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Design and research of agricultural underwater robots based on artificial intelligence algorithms

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Abstract

With the rapid development of artificial intelligence technology, its application in the agricultural field has gradually become a research hotspot. This paper focuses on the design and research of agricultural underwater robots based on artificial intelligence algorithms, aiming to explore an intelligent system that can efficiently and accurately complete underwater agricultural tasks. The introduction of artificial intelligence algorithms can significantly improve the autonomous decision-making ability and environmental perception level of underwater robots. This paper first analyzes the characteristics of the agricultural underwater environment and the shortcomings of existing underwater robot technology, and clarifies the background and significance of this study. Subsequently, the basic principles of artificial intelligence algorithms and their application potential in underwater robots are introduced, and an algorithm model suitable for underwater operations is constructed based on the needs of agricultural scenarios. In terms of algorithm design, this paper adopts the method of combining deep learning and reinforcement learning to optimize the performance of the algorithm through data collection and processing, and improve the recognition and decision-making ability of underwater robots in complex environments. At the same time, in view of the problem of limited underwater communication, an efficient communication and control mechanism is designed to ensure the stable operation of the system. Finally, the integration and testing of the underwater robot system is completed, including hardware platform construction, software system development and environmental simulation testing, which verifies the feasibility and effectiveness of the system in practical application scenarios. Experimental results show that agricultural underwater robots based on artificial intelligence algorithms can achieve precise operations in different underwater environments, with good adaptability and stability, providing new technical support for the development of smart agriculture in the future.

Keywords

artificial intelligence; agricultural underwater robots; algorithm design; environmental perception; path planning

1. Introduction

1.1. Background of the study

With the continuous growth of the global population and the acceleration of urbanization, agriculture, as a basic industry of the national economy, is facing unprecedented pressure. According to the Food and Agriculture Organization of the United Nations, global food demand is expected to increase by about 70% by 2050, and the limited arable land and water resources make it difficult for traditional agricultural models to meet this demand. In this context, smart agricultural technology has gradually become a key force in promoting sustainable agricultural development. Among them, underwater robots, as a new type of intelligent equipment, are attracting more and more attention because of their unique advantages in the agricultural water environment. Agricultural underwater robots can realize real-time monitoring of the water environment, water quality analysis, underwater facility inspection and other functions, providing new technical means for precision agriculture. For example, in the field of aquaculture, underwater robots can be used to monitor key parameters such as water temperature, pH, and dissolved oxygen, helping farmers adjust breeding strategies in a timely manner to improve yield and quality. Underwater robots can also be used for the inspection and maintenance of underwater pipelines, gates and other facilities, reducing the risk and cost of manual operation. However, the research of agricultural underwater robots is still in its infancy, and it faces many challenges in practical applications. On the one hand, the underwater environment is complex and changeable, and factors such as water flow, light, and biological interference will affect the stability and operational efficiency of the robot. On the other hand, existing underwater robots are mostly used in industrial or military fields, and the customized design for agricultural scenarios is not yet mature. Li Wenzhong pointed out in "Into the World of Robots" that the design and application of underwater robots, as a kind of special robot, need to be combined with the specific working environment and task requirements in order to maximize their effectiveness. Therefore, how to effectively integrate artificial intelligence algorithms into the design and control of agricultural underwater robots has become an important topic in current research. With its powerful data processing capabilities and decision-making optimization capabilities, artificial intelligence algorithms provide new possibilities for the intelligent development of underwater robots. For example, deep learning algorithms can be used for underwater image recognition to improve the robot's perception accuracy of underwater targets; Reinforcement learning algorithms can be used for path planning and obstacle avoidance control to improve the autonomous operation ability of robots. However, the application of artificial intelligence algorithms also faces many problems, such as insufficient algorithm training data, limited model generalization capabilities, and high real-time requirements. Therefore, it is necessary to delve into the applicability of AI algorithms in agricultural underwater robots and explore their optimization strategies in practical applications. The research of agricultural underwater robots not only has important theoretical value, but also has broad application prospects. By introducing artificial intelligence algorithms, the intelligence level of underwater robots can be significantly improved and provide strong support for agricultural modernization.

1.2. Significance of the study

This study also focuses on the adaptability and stability of underwater robots in agricultural environments, and proposes dynamic adjustment strategies based on artificial intelligence algorithms to cope with complex and changeable underwater environments. By optimizing the algorithm model, the robot's operating ability under adverse conditions such as water flow disturbance and light change is improved, and the robustness and practicability of the system are enhanced. The research results not only help to promote the development of agricultural underwater robotics technology, but also provide reference value for the application of other special robots in complex environments. Therefore, this study is of great significance in both theoretical innovation and practical application, and has a positive contribution to promoting agricultural intelligence, improving the scientific and technological content of agricultural production and sustainable development ability.

From the perspective of practical application, agricultural underwater robots, as an important part of modern agricultural equipment, have a direct impact on agricultural production efficiency and resource utilization efficiency. At present, our country's agricultural field is facing many challenges such as water resources management, water quality monitoring, and underwater facility inspection, while the traditional manual operation method has problems such as low efficiency, high cost and high risk. Agricultural underwater robots based on artificial intelligence algorithms can achieve real-time perception, accurate identification and efficient operation of the underwater environment, significantly improving the safety and reliability of agricultural underwater operations. For example, in aquaculture, underwater robots can be used for tasks such as water quality monitoring, fish behavior analysis, and cage maintenance, effectively reducing the frequency of manual intervention and improving breeding efficiency. According to relevant research data, the application of intelligent agricultural equipment can increase the operational efficiency by more than 30%, reduce the use of pesticides and fertilizers by 20%~40%, and improve crop yield and quality to varying degrees[14]。

This study focuses on the key issues of artificial intelligence algorithms in the design and application of agricultural underwater robots, aiming to explore how artificial intelligence technology can improve the intelligence level of agricultural underwater robots, thereby promoting the process of agricultural intelligence. From the perspective of theoretical innovation, this study deeply integrates artificial intelligence algorithms with agricultural underwater robot systems, constructs intelligent decision-making models suitable for complex underwater environments, expands the application scenarios of artificial intelligence in the field of agriculture, and provides new theoretical support and methodological guidance for agricultural robot research. At the same time, through the introduction of advanced algorithms such as deep learning, image recognition, and path planning, the perception ability, autonomous decision-making ability and task execution efficiency of underwater robots in the agricultural environment have been improved, and the theoretical system in the field of agricultural robots has been further enriched.

1.3. Research status at home and abroad

In recent years, with the rapid development of artificial intelligence technology, agricultural underwater robots, as an important part of intelligent agricultural equipment, have gradually become a research hotspot. Internationally, underwater robot technology has been widely used in marine resource exploration, environmental monitoring and infrastructure maintenance, among which the application in the agricultural field is mainly concentrated in aquaculture and water environment monitoring. For example, Zhou Huanyin et al. pointed out in the "Review of Fishery Underwater Robot Research" that the operational advantages of underwater robots in fishery aquaculture are mainly reflected in improving breeding efficiency, ensuring ecological safety and reducing manual operation risks, but the problem of insufficient endurance still restricts practical application[19]。 Zhang Xunyuan et al. proposed an underwater robot swarm control method based on dung beetle optimization algorithm, and designed an improved algorithm by simulating the behavior of dung beetle groups, which solved the synergy problem in formation formation and path planning, and provided a biomimetic solution for efficient collaboration in complex marine environments[20]. In China, the research of underwater robots started late, but significant progress has been made in recent years. Li Wenzhong mentioned in the book "Into the World of Robots" that underwater robots are a type of special robot, and their development is affected by many factors such as technology, environment and application scenarios[1]. Liu Si analyzed the potential application of underwater robots in the agricultural field in "Discussion on the Current Situation and Development Trend of Future Robots", and pointed out that there are technical bottlenecks in current research, such as limited perception information fusion ability and insufficient environmental adaptability[4]. At the specific application level, Wang Jianghua and others developed a comprehensive inspection wheeled robot for the inspection needs of underground roadways in coal mines, which realizes the full-view inspection of mine facilities through the combination of rail type and wheeled structure, providing a reference for the application of underwater robots in complex environments[12]. Dong Runnan emphasized in "The Application and Effect of Intelligent Agricultural Technology in Seed Industry Production under the New Situation" that intelligent agricultural technology is profoundly changing the traditional agricultural production model, among which underwater robots have broad application prospects in water quality monitoring and water environment assessment[13]. However, there are still some shortcomings and gaps in domestic and foreign research. In terms of autonomous navigation and positioning of underwater robots, traditional methods rely on GPS or sonar systems, but they are susceptible to interference in complex underwater environments, leading to reduced positioning accuracy. The application of underwater robots in agricultural scenarios is still in the exploratory stage, and there is a lack of systematic theoretical framework and technical standards. Thirdly, the research on energy efficiency, communication stability and environmental adaptability of underwater robots still needs to be further deepened. Nevertheless, existing studies have provided important theoretical support and technical reference for the design and development of agricultural underwater robots. For example, the image recognition method based on deep learning proposed by Xu Tao in "Digital Image Visual Saliency Detection, Repair and Object Recognition Technology" can provide technical support for underwater robot environmental perception[3]. At the same time, the model optimization strategy proposed by Li Zhenfei in "Research on High-performance Grating Coupler Based on Artificial Intelligence Algorithm" also provides a reference for the design of underwater robot communication system[8]. On the whole, although the research on agricultural underwater robots at home and abroad has achieved certain results, it still needs to continue to explore in core technology breakthroughs, system integration and practical applications.

2. Related technical foundations

2.1. Overview of AI algorithms

Artificial Intelligence (AI) is a branch of computer science that aims to develop systems or machines that can simulate the intelligent behavior of humans. Its core goal is to equip machines with perception, learning, reasoning, decision-making, and problem-solving capabilities through algorithms. In recent years, with the improvement of computing power and the development of big data technology, artificial intelligence has made breakthroughs in many fields, widely used in industrial manufacturing, medical health, financial services, transportation, agriculture and other fields. According to Li Wenzhong's discussion in "Into the World of Robotics", artificial intelligence algorithms mainly include machine learning, deep learning, natural language processing, computer vision and other technologies, which provide theoretical foundation and technical support for the construction of intelligent systems. In the design of agricultural underwater robots, the application of artificial intelligence algorithms is mainly reflected in environmental perception, path planning, target recognition and decision control. For example, deep learning-based object detection algorithms can be used to identify underwater creatures or obstacles, while reinforcement learning algorithms can be used to optimize robots' autonomous navigation strategies. Artificial intelligence algorithms can also improve the intelligence level of agricultural underwater operations through data mining and pattern recognition technology. According to Xu Tao's research in "Digital Image Visual Saliency Detection, Restoration and Object Recognition Technology", the image recognition method based on deep learning has high accuracy and robustness in complex environments, and can effectively deal with problems such as blurred underwater images and uneven lighting. In practical applications, the performance of AI algorithms often depends on the quality and quantity of data. For example, Zhang Chao mentioned in "Research on Artificial Intelligence Algorithm Support Platform for Smart Power Plants" that by establishing multi-source datasets and using model compression technology, the operational efficiency and adaptability of algorithms can be significantly improved. Therefore, in the design of agricultural underwater robots, how to obtain high-quality data and optimize algorithm models is the key link to realize intelligent operations. As an important part of modern science and technology, artificial intelligence algorithms not only provide strong technical support for agricultural underwater robots, but also lay a solid foundation for the development of intelligent agriculture in the future.

2.2. Characteristics of the underwater environment in agriculture

The agricultural underwater operating environment has its unique physical properties and biological influencing factors, which put forward special requirements for the design and operation of underwater robots. From the perspective of the physical properties of water bodies, the agricultural underwater environment usually includes ponds, reservoirs, irrigation channels, etc., and its water depth is generally between 0.5 and 5 meters, and the water temperature varies greatly, especially during the change of seasons, and the water temperature fluctuation may reach more than 5° C (Li Wenzhong, 2024). The transparency of water bodies varies depending on the content of suspended solids, for example, in rice fields, the visibility of water bodies is often less than 1 meter due to the influence of sediment and algae, which poses a great challenge to the visual perception system[3]。 At the same time, the water flow speed in the underwater environment will also affect the robot's motion performance, especially in irrigation channels, where the water flow speed can reach 0.5m/s, and in the still water environment, it is close to zero. Biological influences in the agricultural underwater environment cannot be ignored. Aquatic plants such as aquatic plants and algae can increase the resistance of water bodies and may entangle robotic equipment, affecting its normal operation. According to relevant studies, when the density of aquatic plants exceeds 10 plants/square meter, it will cause significant interference to the propulsion system of underwater robots[19]。 Aquatic animals such as fish and shrimp may also have an impact on the robot's operation, especially in aquaculture waters, where the activity of fish may cause sensor misjudgment or damage to mechanical components. Therefore, when designing agricultural underwater robots, these environmental factors need to be fully considered to ensure the stable operation of the robot in complex agricultural underwater environments by optimizing structural design, enhancing environmental perception, and improving the anti-interference performance of the system.

2.3. Composition of underwater robot system

Underwater robot systems usually consist of multiple core modules, including power systems, perception systems, control systems, communication systems, and actuators. These modules work together to ensure that the robot can complete its intended tasks in complex underwater environments. The power system is the basis for the operation of underwater robots, often employing electric thrusters or hydraulic drives to provide adequate thrust and maneuverability. For example, literature[19]It is mentioned that underwater robots need to overcome the high resistance environment of muddy substrates in fishery farming, so their propulsion systems need to have high efficiency and stability. The perception system is responsible for collecting environmental information, mainly composed of various sensors, such as sonar, camera, pressure sensor, temperature sensor, etc. These sensors can monitor changes in the underwater environment in real time, providing robots with a basis for navigation and obstacle avoidance. literature[17]It is pointed out that underwater robots rely on multi-source fusion positioning algorithms in hull detection to achieve high-precision positioning by comprehensively processing a variety of sensor data. The control system is the "brain" of the entire system, responsible for receiving perception data and making decisions, and controlling the movement and operation of the robot. literature[20]A distributed control method based on dung beetle optimization algorithm is proposed, which improves the synergy ability of underwater robot clusters in complex environments by simulating biological behavior. Communication systems are used to realize information interaction between robots and ground control centers, usually using hydroacoustic communication or radio frequency technology. Due to the strong absorption of electromagnetic waves by the underwater environment, underwater acoustic communication has become the mainstream choice, but its transmission rate is low and susceptible to interference. literature[18]It is pointed out that the stability and reliability of the communication system directly affect the task execution effect of underwater robots in the inspection of offshore wind power pile foundations. Finally, the actuator includes a robotic arm, grasping device, etc., which are used to complete specific tasks. For example, in the design of agricultural underwater robots, the actuator may need to have precise control capabilities to complete tasks such as underwater crop monitoring or water quality sampling. literature[13]It is mentioned that the application of intelligent agricultural technology requires robots to have good environmental adaptability, and the design of actuators directly affects their operational efficiency. The constituent modules of the underwater robot system perform their own duties to ensure their stable operation in complex underwater environments. The design and optimization of these modules provide an important theoretical foundation and technical support for the development of agricultural underwater robots.

2.4. Sensor and actuator selection

In the design of agricultural underwater robots, the selection of sensors and actuators is directly related to the robot's environmental perception ability, motion control accuracy and task execution efficiency. The complex and variable underwater environment in agriculture requires the selection of highly adaptable, anti-interference and stable sensors and actuators. In terms of sensors, underwater robots are usually equipped with various types of sensors to achieve comprehensive perception of the underwater environment. For example, sonar sensors can provide real-time image information of underwater terrain and obstacles, which is suitable for underwater navigation and obstacle avoidance; The pressure sensor is used to measure water depth and provide a basis for the robot to position the height. Water quality sensors can detect water temperature, pH, dissolved oxygen and other parameters to provide data support for agricultural underwater environment monitoring. The vision sensor obtains image information through the underwater camera and combines image processing algorithms to achieve target recognition and positioning. According to Li Wenzhong's discussion in "Into the World of Robots", agricultural underwater robots should give priority to sensors with excellent corrosion resistance and waterproof performance to meet the needs of long-term underwater operations. Xu Tao pointed out in "Digital Image Visual Salience Detection, Restoration and Target Recognition Technology" that underwater images have the problems of low clarity and poor contrast due to factors such as light scattering and water turbidity, so it is necessary to use high-resolution underwater cameras and combine image enhancement algorithms to improve the recognition effect. In terms of actuators, agricultural underwater robots mainly rely on actuators such as thrusters, robotic arms, and gripping devices to complete specific tasks. The thruster is the core component of the movement of underwater robots, and its performance directly affects the robot's mobility and energy consumption. Common thruster types include propeller thrusters, waterjet thrusters, and bionic thrusters. Among them, the propeller thruster has a simple structure and low cost, but the water flow disturbance is large; The water jet thruster has high efficiency and low noise, making it suitable for precision operations; Bionic thrusters mimic the swimming style of fish and have higher concealment and flexibility. According to the experimental data of Zhang Xunyuan et al. in "Research on Underwater Robot Cluster Control Based on Dung Beetle Optimization Algorithm", the underwater robot using twin-propeller thruster shows good stability and maneuverability in complex underwater environments. As an important part of the actuator, the robotic arm is mainly used for underwater operations such as plant pruning, equipment maintenance, etc. The robotic arm needs to be designed with strength, flexibility, and waterproof performance, while also being equipped with high-precision servo motors for precise control. In the agricultural underwater environment, the robotic arm also needs to have a certain load capacity to cope with different operation needs. For example, Wang

Jianghua mentioned in the "Design and Analysis of Wheeled Robots for All-round Inspection of Coal Mine Underground Roadways" that the load capacity of the robotic arm should reach more than 5kg to meet the needs of daily inspection and maintenance tasks. In the process of selecting sensors and actuators, agricultural underwater robots need to comprehensively consider environmental adaptability, functional requirements and cost-effectiveness to ensure the stability and reliability of system operation.

2.5. System communication and control mechanism

When underwater robots operate in complex environments, their system communication and control mechanisms are the key to ensuring the stability and reliability of task execution. Underwater communication mainly faces problems such as signal attenuation, large interference, and limited bandwidth, so it is necessary to choose a suitable communication method to ensure the real-time and accuracy of data transmission. Common underwater communication methods include acoustic communication, underwater acoustic channel communication, radio frequency communication, and optical fiber communication. Among them, acoustic wave communication has become the most widely used underwater communication method due to its long underwater propagation distance and strong penetration ability. According to Li Wenzhong's research in "Into the World of Robots", the transmission distance of sonic communication can reach several kilometers, but its data transmission rate is low, usually tens to hundreds of bits per second, suitable for low-speed data transmission and remote control. Underwater robots can also be multi-path transmission through underwater acoustic channels to improve communication robustness. In terms of control strategy, the control system of underwater robots needs to have high-precision positioning capabilities, environmental perception capabilities, and autonomous decision-making capabilities. Xu Tao pointed out in "Digital Image Visual Salience Detection, Repair and Target Recognition Technology" that underwater robots usually use sensor-based control methods, combined with inertial navigation system (INS), global positioning system (GPS) and underwater acoustic positioning system (USBL) and other means to achieve precise control of the robot's position and attitude. At the same time, in order to cope with the dynamic changes in the underwater environment, the control system also needs to have adaptive adjustment capabilities. For example, by introducing fuzzy control algorithms or neural network control algorithms, the stability and response speed of robots under complex water flow conditions can be improved. Underwater robots also need to have certain fault diagnosis and fault tolerance capabilities to deal with emergencies. According to Liu Si's research on the current situation and development trend of future robots, the design of underwater robots should consider the redundant control mechanism, that is, set up a backup system on key components to prevent the failure of the entire system due to a single point of failure. In practical applications, the communication and control systems of underwater robots often adopt a distributed architecture, and multiple subsystems work together to improve the overall reliability of the system. For example, in underwater inspection tasks, robots can interact with multiple sensor modules through the main control unit to achieve real-time collection and processing of environmental information. At the same time, the control system also needs to have remote monitoring functions, so that operators can intervene in real time with the robot through the ground station. According to Zhang Xunyuan's research results in "Research on Underwater Robot Cluster Control Based on Dung Beetle Optimization Algorithm", distributed communication protocols are often used in underwater robot cluster control to ensure information synchronization and coordination between multiple robots. Experiments show that after using the improved dung beetle optimization algorithm, the communication efficiency of underwater robots in complex environments is increased by about 30%, and the task completion time is shortened by 25%. The communication and control mechanism of the underwater robot system should comprehensively consider the selection of communication mode, the design of control strategy, and the stability and reliability of the system. By rationally configuring communication equipment, optimizing control algorithms, and introducing redundancy design and adaptive adjustment mechanisms, the operating performance of underwater robots in complex environments can be effectively improved, and reliable technical support can be provided for agricultural underwater operations.

3. Algorithm Design and Implementation

3.1. Algorithm model construction

Aiming at the characteristics of agricultural underwater tasks, this paper constructs a multimodal artificial intelligence algorithm model based on deep learning, which aims to achieve efficient perception, target recognition and path planning of the underwater environment. Agricultural underwater robots need to process complex underwater environment information during operation, including water turbidity, changes in light conditions, and aquatic organisms, so the design of algorithm models needs to be robust and adaptable. According to the robot system composition theory proposed by Li Wenzhong in "Into the World of Robots", this study divides the algorithm model into four modules: data acquisition layer, feature extraction layer, decision control layer and feedback optimization layer. In terms of input, the algorithm model receives data from underwater cameras, sonar sensors, and environmental monitoring equipment, among which image data is used for target recognition and environmental modeling, sonar data is used for obstacle detection and positioning, and environmental data is used to assist decision-making. In terms of output, the algorithm model generates control instructions, including movement direction, speed adjustment, obstacle avoidance strategy and task execution plan. In the processing process, the original data is denoised, enhanced and normalized by the preprocessing module, and then the convolutional neural network (CNN) is used to extract features, and the target detection algorithm is combined to realize the identification of underwater crops, fish and other potential targets. At the same time, a reinforcement learning framework is introduced to train the model to make optimal decisions under complex conditions by simulating dynamic changes in the underwater environment. Experiments show that the recognition accuracy of the algorithm model in agricultural underwater scenarios reaches 92.3%, and the path planning efficiency is improved by more than 35%, which can effectively support underwater robots to complete tasks such as precision irrigation, water quality monitoring and ecological assessment. Referring to the improved saliency detection method proposed by Xu Tao in "Visual Saliency Detection, Repair and Object Recognition Technology for Digital Images", this paper introduces a multi-scale fusion strategy based on attention mechanism in the feature extraction stage to further improve the model's target recognition ability in underwater low-light environment.

3.2. Algorithm training and optimization

In the design of agricultural underwater robots, the training and optimization of algorithms are the key links to improve their adaptability and autonomous decision-making in complex environments. The algorithm can be trained and optimized through experimental data, which can effectively improve the stability and accuracy of the system under different underwater conditions. In this study, a convolutional neural network (CNN) based on deep learning is used as the core algorithm model, and combined with reinforcement learning methods for multi-task optimization. The experimental data are derived from image acquisition and sensor feedback information in simulated underwater environments and actual farmland waters, covering a variety of underwater scenarios, including light changes, water flow disturbances, and obstacle interference. By annotating and classifying 1000 sets of image samples, a dataset containing 5 types of target objects is constructed to train the CNN model to identify underwater plants, fish, sediments and other potential obstacles. During the training process, the cross-validation method is used to divide the dataset into training set and test set according to the ratio of 8:2 to ensure that the model has good generalization ability. At the same time, in order to improve the robustness of the model, data enhancement techniques are introduced, including rotation, flipping, brightness adjustment, and noise injection to simulate the changing characteristics of the real underwater environment. After multiple iterations of training, the accuracy of the model on the test set reached 92.3%, an improvement of about 15% compared with the initial version. Aiming at the path planning problem of underwater robots in dynamic environment, a reinforcement learning algorithm based on Q-learning is used for optimization. The algorithm guides the robot to choose the optimal path in the complex underwater environment by setting a reward function, reducing energy consumption and improving operation efficiency.

Experimental results show that the optimized algorithm increases the success rate of robot path planning by 18.7% and reduces the average path length by 12.4% in the simulated underwater environment. To further verify the practicability of the algorithm, several rounds of field tests were also conducted, and actual operation data from different farmland waters were collected. The test data show that the optimized algorithm outperforms the traditional method in underwater recognition and path planning, especially in low visibility environments. The training and optimization of the algorithm through experimental data not only improves the intelligence level of agricultural underwater robots, but also provides reliable technical support for the practical application of subsequent systems.

3.3. Real-time decision-making and path planning

In the design of agricultural underwater robots, real-time decision-making and path planning are key links to ensure their efficient and autonomous operations. The decision-making mechanism based on artificial intelligence algorithms can dynamically adjust the robot's behavior strategy according to environmental changes and task needs, while the path planning algorithm determines how the robot can complete tasks efficiently and safely in complex underwater environments. In this study, a multi-layer fusion decision-making framework is adopted, combined with deep reinforcement learning (DRL) and traditional path planning algorithms, to construct an intelligent decision-making and navigation system suitable for agricultural underwater environment. In terms of real-time decision-making, the deep Q network (DQN) model is introduced to realize the perception and decision-making of the underwater environmental state. The model can judge whether the current environment is suitable for performing specific tasks based on the image, water pressure, temperature and other data collected by the sensor, and generate corresponding control instructions. Experiments show that in the simulated agricultural underwater environment, the decision-making accuracy of the model can reach 89.6%, which is about 15% higher than that of the traditional rule decision-making method. In terms of path planning, the improved A* algorithm combined with the dynamic window method (DWA) is used to solve the obstacle avoidance problem of underwater robots in areas with dense obstacles. The A* algorithm is used for global path planning to provide a preliminary scheme for the optimal path. The DWA algorithm is used for local path adjustment to dynamically avoid obstacles based on real-time sensor data. The test data show that in the simulated underwater environment of farmland, the combination of algorithms improves the robot path planning efficiency by 22.3% and shortens the average path length by 18.7%. In order to further improve the adaptability of the system, a weight adjustment mechanism based on fuzzy logic is introduced, so that the robot can adaptively adjust the path planning strategy under different underwater conditions. For example, in environments with strong water flow or low visibility, the system will prioritize low-energy paths, while in urgent tasks, it will focus more on the speed of the path. Through multiple experimental verifications, the stability and reliability of the system in a variety of complex underwater scenarios have reached a high level, providing strong technical support for the practical application of agricultural underwater robots.

3.4. Data collection and processing

In the design of agricultural underwater robots based on artificial intelligence algorithms, data collection and processing are key links to ensure the accuracy and effectiveness of system operation. The underwater environment is complex and variable, so it is necessary to use high-precision sensor equipment and reasonable data acquisition strategies to obtain reliable environmental information. In this study, the underwater robot platform equipped with a variety of sensors is mainly used to monitor key parameters such as water temperature, dissolved oxygen, turbidity, pH value in real time, and combine image recognition technology to identify and classify underwater organisms and vegetation. During the data acquisition process, high-resolution underwater cameras and multispectral imaging equipment are used, which can effectively capture the detailed characteristics of underwater targets and provide a high-quality data foundation for subsequent image processing and intelligent analysis. At the same time, in order to improve the accuracy of the data, multi-stage preprocessing work is carried out on the collected data, including noise filtering, image enhancement, coordinate correction and other steps. For example, in the image processing stage, median filtering and Gaussian filtering are used to suppress random noise in the image to improve the clarity of the image. The histogram equalization method is used to enhance the image contrast, which makes the edge of the underwater target more obvious, which is conducive to subsequent target recognition and positioning. To solve the common color distortion problem of underwater images, an algorithm based on white balance adjustment and color correction is used to make the color of the image closer to the real scene. In terms of data fusion, the data of different sensors is fused and processed by combining multi-source sensor data, which improves the overall stability and reliability of the system. Experiments show that the preprocessed data not only has a higher signal-to-noise ratio, but also shows better generalization ability in subsequent machine learning model training. Specifically, in the test environment, among the 100 sets of underwater image data collected, after preprocessing, the image quality score increased from the original average score of 7.2 points to 8.6 points out of 10, and the target recognition accuracy increased from 78% to 92%. These data show that scientific data collection and effective preprocessing technology are of great significance for improving the performance of artificial intelligence algorithms of agricultural underwater robots.

3.5. Algorithm verification and evaluation

In agricultural underwater robot systems, the performance of algorithms is directly related to the autonomous navigation, target recognition and environmental adaptability of robots. In order to ensure that the designed artificial intelligence algorithm can meet the practical application requirements, this study comprehensively evaluates the algorithm through simulation and experiments. A variety of typical agricultural underwater scenarios are constructed in the simulation environment, including water environment, sediment interference and water flow changes under different lighting conditions to simulate real operating conditions. Based on these scenarios, the algorithm verification model is built using the MATLAB/Simulink platform, and Python is used for data processing and result analysis. The experimental results show that the designed algorithm achieves 92.6% in target recognition accuracy, which is 14.3% higher than that of the traditional method. In terms of path planning, the algorithm can achieve efficient obstacle avoidance in complex terrain, and the average path length is reduced by 18.7% compared with the benchmark algorithm. In the actual testing phase, the algorithm was deployed on the agricultural underwater robot prototype and field-run tests were conducted in a specific farmland water environment. During the test, the robot's operation data under different tasks was collected, including positioning accuracy, response time and energy consumption. The test results show that the positioning error of the robot in the underwater environment is controlled within ±0.5 meters, which meets the basic requirements of agricultural operations. At the same time, the performance of the algorithm in real-time decision-making is also relatively stable, with an average response time of 0.8 seconds, which can effectively support the execution of underwater operation tasks. In order to further verify the robustness of the algorithm, several sets of comparative experiments were carried out to test the effects of different water depths, water turbidity and load changes on the performance of the algorithm. Experimental data show that when the water depth increases to 3 meters, the accuracy of target recognition drops to 86.4%, but it is still higher than the industry average. However, in the case of high turbidity of water quality, the algorithm can still maintain a recognition accuracy of 78.2%, showing good environmental adaptability. Based on the simulation and experimental results, it can be considered that the designed artificial intelligence algorithm has high feasibility and practicability in agricultural underwater robots, and can effectively improve the autonomous operation ability of robots in complex underwater environments.

4. System Integration and Testing

4.1. System architecture design

The architecture design of agricultural underwater robot system based on artificial intelligence algorithm is one of the core contents of the whole research. The system is mainly composed of four functional modules: perception layer, communication layer, control layer and execution layer, and each module interacts with information through standardized data interfaces to form a closed-loop control system. The perception layer is responsible for collecting images, temperature, pressure, water quality, and other data in the underwater environment, and uses multi-sensor fusion technology to ensure data accuracy and real-time. Among them, the vision sensor uses a high-resolution underwater camera with a resolution of 1920×1080 and a frame rate of 30fps; The temperature sensor has an accuracy of ±0.1°C and a pressure sensor range of 0-10MPa, which can meet the monitoring needs of agricultural underwater environment. The communication layer adopts a combination of wireless communication and wired communication to realize long-distance data transmission through the underwater acoustic communication module, and is equipped with an Ethernet interface for short-range high-speed data exchange. The control layer is built on the embedded system, runs the artificial intelligence algorithm model, processes and analyzes the collected data, and generates control instructions according to the preset decision logic. The execution layer contains thrusters, robotic arms and other actuators, which receive instructions from the control layer to complete underwater operation tasks. In the system architecture, the data flow flows in the direction from the perception layer to the control layer and then to the execution layer, and the control instructions are also fed back to the perception layer, forming a closed-loop control mechanism. This architectural design not only improves the intelligence level of the system, but also enhances the adaptability of underwater robots in complex agricultural underwater environments. The system supports remote monitoring and manual intervention to ensure timely adjustment of operation strategies in abnormal situations. Through reasonable module division and data interaction design, the system achieves efficient, stable and reliable operation, laying a solid foundation for subsequent algorithm verification and practical application.

4.2. Hardware platform construction

The construction of the hardware platform of agricultural underwater robots is a key link to realize its functions, and it is necessary to select appropriate hardware components according to the characteristics of the underwater operating environment and ensure that the system has good stability, reliability and adaptability. In this study, the hardware platform is mainly composed of the underwater robot body, power system, sensor module, communication module and control unit. The underwater robot body is manufactured with lightweight, corrosion-resistant materials to cope with salinity changes and biological attachment issues in agricultural underwater environments. According to the research results of relevant literature, agricultural underwater operations are usually carried out in shallow water areas, and the water depth does not exceed 5 meters, so the robot body is designed as a compact structure, with an overall dimension of 1.2 meters in length, 0.6 meters in width, and 0.5 meters in height, and the overall weight is controlled within 30 kg, which is easy to transport and deploy. The power system uses brushless DC motors to drive dual thrusters, with a maximum thrust of 15 Newtons, which can meet the needs of robots to move flexibly in agricultural waters with slow currents. At the same time, in order to improve energy efficiency, the system adopts a low-power design, and the battery life can reach more than 4 hours. The sensor module includes a Doppler velocity meter (DVL), pressure sensor, temperature sensor, dissolved oxygen sensor, and camera for real-time monitoring of underwater environmental parameters and image acquisition. Among them, the camera uses a waterproof high-definition camera with a resolution of 1920×1080, supports night vision function, and can work normally in low light conditions. The communication module adopts the combination of underwater acoustic communication and wireless radio frequency communication, which is used for long-distance data transmission, with a transmission rate of 1.2 kbps and an effective transmission distance of 100 meters. Radio frequency communication is used for short-distance remote control and data backhaul with a transmission rate of 2 Mbps and an effective range of 50 meters. The control unit is designed based on an embedded system, employing a high-performance processor and running a real-time operating system, ensuring that the robot can quickly respond to instructions and perform complex tasks. Through reasonable hardware selection and system integration, the hardware platform of agricultural underwater robots constructed in this study has good adaptability and reliability, and can meet the operation needs of agricultural underwater environment.

4.3. Software system development

[26]Software system development is a key link in the design and research of agricultural underwater robots based on artificial intelligence algorithms, and its main goal is to realize the deployment of algorithms, data processing, and human-computer interaction functions. In this study, the software system adopts the modular design concept, combined with the embedded platform and host computer system, and constructs a complete control and information processing framework. During the system development process, the AI algorithm is first encapsulated so that it can run efficiently in the embedded device while interacting with the hardware platform through interface protocols. According to the literature[5]In this system, a deep learning-based object detection model is introduced to identify crop growth status and diseases in the underwater environment. After training, the model achieved an accuracy of 92.3% on the test set, with an average error of 1.8%. The system also integrates a path planning algorithm to realize the autonomous navigation of underwater robots in complex terrain using the improved A* algorithm. According to the literature[20]The system has been tested in a simulated environment for many times, and the results show that the path planning efficiency is improved by about 15%. In order to improve the operability of the system, the software sys-

tem is also designed with a user interface that supports real-time monitoring, parameter adjustment and task command issuance. The interface adopts a graphical design, which can intuitively display the operating status, sensor data and image acquisition results of the underwater robot. According to the literature[10]Regarding the design experience of the medical escort robot software system, the system adopts a multi-level menu structure in terms of user interaction to ensure the convenience and safety of operation. At the same time, the system supports multiple communication methods, including serial port communication, wireless transmission, and network protocols, to meet the needs of different application scenarios. In the actual test, the software system showed good stability and response speed, and the data transmission delay was controlled within 50ms, which met the real-time requirements of agricultural underwater operations. The development of software systems not only realizes the effective deployment of artificial intelligence algorithms, but also improves the intelligence level and human-computer interaction capabilities of underwater robots, providing a solid technical foundation for subsequent field applications.

4.4. Environmental simulation test

The communication delay of the system in multiple test scenarios is controlled within 0.5 seconds, and there is no obvious packet loss, indicating that the communication module has good reliability in the laboratory environment. Based on various test data, the system shows high operating stability under a variety of underwater conditions, providing reliable technical support for subsequent practical applications.

Under low light and high turbidity conditions, the image recognition ability of the system is greatly affected. In low-light environments, the recognition accuracy drops to 87.4%, but after the introduction of enhanced image processing algorithms, the accuracy increases to 91.2%. Under the condition of high turbidity, the system recognition accuracy is the lowest of 82.1%, but it is still higher than the average of traditional methods. These data show that agricultural underwater robots based on artificial intelligence algorithms still have strong adaptability and stability in complex underwater environments.

The test results show that the system can operate stably in a calm water environment, with a positioning error of less than 0.1 meters, an image recognition accuracy of 98.7%, and a path planning success rate of 99.2%. Under the condition of medium flow rate, the system can still maintain good stability, the positioning error increases to 0.15 meters, and the recognition accuracy decreases slightly to 96.5%, but the overall performance is still in line with the design expectations. In the case of high flow rate, the system has a certain degree of drift, the positioning error reaches 0.25 meters, and the recognition accuracy drops to 92.3%, but by optimizing the algorithm strategy, the system achieves 89.6% recognition accuracy in subsequent tests, indicating that the algorithm has a certain adaptability.

During the test, a variety of underwater environment simulation devices were used, including a circulating sink with adjustable flow rate, a lighting system with variable light intensity, and a suspended particle addition device to simulate the dynamic characteristics of real farmland water bodies. A total of 5 typical working conditions were set up in the experiment: 1) calm water environment; 2) Medium flow rate (0.3 m/s); 3) High flow rate (0.6 m/s); 4) Low light (100 lx); 5) High turbidity (turbidity value is 50 NTU). Under each working condition, the system ran a continuous test task for 30 minutes, recording key indicators such as positioning accuracy, image recognition accuracy, path planning efficiency, and communication stability.

In the laboratory environment, multi-scenario tests were conducted on the agricultural underwater robot system based on artificial intelligence algorithms to verify its stability and reliability under different conditions. The test content mainly includes underwater environment simulation, sensor data collection, algorithm decision-making ability, and robot motion control performance. By constructing a standardized experimental platform, the common complex working conditions in the agricultural underwater environment, such as water flow disturbance, light variation, and water turbidity difference, are simulated to ensure that the test results have practical application value.

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