To cite this article: JIN K F, WANG H D, YI H, et al. Key technologies and intelligence evolution of maritime UV[J/OL]. Chinese Journal of Ship Research, 2018, 13(6). http://www.ship-research.com/EN/Y2018/V13/I6/1.

DOI:10.19693/j.issn.1673-3185. 01293

Key technologies and intelligence evolution of maritime UV

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Abstract: In recent years, the technologies of maritime Unmanned Vehicle (UV) have developed rapidly, and especially because the development of artificial intelligence technology, it has made great breakthroughs in the functions and performance of the maritime UV. The development status of the maritime UV technology at home and abroad is reviewed, and then the key technologies for the maritime UV are analyzed. On this basis, a set of classification criteria for the intelligent levels of the maritime UV is proposed, and the operational capabilities and characteristics of the UVs at different intelligent levels are defined in detail, and the key technologies for evolution between levels are clarified. This provides a theoretical basis for the development of the maritime UV.

Key words: Unmanned Vehicle (UV); artificial intelligence; intelligence evolution; Unmanned Surface Vehicle (USV); Unmanned Underwater Vehicle (UUV)

CLC number: U674.941

0 Introduction

The ocean not only contains a lot of precious resources, but also witnesses countless wars. In the 21st century when science and technology are developing rapidly, it is inevitable to gradually exploit maritime resources with the growing scarcity of land resources. As artificial intelligence technology is developing, the technologies of maritime Unmanned Vehicle (UV) have advanced by leaps and bounds. Maritime UV has the advantages of low cost, multiple functions, and high maneuverability. It can play a huge advantage in detecting pre-buried submarine facilities, mine detection, tracking and striking, and other maritime operations [1-2]. In order to be in a favorable position in the possible future war, it is necessary to vigorously develop unmanned intelligent equipment and improve the intelligence level of UV [3].

Ranking the development of unmanned intelligent equipment helps to accurately measure the current technical level and clarify the research direction of the next stage. In 2004, in the Master Plan of Navy Unmanned Underwater Vehicle (UUV) of the US [4], UUV is divided into the following four levels according to load capacity: portable, lightweight, heavyweight and giant. In 2007, in Master Plan of Navy Unmanned Surface Vehicle (USV) of the US [5], the USV is divided into X-class, seaport-level, "Snow Kohler"-level and fleet-level according to the characteristics and dimensions of the operation.

However, the performance and functional characteristics of maritime UV cannot be not well measured by the standard of load capacity alone. In the future ocean war, it is inevitable to require intelligent operation of maritime UV formation. By then, the intelligence level of maritime equipment will be the key to

Received: 2018-05-17

Supported by: Project of Department Consulting and Evaluation of CAS Academic Divisions (17Z20320037); Shanghai Sailing Program for Youth S & T Talents (18YF1411500)

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determining the operational capabilities of a country. Compared with less intelligent equipment, highly intelligent maritime UV can perform more complex tasks, with a wider range of operations and higher mission reliability. At present, the intelligence level of various maritime UV varies, but there is still no uniform standard for the intelligent level division of maritime UV, and it is difficult to guide the intelligent development of maritime UV. This paper will plan the intelligent evolution route of maritime UV, which will help to judge the current technical level of China's maritime UV, clarify the technology that China's intelligent system lacks from the next intelligent level, and determine the research direction of next stage.

1 Development status of maritime UV

Maritime UV mainly includes USV and UUV. Compared with other UVs, maritime UV starts late. Due to the special nature of the ocean, its technology development is relatively slow. However, with the continuous development of technology, maritime UV has gradually ushered in a period of rapid development.

1.1 USV

In 1898, the famous inventor Tesla invented the world's first USV called "Wireless Robot." By the 1950s and 1960s, the USV was initially used in combat. However, limited by technology, the USV at that time was mainly used to launch suicide attacks on enemy [6], or as a maritime target in exercise. It was not until the 1990s that the USV's advantages of low cost, no personnel danger and long-time guard began to emerge, and people gradually deepened the awareness of USV. With the continuous development of technology, USV has ushered in a period of rapid development. The 2007 Master Plan of Navy Unmanned Surface Vehicle (USV) issued by US Navy[5] identifies the seven main tasks of USV: anti-mine, anti-submarine, maritime security, maritime operations, combat assistance of special forces, electronic warfare, water surface interception and fire blockade mission support.

Today, USV plays a huge role in anti-submarine, anti-mine, intelligence reconnaissance and geographic exploration. The "Spartan Scout" UV belonging to the fleet-level UV is jointly developed by the US Naval Undersea Warfare Center and related companies in France and Singapore, with the length of 7-11 m, the maximum speed of 50 kn, the navigation time of 8-48 h, and the voyage of 150 n mile (1 000 n mile at the maximum). It is equipped with four task modules of intelligence reconnaissance, anti-mine, precision strike and anti-submarine, and both remote control and autonomous navigation are supported [7]. The "Protector" developed by Israel is 11 m long and has a speed of 40 kn. The vehicle is equipped with a variety of sensors and weapons. It adopts modular design and uses lightweight materials to control weight, and several mission modules can be added. The "Sea Hunter" USV developed by US Defense Advanced Research Projects Agency (Figure 1) has a length of 40 m, the maximum speed of 27 kn, and a cruise duration of two to three months, with anti-submarine and continuous tracking as its main task. It is expected to be put into use in 2018. The "Tianxiang I" [8] developed in China has a cruise duration of up to 20 days, which can detect sea weather and successfully completed the mission during the Olympic sailing competition in Beijing. The "Jinghai" series of UVs developed by Shanghai University can complete tasks such as autonomous positioning, trajectory tracking and autonomous obstacle avoidance. The Yunzhou M80B USV for submarine detection (Figure 2) can successfully perform seabed topographic surveys in the harsh Antarctic waters.

Fig.1 Sea Hunter USV

Fig.2 Yunzhou M80B USV

1.2 UUV

As early as the 1950s, some countries began to develop UUV. The functions of early UUV were relatively simple, mainly for the purpose of exploiting offshore oil and natural gas. By the end of the last century, UUV technology has been further developed, with more powerful performance and more abundant functions. It can complete seabed information detection, assist underwater scientific research, maintain submarine pipeline, and perform long-term underwater reconnaissance and other tasks. UUV research centers have been established in many countries, such as the AUV Laboratory of the Massachusetts Institute of Technology, the Intelligent Underwater Vehicle Research Center of the US Naval Postgraduate School, the Robotics Application Laboratory of the University of Tokyo, and the British Maritime Technology Center [9]. In China, the Institute of Underwater Engineering of Shanghai Jiaotong University, the Underwater Robot Laboratory of Harbin Engineering University and other institutions are also committed to this research.

At present, countries have made certain achievements in the research and development of UUV [10]. The unmanned search system of U.S. Naval Space and Naval Warfare Systems Command has a submerged depth of 6 000 m, which is capable of transmitting charge coupled device video and sonar data from the deep ocean to the surface. The US Naval Research Office sponsors the wingbody blending water glider X-Ray developed by the Washington Applied Physics Laboratory, which can well detect and track low-noise submarines in shallow waters. It has several months of operational capability and its second generation Z-Ray has better performance in hydrodynamic performance. Russia is currently working on a high-speed autonomous underwater robot capable of carrying nuclear weapons. It is expected to have a cruising range of 10 000 km and the maximum speed of 56 kn. The "Haima" remotely operated vehicle (ROV) led by Shanghai Jiaotong University (Fig. 3) can reach a diving depth of 4 502 m [11], which can complete underwater cable arrangement, seabed sediment sampling and seabed detection equipment layout, and can conduct some scientific experiments underwater. The "Zhishui" series of underwater robots of Harbin Engineering University have realized many functions such as underwater autonomous route-planning and simulation of autonomous target-clearing [6].

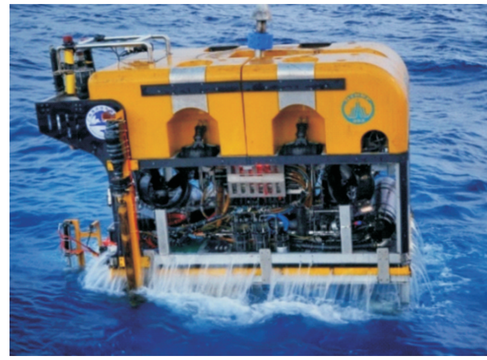

Fig.3 "Haima"-4500 ROV

2 Key technologies for maritime UV

It can be seen from the development status in the world that in recent years, maritime UV technology has developed rapidly and various performances have been continuously improved, mainly reflected in the following technologies: equipment high-reliability technology, equipment modularization technology, maritime communication technology, long-term voyage technology and artificial intelligence technology. These technologies are the keys to whether the maritime UV can be intelligent and give full play to its advantages, which can greatly expand the scope of missions for maritime UV, improve operational capabilities, and enable intelligent strategies to be better realized.

2.1 High-reliability technology of equipment

Reliability refers to the ability to perform a specified function under specified conditions within a specified time [12]. Maritime UV will not only be affected by the natural environment such as wind, waves, and current, but also will be subject to malicious interference from the enemy. Since no one can maintain it, once the fault occurs, it may directly lead to the failure of the mission. Therefore, how to ensure the high reliability of the equipment under severe conditions is essential. In order to improve the reliability of maritime UV and reduce the failure rate, the potential failure modes of all equipment should be fully analyzed. The possibility of failure occurrence should be evaluated based on specific working condition, and effective improvement or preventive measures should be made. At the same time, equipment evaluation standards with different key importance are different. For important equipment that will have a great impact on equipment operations, if it malfunctions, it should be ensured to have sufficient reliability.

2.2 Equipment modularization technology

The modularization of equipment has greatly promoted the development of maritime UV technology. On the one hand, maritime equipment, including sensors, computing chips and other hardware as well as intelligent control software, is rapidly being updated. On the other hand, the evolution of the equipment itself is relatively slow. In order to be able to update the equipment on the UV in time, it is necessary to design the structure of the UV in a modularized way. The "plug and play"-type task module is adopted [6] to carry out generalized and standardized process on the interface and carrying manner of different equipment and components, so as to achieve real-time updating of equipment, and reduce the updating cycle and cost of new equipment. In addition, mounted modules can be easily replaced according to the tasks performed to meet different operational requirements, thus ultimately achieving "one-body with multi-purposes".

2.3 Maritime communication technology

Safe and reliable high-speed data transmission communication capability is the key technology of unmanned systems [13]. Communication of maritime UV is usually divided into:

1) Communication between equipment and base station. The communication mainly transmits the operation progress of carrier, and detects the obtained valid information and the instruction information issued by the base station. Due to the long distance, satellites are usually used for communication. In order to improve the information transmission distance and the information transmission capacity, multiple beams and narrow beams can be used for operation, and it is developed towards higher frequency bands.

2) Communication between smart equipment in the same formation. The communication mainly transmits data information that needs to be shared within the formation, control information for formation cooperation, etc. Due to the short distance between the equipment in the formation, the ultrashort wave band is usually used for communication [14]. In order to solve the problem of time-varying dispersion and high-level interference of short-wave channel and improve the quality of short-wave communication, adaptive technology can be adopted to make the system capable of actively adapting to environmental changes and resisting human interference [2].

2.4 Long-term voyage technology

At present, in order to carry out long-term cruise and guard, intelligence gathering and reconnaissance, anti-submarine, anti-mine and other tasks, the cruising ability of UV has received more and more attention from all countries. Whether the continuous operation can be carried out at sea for several days or even months has affected the operational capacity of maritime UV to great extent. In order to achieve the long-term cruising ability, the only use of traditional fuel energy is not enough, so the effective use of new energy also needs to be developed.

Because there are abundant renewable new energy sources such as solar energy, wind energy and wave energy at sea, compared with other intelligent equipment such as drones and driverless cars, maritime UV has an advantage in acquiring new energy. During the operation, UV can charge the system using the above new energy. In addition, wind energy can not only supply power to the system, but also can even directly provide driving force for UV. With the improvement of new energy utilization capacity, the cruising ability of maritime UV will gradually increase, and its operating capacity and application range will be further expanded [15].

2.5 Artificial intelligence technology

Artificial intelligence technology mainly includes supervised learning, unsupervised learning and intensive learning. In recent years, it has achieved breakthroughs in many fields. It is the key technology to realize the intelligentization of maritime UV, usually reflected in visual identification and policy control:

1) Visual recognition is the basis for intelligentization. It mainly includes: identification of obstacles, detection of river banks and coasts, and identification of mission objectives. Traditional computer vision can be roughly divided into the following steps: feature perception, image preprocessing, feature extraction, feature selection, and inference prediction and recognition [16]. Deep neural networks create neurons by mimicking the way the human brain works, abstracting image data and extracting features. With the continuous development of hardware technology and the introduction of efficient algorithms, the deep neural network model represented by Convolutional Neural Network (CNN) [17] and Generative Adversarial Networks (GAN) [18] has made breakthroughs in the fields of target recognition [19], visual reasoning [20-21], real-time tracking, and other aspects, and it has approached or even surpassed the accuracy of human discrimination to some extent.

2) The strategy control system makes control com-

mands for maritime UV through the information obtained by visual recognition. Being able to autonomously implement strategic control is a necessary capability for intelligent maritime UV. Intensive learning, as a learning method that interacts with the environment through continuous "trial and error–optimization" and explores the optimal strategies of sequential decision–making problems in nature, social sciences, and engineering [22], is the key to realizing the intelligentization of maritime UV. The traditional intensive learning strategy takes the results of visual recognition as input, continuously explores the environment, and implements the optimization process based on feedback. In recent years, deep intensive learning [23-24], imitation learning [25] and other technologies have developed rapidly, making end–to–end control strategies possible [26]. The technology skips the visual recognition process, directly inputs the original pixel data, returns control commands, avoids the error accumulation of secondary training, and strengthens the working ability of intelligent body. In addition, by combining with migration learning [27], the intelligent body in the simulation environment can be directly migrated to maritime UV, which not only avoids the adverse consequences caused by wrong attempts during training, but also greatly shortens the training period at the same time. The meta–learning method [28] creates core values for the model by exploring the task distribution, and forms the experience accumulation of meta–knowledge in the process of learning tasks, so that the intelligent body can learn how to learn and further enhance its intelligence level.

3 Intelligent evolution level

The development of equipment high–reliability technology, equipment modularization technology, maritime communication technology, and long–term voyage technology ensures the operation capability of maritime UV in terms of hardware and expands its mission scope. However, the artificial intelligence technology determines whether the maritime UV can use its own functions and develop a reasonable strategy to accomplish the target task in the case of autonomous operation. In order to better measure the intelligent level of maritime UV and plan the development direction of intelligent systems, oriented by task, this paper proposes a set of classification standards for intelligent evolution level according to different operational capabilities, and divides the intelligence level as follows:

1) Remote measurement and control level;
2) Stand–alone autonomous level;
3) Cooperative interaction level;
4) Independent learning level;
5) Intelligent confrontation level.

3.1 Remote measurement and control level

This level of maritime UV can complete tasks under human remote control.

This level of UV has the execution power required to complete the mission but without independent decision–making level. When working, it is connected to the mother vehicle through a cable, or communicates with the base station through wireless, and it has image capturing capability for external things. Its operation process relies on human recognition and judgment of the target, and it executes macro–instructions from the base station. During the operation, the equipment of this level can provide the information for assisting navigation using multiple sensors such as port information, chart information and sea current status, as well as the information of the navigational status of vehicle itself such as real–time and reliable navigation positioning and attitude motion information, thus providing a reference for human decision–making. Finally, the UV receives the macro–commands from the base station and optimizes the execution commands through calculation, i.e., automatically achieving the optimal rudder angle, determining the steering time, selecting the best route, judging and achieving the ideal speed according to the current sea conditions, etc.

Because there are people in the background control, this level of UV can still complete most of the missions that can be done by manned vehicles, such as freight, and patrol. In addition, because it is unmanned, it is applicable to dangerous missions that are not suitable for people, such as hydrological detection in complex sea conditions, intelligence reconnaissance in dangerous sea areas, and mine detection. Maritime UV of remote monitoring and control level mainly relies on automatic control technology and a certain degree of intelligent optimization, and its technology has been relatively mature. At present, many countries have begun to develop commercial cargo vehicles of this level. For example, Rolls Royce Company has revealed that its sea transportation department is developing a sample vehicle that can autonomously sail along the coast. The world's largest mining group BHP Billiton is currently developing a giant automatic navigation cargo ship; European companies are advancing the development of autonomous unmanned vessels with the support of governments, and they intend to achieve full remote-controlled ship operations in the Baltic Sea within the next three years. It is believed that after several years, UVs of remote measurement and control level will emerge in large numbers.

3.2 Stand-alone autonomous level

This level of maritime UV can perform tasks autonomously, communicate with the base station, feed back the progress of operation, and accept remote control operations from the base station at any time.

In order to be out of human control, stand-alone autonomous maritime UV must have target recognition capability and independent decision-making level. Target recognition ability is the basis for ensuring autonomous operations, including the identification of obstacles, the detection of river banks and coasts, and the recognition of mission objectives, which is the key to the realization of autonomous intelligence of maritime equipment [29]. According to different sea conditions in the working waters, the target recognition capability must ensure high reliability under severe sea conditions. The decision-making level is mainly implemented by artificial intelligence technology. Before setting sail, a sample of learning needs to be provided manually. After a lot of study, the basic autonomous navigation can be achieved and the task can be completed.

The stand-alone autonomous UV can feed back the operation situation to the base station in real time while realizing the autonomous operation, including the operation of the equipment itself, which is convenient for the background personnel to monitor, and can be adjusted to the remote control when necessary. However, this level of UV does not have the ability to cooperate with other units, and can only work independently. For tasks such as arrival at port and unloading that require interaction with other devices, human control is still required. In addition, since this level of UV can only handle events learned through the sample, it does not have good processing ability for unknown events. Therefore, stand-alone autonomous maritime UV is only suitable for predictable working environments.

3.3 Cooperative interaction level

This level of UV can communicate with other equipment and cooperate to complete the task.

Through a large number of cluster training, maritime UV of cooperative interaction level can organize into teams and cooperate with other equipment based on interconnected communication. Different equipment is responsible for different tasks in operation strategy to achieve the same goal, such as formation round-up, escort, and combat. At present, the main methods of USV formation control are: behavioral-based method, virtual structure method and pilot-follower method [30]. Among them, behavioral-based method realizes the overall control by decomposing the overall behavior of the formation into the behavior of each unit. The virtual structure method proposes to set a rigid formation for the formation system, and each unit takes the corresponding reference point in the formation during operation as the expected position state. The pilot-follower method establishes one or several pilots for the formation, and the other units act as followers to follow the pilot through certain strategies to control the formation movement by controlling the pilot. This method is simple to control and easy to implement centralized or distributed control, which is widely used in vehicle formation control.

In a complex operation, it usually requires multiple functions to work together, such as fire strike, reconnaissance communication and environment awareness. It is often difficult to achieve all functions well in a separate operation. The formation integrates multiple units, and each unit can take charge of different tasks, maximize the use of all resources, and share information through communication technology to compensate for the lack of capacity of individual units. In addition, the formation operations are more fault-tolerant, and each unit is only responsible for some of the tasks in the operation. Even if individual units are damaged, other units can replace the unit in time, so that their operational capabilities, scope and reliability are greatly improved, thus accomplishing high-intensity, high-difficulty and high-demand tasks.

Formation cooperation can maximize the overall advantages and the power of equipment and weapons, flexibly transform the formation in real time, work closely together, and facilitate the overall command and tactical layout. However, the scope of work for cooperative interactive maritime UV is still limited to known tasks. For the unknown situation that occurs during the operation, it is still impossible to take a better solution. In order to solve this problem, equipment of cooperative interaction level can be combined with remote measurement and control equipment. A certain number of remote measurement and control equipment is added to the system formation. During the operation, the remote measurement and control equipment is used as the pilot, and the cooperative interaction equipment is used as the follower. When encountering an unknown event, its operational capabilities are enhanced by the guidance of human-controlled equipment of remote measurement and control level and the collaborative operation with equipment of cooperative interaction level.

3.4 Independent learning level

Maritime UV of independent learning level can continue to learn in the process of completing the work, and constantly improve its level of intelligence.

The learning process of this level of maritime UV is no longer limited to the artificially provided learning samples. It can continuously learn and synchronize the learning in time when performing tasks. Therefore, it can cope with unknown events that occur during the operation to some extent. In order to realize the self-learning ability of maritime UV, a deep learning strategy of intensive learning [31] can be adopted. When encountering an unknown event, intensive deep learning first tries to make some behavior to get the consequences of the event for this behavior, then optimizes the strategy through the feedback generated by the environment under the result, and makes better judgments when the event is met next time. As the number of feedback learning increases, the maritime UV of independent learning level gradually grasps the way of handling the event.

However, when performing a high-risk task, a wrong attempt is likely to destroy the unit, and the results of "learning" will be lost. Therefore, all units in the formation must be able to share each attempted action and the obtained results in real time, so that "learning" is not an individual behavior, and each unit can learn from the behaviors and outcomes of other units and timely transfer the "learning results" to the base station. In this way, the poor results caused by erroneous attempts which may result in the loss of learning outcomes and the stagnancy of learning process are prevented.

In the process of dealing with unknown situations, because there is no accumulation of corresponding samples, the feedback of the results of intensive learning process may have a certain delay. Therefore, a correct judgment can only be made after multiple "trial and error-optimization". In order to accelerate the learning and maximize the use of resources, all maritime UV units are planned uniformly and mission samples are transmitted to the base station in real time. At the same time, the base station synchronizes each learning sample to all maritime UV in time, realizing the simultaneous improvement of the intelligent level of all maritime UV of independent learning level and shortening the learning period.

The maritime UV of independent learning level can well handle unknown events, which is suitable for performing difficult tasks with lack of detailed information, high uncertainty and high degree of unknownness. With the increase in the number of performed tasks, the maritime UV of independent learning level will gradually enhance the operational capabilities, expand the scope of operations, and enhance the level of intelligence.

3.5 Intelligent confrontation level

Maritime UV of Intelligent confrontation level has a fairly high level of intelligence and can learn as fast as humans.

Based on the intelligence level of independent learning level, maritime UV of intelligent confrontation level can form its own core value through meta-learning, realize common operational ability, adapt to the unknown task environment and complete the task in a short time. In combat, this level of maritime UV can quickly judge the surrounding situation and battle situation, evaluate the enemy's combat effectiveness, make predictions for future development, upload effective information to the base station in time, and provide the current analysis of the battle. In addition, in the event of an unknown event, maritime UV of intelligent confrontation level can quickly understand the status quo through the accumulation of existing meta-knowledge, realize rapid learning and make judgments, and formulate reference operating strategies.

This level of maritime UV is powerful and reliable, and the operating mode is not limited to a single task. It can perform multiple parallel tasks and support real-time switching of operating content. In addition, the intelligent confrontation level maritime UV is no longer just a tool to complete the mission, but also a mobile command set that penetrates the battlefield. It can not only timely provide battlefield information, but also can analyze the information and provide strategic advice to the commander.

Table 1 summarizes the above-mentioned ways of intelligent evolution and the differential advantages.

Table 1 Intelligence evolution

No.	Intelligence class	Intelligent level	Differential advantage
1	Remote measurement and control level	Optimizing execution commands and providing auxiliary information	
2	Stand-alone autonomous level	Target recognition, autonomous navigation, and autonomous completion of mission	Completely independent operation without human interventio
3	Cooperative interaction level	Information fusion, multi-unit collaborative interaction and formation operations	Wider range of tasks, greater operational capabilities and higher reliability
4	Autonomous learning level	Independent learning in the course of the task and simultaneous optimization of each unit	Lifelong learning and continuous improvement of its ability
5	Intelligent confrontation level	Forming its own core values, quickly adapting to unknown situations, and learning quickly	Quickly understanding the environment and the situation, reasonably responding to unknown events, and providing confrontation strategies

At present, the technology of the first intelligent level is relatively mature, and the intelligent level of maritime UV in the world is still between the second level and the third level: the overall behavior of the formation still needs human intervention. Compared with the completely independent unmanned units, the unmanned units as pilots still rely on artificial remote measurement and control. With the development of technology, the UV system of cooperative interactive level will finally conduct cloud deployment of intelligent equipment for underwater, surface and sea space, as well as complete the in-depth collaborative work of various types of intelligent equipment such as UUV, USV, and maritime drones and the wide-area task chain integrating cruise, reconnaissance, tracking, escort, counterattack and other tasks. Hence, 365 days of uninterrupted defense of the maritime territory can be achieved. Maritime intelligent equipment formation of cooperative interaction level, as a complex operating system with a wide range of tasks and high robustness, will become the main development direction of maritime intelligent equipment in the next few decades and an important part of maritime warfare. The fourth-level UV compensates for the possible omissions caused by human pre-programming. By interconnecting the intelligent bodies, sharing the task process, and collecting a large library of operation samples, it can realize the self-alternation of intelligent level. The fifth-level UV, as the final form of the maritime unmanned intelligent body, has its own core value. It has a considerable understanding and understanding of the battlefield environment and task content, and can formulate a reference strategy based on the new battle conditions and operational tasks. In recent years, artificial intelligence technology and ship and sea subjects are gradually intermingling, driving the development of unmanned and intelligent maritime equipment. Although the intelligence level of maritime UV is still at a certain distance from the fourth and fifth levels, the related technologies are developing rapidly and it is believed that it will be realized in the near future.

4 Conclusions

This paper expounds the significance of developing maritime UV and its status quo of development in the world, and analyzes the impact of the development of artificial intelligence on maritime UV. The five necessary technologies for realizing the intelligentization of maritime UV are introduced in detail: equipment high-reliability technology, equipment modularization technology, maritime communication technology, long-term voyage technology and artificial intelligence technology. The intelligence level is graded according to their operational capabilities and characteristics, mainly including remote measurement and control level, stand-alone autonomous level, cooperative interaction level, independent learning level and intelligent confrontation level. The operational capabilities, task content and other details of each level are described, and the key technologies and functional differences among various levels of evolution are clarified.

The advantages of low cost, many functions and strong maneuverability of maritime UV make it have broad application prospects, and the development of artificial intelligence technology has further improved its performance. In the future, maritime UV will greatly affect the pattern of ocean transportation and maritime resource development, and a large number of unmanned military equipment will also be used in warfare and become an important part of the ocean war. To this end, China should formulate an intelligence evolution route for maritime UV and increase support for research and development of maritime UV as soon as possible, thus providing strong equipment support for accelerating the construction of a maritime power.

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对转桨推进的高速水下航行体实尺度自航计算与分析

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摘　要:[**目的**] 为了实现对转桨(CRP)推进的高速水下航行体自航因子的数值预报,[**方法**] 建立实尺度航行体阻力、自航及对转桨敞水的RANS模拟方法,进行阻力和敞水计算精度验证,分别采用准定常和非定常方法进行自航模拟,并对自航因子进行分析和比较。[**结果**] 模型尺度的计算与试验比较表明,航行体阻力计算误差小于3%,对转桨推力、扭矩计算误差分别小于2%和4%;实尺度阻力计算结果与基于模型试验的预报结果相差约3%;实尺度自航计算得到的自航因子值均在合理范围;自航因子的准定常与非定常计算结果之差小于2%,说明准定常方法适合于工程应用。[**结论**] 研究方法可为对转桨设计提供较准确的输入数据,可为提高设计精度、缩短设计周期提供技术支撑。
关键词: 高速水下航行体; 对转桨; 自航; 实尺度; RANS; 计算流体力学

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海上无人装备关键技术与智能演进展望

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摘　要: 近年来,海上无人装备技术发展迅速,尤其是人工智能技术的发展,使海上无人装备的功能以及性能有了极大的突破。为了明确人工智能技术在海上无人装备应用的研究方向以及演进路线,首先,对国内外海上无人装备技术的发展现状进行综述,随后,分析实现海上无人装备的关键技术。在此基础上对海上无人装备的智能化水平提出一套等级划分标准,并详细定义不同智能等级装备的作业能力以及特点。通过分析,明确了各级之间演进的关键技术。可为海上无人装备的发展路线提供理论基础。
关键词: 无人装备; 人工智能; 智能演进; 无人水面艇; 无人水下机器人