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A Novel Control Method for Shallow Underwater Robot

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Abstract

For the coordination and control of robot behavior, behavior decision is the foundation and the determinant of robot intelligence. Based on autonomous underwater vehicle (AUV), through the analysis of domestic anti-surge technology research status and inrush current model, a control technology with the use of behavioural decision upper and lower piecewise integration control between PID and FPID(Fuzzy PID) is designed. Then, according to the characteristics of underwater robotics and inrush current optimal path planning, AUV can get information and plan a different anti-surge behavioural decision, which makes underwater robot better complete the underwater operations. Finally, the simulation of anti-surge behaviour underwater robot is done. The results show that it achieves a good control performance, and the environmental adaptability of AUV has been improved.

Keywords: *Behavior decision; AUV; Anti-surge; Fuzzy PID*

1. Introduction

With continuously expanding the range of applications of the robot, the working environment becomes more and more complex [1]. Usually, it is unknown, dynamic and unstructured. The underwater work of the AUV is interfered inevitably by the surge. The surge is defined as the impact of water in the burst state [2]. The surge is sudden, huge impact with kinetic energy and uncertain impact direction. When underwater vehicle is interfered by the surge, AUV may sway, heave and roll. The problem of the surge interference has a great influence on underwater vehicle [3]. To solve it, the AUV behavioral decision control is proved in this paper.

Environment perception, behavioral decision and action implementation are the main content of the intelligent vehicle system's structure. Robot decision-making system is one of the most important parts, which reflects intelligent, reliability and robustness of robot [4, 5]. The structure of AUV behavior decision control system includes inclusive type and reactive type [6, 7]. Based on priority stratification, inclusive type structure has fast response and simple design. However, when dealing with complicated tasks, it has some disadvantages. Based on weighted summation behavior, reactive structure is good at dealing with complex environment. But the biggest difficulty is to control the weighted number. As for the underwater vehicle wave impact theory, it references the theory of surge to submarine action [8]. The action of near surface wave to the submarine can be divided into two kinds of research [9]: the first one is dividing the surge into first order wave force (linear component) and second order wave forces (nonlinear component); the second one is researching the whole submarine force under the environment directly.

Zanoli, Silvia M and Giuseppe Conte [10] simulated the posture control with fuzzy PID control for the underwater vehicle in the interference of the depth. They pointed out that inhibit overshoot was one of the most important indicators for underwater vehicle anti-interference control.

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Zhenbang Gong and Heping Liu [11] researched the rolling posture control problem with adaptive synovial control method. Through calculation and simulation, the result shown that it could get a good control performance.

J.Yuh and Ranganath Lakshmi [12] used the neural network theory for underwater robot control and it achieved certain effects in dealing with time-varying parameters ROV and random noise.

Soylu and Serdar [13] proposed a non-chattering sliding mode controller for ROV path tracking and conducted experiments. The results showed that the path can be a good tracking.

Xinqian Bian and Zheng Qin [14] put forward behavioral dynamics method for the AUV motion planning under dynamic uncertain environment. Based on this method, the horizontal AUV autonomous behavior agent was established. The result shown that autonomous behavior agent responded quickly, correctly and effectively in non-structural environment.

Shuyong Liu etc. [15] researched the tracking control and the posture control with nonlinear feedback control in the shallow water. The simulation results shown that the control method could effectively improve the robustness and stability of the underwater vehicle1.

It seems that the AUV control method develops gradually from the traditional PID control, fuzzy control, neural network control and sliding mode control and other modern control methods which are constantly trying to apply to the control of AUV. But the traditional PID control method is very dependent on the accurate linear model. For strongly nonlinear underwater robots, it needs to design a set of PID parameters to cover the entire operating range and it is very difficult. The sensitivity of fuzzy control problems restricting its use, for the real-time demand of underwater robot is high. Since structure and parameters of Neural network are difficult to determine. When the environment changes heavily, and the high requirement of real-time system, neural network learning appears obvious hysteresis and the control is easy to oscillate. For sliding mode control method, due to its fluctuations in the sliding surface, the system will have the chattering problem. Fuzzy control, neural network control and sliding mode control methods or their combination in the control of AUV are worth exploring and further deepening.

In view of the shortcomings of the above control algorithms, in this paper, the underwater robot's behavior as a starting point, in view of the complex underwater environment, a control technology with the use of behavioural decision upper and lower piecewise integration control between PID and FPID is designed. Using PID and FPID controller with behavior control, through the behavioral decision system to dynamically organization and scheduling of various basic behavior module, and coordination with the various behavior, by constantly interact with the environment to resist surge. Use attitude sensor data collection, and the corresponding control and data acquisition control circuit. The resistance to flow to the system behavior experiment, verify the validity of the system under the surge.

2. Piecewise Integration Control between PID and FPID

In order to better adapt to the rapid changes in the underwater environment and overcome the delay and error caused by mechanical transmission, the system need be optimized [16, 17, 18]. Therefore, piecewise integration control between PID and FPID will be used in this article. When the angle deviation is much larger than the threshold value, the PID control is used; when the angle deviation is less than the threshold value, FPID is used. By applying different methods to varied phases, it not only is able to inherit the low error and good static stability of routine PID , but also has fuzzy controls advantage of fully acclimatizing itself to the object. Then, the system can reduce the shock, increase stability and improve the work efficiency.

First, the collection of the angle of the current control is needed. According to the set value, the current value of the angle of deviation and deviation rate, and the value of the deviation angle, FPID or PID is used. If PID, the output value is calculated directly; if FPID, firstly EC and EC (k) are fuzzified. According to the fuzzy rule, the control parameters are set. Finally the values output, the software flowchart as shown in Figure 1.

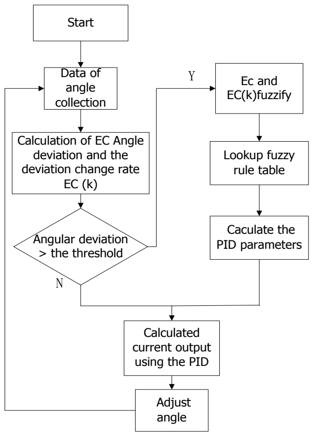

Figure 1. The Result of PID and FPID Control

3. Behavior Decision Algorithm

Decision-making control system is the core of the underwater robot control system and is an important part in the study of underwater robot. Decision control system gets access to environmental information by sensor and gets operation mode according to the upper mission planning module, and then find the optimal path and complete the operation mode switch.

3.1. Behavioral Decision Algorithm Design

In complex underwater environment, except for emotional behavior, AUV also needs rational behavior, such as mission planning behavior, scheduling behavior. Among these behaviors, complex behavior is difficult to control with the general method like obstacle avoidance behavior.

In this paper, we propose a multiple decision-making methods to realize the behaviour decision. The entire decision-making system is divided into rational behavior layer and emotional behavior layer, as shown in Figure 2. Rational behavior system is composed of control algorithms, through behavioral decision algorithm for mission planning, path planning and scheduling. Mission planning behavior is responsible for underwater robot global task of planning and scheduling. To set for AUV multiple activities at the same time, and then through the act of mission planning for task allocation; Path planning behavior is responsible for suspension flow motion, and changes according to the real-time changes. Plan out a best motion path from the starting point to the target point; Scheduling behavior is responsible for interacting with emotional behavior system and receives emotional behavior feedback of all kinds of status information.

Rational behavior system doesn't control AUV directly, but through emotional behavior system. So, the rational behavior has the characteristics of non real time. From the mission planning behavior, analyze the situation and give the order to the path planning behavior and feedback the implementation. Through the scheduling behavior, ensure the AUV according to determine the path of action and feedback data constantly.

Emotional behavior system controls underwater robot in real-time. The anti-surge behavior and posture remaining behavior is included in this paper. The anti-surge behavior could take different measures to resist surge in real time according to the real situation; posture remaining behavior maintains a certain attitude for underwater vehicle based on attitude sensor. AUV action of execution is weighted and multiple basic behavior, rather than a certain behavior for the output. By adjusting the relative size of the weighted coefficient λ, the behavior of the AUV personality and overall performance can be changed. As long as the important behavior of the weighted coefficient λ is bigger, the behavior can be the output. And the weighted coefficient λ can be get from the MATLAB fuzzy logic toolbox.

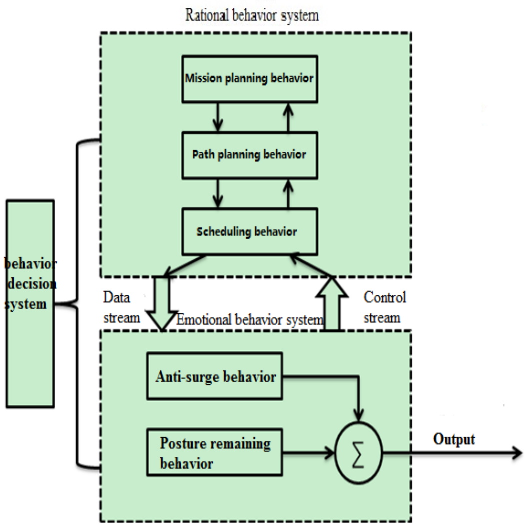

Figure 2. Multiple Decision-making System

The system is MIMO (Multiple-Input Multiple-Out-put)) system to control a plurality of paddles (implementation perspective, attitude adjustment purposes) and propeller-driven. Coupling between the various actors, the system is an integrated control platform. In this paper, the 3DM-GX system is used for obtaining attitude information. According to the attitude information, the impact force and momentum are obtained by Newton's theorem to predict and control.

(1)Anti-surge behavior

1) Reasonable crossing

When little or no surge, the task of underwater robots behavioral decision is to design a plan by the current point A to point B, as shown in Figure 3. When the surge is small, the optimal distance between two points is a straight line. Underwater robot posture may change since the impact of water in the movement process. Then, the attitude angle of the underwater robot needs to be controlled. The control goal is to make the underwater robot with a predetermined attitude to run forward.

Figure 3. Reasonable Crossing Path Planning

2) Active avoidance

When the surge is large, underwater robot takes the mode to the dive. When inrush current is less than the active force of underwater robot, the underwater robot goes up again, as shown in Figure 4. The control is still used for segment PID control in this process.

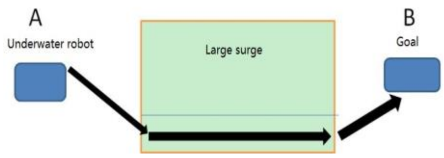

Figure 4. Active Avoidance Path Planning

(2) Posture remaining behavior

In the independent mode, AUV gets the attitude data from the sensors and adjusts attitude to maintain the stability of attitude as shown in Figure 5.

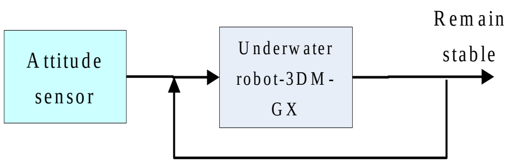

Figure 5. Posture Holding Behavior

3.2. Behavioral Decision Algorithm

The underwater vehicle behavior decision-making system works as an intelligent decision-maker in whole AUV movement behavior. In order to solve the possible problem caused by surge. Two different modes, obstacle avoidance and obstacle crossing are used for path planning in this paper. When AUV can't resist the surge, control pump makes the AUV sink until the force is bigger than the surge force and goes upward again. If the surge flow is bigger, continued downward in turn. In path planning, the piecewise FPID and PID control is used to guarantee the stability of underwater robot in the preset Angle and depth, which can be stable in the large flow through the control of underwater robot operation.

The flow chart is shown in Figure 6.

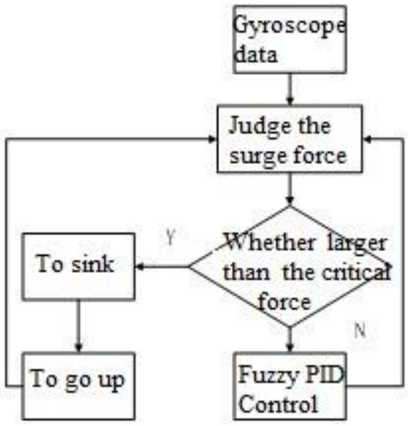

Figure 6. Underwater Vehicle Path Planning Process

The force of inrush current can be measured by gyroscopes. According to analysis, we can know whether the force is bigger than servo output. The 3DM-GX system collects real-time data, to ensure that the upper behavior of decision-making algorithm operate normally.

4. Simulation and Experiment

4.1. Simulation

To simulate the movement of the underwater vehicle, we need to conduct a study on the flow. Inrush current model is very complex, which is consisted by the first-order and second-order turbulence force. In the simulation, instead of inrush current we adapt general water model and described some basic unconventional surge force. Surface waves can be approximately deemed as stationary random process, which can be seen as the superposition of many different cycles and different random initial phase of the cosine wave. Due to the impact of the mutual coupling between the nonlinear characteristics of the second-order wave forces, and the underwater vehicle direction of movement disturbance, it becomes very difficult to makes the accurate calculation of second-order wave force. As current theories and methods cannot be fully resolved, it needs further research. When we research a point on wave and kinetic energy in shallow water under the simulation conditions, taking into account the practical application, the higher harmonic can be ignored, then:

$$\delta(t) = \sum_{i=1} \delta_{ai} \cos(K_i X_o - \omega_i t + \varepsilon_i) \tag{1}$$

Among them, δ represents the distance between the wave to the horizontal surface, Xo represents the axis to the horizontal plane coordinates, and δai, Ki, ωi, εi represent the amplitude, the wave number, frequency, initial phase.

We have had the anti-surge experiment in the school pool. The entire simulation was divided into two parts: the first part was fuzzy PID control; the second part was added the behavior decision-making control to fuzzy PID control. The whole simulation was in LABVIEW simulation. The system analyzed the different conditions of underwater vehicle under different algorithms. Criterion is the deviation angle control posture. The smaller attitude angle deviation is and the faster stable is, the better the control effect is.

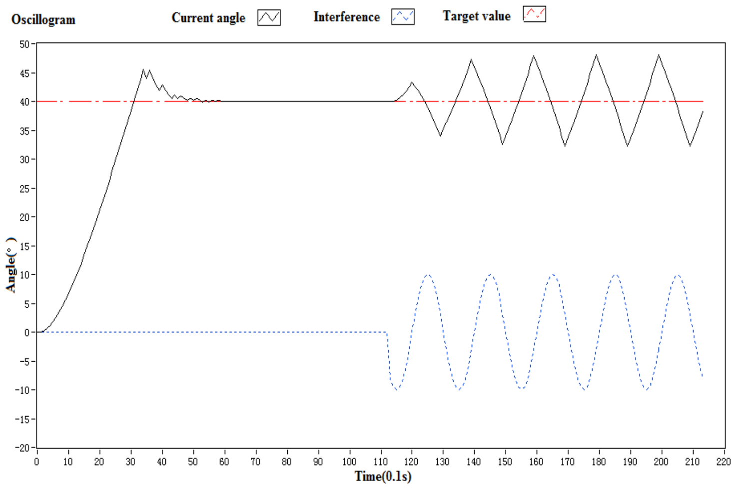

Figure 7. Results Figures of PID Control

In the first part of the experiment, the experiment is divided into twice. First one is controlled by PID alone. The simulation is shown in Figure 7. The left ordinate indicates the angle. The black line represents the current angle of the underwater vehicle; the blue dotted line represents the interference value; the red dash dot line indicates the target value. The default is defined as 40 degrees. When the disturbance of underwater robot deviates from normal orbit, the values are adjusted through the PID algorithm. From the graph, current angle deviated from the target curve large. Using a single PID, anti-interference performance is poorer and unfavorable to the normal operation.

Second one is controlled by PID and FPID, which is divided into deflection and rolling, as shown in Figure 8 and 9. In the figure, the black line represents the current angle of piecewise integration control; the blue dotted line represents the current angle of FPID control; the red dash dot line indicates the interference value. For deflection and rolling, the value of angle is closed to the value of expectation and the error is smaller. The demand of underwater robot for stability and anti-jamming is higher, so the optimization algorithm has certain feasibility.

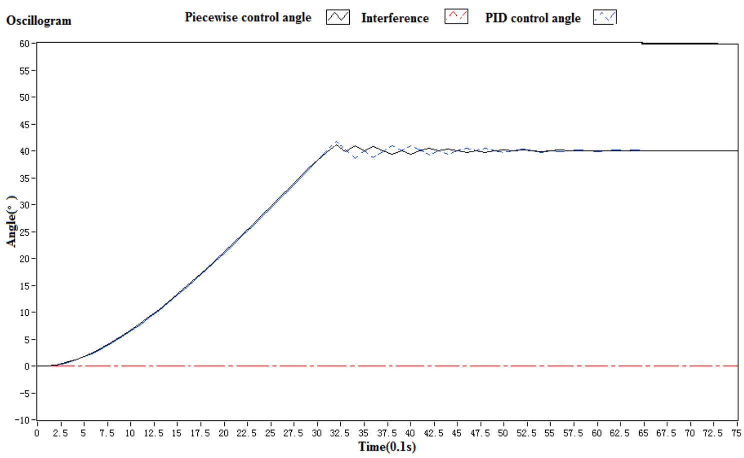

Figure 8. Deflection with PID and FPID

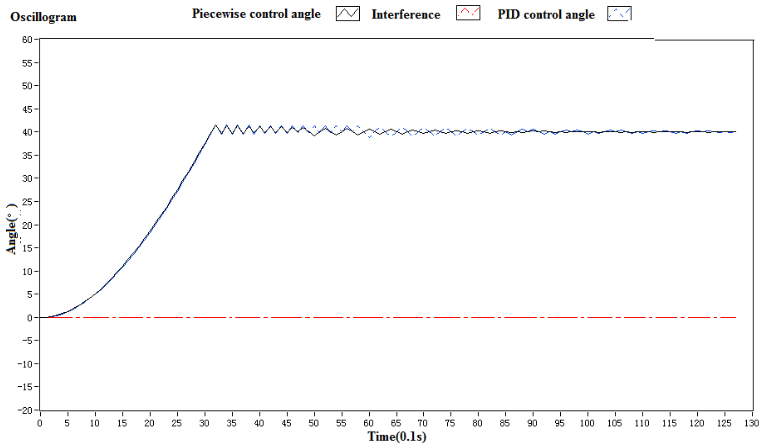

Figure 9. Rolling with PID and FPID

In the second part of the experiment, on the basis of the fuzzy PID, the behavior decision algorithm is added. In order to verify the reliability of algorithm, the simulation is divided into four different conditions: one is the continuous larger flow using path planning; two is the continuous larger flow without using path planning; three is a kind of intermittent flow; last one is the small flow case.

The underwater robot trajectory is shown in Figure 10, 11, 12 and 13. The left ordinate indicates the depth, and the right vertical axis represents the angle. The black dotted line represents the surge high; the black dash dot line indicates the dive default values; the black solid line represents the current depth and the value of the diving depth is controlled by fuzzy PID; the red dotted line indicates rolling motion default curve and we set the roll motion default value of 0 °; the blue solid line represents the current angle of deflection; the blue dashed line is the default value curve deflection; the freedom of movement on the default value is also 0 °.

As shown in Figure 10, because the wave is large, AUV will sink until the surge force is smaller than the critical force. Using behavior decision algorithm, in the given environment both rolling and deflection current angle is closed to the setting angle. What's more, angle deviation becomes smaller and smaller. The stable process is fast and only takes 3s. The underwater robots action can greatly reduce the impact of the surge and remain relatively stable movement in a continuous wave. Otherwise, without behavior decision algorithm, both rolling and deflection angle deviation is huge. Underwater robots will roll and yaw heavily and cannot remain stable motion, as shown in Figure 11.

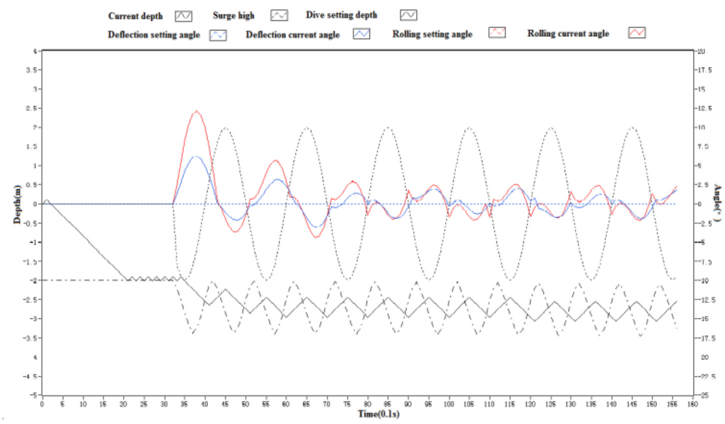

Figure 10. Motion Simulations using Behavioral Decision

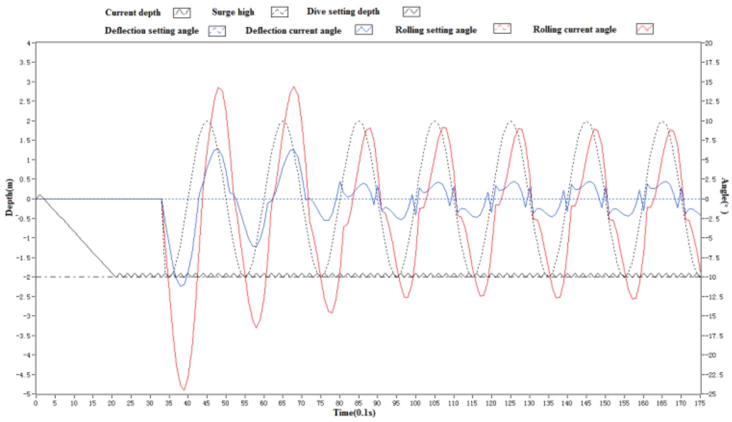

Figure 11. Motion Simulations not Using Behavioral Decision

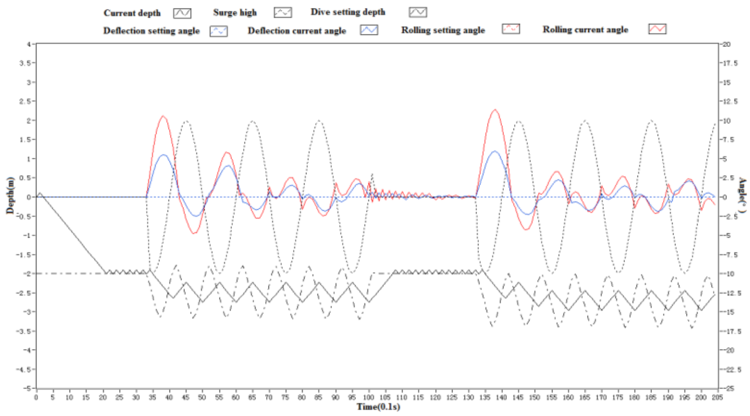

Figure 12. Motion Simulations Under Intermittent Wave

In the interference of intermittent wave, using behavioral decision algorithm, AUV can also have a good solution and remain stable motion, as shown in Fig12. Both rolling and deflection current angle is closed to the setting angle. When AUV tends to be stable, another current is coming and AUV can also maintain stable quickly. Angle deviation becomes smaller and smaller.

When the surge is small, simulation diagram is shown in Figure 13. The underwater robot can control the movement of the steering gear to maintain relatively stable and it don't need to sink. AUV can go forward with a predetermined attitude.

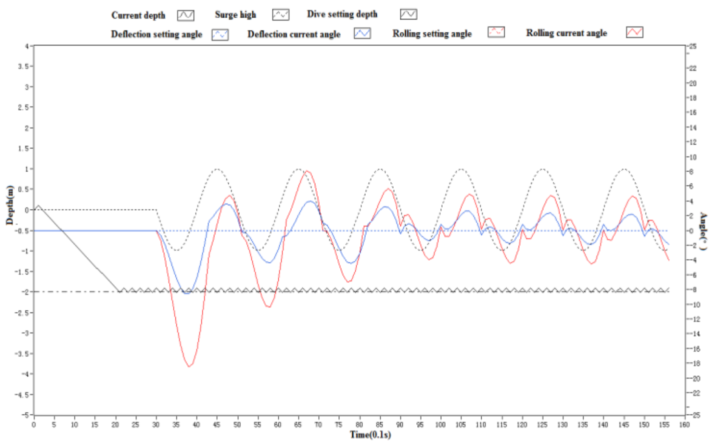

Figure 13. Underwater Vehicle Movements when Surge Small

4.2. Experiment

In order to verify the control method, we have had a experiment. In this paper, we adopt Poseidon SB - 1 submarine of Taiwan LeiHu Company, as shown in Figure 14. Mechanical part of the underwater robot prototype mainly is used, and its control system is redesigned. The attitude sensor is added, to meet the demand for control in this project. The main parameters of the underwater robot:

1) displacement: 7.7 kg (floating on the surface of the water), 7.95 kg (descend)
2) total length: 774 mm
3) total width: 290 mm
4) hull width: 200 mm
5) total height: 285 mm
6) propulsion: 12 v DC motor
7) propeller: 3 leaf propeller, diameter: 40 mm, section: 41 mm

The shell of submarine is solid. Built-in pulse pumps and water bags can be static ups and downs. There a gyroscope that can detect attitude angle. By the attitude sensor, real-time data is processed.

Figure 14. Underwater Vehicle Platforms

Through practical launching and online debugging of underwater robot, the underwater robot can all run smoothly. In the small surge, AUV went forward with a predetermined attitude, as shown in the left picture of Figure 15. In the continuous wave and intermittent wave, the algorithm can guarantee the stability of underwater robot, as shown in the right picture of Figure 15.

Figure 15. Experiment of AUV

5. Conclusion

In order to better adapt to the underwater environment of rapid change, a kind of AUV multilayer control reactive decision control system structure is designed in this paper based on fuzzy PID algorithm, planning for the anti-surge behavior of AUV. Multiple decision table reactive decision-making system and FPID and PID subsection integration control are designed in this paper. According to the size of the angular deviation, different piecewise PID or FPID processing are adopted to reduce the oscillation of the system and increase the stability. The simulation results show that both the continuous surge, intermittent surge and small surge, the decision-making system can be a very good deal with this behavior. And steering gear can keep relatively stable movement, which raises the AUV's ability to adapt to the environment. Actual experimental results that the underwater robot can better stable movement, shows that the system can well realize the stability of the underwater robot movement. For underwater robot control, under complicated environment and multitasking will be the direction of further research.

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