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R Bhargavi
Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Nagapattinam, Tamil Nadu, India

C Ganesh
PV Narsimha Rao Telangana Veterinary University, Hyderabad, Telangana, India

Ishani S Gowda
Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Nagapattinam, Tamil Nadu, India

Bhanuprakash Ch
PV Narsimha Rao Telangana Veterinary University, Hyderabad, Telangana, India

Corresponding Author:
R Bhargavi
Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Nagapattinam, Tamil Nadu, India

Advancements in aquaculture technologies

R Bhargavi, C Ganesh, Ishani S Gowda and Bhanuprakash Ch

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Abstract

Aquaculture is a key contributor to global food security, but efficient farm management is essential facing challenges such as water quality degradation, and inefficient resource utilization for sustainability and productivity. Traditional monitoring methods, which rely on manual labor and periodic sampling, can be time-consuming, costly, and prone to human error. Unmanned technologies work under principle of automization (Newell & Simon, 1956) including drones, autonomous underwater vehicles (AUVs), remote sensing, and Internet of Things (IoT)-enabled sensors, are transforming aquaculture farm monitoring by providing real-time, high-resolution data.

Keywords: Aquaculture, food security, unmanned technologies, automation, drones

Introduction

From 19th century till 21st century four stages of aquaculture development has done. Aquaculture 1.0 mainly focus on Smallholder Production, which rely on on manual, hand tools, experience-based farming. Aquaculture 2.0 involves equipment production with automization principle. Aquaculture 3.0 using IoT technology to manage computer software as core, automated Manufacturing will be done. Aquaculture 4.0 with Unmanned System including artificial intelligence & robots. Aquaculture Farm monitoring system of future: Sensors help in observation of all water quality parameters, feed acceptance, diseases related problems and reporting is done after evaluation through decision support system. Finally, interpretation of data is done through data analysis and processing.

Problems in aquaculture

Traditional aquaculture monitoring is time consuming and labor- intensive. Stress induced by manual handling can lead to inaccurate health assessments. Lack of reliable technology to monitor the feeding and behavioural responses of farmed species. Absence of real-time access to critical pond parameters. Need for automation and AI integration unmanned technologies in aquaculture farms. Lack of demand for improved disease management strategies.

Advanced technologies in aquaculture

Water quality detection equipment, under water drones, remote control intelligent feeding, biomass estimation equipment, Unmanned Aerial Vehicle (UAV) mainly work based on the principle automization. Why automization? The cost of production per kilogram in aquaculture is high mainly due to high input cost especially feed cost (60-80%) skill labor requirement higher risk involved continuous monitoring requirements of water quality, biomass, growth etc. (Stickney, 2022) [21]. It involves aquaculture equipment, intelligent equipment, network monitoring (AI), unmanned operation (robotics)

Functions of advanced technologies

Regarding production, advanced unmanned technologies help in forecasting growth, estimating biomass, counting fish/shrimp, and optimizing feeding. In case of health to predict disease outbreaks, count parasites, monitor disease and health, predict water quality threats, monitor algae blooms, optimize aeration, and automate quality alerts.

Unmanned Vehicles an Emerging Technology

Unmanned vehicles in aquaculture may go to far-flung locations with minimal time and effort because they are readily available and reasonably priced. With just a remote control or a smartphone app, users may manage the flight or navigation. Unmanned aerial vehicles (UAVs) and submersible drones can now detect illicit fishing activities and are less expensive.

Unmanned vehicles' potential as a conduit for communication: The functionalities of current commercial systems, the Internet of Things, and artificial intelligence integrated with drones are also delineated to establish an accurate aquaculture framework. This new connectivity improves labor efficiency, lowers operational expenses, and boosts production.

Drones in aquaculture farms: Drones capture data from the aquaculture site by connecting underwater cameras and sensors to the cloud as a Wi-Fi gateway for precise aquaculture. The establishment of an integrated control system will enable us to build efficient and stable smart farms. Conventional underwater cameras used in fish farms can only shoot limited areas and cause underwater contamination. Aerial drone cameras are limited in their ability to record submerged activities.

An aerial drone, also known as an intelligent flying robot, uses visual surveillance to keep an eye on fish feeding operations, spot nets, moorings, and cages, and record important information and far-off objects. With the help of a navigation system and data from the cloud, the autonomous aerial drone can determine the location of the target objects. Underwater Drones Underwater monitoringof fish farms, underwater imaging, and monitoring fish behavior. Their capacity to operate autonomous underwater drones lessens the requirement for human contact. Additionally, they can control the feeding schedule, which will get rid of issues like overfeeding and water contamination.

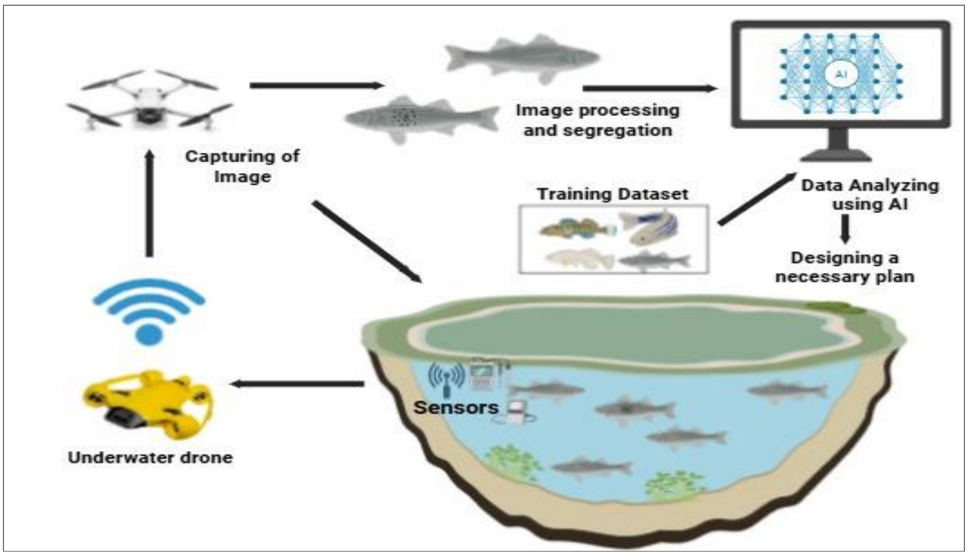

Fig 1: An Autonomous Aquatic drone for smart Aquaculture Management

Types of drones: Autonomous drones, Human engagement is less necessary when a site is autonomous; actual site monitoring and inspection tasks can be reduced or regulated. It is cleverer than the typical drone navigation system since it can comprehend the position of the target items using the data supplied by the cloud. It develops into a sophisticated flying robot that can gather important data and far-off things. Use the path planning that the cloud has produced to execute a new route. Non-autonomous drones require more human interactions and inspection activities. Positions of target objects are not clearly understood. It cannot capture distant objects and valuable data. Drone that isn't autonomous and just follows a predetermined route. Equipped with multi-parameter water quality sensors and a high-resolution camera to observe the behaviour of fishes. Propelled by jet propulsion for efficient locomotion and integrated on-board processor with a data logger. Built-in GPS and handheld controller for precise navigation. By lowering farm fatalities, drones can stabilize the supply and demand for labour.

Concept of advanced underwater drone: Development of drone control unit (CU) along with sensory unit (SU) (water quality sensors). A boat equipped with a fully developed submersible drone integrated with CNU (Centralized Network Unit) for full-scale development. AI integration for disease prediction& suggesting the corrective measures. Centralized network unit Integrates farm components to the cloud, and the drone automates equipment based on drone readings. Ensures seamless data sharing among drones and report generation.

Drones: Monitoring tools for seaweeds using a low-cost aircraft aerial and underwater drones have enormous potential for high-frequency monitoring of offshore kelp aquaculture farms to maximize production and optimize their nutritional content. For small-scale aquaculture/oyster farms that use robots and artificial intelligence for monitoring, ROVs were also used to detect and count oysters.

Drone: An intelligent flying robot: Semantic scene modeling: Using an IoT platform, autonomous drones and a cloud-based aquaculture system monitor fish, people, nets, and feeding levels every day by sending data to the drone via the aquaculture cloud.

Intelligent aquaculture farms are capable of 1. water quality control, 2. intelligent feeding, and 3. estimation of biomass.

4. Diagnosis of diseases, behavior analysis, and equipment functionality integrate artificial intelligence (AI) for a smarter fish farm using technology like sensors and unmanned systems.

1. Water quality control: Sensors are used by an intelligent fish farm to gather data on water quality. Long-term, precise aquaculture water quality parameter detection offers a trustworthy data source for automated management and wise fish farm decision-making (Wang *et al.*, 2021) [25]. For aquatic products to flourish in a healthy environment, accurate, consistent, and real-time water quality monitoring is essential. Technical assistance for the implementation of comprehensive real-time water quality monitoring can be given by intelligent unmanned equipment (Dane *et al.*, 2021) [16]. Dissolved oxygen sensors have advantages such as fast response time, stable measurement results, and low maintenance (Tai *et al.*, 2016) [22]. A sophisticated aeration system precisely regulates DO. A pH sensor helps in potentiometric pH measurement. In order to detect the pH of water, these sensors are often constructed from pH glass electrodes with AgCl reference electrodes (Aakash, 2019) [12]. Temperature sensor: the temperature range that waterproof temperature sensors can measure is between -55 and +125 degrees Celsius. A temperature limit alarm system, ground wire, and power wire make up this system (Barman *et al.*, 2015) [15]. Nitrogen ion sensor: Using UV LED technology, the nitrite/ammonia sensor evaluates the water's absorption of ultraviolet (UV) light to determine the amount of dissolved nitrite or ammonia as nitrogen in the water (Menon and Menon, 2021; Pellerin *et al.*, 2013) [19, 20]. The sensor-based monitoring system continuously measures several water quality parameters, controls, connects to a PC, alarms, and has powerful desktop software.

2. Astute feeding: Fish that are fed in accordance with the requirements of aquaculture objects are said to be fed accurately. The development of scientific feeding techniques that can successfully reduce feed waste and water pollution depends on the real-time detection and monitoring of feed particle consumption. Numerous advanced technologies can automate procedures. For example, underwater cameras can be used to visually view fish in cages and observe their behavior and characteristics. For power-supplying underwater cameras (e.g., solar power) that are equipped with batteries but can only work for a limited time.

Feeding management system: Automatic feeding systems in some developed countries, such as Norway, Japan, and the United States, have entered the application stage, which has achieved accurate control in the links of feed transport, storage, and delivery (Wang *et al.*, 2021) [25]. The net cage automatic feeding system developed by the Norwegian fishery equipment enterprise consists of a management system, an online monitoring system, and modules for feeding. The Arvo-Tec firm in Finland created the robot feeding control system, precision feeding, water quality enhancement, and remote feeding control. Arvotec, 2021 [14]. Smart feeder: automatically guarantees that shrimp receive the right amount of meal by adjusting the feed according to weather and water quality data. It is possible to configure feeding schedules. A smartphone app using mobile-based technology to optimize your shrimp's nutrition reduces FCR by 30% while increasing profit margins. The system of acoustic feeding involves intelligent feeding based on appetite, a 24x7 feeding system, superior production performance, and reduced feed wastage.

Shrimp Auto-Feeder with Intelligent Feeding Sensor
The controller, which might be on the beach or on the feeder, receives signals from the hydrophone, which records the pond's soundscape. After evaluating the relative feeding activity, the controller automatically modifies the feeding ratio. The farm's office computer receives acoustic and feeding data on a regular basis (Tailly *et al.*, 2021; BioRender.com) [23].

Camera View in Feeding Zone
The number of fish under the camera view (i.e., feeding zone) drastically increases immediately following the release of fish food, peaks, and then falls after they have eaten the meal (Alexkychen, 2022) [13].

Biomass estimation: Fish biomass estimation includes counting, weight estimation, and length estimation, from the initial fry to the final sale of fish. Estimating biomass in dense and sheltered environments is a challenging task in modern aquaculture (Abinaya *et al.*, 2022, Hao) [11, 17]. The accurate estimation of biomass provides data support for accurate feeding. Biomass estimation: the size of fish is a basic indicator of breeding and marketing. Fish weight and body length are usually determined by measurement methods, which are time-consuming and laborious and can cause damage to the fish. Machine vision based on visible light, machine vision based on infrared light, and acoustic-based methods are used for biomass estimation.
Mass measurement: Length-weight & area-weight, counting: Area counting & object tracking, image getting (camera), image processing, and statistical analysis are done. Pretreatment is done through calibration and feature extraction: size, color, and texture. An automated feed tray captures the images of shrimp, shrimp size and distribution are analyzed, and disease symptoms are identified via computer vision.

4. Fish Health and Welfare
Unmanned technologies like underwater drones used to diagnose fish diseases in fish farms automatically connect to sensors, cameras, and a personal computer (PC). It is presented in three consequent stages (Waleed *et al.*, 2019) [24]. An underwater drone camera detects fish lice, and lice counting is done.

Precision fish farming: Precision fish farming applying control engineering principles in fish production to improve farm monitoring makes commercial aquaculture transition from a traditional production method to a knowledge-based production method using emerging technologies and automated systems. Aim: To improve the accuracy, precision, and repeatability of farming operations. Precision farming helps farmers respond to natural fluctuations. Technological innovations (such as unmanned vehicles equipped with aerial cameras, sensors, feeds, and vaccines) have enabled the growth of the aquaculture industry. Radical and systemic innovations such as integrating smart fish farming are necessary to achieve the ecological and social sustainability of aquaculture.

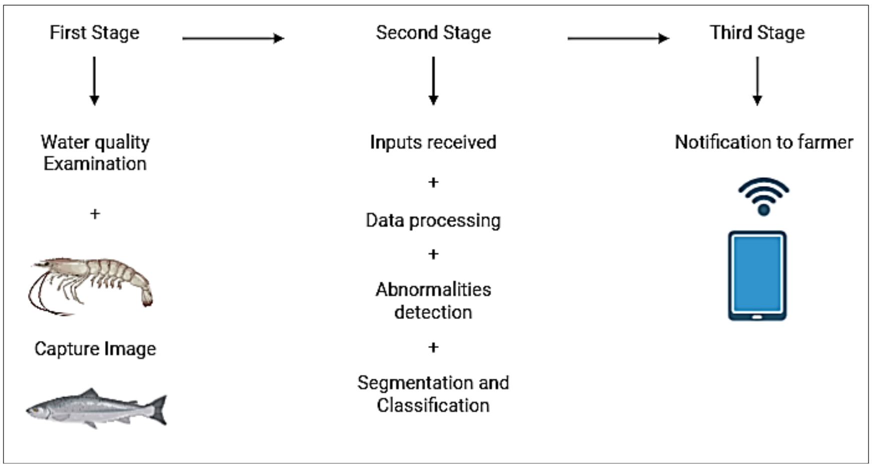

Fig 2: Aquaculture automated monitoring system flow

Unmanned Vehicle System Platforms

Unmanned vehicles can improve mission safety and repeatability and reduce operational costs. The tasks performed by unmanned vehicles are typically dangerous or relatively expensive to use humans to execute. They are simple but repetitive and less expensive to implement without humans, but many still require customization to meet the specific requirements for aquaculture monitoring and management. Although it does not focus on aquaculture, underlying principles and requirements can be adopted in aquaculture monitoring.

Classifications of unmanned vehicles

Unmanned aerial vehicles (UAVs), 2. autonomous underwater vehicles (AUVs), and 3. unmanned surface vehicles (USVs).

Unmanned aerial vehicles (UAVs) provide a different platform that overcomes the drawbacks of surveys conducted by manned aircraft. UAVs must be compact, powered by an electric motor, user-friendly, and capable of recording and storing data while in flight. Although UAVs have a lot of potential for aquaculture monitoring, their effectiveness will rely on the kind of sensor, the intended use, and the operational regulations for a certain platform. Benefits of UAVs Reduced operating expenses and reliable picture and flight path acquisition.

Autonomous underwater vehicles (AUVs) have cameras to take pictures as well as other sensors; they are waterproof and submersible in water to collect data such as water quality. UAV embedded systems involved in offshore underwater inspections for salinity, hydrocarbons, nutrients, and chlorophyll combined to create a functional system for improved performance. Challenges the amount of light in the underwater environment, which is low because of light scattering, affects AUV image captures. Since AUVs cannot receive GPS signals, they must navigate using acoustics, sonar, cameras, or a mix of these technologies.

Unmanned Surface Vehicles (USVs) on the water function without the assistance of a human. They were created to facilitate unmanned tasks like data collection and environmental monitoring. In the field, USVs should be robust, maneuverable, and easy to manage. USVs are able to swiftly approach targets or objects in order to obtain high-resolution pictures. Challenges: Wind, waves, currents, marine fog, and water reflection all have an impact on the aquatic environment. Although they can overcome issues brought on by light conditions (such as fog), infrared vision can function both during the day and at night. However, their accuracy is poor.

Advantages of Unmanned Vehicles

Increased precision and monitoring effectiveness through extensive automation and real-time detection of water quality changes. Feed Distribution: Reduce manpower, and distribution is faster and more efficient by minimizing fish stress. Optimized resource utilization: Reduction in excess feed use and minimal chemical intervention. Cost reduction: Lower labour costs and decreased need for frequent manual inspections. 24/7 real-time pond surveillance Enhanced Pond system management. Helps to prevent the disease outbreak pertaining to water quality.

Use of Drones in the Fisheries Sector

Drones offer innovative solutions to a variety of challenges in the fisheries sector, with key applications in water sampling, disease detection, monitoring activities, feed management, and fish transportation. Drones support precision fishing and stock assessment. Underwater drones further enhance capabilities by monitoring fish behavior in natural habitats, identifying signs of distress such as erratic swimming patterns. Drones are involved in managing aquaculture farms and assessing the damage to infrastructure and aid in rescue operations during natural disasters.

Future interventions of the intelligent unmanned aquaculture

- **Virtual Reality:** The eyes of the next generation on aquaculture, training & education, visit a fish farm and teach about fish welfare and disease prevention.
- **Remote Operated Vehicles (ROVs):** Monitor the feeding process and stock health and observe fish behavior. Underwater drones: To explore how drone-assisted monitoring enhances aquaculture management by improving precision management and using real-time analysis.

Conclusion

In addition to replacing humans, cutting-edge intelligent machinery can decrease danger, boost output, and lighten labour strain. The use of drone technology offers a sustainable and scalable solution for aquaculture management. Its real-time monitoring capabilities boost productivity, enhance pond management, lessen environmental effects, prevent disease outbreaks, and contribute to a more productive aquaculture industry and sustainable aquaculture. Given the rapid advancement of sensors, artificial intelligence, the Internet of Things (IoT), and robotics in aquaculture, intelligent unmanned devices, such as robots, have garnered increased interest (Manley *et al.*, 2016) [18].

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