Design and Experimental Analysis on Autonomous Control System of Wave Glider

Jian Shi¹, *, Zhanfeng Qi¹, Yufeng Qin¹, Xuewu Hong² and Jian Zhao²

¹National Ocean Technology Center, Tianjin, China  
²Tianjin Chengjian University, Tianjin, China

*Corresponding author e-mail: 596365272@qq.com, shijian53681@163.com

Abstract. In order to realize the unattended and autonomous navigation of Wave Glider in the ocean, an autonomous control system is designed, which mainly includes the control circuit part, motor driver part and control algorithm part. System integrates solar energy charging module, wireless communication module, satellite communication module, rudder motor module and data acquisition module etc. In order to improve the intelligence and autonomy, the algorithm of Gaussian earth algorithm, visual tracking algorithm and BP neural network PID control algorithm are used to ensure the navigation accuracy of Wave Glider. To verify the reliability of the system, Wave Glider is tested in the ocean in the aspects of long time running, target points tracking, velocity keeping, and data acquisition. The experiment shows that under normal ocean conditions, Wave Glider can realize the long term autonomous navigation tracking in the ocean, but the speed fluctuates significantly by the current ocean condition; The acquisition of sensor data is normal, stable and reliable, which meets the requirement of long term using in the ocean.

1. Introduction

Wave Glider is a new type of multi-functional marine autonomous moving platform that can use abundant ocean energy to maintain continuous marine environmental monitoring task [1]. The main structure includes three aspects: the mother ship on the water surface, the connecting cable and the underwater tractor. The mother ship carried the solar panel, the main control system and various sensors, which is the processing and decision-making part of the Wave Glider. The connection cable is made of rubber and contains electric wire, it is the key hub for connecting the mother ship with the underwater tractor. The underwater tractor consists of 12 wings, included electronic compass and connected rudder inside. The electronic compass can collect the azimuth angle of the underwater traction and calculate it through the main control system of the surface mother ship so as to control the rudder of the underwater tractor to achieve steering.

In the past ten years, developed countries such as the United States have successively developed various models of Wave Glider as an ocean observation platform, and have invested in marine hydrological data detection and military applications [2]. In recent years, China has also vigorously developed marine science and technology, and related research projects have also received emphasis support from the state. In particular, the funding of the 863 Program has greatly promoted the development of Wave Glider in China [3]. In view of the unsupervised and autonomous navigation
control issue of the Wave Glider on the ocean, this paper adopts a method of combing of theoretical research, data simulation, and experimental verification to design an autonomous control system for Wave Glider. Based on this, Gaussian geodetic algorithm, visual tracking algorithm, BP (Back Propagation) neural network PID algorithm and other algorithms is deeply studied. Finally, based on the engineering prototypes successful developed independently, a large number of marine experiments were conducted to verify the reliability of the Wave Glider control system.

Figure 1. Structure composition

Figure 2. System framework

2. Overall Design of Autonomous Control System

The Wave Glider control system mainly includes embedded control system, communication equipment, executive mechanism, energy management system, sensor equipment and data storage equipment. Among them, the embedded main control system LPC2478 is a multi-functional integrated core board based on the NXP2400 as a core [4], which is the "brain" of Wave Glider for the entire system to realize scheduling and management; Communication module includes Beidou, iridium and wireless devices, respectively to achieve long-distance communication, short range communication and debugging function. Actuators are mainly composed of propeller and servo to provide forward and steering power respectively. Navigation sensor equipment, including GPS and compass, provide positioning and azimuth data respectively. Data acquisition equipment includes mainly a number of scientific sensors, such as AIRMAR weather station, CT sensor, wave sensor and ADCP (Acoustic Doppler Current Profilers) etc. The schematic diagram of specific system structure connection is shown in Fig.2.

Based on the hardware part of the Wave Glider control system, the software part is designed. The architecture of the software part is hierarchical form and adopts a modular programming concept. It mainly includes the communication layer, controlling layer, and execution layer [5], as shown in Fig.3. The mission of Wave Glider cruising in the ocean mainly includes sensor information acquisition and navigation controlling. Wave Glider is initialized after powered up and begins to perform navigation task until Wave Glider cruises ends. Wave Glider collects data of the loaded sensors in real time during the execution of the navigation task, and performs real-time information transmission through the satellite and backup the data by SD card. During the execution of the navigation task by Wave Glider, the target points switching task is executed at the end of each path tracking task.
3. Control Algorithm Research and Simulation

In addition to design the basic hardware and software of control system, Wave Glider must have real-time, fast response, and closed loop feedback control algorithm to achieve the goal of unattended navigation [6]. This paper studies the visual tracking algorithm based on the inverse solution of the Gaussian earth algorithm, and realizes the function of tracking the fixed points according to the preset tracking points of Wave Glider. In addition, a PID control algorithm based on BP neural network was studied. Based on the dynamic model of Wave Glider, a BP neural network PID control algorithm model was constructed. The actual heading angle and expected angle of Wave Glider were used as the input parameter, controls the servo to steer via calculation, finally Wave Glider realizes the function of tracking and virtual anchoring.

3.1. Visual tracking algorithm based on inverse solution of Gaussian earth algorithm

The so-called Gaussian earth thematic reversal refers to the process of solving other earth elements based on the known earth elements [7]. The earth elements known in this paper are longitudes and latitudes of two points on Earth, these parameters are used to calculate the distance and the azimuth angle between the two points. With the constantly moving of Wave Glider, the current coordinate point changing accordingly, so the distance between the current coordinate point and the target point also changing at the same time. When Wave Glider moves to the target point nearly and the distance between the two points has been so short that we consider that Wave Glider has entered into the range of the error circle, this target point approaching ends simultaneously. In this process, the difference between the current heading angle of Wave Glider and the azimuth angle calculating by current coordinate point and target point serves as a basis for steering of servo during the moving of Wave Glider. After the geodetic distance and azimuth angle are solved based on the Gaussian geodetic algorithm, Wave Glider needs to implement the visual tracking algorithm [8, 9] in order to track the target coordinate points. The so-called visual tracking algorithm means that Wave Glider performs only heading regulation during the autonomous navigation process and moves toward the next specified target point. During the operation, Wave Glider records the current coordinate point through GPS and calculates the Gaussian geodetic distance between the current coordinate point and the next
target coordinate point by Gaussian earth thematic reversal algorithm, and determines whether Wave Glider reaches the specified target path point [10]. After reaching the specified target path point, Wave Glider will automatically switch to the tracking of the next target point until all the target points are completed. The schematic diagram thereof is shown in Fig.5.

![Figure 4. Visual tracking algorithm](image)

![Figure 5. Neural network algorithm model](image)

3.2. **PID control algorithm based on BP neural network**

In order to realize the unattended and autonomous navigation of Wave Glider on the ocean, in addition to the wave power provided by ocean waves, rudder system is needed to control the direction during the navigation. The LPC2478 microcontroller used by Wave Glider collects data through electronic compass. After data analysis and processing, the servo is driven to adjust the direction of Wave Glider during navigation to achieve optimal steering effect.

There are various algorithms for controlling the rudder angle. Commonly used are open-loop control algorithm, incremental PID algorithms and BP neural network PID algorithms [11]. In this paper, a self-learning, adaptive BP neural network PID control algorithm is used.

According to the BP neural network PID control model constructed by Wave Glider, the final $u(k)$ expression is obtained [12], as shown in Fig.6. The actual representation of $u(k)$ in the algorithm model is the steering angle of the rudder, $u(k)$ is used as the input of Wave Glider dynamic model, and the output is the actual heading angle $\theta(k)$ of Wave Glider. During the operation of Wave Glider, three parameters $K_P$, $K_I$, and $K_D$ of the PID model are continuously adjusted according to the change of the desired angle and the actual heading angle, so as to achieve accurate steering of Wave Glider. Using MATLAB software to simulate and the simulation results is shown in Fig.7.

In the diagram, from 0 to 400s, the desired heading angle $\theta_e$ of Wave Glider is -8°, and the actual heading angle $\theta_c$ converges from 0 to 50s, which is ultimately consistent with the desired heading angle. The same reason can be analyzed in each section of 400s, the conclusion is consistent and achieve the desired goal.
4. Autonomous Control System Test Verification

4.1. Long range path tracking test analysis
To verify the stable working life and path tracking ability of Wave Glider, a marine test on May 22, 2016 near Qianliyan which is 20 nautical miles to the east of Laoshan in Qingdao is carried out. Fig. 8 shows the prototype of Wave Glider. The test set a total of 10 target points from 1 to 10. Wave Glider is deployed near the target point 1, and a circular path plan is made according to the target point 1 to 10, and the target point 1 is restarted after the 10 point is over. Finally, the total test time was 99 days and the cumulative range was about 3595 kilometers, as shown in Fig. 9. The red marker 1~10 is the target points, and the blue circle is the tracking point operated by Wave Glider. In 99 days, the probability of tracking deviation of Wave Glider at 10 points is less than 1000 meters with a probability of 86%. Through the experiment proved that the tracking ability of Wave Glider is better and satisfies the technical requirements.

4.2. Speed maintenance and survival survivability test analysis
In terms of speed maintenance, Wave Glider is affected by the sea conditions. Fig. 10 shows the instantaneous velocity distribution of Wave Glider in 24 days. From Fig. 11, it can be seen that in different sea conditions, Wave Glider can reach a maximum sailing velocity of 1.2 m/s, and the basic sailing velocity also remains between 0.2 m/s and 0.5 m/s. By calculating the average velocity, it can
be seen that the average sailing velocity of Wave Glider can reach 1.12 m/s in 3 hours, and the basic velocity can be maintained at 0.5 m/s, which satisfies the actual sailing demand.

From Fig.12 and Fig.13, through the wave sensor mounted on the Wave Glider, the maximum 1/10 wave height was measured to be 7.33m and the maximum effective wave height was 6.57m during the 99-days operation. The normal running after encountering typhoon Hato and typhoon Pakhar verified the survivability of Wave Glider in harsh environments, as is shown in Figure 14.
4.3. Data acquisition capability test analysis

Wave Glider hangs AIRMAR weather station, CT sensor, wave sensor and ADCP. This article mainly analyzes the temperature and pressure collected by the weather station.

912 hours of data were selected, and the data graphs of Fig.15 and Fig.16 were analyzed. The data is continuous and complete, real and reliable. It lays the foundation for the next step in mounting multiple types of multi-element sensors by Wave Glider.

5. Conclusion

In this paper, the software and hardware scheme of the self-control system for Wave Glider is designed and applied to the engineering prototype. Based on the engineering prototype, the key algorithms of the self-guided navigation of Wave Glider is studied, including Gaussian geodesic algorithm, visual tracking algorithm and BP neural network PID algorithm. The key technologies in the process of autonomous control is solved, including heading control methods, task path planning methods, path points tracking methods and remote data collection methods. On this basis, the path points maintenance, speed controlling, and data acquisition were tested and verified. The test results were in line with expectation, the goals were basically achieved, and the results were highly reliable. It provides a basis for optimizing Wave Glider in the next step and improving the performance index of Wave Glider. At the same time, it has important guidance for the research and analysis of the water surface and underwater autonomous mobile monitoring platforms represented by Wave Glider.
Acknowledgments
This work was financially supported by Key Laboratory of Integrated Marine Monitoring and Applied Technologies for Harmful Algal Blooms, S.O.A., MATHAB (MATHAB201807), Natural Science Foundation of Tianjin (18JCQNJC08700, 16JCZDJC38600).

References
[1] PAN De-lu, Development Strategy for China’s Marine Engineering Science and Technology to 2035 [J]. Engineering Sciences, 2017, (01): 108-117.
[2] HUANG Shao-an, Marine Sovereignty, Marine Property Rights and Maritime Rights Maintenance [J]. Theory Journal, 2012, (09): 33-37.
[3] Kraus N, Bingham B, Estimation of wave glider dynamics for precise positioning, Oceans'11 MTS/IEEE KONA, 2011.
[4] ZHOU Li-gong, ZHANG Hua, Easy to Understand ARM7: LPC24xx [M], Beijing: Beihang University Press, 2005.
[5] SHI Jian, Gong Wei, Motion Control and Navigation Strategy for Autonomous Underwater Glider [J], Journal of Ocean Technology, 2014, 33 (6), 40–45.
[6] ZHAO Chang-sheng, Iterative Arithmetic of Gauss Average Coordination Inverse Solution on Terrestrial Ellipsoid [J], Bulletin of Surveying and Mapping, 2004, 10 (3), 11–12.
[7] SHI Jian, GONG Wei, QI Zhan-feng, etc. Research of Wave Glider Navigation Control Strategy Based on Multi-sensor [J]. Transducer and Microsystem Technologies, 2014, 33 (6), 23–26.
[8] T.Daniel, J. Manley, N. Trenaman, “The Wave Glider: enabling a new approach to persistent ocean observation and research,” Ocean Dynamics 61, 2011: 1509-1520.
[9] J.Manley, S. Willcox, “The Wave Glider: A New Concept for Deploying Ocean Instrumentation,” IEEE Instrumentation & Measurement Magazine 13, 2010: 8-13.
[10] DING Shi-jun, YANG Yan-mei, SHI Jun-bo, etc, Some issues concerning several different algorithms against geodetic problems in the calculation [J], Journal of Heilongjiang Institute of Technology, 2013, 27 (3), 1–5.
[11] LIU Jin-kun, Advanced PID Control MATLAB Simulation [M], Xian, Publishing House of Electronics Industry, 2011.
[12] Sun Xiu Jun, Shi Jian, Yang Yan, Neural networks based attitude decoupling control for AUV with x-shaped fins [C], Advanced Materials Research, 2013, 819, 222–228.