound and light information; the data processing device is composed of a data acquisition board, a signal conditioning board and a DSP board, which can filter the analog signals collected, Power amplification, A/D conversion, and digital processing, etc., the solution results are transmitted to the industrial computer through the switch, guiding the aircraft for control and guidance.

3.2 Power system

The powertrain includes a main controller, power board, drive board, thrusters, and robotic arms. The system uses STM32F103ZG model ARM board as the main controller, executes the upper computer command, carries out the motion control and communication management of the aircraft, internally adopts RS-485 serial communication protocol, and connects and communicates with the main controller by UART-USB port, Provides large data traffic and high work efficiency, ensuring system stability. The power supply board performs voltage regulation on the power supply system to meet the driving voltage requirements of each module. At the same time, the main controller also provides enough PWM channels and I/O ports to control the drive plate to the robot arm and multiple sets of thrusters.

4 System software design

Modern control pays more attention to solving high-level decision-making problems and needs to implement intelligent control based on target tasks. Task control is an important research content of intelligent autonomous control systems [4-5]. In this paper, the autonomous underwater vehicle is taken as the research object, and the software control system of "NEMO III" AUV is designed and implemented.

The AUV control system enables the AUV to perform mission planning and target information detection and identification based on the characteristics of the aircraft's attitude and position during driving, and independently complete underwater missions. The main functions include mission planning, path planning, and underwater target information. Identification and tracking, information processing of images, and positioning guidance of underwater sounds. Mission planning is to plan the mission plan that AUV needs to perform; path planning is to design a physical achievable route for AUV according to the task list that needs to be performed; the identification and tracking of underwater target information can capture the feature information we need to ensure The AUV is stably traversed according to a preset route; the information processing of the image is based on the feature points of the segmented target information, and the image processing technology is used to guide the navigation and navigation of the robotic arm to complete the underwater target capture task; The orientation can detect the orientation information of the beacon. The system software design of "NEMO III" AUV mainly includes strategy control system, image processing system and underwater acoustic orientation system.

4.1 Policy control system

The environment in which the AUV is navigating underwater is very complex. In different situations, it is necessary to use a variety of different sensors or detectors to perceive the surrounding environment and guide the decision control of the aircraft. Accurate strategic control is an important guarantee for the aircraft to complete tasks underwater.The system adopts the inertial navigation track estimation algorithm, which combines the information of each sensor and transmits its own attitude information to the industrial computer to drive the aircraft to complete underwater navigation control, including: control module, communication module, task assignment module, parameters. Load the module and the remote control module.

4.2 Control module

Mainly responsible for mission planning, it is the core module that is tightly connected to the software control system. According to the actual mission requirements, based on the current fusion information of attitude, depth, speed, vision and acoustics, the reference motion state is calculated. The main controller accepts the upper computer command and controls the propeller action through the motor input signal and the PID control algorithm.The software architecture of the "NEMO III" AUV strategy control system adopts the master-slave distributed control method, which is self-contained and can adjust the strategy and scheme according to the actual task requirements to complete the corresponding navigation control tasks. The control system is divided into two parts of the upper and lower position machine. The industrial computer of the i7 processor and the STM32F1 series single-chip microcomputer are used as the control chip to ensure the stable and reliable operation of the whole system. The lower position machine is mainly responsible for driving 8 motors, turning on and off 12 relays, obtaining depth information, stabilizing the attitudes such as depth, pitch and roll, and receiving commands from the upper computer; the upper computer is responsible for reading water. Sound, INS information, and the operation of the image program, according to the requirements of the task, the information is processed, the control decision function is run, and the control command is issued to the lower computer.

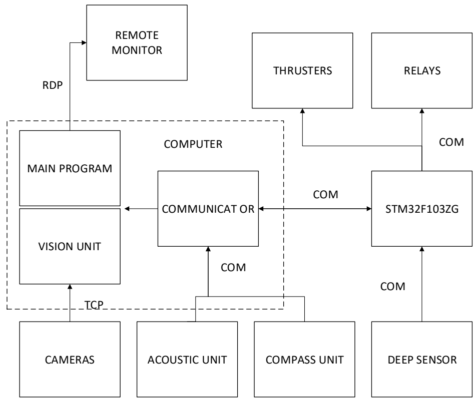

Figure 3 Control module diagram

4.3 Communication module

It is mainly responsible for data communication between various sensors for receiving commands and transmitting module data. Serial communication is a bridge for information exchange between the computer and each interface sensor. The RS485 communication protocol is adopted to ensure a high data transmission rate of the entire system. The communication program is responsible for acquiring the inertial navigation, underwater acoustic data, and sending it to the STM32 and the main program; it is also responsible for forwarding data and instructions between the main program and the STM32. The communication module is implemented by the transceiver class, receives the information sent by the communication program and transmits the control command to the communication program. The received signal is stored in the form of a FIFO queue, which solves the problem of frame loss caused by serial port communication, data frame truncation and other abnormalities, and each frame signal can be processed to ensure reliable communication.

4.4 Task assignment module

When the main program starts, it reads all the task list files in the specified directory and displays them on the interface for the user to select. When preparing to start the task, the interface part generates a list containing the task identifiers and sends them to the controller according to the current selection of the user. According to the table, the controller adds the corresponding task description structure to a linked list of task queues in order, and then points the current task pointer to the list header to start scheduling tasks.

The task description structure contains a task initialization function pointer, a control frame function pointer, and a task end function pointer. The initialization function pointer points to the initialization configuration function of the current task. The function of the function has the counters required to initialize the task, the current task status, the notification image unit ready, the initial setting of parameters such as PID, and the like. The control frame function first checks the current state data of the aircraft, determines the action to be performed, and calls the corresponding action function. The task end function is responsible for destroying the proprietary variables used by this task after the task is finished, and placing the aircraft in an idle state to wait for the next scheduling.When scheduling a task, the controller first performs the necessary general initialization steps, then takes the initialization function pointer from the current task pointer and executes it, and finally associates the control frame timer with the current control frame function pointer. Thereafter, the timer periodically calls the control frame function to perform control amount correction. When the decision task is completed, the task function calls an (endTask) framework function, which is taken over by the framework. At the end of each task, the (endTask) function does some general cleanup work, and then passes control to the (nextTask) function to schedule the next task.In the task scheduling process, the circular linked list is used to arrange the tasks. When the task sequence and the control logic change, the task queue can be changed, and the tasks that need to be changed or introduced can be inserted into the appropriate positions in the linked list, which is very convenient.

Figure 4 Task list

4.5 Remote control module

The remote control interface has its own independent data flow, which can be used as single-step start control, such as pusher start and rotation, opening and closing of the robot arm, etc., and load the interface function into the task state structure by clicking on the main interface widget. Button to view and change the current task status.

5 Image processing system

The image processing system is the basis for the underwater vehicle to detect, sense and identify the underwater object environment.

Figure 5 Manta G-046C (left) and Computar 5 mm wide-angle lens (right)

The Manta G-046C industrial color camera from Allied Vision Technologies has been selected as a front and rear camera with a fixed focal length; a 5 mm wide-angle lens; high resolution and fast frame rate. This camera lens captures very high quality images because of their high precision and flexibility in terms of focal length, aperture and white balance. To ensure a high signal transmission rate, the camera communicates with the onboard computer via a Gigabit Ethernet connection switch to meet visual recognition and navigation tasks.

Considering the complex underwater imaging environment, floating objects in the water and intense illumination can seriously degrade the image quality. Accordingly, image information preprocessing operations are unavoidable. Including: adaptive exposure increases the white balance control of the image; based on the image enhancement algorithm, the histogram equalization is used to improve the quality of the photo; edge detection, color threshold, morphological operation, etc. are performed on each frame image to detect the target position, The segmentation process and the decision classification are performed by a preset threshold. According to the processed geometric feature information of the object, the position of the aircraft and the underwater target can be accurately located.

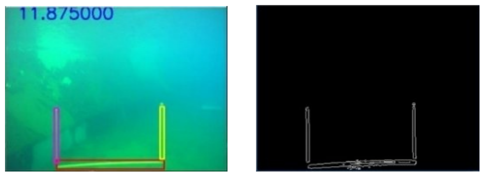

Figure 6 Source image (left) and preprocessed image (right)

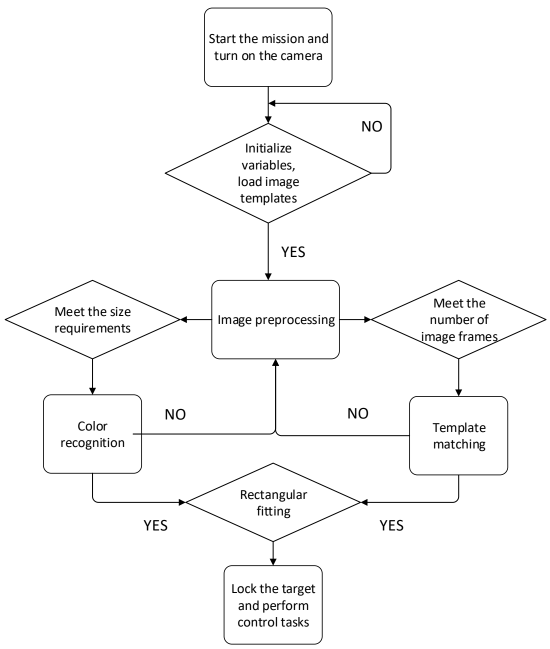

Figure 7 Image recognition detection flow chart

As shown in Figure 6 and Figure 7 , according to the source image captured by the camera, after the image is preprocessed, the region of interest is created, and the color recognition and threshold segmentation are performed. First, the template matching method is performed. After the template matches a certain number of frames, the template is considered to be in the template. The target object has been found under the matching method; then the color recognition is performed, the image feature information is extracted by adjusting the weight component of the image RGB, the target edge contour information is fitted, and the area of the identified object is detected, that is, when the required number of frames is reached, the target is locked. Transfer to the control system for navigation.

6 Acoustic orientation system

The precise orientation of underwater targets is the main task of underwater detection. The underwater sound positioning system is mounted on the AUV, which can complete the orientation and positioning of underwater targets, thereby achieving functions such as autonomous navigation, target detection, and search. The underwater vehicle is composed of four hydrophones and a four-element trapezoidal array receives the signals transmitted by the acoustic beacon. The angular position uses a cross-spectral algorithm[7] to solve the noise interference during underwater target detection and information transmission. problem.

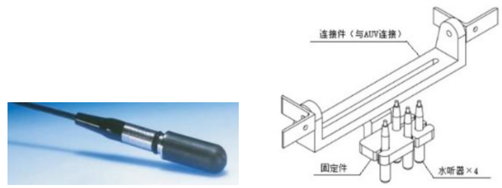

Figure 8 Hydrophone and assembly drawing

As shown in Figure 8, the Teledyne RESON Hydrophone TC4013 hydrophone provides a range of frequencies from 1 Hz to 170 kHz with high sensitivity relative to its size. It also provides uniform omnidirectional sensitivity in high frequency horizontal and vertical planes, and can receive signals from any direction.

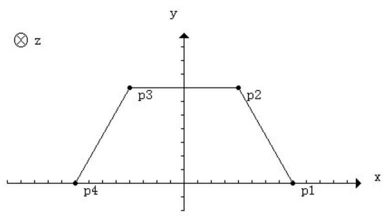

Figure 9 Isosceles trapezoidal quad array

The passive underwater acoustic positioning system mounted on the AUV is generally composed of a receiving matrix, a signal conditioning module, a signal acquisition module, and a signal processing module, wherein the receiving matrix receives signals; the signal conditioning module performs preprocessing on receiving signals for amplification, filtering, and the like. The signal is adjusted according to the center frequency and the passband width; the signal acquisition module uses the DAQ EM-9118B with 16-bit sampling resolution for real-time synchronous spatial sampling of the processed four-channel signal; the signal processing module uses the Texas quad-core instrument TMDSEVM6678L (1.0GHz). The data is processed by the cross-spectrum method, and finally the azimuth of the acoustic beacon relative to the aircraft is measured to realize signal detection and sound source target positioning.

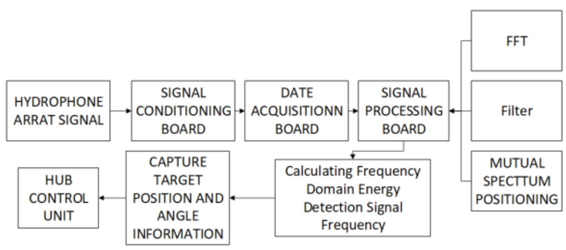

Figure 10 Flow diagram of underwater acoustic orientation system

The underwater acoustic positioning system is used as the underwater target search and positioning technology. The purpose is to convert the underwater acoustic signal into an electrical signal, and process the signal through the signal conditioning board, data acquisition board and DSP board, and pass signal detection and frequency detection. The delay estimation and other steps are used to solve the specific position information of the acoustic beacon and transmitted to the industrial computer to guide the "NEMO III" AUV positioning control. In the case of quaternary sparse array with limited number of array elements, combined with the corresponding DOA estimation algorithm to achieve spatial direction estimation, the multi-path effect of acoustic waves in shallow waters is easily solved, and the estimation accuracy of the direction is improved. The purpose of accurately positioning the acoustic signal is achieved.

7 Test results

Aiming at the "NEMO III" AUV control system developed and constructed in this paper, the test experiments were carried out in the swimming pool, including guiding the door task and capturing the target object. The experiment verified the reliability and feasibility of the control system and the sound and light algorithm.

As can be seen from Figure 11, the "NEMO III" AUV can independently plan the mission path and perceive the target feature information according to the underwater scene environment, and control the robot to complete the relevant underwater operation tasks. Figure 11 (left) is the task of guiding the door. The underwater target (door) is detected by the forward-looking camera and combined with the current position and attitude information of the aircraft to be transmitted back to the industrial computer, and the acquired sensor information is merged. The PID control algorithm calculates the precise positional relationship and issues the navigation drive command to adjust the direction of the

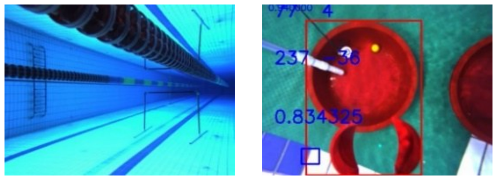

Figure 11 guides the door (left) grab the target (right)

propeller to control the path planning of the aircraft, so that the aircraft can align the door and successfully complete the guided door task. Figure 11 (right) is the task of the robotic arm grabbing the underwater target (ball), and accurately calculates the azimuth information of the target through the underwater acoustic orientation system, driving the aircraft to track around the target object, and then the image processing system takes over and opens. The down-view camera uses color recognition and template matching processing algorithms to extract target feature information and control the robotic arm to grasp underwater objects.

The experiment verifies the reliability and stability of the "NEMO III" AUV control system, which can be used for high-precision underwater operations, and has broad application prospects in the fields of navigation control and information fusion integration.

8 Conclusion

Under the marine ocean environment, underwater robot technology has been extensively researched at home and abroad, and has been widely used in practical engineering. It is a future development to realize high-precision, long-distance, fully automatic intelligentization of underwater vehicles. The inevitable trend. This paper builds a complete underwater vehicle development and debugging system, and introduces the mechanical structure design, hardware electronic design and system software design of the aircraft. The system software design part includes strategy control system and image processing. The system and the underwater acoustic orientation system use PID control algorithm and are applied to the navigation track control of the system. In order to realize the high-precision underwater task of the aircraft, the cross-spectral algorithm is applied to the acoustic beacon directional positioning task. The target object in the underwater environment, combined with the image recognition and feature matching algorithm and the underwater acoustic directional guidance detection method, demonstrates the effectiveness of the whole system structure applied to the "NEMO III" AUV control. At the same time, the actual flight test verified that the self-developed "NEMO III" AUV can independently plan the mission path and perceive the target feature information according to the underwater scene environment, and control the autonomous operation of the aircraft to complete the underwater operation task, indicating that the technology can be applied to engineering. actual.

About the Author

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