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THE UTILITY OF ROBOTIC SYSTEMS IN AQUACULTURE

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Abstract: With the increase of the global population, the problems related to resources, scarcity and environmental degradation are becoming more and more serious, and land resources are no longer sufficient to meet the needs of social development. Aquaculture is defined as the recreational or commercial development of aquatic organisms in protected aquatic habitats, where plant and animal reproduction, growth, and harvesting happen, aquaculture being one of the fastest growing forms of food production. The paper presents considerations for the use of intelligent robotic equipment in aquaculture, taking into account inspection, water quality monitoring, biomass estimation, as well as feeding aquatic organisms.
Keywords: aquaculture, system, robotic, quality, management

INTRODUCTION

As the global population grows, issues of resource scarcity and environmental degradation become increasingly prominent, and land resources are no longer sufficient to meet the needs of social development. Aquaculture will represent a new area for human survival and development, with fish being a high–quality protein source and essential food source for humans. To meet the demands of a growing world population, which is expected to reach 10 billion by 2050, new technological advancements in aquaculture have played a crucial role in its continued growth. These advancements provide appropriate solutions to the pressing needs in this field (*Rowan, N. J., 2023; FAO, 2020*).

The global agri–food sector is facing significant challenges, including the influence of societal demands, growing competition, adapting to climate change, shifts in diets, demographic changes, fluctuations in national and global markets, wage disparities, and advancements in technology. The current aquaculture practices are largely artificial, with tasks such as water quality testing, biomass estimation, monitoring, feeding, cleaning, and more. However, these operations often involve high levels of manual labour and come with risks in breeding, resulting in low efficiency. To address the shortage of labour and enhance production efficiency, the application of artificial intelligence technology plays a crucial role in areas such as intelligent feeding, real–time water quality monitoring, and inspection (*Wu, Y. et al., 2022; Føre, M. et al., 2018*).

The full potential of automated data collection and analysis through ICT (information and communications technology) and the use of precision technologies in the agri–food system can only be realized by considering and addressing the entire system, including its dynamics and responsiveness as a whole. The use of blockchain technology can enhance the safety of fishery business models by reducing fraud and improving traceability from farm to fork, as well as reducing food waste and the risk of food–borne diseases. The clustering of stakeholders in fisheries aligns with the concept of Agriculture 4.0, which will improve business models, enhance decision–making and planning in management, and reduce waste through increased efficiency and better risk mitigation for improved performance (*Hrustek, L., 2020; Wang, C. et al., 2021*).

Fish products, due to their rich content of protein, vitamins, minerals, and fats, have garnered considerable attention. Yet, given the perishable nature of fish, proper processing and packaging are necessary to preserve their quality. The utilization of digital technologies has the potential to revolutionize food processing. This is achieved through the capability for complete monitoring, which facilitates the standardization of processes and allows for the implementation of incremental, innovative solutions. Apart from the feeding phase, the growing phase requires the performance of several operations, such as: classifying the fish according to size and distributing them, so as to ensure the maintenance of acceptable population densities, monitoring the water quality and the well–being of the fish, cleaning and maintaining the nets and of the entire structure, mandatory operations to obtain a high percentage of profitability and sustainability in production (*Ahmed, N. et al., 2019; Grealis, E. et al., 2017; Bao, J. Et al., 2020*).

Nowadays, the sensing technologies for underwater robots have gained significant consideration in the fields of marine engineering and resource exploration. Underwater robots are required to possess the capability of environmental perception as well as to conduct autonomous navigation and obstacle avoidance. Furthermore, the efficiency of underwater robots is reliant on their sensing technology which enables them to undertake several practical applications such as object detection, underwater robot grasp, and underwater high–precision 3D measurement. Hence, it can be concluded that underwater robot sensing technology is becoming increasingly crucial in the domain of robotics (*Cong, Y., et al., 2021; Ubina, N.A. and Cheng, S.–C., 2022*).

The use of robotic systems in aquaculture has several potential benefits, including increased efficiency, lower costs, reduced labour requirements, and improved animal welfare. For example, robots can be programmed to feed fish at specific times and in specific quantities, reducing the risk of overfeeding and the associated problems of water quality degradation and fish mortality. Additionally, robots can be used to monitor water quality, reducing the need of manual testing and allowing for faster detection of problems. This can improve the overall health of the aquatic environment and the organisms living within it (*Jensen K. A. et al., 2018; Wang, Y. et al., 2020*).

The challenges of using robotic systems in modern aquaculture have revealed the need for specialized projects of underwater vehicles, which have been addressed in several experimental researches (*Karlsen, H. Ø. et al., 2021; Bjelland, H. A. et al., 2015*).

Robots can also be used to monitor the behaviour of fish and other aquatic animals, providing valuable data on their bearing and biology. This information can be used to improve the design and management of aquaculture operations, leading to better conditions for the animals and improved yields. Precision aquaculture will have to perform water quality control, biomass estimation, disease diagnosis, analyse the behaviour of aquatic organisms and warn when malfunctions occur through modern technologies that involve the use of sensors and unmanned systems to integrate artificial intelligence (AI) for a smart fish farm (*Danancier, K. et al., 2019; Dunbabin, M.D. et al., 2019; Xiang, X. et al., 2015*).

Underwater robots require various sensors to perceive their environment, perform autonomous navigation and obstacle avoidance. These sensors include acoustic, optical, and electromagnetic sensors, as well as bionic sensors that mimic the sensory organs of marine organisms (*Koser, K. and Frese, U., 2020*).

Acoustic sensors, such as sonars, estimate the position of submerged objects by measuring the time it takes for acoustic impulses to travel and the phase difference. Optical sensors, on the other hand, capture light rays to obtain environmental information and can provide higher resolution and refresh rates. Electromagnetic sensors can accurately estimate distance in an underwater environment, but they can present interference. Bionic sensors have been studied but are not yet mature enough for practical applications. Therefore, in practice, multiple detection methods must be combined to perform various underwater exploration tasks (*Kwak, K. et al., 2016; Yang et al., 2010*).

This paper provides insights into the implementation of intelligent robotic equipment in aquaculture, with a focus on tasks such as monitoring water quality, estimating biomass, conducting inspections, and feeding aquatic organisms.

MATERIALS AND METHODS

Underwater robots have become an essential tool for exploring, surveying, and monitoring the marine environment. These robots can be classified into several categories based on their design, propulsion system, and operational capabilities.

Underwater robots are remote–operated vehicles designed to operate in a submerged environment. They can be used for a variety of applications such as oceanography, geology, marine biology, and aquaculture. The design and capabilities of these robots vary depending on the intended application. Underwater robots can be classified into four categories: Remotely Operated Vehicles (ROVs), Autonomous

Underwater Vehicles (AUVs), Hybrid ROV/AUV, and unmanned surface vehicles (USVs).

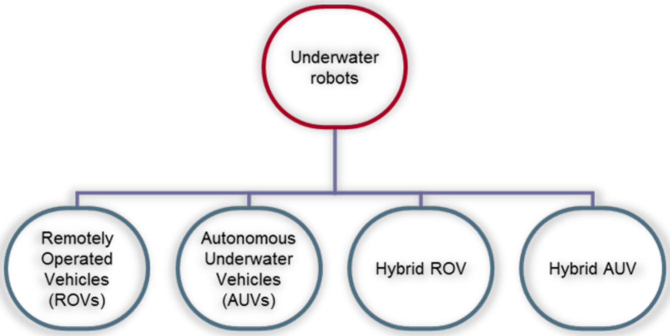

Figure 1 – Classification of underwater robots

ROVs: Remotely Operated Vehicles are tethered robots controlled from a surface vessel or land station. They are capable of operating at great depths and can be used for a variety of tasks such as pipeline inspection, oil and gas exploration, and search and rescue operations. ROVs are typically equipped with cameras, manipulators, and sensors that enable them to perform a variety of tasks. ROVs are increasingly being used in aquaculture to assist with a range of tasks, including fish feeding, monitoring fish health, and inspecting fish pens and infrastructure.

In fish farming, ROVs can be used to inspect the fish cages and infrastructure, monitor water quality, and identify areas of the fish pens where additional maintenance may be needed. ROVs can also be used to monitor the fish themselves, providing data on their behaviour, health, and feeding patterns. One key benefit of using ROVs in aquaculture is that they can reduce the need for divers to enter the water, which can be both dangerous and expensive. With an ROV, aquaculture operators can remotely inspect and maintain fish pens, reducing the need for costly and time–consuming manual inspections. ROVs can also be equipped with specialized tools, such as underwater cameras, thrusters, and manipulators that enable them to perform a range of tasks in the fish pens, such as cleaning, feeding, and removing dead fish.

AUVs: Autonomous Underwater Vehicles are untethered robots that operate independently of human control. They use onboard sensors and propulsion systems to navigate and perform their tasks. AUVs can be used for a variety of applications such as oceanographic surveys, underwater mapping, and environmental monitoring. They are particularly useful for areas that are difficult to access by manned vehicles. One key benefit of AUVs is that they can operate autonomously, without the need for human operators to control them. This makes them particularly useful for collecting data in remote or hard–to–reach areas, as they can be programmed to follow a pre–determined course and perform specific tasks, such as taking water samples or measuring environmental parameters.

In aquaculture, AUVs can be used to monitor water quality, such as temperature, salinity, and dissolved oxygen levels, to ensure the health and well–being of fish. They can also be used to map the seabed and identify suitable locations for aquaculture operations, or to monitor and track fish populations.

AUVs can be equipped with a range of sensors and tools, including cameras, sonar, and other environmental sensors, which enable them to gather detailed data about their environment. This data can be used to take management decisions, such as when to feed the fish, when to harvest them, and when to conduct maintenance on the infrastructure.

Hybrid ROV/AUVs: These robots combine the capabilities of both ROVs and AUVs. They are designed to operate as an AUV when in transit and as an ROV when performing a task. Hybrid ROV/AUVs are used for a variety of applications, including underwater surveys and inspections. Hybrid ROV/AUV systems are becoming increasingly popular in the aquaculture industry as they combine the benefits of both ROVs and AUVs. These systems are capable of operating in both autonomous and remotely operated modes, providing flexibility and adaptability to the needs of the operator.

Hybrid ROV/AUV systems can be used for a wide range of tasks in aquaculture, from inspecting and maintaining fish pens and infrastructure, to monitoring fish behaviour and health, and mapping the seabed.

In autonomous mode, the AUV component of the hybrid system can be used to collect data on water quality and environmental parameters, such as temperature, salinity, and dissolved oxygen levels. The AUV can also be used to map the seabed and identify suitable locations for aquaculture operations.

In remotely operated mode, the ROV component of the system can be used to perform tasks such as inspecting and maintaining fish pens and infrastructure, and monitoring fish behaviour and health. The ROV can also be equipped with specialized tools, such as underwater cameras, thrusters, and manipulators, to perform a range of tasks in the fish pens, such as cleaning, feeding, and removing dead fish.

Hybrid ROV/AUV systems can be particularly useful in large–scale aquaculture operations, where there may be a need for continuous monitoring and maintenance of the fish pens and infrastructure. These systems can help improve efficiency, reduce costs, and ensure the health and well–being of the fish grown by providing a comprehensive, multi–functional solution to aquaculture management.

Underwater robots are equipped with a variety of sensors that allow them to perform their tasks. These sensors include cameras, sonars, magnetometers, acoustic doppler current profilers, and environmental sensors. The choice of sensor depends on the intended application and the environmental conditions.

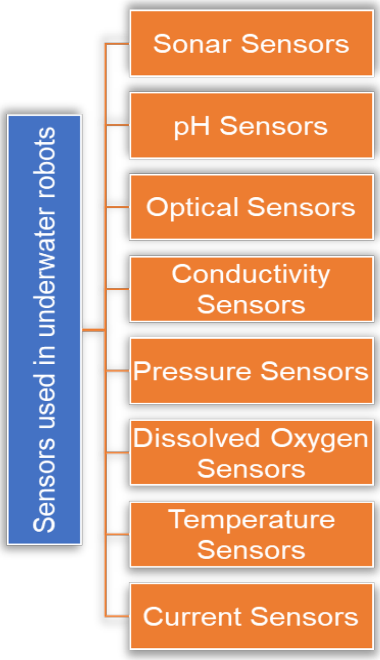

Figure 2 – Sensors used in underwater robots for aquaculture

Some common sensors used in underwater robots for aquaculture include:

- Sonar Sensors. These sensors use sound waves to detect the location of objects, such as fish, in the water. They can also be used to measure water depth and map the underwater environment.
- pH Sensors. These sensors measure the acidity or alkalinity of water, which is important for maintaining a healthy environment for fish and other aquatic life.
- Optical Sensors. These sensors use light to measure various properties of the water, such as turbidity, chlorophyll levels, and dissolved oxygen. They can also be used to track fish movements and behaviour.
- Conductivity Sensors. These sensors measure the electrical conductivity of water, which can be used to determine the salinity and nutrient content of water.
- Pressure Sensors. These sensors measure the pressure of the water, which can be used to determine water depth and monitor changes in water level.
- Dissolved Oxygen Sensors. These sensors measure the amount of oxygen dissolved in the water, which is important for monitoring the health and behaviour of fish and other aquatic life.
- Temperature Sensors. These sensors measure water temperature, which can be used to monitor the health and behaviour of fish, as well as to detect changes in water temperature that may indicate environmental changes.
- Current Sensors. These sensors measure the speed and direction of water currents, which can be used to monitor the flow of water and detect changes in ocean conditions.

RESULTS

Underwater robots are increasingly being used in aquaculture operations for functions such as monitoring and inspection. These robots can conduct operations such as fish counting, water quality monitoring, and equipment inspection, with AUVs being especially effective for mapping the seafloor and monitoring fish populations, and ROVs capable of pen inspection, feed monitoring, and cleaning. This technique has the ability to increase efficiency, lower labor costs, and lessen environmental impact.

Yet, there are certain disadvantages to utilizing robots in aquaculture. They include substantial development and deployment costs, programming and control issues, and constrained technical capabilities. Moreover, ethical and legal considerations arise, such as liability for robot–caused harm and the possible influence on aquatic life and the environment. Compatibility problems between different types of robots constitute another barrier when it comes to integrating them into aquaculture operations and maximizing their benefits.

CONCLUSIONS

- The use of robotic devices in aquaculture has the potential to change techniques of controlling and producing fish populations.
- These machines have the ability to improve the profitability and wellbeing of aquatic species in aquaculture operations by

providing an effective and sustainable way of monitoring and managing the environment.

- Looking forward, robotic technology improvement will be critical to the field's continued expansion and success. This might entail the development of new technologies, such as artificial intelligence and machine learning, to improve robot control and performance.
- Yet, further study is needed to solve the technical and economic barriers involved with integrating robotic systems in aquaculture, allowing for more industry adoption and usage of these technologies.

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