



Robotics in Aquaculture: The Future of Automated Fish Farming

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Robotics and automation are emerging as important technologies for improving the efficiency, precision, and sustainability of modern aquaculture systems. The integration of robotics, artificial intelligence (AI), machine vision, and autonomous sensing enables continuous monitoring and real-time management of farming operations. These technologies can automate critical activities such as feeding, underwater inspection, water-quality monitoring, fish health assessment, and biomass estimation. By reducing dependence on manual labour and improving operational accuracy, automated systems can minimize feed wastage, environmental stress, and production losses. The development of autonomous and data-driven aquaculture therefore represents a significant step toward more efficient, sustainable, and intelligent fish farming (Wang et al., 2021).

Concept and evolution of robotics in aquaculture

Robotics in aquaculture represents the application of automated machines, robotic platforms, sensors and intelligent control systems to perform farming operations with reduced human intervention. Traditionally, activities such as feeding, water-quality observation, fish inspection, biomass estimation and cage maintenance were largely dependent on manual labour, making aquaculture time-consuming and labour-intensive. With technological advancement, aquaculture has gradually progressed from manual operations to mechanization, automation and, more recently, intelligent and unmanned systems. Early automation mainly involved mechanical feeding and basic monitoring equipment, whereas modern systems integrate sensors, Internet of Things (IoT), machine vision, artificial intelligence (AI) and robotic platforms for real-time farm management. Intelligent equipment is now being developed for precise feeding, continuous water-quality monitoring, non-invasive biomass estimation and underwater cage inspection. Underwater robotic systems, including remotely operated and autonomous vehicles, can collect information from submerged environments and inspect aquaculture infrastructure while reducing the need for frequent manual underwater operations (Lim et al., 2024). More recent research has moved towards mobile robotic systems that combine multiple sensors with AI-based decision-making, allowing robots to interact with the farming environment and support adaptive monitoring and management. A recent 2026 review further highlights the integration of robotics with AI, sensor fusion, autonomous navigation and real-time monitoring as an important direction for next-generation aquaculture systems. Thus, the evolution of robotics is transforming aquaculture from conventional labour-dependent production towards smart, precise, automated and increasingly autonomous fish-farming systems.

Major robotic technologies used in aquaculture

Autonomous underwater vehicles (AUVs)

Autonomous underwater vehicles (AUVs) are self-propelled robotic platforms capable of operating underwater with limited or no direct human control. In aquaculture, AUVs can be equipped with cameras, sonar, water-quality sensors and navigation systems to monitor submerged environments. They can be used for cage inspection, fish behaviour observation,

environmental monitoring and collection of underwater data. Their autonomous operation allows repeated monitoring of large farming areas and reduces the need for manual underwater inspection. Integration of computer vision and artificial intelligence is further improving the ability of AUVs to identify fish and environmental changes.

Remotely operated vehicles (ROVs)

Remotely operated vehicles (ROVs) are underwater robotic systems controlled by an operator from the surface through a cable or communication system. Unlike AUVs, ROVs allow farmers or technicians to directly control the robot and observe underwater conditions in real time. In aquaculture, ROVs are particularly useful for inspecting cage nets, mooring structures, feeding systems and fish stocks. Cameras and other sensors mounted on ROVs can provide visual information from areas that are difficult for humans to access. They can also assist in detecting damaged nets, fouling organisms and other structural problems in cage-based farming systems.

Robotic feeding systems

Robotic feeding systems are among the most practical applications of automation in aquaculture. These systems use programmable controllers, sensors and, increasingly, computer vision and AI to deliver feed according to predetermined or real-time requirements. Automated feeders can regulate feeding quantity, timing and frequency, thereby reduce feed wastage and improve feed-use efficiency. Advanced systems can analyse fish behaviour and feeding activity and modify feeding according to the observed response of fish. This approach supports precision feeding, reduces unnecessary nutrient discharge and can contribute to better growth and production performance (Nautiyal and pankaj, 2024).

Robotic monitoring and sensing systems

Robotic monitoring systems combine mobile robotic platforms with sensors and imaging technologies to continuously assess fish and environmental conditions. Depending on the farming system, these robots may monitor temperature, dissolved oxygen, pH, turbidity, fish distribution, swimming behaviour, biomass and health-related indicators. Computer vision cameras can analyse fish images and movement patterns, while sensor networks provide real-time environmental information. The collected data can be transmitted to farm-management platforms, where AI-based systems can assist in identifying abnormal conditions and supporting timely management decisions. Consequently, robotic monitoring can reduce dependence on manual observation and improve the precision of aquaculture management.

Applications of robotics in automated fish farming

Automated feeding and feed management

Robotic feeding systems are increasingly being used to improve the precision and efficiency of feed delivery in aquaculture. Automated feeders can dispense feed at predetermined times and quantities, while advanced robotic systems use cameras, sensors and artificial intelligence to assess fish feeding activity and adjust feed delivery accordingly. Such systems help reduce overfeeding, feed wastage and unnecessary nutrient loading in culture water. Real-time monitoring of feeding behaviour can also support more accurate estimation of feed requirements and improve feed-use efficiency. Thus, robotic feeding contributes to precision nutrition and more consistent farm management.

Fish health and behaviour monitoring

Robotics combined with underwater cameras and computer vision provides a non-invasive approach for monitoring fish health and behaviour. Robotic platforms can continuously observe swimming activity, schooling patterns, feeding response, abnormal behaviour and changes in fish distribution. Deviations from normal behaviour may provide an early indication of stress, disease or poor environmental conditions. AI-based image analysis can process large amounts of visual information and assist farmers in identifying abnormal patterns at an early stage. This continuous surveillance can reduce dependence on periodic manual observation and support timely health-management decisions.

Water quality monitoring

Maintaining suitable water quality is essential for fish growth, survival and health. Robotic systems equipped with sensors can measure important parameters such as temperature,

dissolved oxygen, pH, turbidity, salinity and other environmental variables at different locations and depths. Mobile underwater robots can collect measurements from areas that may not be adequately represented by fixed sensors. Real-time data can be transmitted to farm-management systems, allowing farmers to identify undesirable changes and respond rapidly through aeration, water exchange or other corrective measures. Integration of sensors, IoT and AI can further improve automated environmental management.

Cage and pond inspection

Robotic systems can perform routine inspection of aquaculture cages, ponds and associated infrastructure. Underwater robots equipped with cameras can examine net integrity, biofouling, structural damage, mooring components and submerged equipment without requiring farmers or divers to conduct frequent manual inspections. In pond-based systems, robotic platforms can also be used for environmental mapping and monitoring of pond conditions. Regular robotic inspection can help identify structural problems at an early stage and improve maintenance efficiency while reducing the risks associated with underwater manual operations.

Fish counting, grading and harvesting

Computer vision and robotic handling technologies are increasingly being applied to fish counting, size estimation, grading and harvesting. Cameras can capture images or video of fish, while image-processing and AI algorithms can estimate fish number, body length, weight and size distribution. Robotic grading systems can then separate fish into different size categories with greater consistency than manual sorting. Automated harvesting systems can also assist in collecting and transferring fish, thereby reducing labour requirements and physical handling. These technologies have particular potential for large-scale aquaculture, where rapid and accurate stock assessment and harvesting are important for efficient production management.

Artificial intelligence and robotics in aquaculture

Artificial intelligence (AI) and robotics are enabling the development of smart and precision aquaculture systems. AI can analyse data from cameras and sensors to monitor fish behaviour, estimate biomass, optimize feeding and detect abnormal conditions, while robots perform monitoring, feeding and inspection tasks. The integration of machine vision, IoT, AI and autonomous robotic systems support real-time farm management, reduces labour requirements and improves operational efficiency. These technologies are therefore important for developing more automated, precise and sustainable aquaculture production systems. In addition, AI-enabled robots can support early disease detection, fish counting, size grading and environmental monitoring (Gokulnath et al., 2024). Continuous data collection allows farmers to identify changes in culture conditions and take timely management decisions. Integration of multiple sensors can improve the accuracy of robotic systems under dynamic farming conditions. However, high initial costs, data requirements and technical complexity remain important considerations for their wider adoption.

Challenges and limitations

Despite their potential, the adoption of robotics in aquaculture is associated with several technical and economic challenges. High initial investment, maintenance costs and the need for skilled technical personnel can limit their use, particularly in small-scale farms. Robotic systems may also face difficulties under variable aquatic conditions such as turbidity, biofouling, poor visibility, waves and changing water quality. The accuracy of AI-based systems depends on the quality and quantity of training data, while species-specific differences can affect the reliability of computer-vision models. Limited underwater communication, battery capacity and autonomous navigation are additional constraints for mobile robots. Furthermore, integration with existing farm infrastructure, data security, system reliability and lack of standardized operating protocols remain important barriers (Hossain et al., 2024). Therefore, further technological development, field validation and cost-effective designs are required for wider adoption of robotic systems in aquaculture.

Conclusion

Robotics is emerging as an important technology for transforming conventional aquaculture into automated, precise and data-driven fish farming systems. Robotic feeders, underwater vehicles, monitoring systems and AI-based technologies can improve feeding efficiency, fish health monitoring, water-quality management, stock assessment and farm operations. The integration of artificial intelligence, computer vision, IoT and autonomous systems further enhances real-time decision-making and reduces dependence on manual labour. Although high investment, technical complexity, maintenance and variable aquatic conditions remain major challenges, continued research and technological innovation can improve the affordability and reliability of these systems. Overall, robotics has considerable potential to support efficient, sustainable and smart aquaculture production in the future.

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