Avenues and Means for Smart Mariculture

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Globally, aquaculture is one of the fast-growing production sectors using water productivity concepts. The term aquaculture refers to the practice of farming/ cultivating aquatic organisms that include finfish, shellfish and microscopic and macroscopic plants both in freshwater and saltwater in controlled conditions under human management. Farming/cultivation implies intervention in the rearing process to enhance production, breeding, nursery rearing, stocking, feeding, protection from predators, etc. It also implies individual or corporate ownership, the planning, development and operation of culture systems, sites, facilities and practices, and production and transport. The social and financial significance of aquaculture is growing consistently at >6% in recent years. India has immense potential for aquaculture development, and the sector contributed ≈70% to its total fish production in 2020. The magnitude and intensity of aquaculture have expanded exponentially with the growing demand for fish and fishery products globally. This has resulted in the increasingly visible manifestation of impacts and consequences on the environment and health through water quality changes, disease outbreaks, and antimicrobial resistance. The labour required in conventional fish farming has increased the cost of production in many parts of the world; the same holds similar in India too. Hence the need for protecting nature, fish health and production at low costs has of late been the focus of development. While, mariculture is the cultivation, management, and harvesting of marine organisms in their natural environment (including estuarine, brackish, coastal, and offshore salt waters) and/or in enclosures such as pens, tanks, cages, channels, raceways, etc. Mariculture is the fastest-growing subsector of aquaculture in India with high growth potential despite the sector being a relatively emerging area in the country. The issues mentioned above about aquaculture are not far distant in the Indian mariculture sector. To resolve these issues, major changes are required in minimising effluents, input and labour costs and maximising human health and environmental benefits. With the available conventional wisdom, the application of digital and electronic know-how, such as computer vision, machine learning, information and communication technologies (ICT), Internet of Things (IoT), cloud-based computing, automation and artificial intelligence (AI) has started showing immense application avenues to sustainably manage and enhance aquaculture production and enhanced environmental, human health and socio-economic returns. This article provides a brief on the current status of the developments and discusses avenues and means for smart mariculture.

Avenues

Artificial Intelligence and Machine Learning along with Virtual Reality and Augmented Virtual Reality, are the major approaches in smart aquaculture systems. Use of complex algorithms to analyse the data input from sensors to create mathematical models that are fed to the performance monitoring in computer to activate specific amelioration actions. Intelligent/ smart aquaculture systems can manage most stages from breeding, nursery and growing out of cultured species. These systems can monitor and manage the water quality, feeding, effluent management, growth and health monitoring, size-based sorting, counting, etc. government of India has hence been giving greater thrust to the fish farming sector. The *Pradhan Mantri Matsya Sampada Yojana* (PMMSY) has recently been launched to bring the "Blue Revolution" to India and sustainable development of the sector. The major objectives of this scheme are the followings.

- Doubling farmer's income
- Increase the fish production from 13.75 MMT (2018-19) to 22 MMT by 2025.
- Increase the total Gross Value Added (GVA) contribution from 7.28% to 9%.
- Doubling export earnings from Rs 46,589 crore to Rs 1 lakh crore.
- Decrease the post-harvest loss from 25 % to 10%.
- Increase the domestic fish consumption from 5 kg to 12 kg.

Traditional or even semi-intensive farming practices, as happening currently, may not be able to meet all demands. Interventions through smart aquaculture, by encouraging research and development for integrating electronics, instrumentation, computer programming IoT, etc. to fish farming can bring a substantial boost to the growth and economy of the sector.

Modules applicable to smart aquaculture

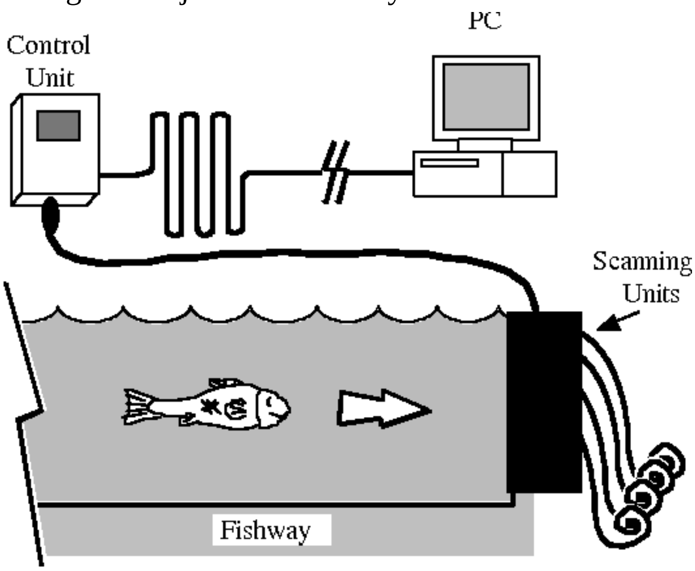
Some of the growing modules applicable in smart aquaculture and mariculture are the following.

Water quality monitoring:

Real-time monitoring of water quality and sending out a warning to farm managers is the most commonly used module. With the advent of AI, human interventions can be minimised through self-contained and managed systems, where the water quality is monitored on a real-time basis using integrated sensors connected to communication and necessary management or ameliorative actuators to take remedial measures by machines.

Counting and sizing/ weighing of fishes:

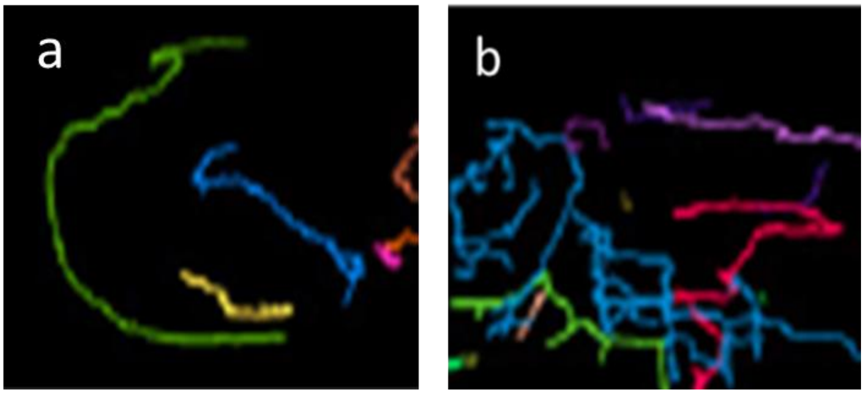
Counting the number of fishes, and sizing/ weighing of cultured species such as fishes are important in aquaculture/ mariculture to determine stocking density, deciding on adjustments in feeding, monitoring growth progression and also for harvest advisories, besides use in the hatchery for counting larval density. The process can decrease costs for operation and management to enhance profit and quality of produce and reduce stress to the fish by avoiding human handling. This can be automated through computer vision technology, including video analysis and image processing. Counting systems for larval stages and juveniles already exist in a number of modern hatcheries around the world. The system detects the images of larvae and juveniles, which then process the images and cunts the number of larvae and juveniles. Similarly, the counting system can be integrated into modules for measuring the length and breadth of the fish, which can be modelled into corresponding weight and then the biomass can be estimated. The pixel size and number that cover an image can also be modelled to estimate the size and biomass of fish.



A scheme of an automatic fish counting system. Source: Cadieux *et al*. (2000)

Disease and health management:

The health of stocked organisms in mariculture is an important concern to the manager as early diagnosis and treatment are major actions that contribute to the economy of operation. In aquaculture, diseases occur due to imbalances among many factors, pathogens, nutrition and environment. There are two major types of disease; infectious (parasitic, fungal, bacterial, viral) and non-infectious (environmental, nutritional and genetic). Besides prevention, timely diagnosis and treatment is the key to managing diseases in aquaculture systems. Machine learning with feature identification algorithms can help detect and alert fish diseases that manifest external symptoms to farmers on a real-time basis to initiate timely interventions. Applications of antibiotics, medicated feeds, etc. are also possible automatically with suitable integration. Tracking the movement of fishes in aquaculture systems using vision-based image processing techniques can help identify unhealthy fishes from their movement pattern by comparing them with the stored healthy movement trajectories of fishes. The pattern of these movements can be compared with

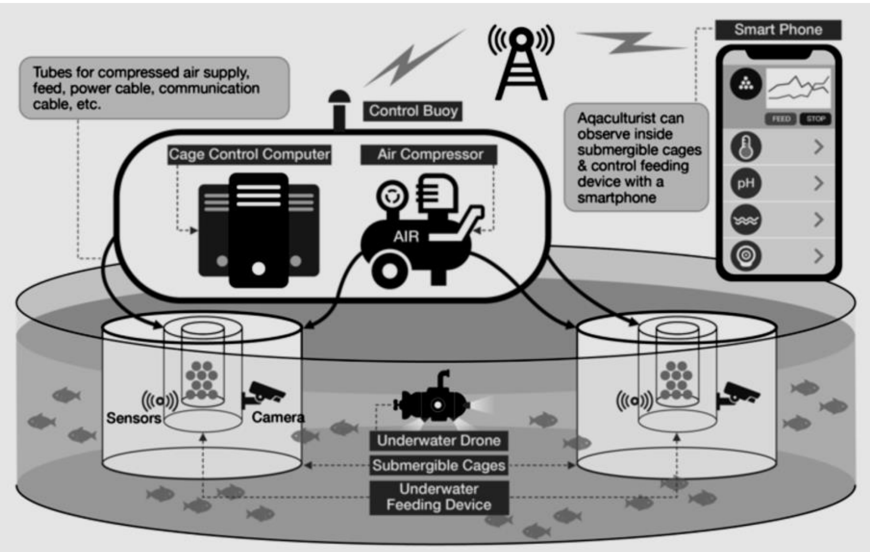


Normal fish trajectory (a) and abnormal trajectory (b) of the same fish captured through object tracking systems.

already recorded and stored patterns associated with different health conditions, deficiency or water quality changes for sending out information to the managers. This varies with individual species; hence requires the population of such information for species of aquaculture/ mariculture value for building digital reference libraries either locally or in the cloud storage system.

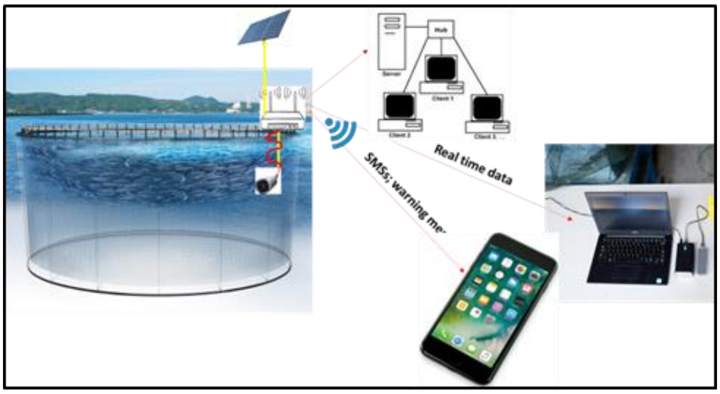
Smart mariculture

Modern science and technological advancement have hugely benefited many fields including aquaculture in reducing labour, enhancing production, friendly to the environment. Smart mariculture or intelligent mariculture attempts to bring smart principles and systems for managing saltwater aquaculture and species through application of intelligent technology, electronics, machine computation, internet and communication technologies with automation and robotics for managing mariculture farms/ installations to ensure sustainability, increasing production and profit. Smart mariculture can provide solutions to a large number of problems to conventional mariculture practices. For example, in offshore cage farms, real-time informed decisions based on the data acquired through sensors and application of quick remedial actions through actuators or by alerting managers. The system can be operated remotely using IoT, big data, artificial intelligence, 5G, cloud computing, robotics, etc. AI and IoT have been increasingly solving problems which exist in traditional mariculture. Smart systems are applied in oceanic cages farms, coastal ponds, hatchery, raceway, re-circulatory aquaculture systems, etc., for water quality monitoring and adjustments, health and growth monitoring of stocked fishes, larval stages, optimising feed ration and schedule, reducing labour and human drudgery and also to ensure human safety, especially in offshore culture installations. Cloud-based mariculture monitoring and control systems are the future of smart mariculture. Web and Android applications can assist us in determining the ideal conditions in a culture pond. In India, feed dispensing sensors and mechanisms have been adopted recently.



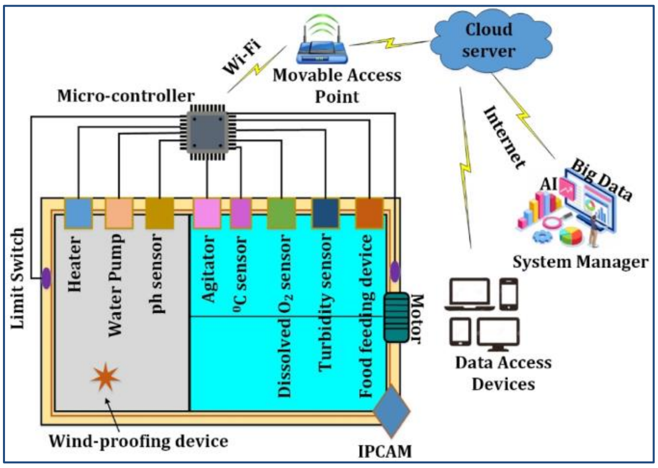
Conceptual framework of a smart aquaculture system (Source: Vo *et al.*, 2021)

Intelligent devices and analytics frameworks are being produced every day throughout the world. For example, salmon cage farming currently resorts to smart systems for daily management in Norway.



Conceptual model for computer vision based monitoring of fishes stocked in marine cages

The advantages of integrating IoT, therefore, in the industry are enormous. It aids in effective monitoring by providing a vast coverage of data from numerous locations, allowing for real-time remedial steps to be implemented using data collected over time through artificial intelligence (AI) and machine learning (ML) technologies to create massive predictive models that can be used for correct decision-making, process automation, and timely warnings, especially for offshore installations. In mariculture, specifically in offshore installations, human labour-based management is expensive and ridden with risks to human health and life. Where automation and smart mariculture systems can play a greater role than in land based systems.



A scheme of multiple sensor-based automatic monitoring and control in a fish pond (Source: Min-Chie *et al*., 2022)

The use of remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs), as well as autonomous surface vehicles (ASVs) have increasingly been used for marine explorations and monitoring recently. ROV solutions, including underwater robotics, are now being developed for mariculture for inspection of offshore installations, especially cages, cleaning of mesh nets of cage farms and water quality monitoring. However, there are challenges, such as reliability, safety, endurance; human-machine interface; real-time dynamic process tracking; event detection and classification, etc. to overcome (Betancourt *et al*., 2000). The use of a non-invasive 3D optical stereo system and computer vision techniques are explored by Rodriguez *et al*. (2015) to study the biological variables in fish. Betancourt *et al.* (2020) developed a novel robotic architecture that includes a RGB camera for real-time video capturing and a set of integrated sensors to measure hydro-climatic data.

Some algorithms are implemented with the aim of inspecting net cages in fish farms. Recently, most of the research has been diverting towards the development of novel smart and intelligent systems for fish feeding and monitoring (An *et al*., 2020). Few recent studies in this direction have shown that fish body patterns can be used for individual identification, but no system for the automation of this exists. In this regard, Cisar *et al*. (2021) have proposed a precision fish farming concept for aquaculture research and industry, which combines new technologies and data processing methods to enable data-based decision-making in fish farming, which is mainly used for fully automatic Atlantic salmon (*Salmo salar*) individual identification. Minami *et al*. (1999) proposed an algorithm for fish tracking with visual serving. It is basically a shape-based tracker which is allowed to evolve through genetic algorithms. In case of improper shape initialisation, it fails to track the object of interest. Chen *et al*. (2015) proposed a mechanism for tracking underwater objects motion in three-dimensional spaces using a single camera. The distance of the object from the imaging device is estimated and injected into the shape information of the object of interest. It has been assumed that the shape information is available a priori. Dark channel prior (DCP) is used to de-haze the scene of view. The tracking result is refined by camera motion compensation. This algorithm can handle deformable objects, provided that the shape information is available. The trajectory estimation is not so accurate, thus may lead to false tracking at times. The dark channel prior (DCP) alone may lead to decrement in the overall intensity of the enhanced scene, thereby the chance of failure increases. An algorithm for underwater fish tracking for moving cameras based on multiple deformable kernels has been developed by Chuang *et al*. (2017). It performs well at low illumination underwater videos and can track single as well as multiple objects. Recently, the use of machine learning techniques along with computer vision concepts have been utilised for smart agriculture (Vo *et al*., 2021). However, in the Indian context, the whole concept is in a nascent stage of research and development, and good investment and convergence of subjects are the need of the hour to develop self-reliance for smart aquaculture/ mariculture systems.

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