ARTIFICIAL INTELLIGENCE IN FISHERIES AND AQUACULTURE: A NEXT-GEN FISH FARMING SYSTEM

Abstract

Intensified aquaculture and expansion of area under aquaculture farms can make it difficult for farm managers to supervise each and every culture system and take customized decisions. In this scenario, machine learning (ML) and artificial intelligence (AI) may assist with real-time decision-making and farm monitoring. Artificial intelligence (AI) is a simulation of human intelligence in robots by providing them with sufficient contextual data. AI can also be applied to capture fisheries and preservation of natural resources. The emergence of blockchain technology has made it possible for ML to efficiently trace the source of fish on a customer's stable and track it along the supply chain. As a result, fisheries and aquaculture may become more environmentally as well as economically sustainable. Due to growing populations and increased demand for protein food sources, there is an apparent rise in the world's food production demand each year. Fish is a desired source of protein across the globe; hence this exerts pressure on the capture fisheries. Relying on advanced aquaculture has become the best option for producing enough fish to fulfill demand. Unfortunately, in contrast to the agricultural and manufacturing sectors, the aquaculture industry has not had a significant impact from technological advancements. The emergence of AI has opened up enormous opportunities for the implementation and integration of information technology in all spheres of life. Drones, bionic robots, nano- and micro-sensors, remote cameras, intelligent sorting, statistical modules, and algorithms are some of the AI techniques and

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tools that will help enhance aquaculture output and minimize human intervention. Through the concept of "replacing human with machine," the intelligent farm attempts in handling precision work such as increasing oxygen input, optimizing feeding, lowering infection, and accurately harvesting in order to completely liberate the manpower and move forward towards green and sustainable aquaculture. In an effort to boost aquaculture productivity and sustainability, AI must be employed throughout the aquaculture value chain to ensure efficiency in tracking, feeding, detection of diseases, growth estimation, monitoring the environment, market information, and other areas. Therefore, innovative technologies will play a significant role in the development of aquaculture operations that call for less human labour, effective maintenance, and efficient utilization of resources. Here, we've addressed the necessity of adopting advanced technology as well as the hurdles to AI adoption in the aquaculture sector. Further, this chapter discusses how AI is deployed in the aquaculture and fishery industries presently and in the future, as well as its potential to revolutionize the aquaculture industry.

Keywords: Artificial intelligence, Deep learning, Machine learning, Robots, Sustainable aquaculture

I. INTRODUCTION

Owing to the substantial growth in the global population as well as the surging per capita consumption of aquatic products, the fisheries sector is facing challenges on account of the demand for protein sources. On the other hand, fish stocks undergo stress due to climate change and an increase of natural resource extraction, specifically in the wild. Compared to proteins from terrestrial animals, fish and fisheries products are rich in protein, essential fatty acids, notably long-chain polyunsaturated fatty acids, and micronutrients (Beveridge *et al.*, 2013). There arises a gap between the demand and supply chains as a result of the significant increase in demand for fish and fishery products and the inadequacy of capture fisheries to fulfill the need. Nevertheless, capture fisheries are not to be considered as the sole source of fish for consumers because they severely jeopardize the marine biodiversity and ecology, thereby necessitating a decrease in reliance on them. Hence, the alternative approach to assuring production efficiency is through applications of technology that enable population density management and cultural management optimization. Regardless of the rapid growth of aquaculture, technological breakthroughs are still required to address issues like water pollution, disease outbreaks, the quality of broodstock and fingerlings, as well as the subpar management techniques (Fearghal 2019; Michael 2019). It is essential to make use of novel technological approaches to overcome the aforementioned issues. The implementation of technological advances to improve efficiency and sustainability in the operation of farms, including the use of IT devices like sensors, drones, autonomous tractors, robotics etc., is considerably higher in the agriculture sector as compared to aquaculture (Brown 2018; R Shamshiri *et al.*, 2018). In addition, recent precision agriculture firms have focused on implementing technologies that enable farmers to maximize production output through addressing every aspect of crop production, including pest stress, soil conditions, and micro-climate (Abdullahi *et al.*, 2015). Technology may offer fisheries and aquaculture the much-needed impetus they need, and while technological advancements have undoubtedly been made; considerable development is yet to be accomplished. Most of the technology currently in use has caused an unsustainable cycle of overfishing.

Sustainable aquaculture is based on the concept of shifting to a more secure, environmentally friendly, and economically viable seafood production. It provides a practical, secure, and sustainable alternative to fishing wild stocks and has the ability for achieving a considerable financial gain. Open-water aquaculture practices often damage the environment, particularly when they are carried out on a big scale and resulted in massive pollution, the depletion of natural resources, the transmission of disease, and the introduction of alien species into marine ecosystems. The intelligent fish farming system, that employs artificial intelligence (AI) equipment to take over manual labour and optimize the deployment of fishery resources using data-driven decision-making, could be an important leap for the initial stage of aquaculture development which will in turn necessitate in adopting an efficient, environmentally friendly, and intelligent aquaculture practices. The farming system is an all-weather, full-process, and full-space automated production mode, which means that in the event of workers unable to enter the fish farm, AI, is used to measure and control the farm remotely or autonomously controlling fishery facilities, equipment, and machinery using robots, in order to manage all production at the fish farm. In order to overcome challenges such as poor efficiency, high risk, and a shortage of skilled personnel in aquaculture, they rely on digital and intelligent technologies. This chapter highlights the deployment of AI in many aspects of aquaculture, their key applications as well as the constraints faced while adopting this technology in fisheries and aquaculture industry.

II. ARTIFICIAL INTELLIGENCE (AI)

AI is sometimes referred to as "the future made from the pieces of the past." By employing algorithms and statistical models to analyze and extrapolate from patterns in data, machines and computer systems can be fed enough data to enable them to learn and adapt without being explicitly instructed. Machine learning (ML) is the term used to describe this method for developing smart machines. It is a domain of computer science that attempts to give machines the ability to learn so they can emulate the cognitive processes of living creatures and make decisions based on past experiences. One of the specialized scientific techniques that are currently employed for AI study involves analyzing algorithms and statistical models that computer systems rely on to perform particular tasks with little human interference (Russell *et al*. 2016). In ML, algorithms are used to create mathematical models based on acquired data in order to predict outcomes without being specifically programmed to do so. The application of AI models (such as modern data science approaches) has grown rapidly in different sectors. However, they have not been sufficiently deployed in the aquaculture industry (Yang *et al*. 2020). Digitalization, big data, and deep learning (DL) offer a chance to use ML approaches in constructing models for aquaculture that can predict unforeseen events and guarantee decision-making efficiency. DL makes use of a great deal of data to analyze, and interpret the data into simpler concepts (Schmidhuber 2015; Yang *et al*. 2021). When it involves recognizing live fish, classification, behavior analysis, selecting foods, size or biomass estimation, and prediction of water quality, DL has been thoroughly examined, producing results that are more accurate than those from conventional techniques (Meng *et al*. 2018; Naddaf-Sh *et al*. 2018). ML can process and interpret numerous tasks more quickly than reliance on experts, thus there will be fewer issues associated with processing multiple tasks. Yang *et al*. (2020) proposed a method for defining operational limitations in aquaculture by combining data from several sources. This approach aims to enable the aquaculture industry, particularly service providers, to establish safe operational decisions for both coastal as well as offshore fish farms. To develop a prediction model to determine operational limits under a particular scenario, they used ML techniques like Bayesian networks, Tree Augmented Na€ıve Bayes (TAN), and algorithms. Due to the fact that AI offers the chance to resolve problems that are based on expertise and background knowledge in order to get pertinent information and make discoveries that previously depend on professionals' experience, research and development are essential for improving statistical models and algorithms used in AI and ML to achieve high prediction accuracy (99.99%) by removing external influences.

III. TRENDS IN AI

The IoT's (Internet of Things) full potential has been primarily fueled by AI, that serves as the brain behind the automatic data processing in which IoT devices has gathered. IoT devices reached an estimated 8.4 billion in 2017. Given the opportunity for learning offered by AI in IoT technology, it was predicted that the number of IoT devices would spike to approx. 30 billion by 2020 (Hsu and Lin 2016; Nordrum 2017). Data-driven water quality sensors, augmented reality (AR) devices, web applications, and servers are being designed, and adopted in aquaculture. As a result, artificial intelligence (AI) has been gaining recognition in the sector recently. These applications encompass crowd management for sea lice infestation inspection to the deployment of autonomous environmental monitoring sensors (Føre *et al*., 2018). Below are some examples of these trends in aquaculture:

To accelerate farm operations in India, (Piplani *et al.* 2015) came up with the data-driven Android software "mKRISHI -AQUA" for aquaculture farm management. Their application provided data collecting, processing, and presentation through procedures such as farm registration, management, creation, and report of pond data. Water quality must be constantly monitored to make sure it is ecologically suitable for aquatic species to survive, as it is essential for choosing an appropriate location for aquaculture and maintenance of sites suitability. Some water quality parameters that must be constantly monitored include DO, temperature, pH, turbidity and salinity. This will ensure safety as well as allowing them to thrive to their full potential. When it comes to measuring water quality indicators, Shetty *et al*. (2018) proposed an end-to-end software service application for Aquaculture Resource Planning System (ARP) and development to address the issues related to time consumption and measurement efficiency. Their technology integrates a wireless sensor network (WSN) based on the Zigbee protocol for tracking water levels with a cloud-based approach (SaaS) for data gathering and processing to assess the site's appropriateness. Similar studies have been carried out, for instance by Gao *et al.* (2019), where they created an IoT-based tracking and control system for intelligent fish farming. Their technology offers automatic water quality control, helps in tracking the breeding and marketing of freshwater fish, and also gives consumers access to historical farming records via a QR code tag on a product. Simbeye (2018) also demonstrated a solar-powered aquaculture harvesting system based on WSNs. They designed a solar-powered oxygenation system to supply aerators for aquaculture oxygenation and remote sensor nodes for water quality monitoring.

For determining fish growth, mortality, reproduction, and recruitment in fisheries, length and weight attributes are essential. Since the fish were taken out of the water to be measured, obtaining these data is generally lengthy and could lead to stress on the fish. Therefore, employing novel techniques is the only way to solve these issues. According to reports of Rahim *et al*. (2020) and Mustafa *et al*. (2013), determining fish length by processing an underwater fish image has an accuracy level ranging from 95% to 99.81%. The variation in accuracy can be primarily caused by differences in the methods and algorithms employed.

IV. DEPLOYING AI IN AQUACULTURE

Aquaculture has been developing swiftly in recent years owing to the invention of novel technologies that gradually transform aquaculture from traditional labour-intensive towards mechanised aquaculture and eventually to fully automated systems, despite the fact that the agriculture industry adopts innovative technologies prior to the aquaculture sector (Li and Li 2020). To enable achieving smart data processing, analysis, and decision-making, the AI could fix shortcomings such as defective performance issues and inadequate data in understanding varied enormous data (Yang *et al*. 2020). Adopting such technologies in salmon farming, recirculating aquaculture systems (RAS) and others are pioneering the development of the aquaculture sector.

1. **In RAS**: Water is disinfected and reused continuously in a closed loop by eliminating or transforming solid waste viz. ammonia and CO_2 into a non-toxic product and in turn reoxygenating the water. The adoption of RAS has resulted in a reduction in the need for labor and a rise in production. Commercial RAS undertakings have experienced a high rate of failure; however, this has been attributed to the high investment capital requirements and prolonged payback periods. Additionally, its production method necessitates highly skilled workers, hence affecting cost-effectiveness (Engle *et al*. 2020; Li and Li 2020). About 90% of the culture water can be reused by the RAS (Moreno-Andres *et al*. 2020). Given that the RAS system includes numerous components, the water loss may be attributed to this. During the recycling process, water loss occurs by evaporation and drum filter backflushing. Interestingly, a new method called the Membrane Bioreactor (MBR) for treating domestic wastewater was developed to make up for the shortage of water (Gukelberger *et al*. 2020).

2. **In Salmon Farming:** Aquaculture technologies have advanced significantly during the past few years. The four major technological advances used in the production of salmon in Canada were (i) land-based, (ii) hybrid, which combine land-based RAS production with marine grow-out, (iii) floating closed containment systems, and (iv) offshore systems employing open or closed containment systems. For effective functioning, these systems make use of technologies like sensors, AI, remote-controlled vehicles, and others (FOC 2019). The emphasis of these technologies entails their capability to continuously monitor water quality. This suggests that water quality is crucial in performance of aquaculture and must be continually assessed. The RAS and salmon cage farming necessitate remote sensors; however, AI is not yet commonly used in these sectors.

V. AREAS OF APPLICATIONS OF AI

1. **AI in Aquaculture Value Chain:** Tracing information of fish value chain is a complex yet essential task for ensuring trust building with customer. Study of the fish value chain enables us to know how a product or service is conceptualized and then delivered to the consumer, through multiple phases of production ‘from sea to fork’. However, lack of data, both in quality and quantity, is the main constraint behind the implementation of AI in the fish value chain. With sufficient data to build strong AI models, the technology can be used not only for tracing the raw material but also in aspects like food integrity, sustainability, processing, logistics, and market. The use of AI would result in increased authenticity of the source and its impact on environment. Application of AI systems in the value chain can make companies more resilient by transforming the production chain towards a low-waste and resource-saving model. The adoption of resilient technology-based solutions across the value chain of any industry requires a fully functional network (supply chain) featuring services that enable traceability and transparency. IoT devices in combination with AI can enhance the ability to precisely trace and access product status at particular stages in the value chain when used in conjunction with a reliable and secure cloud storage solution.

   Significant consequences of AI have been observed throughout the aquaculture value chain, particularly with the deployment of cloud-based traceability systems that make it easier to obtain customer awareness and product quality requirements. These include continuous monitoring of product transport and storage, surveillance of disease transmission, weather forecasting, dietary recommendations, and market data at a global scale. An aquatic food supply chain traceability platform based on the IoT and radio frequency identification (RFID) and electronic product codes (EPC) was designed and developed by Yan *et al.* (2012). This platform provides access to tracking, traceability, and monitoring of food products in the supply chain for consumers, businesses, and the government. The platform features early disease detection to facilitate quality supervision, consumer inquiry and complaint, production information management system, monitoring of water quality, and accessing information flow from breeding to sale (Yan *et al.* 2012). In addition to public health concerns, proper traceability is essential for providing crucial information on the source of the fish, batch, and whether it was correctly stored and transported, as well as its current tracking at any point of time (Cruz and da Cruz 2020).

The fish lots may be tracked back and forth throughout the entire fisheries value chain. Numerous companies and startups have emerged as a result of the integration of AI into the aquaculture value chain in an effort to harness the benefits of developing improved farming. These companies made use of traceability, illness detection, weather forecasting, growth projections, market data, etc. A company like XpertSea, which deploys AI to provide farmers with updated information on shrimp growth viz. weight, and size, thereby, helping farmers predict the most profitable harvest periods. Throughout the whole production cycle, it offers farmers beneficial data-driven insights along with access to quick payments, exposure to network of buyers and sellers, and industry professionals with customer services. Another company, eFishery, offers platforms for the selling and purchase of fish as well as their feed. Companies like Aquacloud and Aquaconnect deploy AI to solve issues of disease outbreaks prior to their occurence by collecting and analyzing information alongside implementing prophylactic measures, as diseases constitute one among the primary drivers of expenses in aquaculture. Accurate weather and water environment forecasting could prevent financial losses brought on by flooding due to excessive rainfall or inappropriate water quality parameters such as DO, pH, etc. Decision-making can be significantly improved by the slightest enhancement in weather prediction.

The National Oceanic and Atmospheric Administration (NOAA) of the United States conducted research on applying AI to improve real-time decision-making for high-impact weather. They concentrated on forecasting storm duration, intense wind and hail, classification of precipitation, and turbulence in aviation, which is relevant to the fisheries sector. It also highlighted how AI approaches can handle "big data," offer insights into extreme weather events, and advance our knowledge of extreme weather for decision-making (McGovern *et al.* 2017). To predict weather conditions over time, there are numerous weather sensors and stations available (Rikasensor). Blockchain makes it easier to track assets in a network and follow the trajectory of transactions. Its administration in the fishing industry has a broad range of advanced ways to track and trace all transactions performed and will also aid in the development of trust and satisfaction among fishermen. For the end-to-end traceability of shrimp exports from Andhra Pradesh to the United States, Walmart Inc. has announced a blockchain technology. This will strengthen the shrimp supply chain and improve customer transparency and traceability.

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2. **In Identification and Measurement:** As DL models are capable of learning distinctive visual traits of species that are not sensitive to environmental fluctuations and variations, they can be used to precisely identify species by using factors like visual characteristics and sound frequencies (Dos Santos and Goncalves 2019). A more precise estimation of fish morphological parameters, such as width, length, abundance and number has been made feasible by the application of DL. To boost fisheries productivity, observation of these characteristics is crucial (Saberioon and Císař 2018; Li *et al*. 2020a).

3. **In Sampling:** Traditional sampling methods are generally lengthy, hard on fish, and arduous. Zhang *et al*. (2020) developed an automated fish counting method to address the previously mentioned problems and enable real-time, precise, and seamless counting of fish populations in distant offshore salmon mariculture. A multi-column convolution neural network was constructed as the front end for gathering feature data from various receptive fields in the hybrid neural network model in which they had developed. According to experimental findings, the suggested hybrid neural network model has a 95.06% counting accuracy.

4. **Intelligent Equipments and Robots:** Traditional aquaculture involves low efficiency, expensive and lack of automation. Given that the operational conditions are complex and often subjected to frequent change, especially in marine cage culture therefore, remotely operated autonomous systems may play a significant role in the future in carrying out various activities at fish farm facilities. Intelligent robots and equipment will incorporate AI, big data and sensors so as to enable effective adaptation to the complex operation environment. They can also significantly lower labour costs and intensity while increasing the productivity. Additionally, to meet the demands of machines; they require the aid of machine vision, navigation, edge computing and precision control technologies (Shi *et al*., 2016).

5. **Intelligent Hardware - Measurement and Control:** Long-term accurate measurement of important water quality parameters offers a trustworthy source of data for automated controlling. Future adoption will be centred on membrane-free DO sensors based on fluorescence and sensors based on improved nanocomposite electrodes. Real-time monitoring of DO, air humidity and water temperature is possible with the intelligent aerator. Further, it can determine the DO in a short time span. RAS integrates technologies to remove hazardous contaminants such as excrement, ammonia nitrogen (Moges *et al*., 2019). The primary concerns of system design are the rapid eradication of ammonia nitrogen and the swift rise of DO in commercialized RAS. Dynamic simulation with computer assistance will be an efficient tool for designing of RAS.

6. **Precision Automatic Feeding System:** Industrial recirculating aquaculture has made extensive use of automatic feeding systems, including automatic feeding robot systems and automatic feeding systems with multi-monomer centralized control. Automated feeding systems are currently in the phase of implementation in several developed nations, such as Norway, Japan, and the US, and they offer precise control over the feed storage, distribution, and transportation chains. A Finnish company Arvo-Tec came up with a robotic feeding system that employs a web interface enabling remote feeding control, water quality improvement, and precision feeding. Bait cost may constitute for 80% of the total input cost for aquaculture. The key for boosting aquaculture profits is

finding strategies to reduce feed costs. It is challenging to create precise bait feeding, which results in fish underfeeding, bait waste, and water pollution. The method of delivering bait is based mostly on the fish's growing environment and breeding history. Feedback on the fish's feeding status is not accessible from the current bait-casting device.

By giving the control system the assessment findings of the impact of the bait-feeding, feeding quantity modifications can be done in real-time. Feed can account to 60% of the total cost of investment. Thus, optimization of feed is essential. Overfeeding can result in wastage, eutrophication and poor water quality. In contrast, underfeeding can result in poor fish growth, disease and cannibalism. Therefore, monitoring appetite can aid in providing precisely the exact amount of feed at the appropriate time. AI, with the help of multiple sensors, may address this issue by studying different vibrations and acoustic signals, which will help distinguish hungry animal from a pack. AI powered products are already available in the market. For example, ‘eFishery’ feed dispenser. In aquaculture, feeding has a significant role in determining the quality of water and cost of production (Li *et al.* 2020b). The majority of large-scale farming uses automated feeding techniques to cut down the costs and save time. Regardless of the physical condition of the water, automatic feeding machines operate on a timely basis and they disperse feed according to a preset time. Thus, using automatic feeding equipment may result in overfeeding and affect the quality of the water (Liu *et al.* 2014). DL and data fusion applications offer a great deal of potential to improve fish feeding behavior recognition (Li *et al*., 2020b).

In an automatic fish feeding system, a control system for automatic feeding is coupled with feedback on environmental monitoring technologies. As a result, feeding in culture systems can be managed and modified or halted entirely depending on the fish's behaviour or the water's quality. For an instance, is the Akvasmart CCS feeding system from AKVA Norway. The system is outfitted with aquaculture video camera, environmental sensor, a Doppler residual feed sensor and other monitoring equipment to observe the underwater environment and provide precise amount of feed. It is controlled via a computer or a smart device (such as an iPad or phone), and it has the ability to manage more than 1000 tanks per unit and 40 feed lines at a time.

7. **Unmanned Patrolling System:** Robotic fish, unmanned surface vehicles (USVs) and unmanned aerial vehicles (UAVs) comprise the patrol equipment in the intelligent fish farm. The patrol equipment can be used to oversee daily underwater operations, collect video data, observe breeding items' activity, and keep an eye on the aquaculture industry's ecological environment. In order to provide the omnidirectional perception of ecological data and feeding details of an intelligent farm, the system is outfitted with remote sensing equipment, cameras and hyperspectral sensors that employs machine vision. In particular, 5G can be employed for high-throughput HD video monitoring and transmission in open sea cage culture to address the issue of expensive and challenging optical cable deployment. Sonar and multi-beam detection devices are incorporated in underwater acoustic systems that provide automatic obstacle avoidance, underwater positioning, biomass assessment and object tracking. A range of sensors are carried by biomimetic robot fish to autonomously evaluate quality of water and the operation status of devices.

Using computer vision technology, it can also keep an eye on fish feeding habits and analyze relevant data to help improve the feeding strategy (Ravalli *et al*., 2017).

8. **Intelligent Harvesting Technique:** With the help of this method, breeding objects will be transported with or without water in the market. , Underwater camera, sonar, and net positioning device are deployed in this system to obtain precision harvesting. The efficiency of fishery production will be substantially enhanced through the use of autonomous ships and vehicles in distributing the aquatic products. In addition to reducing the labour intensity of fisherman, this will facilitate in achieving an energy efficient farming. Automation in aquaculture production will be achieved through the use of intelligent machinery and robots.

9. **Water Quality Soft Measurement Method:** In aquaculture rearing system, water quality is important for fish growth rate, feed intake, and health. The fundamental concept behind this measurement method is to estimate or infer significant factors that are hard to observe using some readily observable variables. Gray box models, ML models based on statistical analysis, and process mechanism models constitute majority of the currently used soft sensor modelling techniques. Traditional approaches for predicting water quality are inaccurate and have a slow convergence rate. They are not appropriate for high-dimensional modelling, limited sample data sets. The key factor impacting the fluctuation in content of ammonia nitrogen were screened using the PCA method by Chen *et al*. (2019), noise was eliminated using the wavelet threshold method, and an ammonia nitrogen prediction model based on the particle swarm optimization (PSO) algorithm and multi-variable deep belief network (MDBN) was proposed. The auxiliary sensor's input variables and the model both predict the soft measurement.

10. **Behavioral Analysis of Species:** Fish's sensory, neurological, immunological, and metabolic systems all play an crucial role in their overall response to stress. The primary concerns with fish behaviour include swimming, feeding, reproducing, aggressive, and carnivorous behaviour. One of the oldest biological monitoring techniques is the fish bioassay, which is particularly useful for examining how fluctuations in pollution affect fish behaviour. Movement behaviour (speed, wagging frequency, turning times), respiratory behaviour (breathing depth, respiratory rate), and group behaviour (communication, dispersion and regional distribution) have traditionally been the main determinants used to monitor and access water quality. When recording 3D data on the movement of *Oryzias latipes* using Bio Fish Meter Lab equipment, Kang *et al*. (2009) successfully addressed the issue of signal plane crossover in video tracking technology. In order to track fish behaviour in real time, Chew *et al*. (2009) created an autonomous system using machine vision image analysis technology. They investigated on fish activity levels, avoidance behaviours, and social interactions, as well as monitoring indicators like balanced loss rate, irregular turns, etc. to obtain a detailed assessment. Traditionally, it has been difficult and time-consuming to detect water quality abnormalities in a timely manner, which can occasionally put the cultivated species at risk. Real-time tracking of the environment, water quality (ammonia, dissolved oxygen, pH, etc.), and fish behaviour are crucial for aquaculture management to take action promptly and avoid risks. The aquaculture environment is monitored using drones, online remote monitoring equipment sensors, and underwater robots. In cage culture, real-time online monitoring technology has been implemented to track water quality indicators in

order to increase effectiveness and minimize culture risks (Raju and Varma 2017). Additionally, fish behaviour reveals a lot about how fish react to their environment. Fish behaviour changes are a sign of the combined effect of stress and changes in the environment on fish. Fish behaviour, including feeding, swimming, response to stress, population fluctuations, etc., can be observed using machine vision, acoustic, or sonar technology (Bae and Park 2014; Føre *et al.* 2018).

11. **Use of AI to Develop more Selective Gear:** Fishing involves catching fish based on species, size, and sex during harvesting operations, and all unwanted catch are released unharmed. Traditionally, fishermen focus on selective gear development for maximizing fish capture. This often leads to increased bycatch. Several fishermen are now adopting intrawl camera systems for scientific monitoring of the trawl operation. These cameras are not equipped with AI; however, the feed from the cameras can be linked with AI for automated fish detection and classification. Recently AI automated data processing was developed that allows near real-time observation, and can be trained for remotely switching lights on the fishing gear to attract or repel fish based on the video feed (e.g., H2020 projects SmartFish84 and DeepVision85).

12. **AI Drones in Aquaculture:** Water quality parameters like temperature, turbidity, dissolved oxygen, etc, analysis can be carried by AI powered drones equipped with different sensors which can be connected with smartphones and easily accessed. 'Shoal' a robotic fish has been developed that works on the same idea, which collects data on pollution, and has the ability to swim underwater and even communicate with each other in low-frequency sound waves. This makes the study of water quality in deep waters much easy and more accurate data can be obtained as number of random locations is explored within a short collection time. They can be a boon in the detection of any abnormalities quicker and mitigation be done.

13. **AI in Prevention of Diseases:** Disease outbreak is a major threat to the aquaculture industry of any culture type, as contamination of the culture environment may result into complete devastation of crop. Furthermore, controlling a disease that spreads underwater is always difficult because diseased animals may not be visible until it is too late. Since the diseases in fish and shellfish are often preceded by deterioration in the water quality, the AI programs can monitor for any aberrations and predict any such outbreak even before it happens. 'Aquacloud' launched by Norway's seafood innovation cluster in 2017 is a cloud-based AI program developed to help farmers to detect and prevent any development of sea lice in cages. This keeps a check on mortalities thus reducing dependence on high-cost treatments and medicines. Different sensors based on vision helps analyze swimming patterns, size, and other parameters of the cultured animals 'Xpercount' an AI based device developed by an 'xpertsea' a futuristic aquaculture innovation company works on the principles of ML and camera to weigh, count, and shrimp size. These data are compared with already programmed data to address any differences in the environment. By identifying the majority of external abnormalities in fish, using AI techniques were proven to diagnose fish diseases. For an instance, the monitoring device for fish disease detection developed by IPI under Singapore's ministry of trade. The device employs a 2D or 3D camera to record fish behavior (fish's accurate viewpoint and trajectory for signs of infections on scales) illuminated by near-infrared light in tiny tanks and cages. To determine depth of the fish, the camera measures the

infrared light and light intensity that is reflected off the fish. This aids in the comprehensive evaluation of distinctive fish skin patterns for behavioral changes (IPI Singapore 2019). Parallel to this, a machine-based smart aquaponics system based on the IoT was created to monitor the environment in real-time to detect diseases in aquatic plants and leaves (Barosa *et al*. 2019). Adopting AI will allow for quick identification and timely treatment of fish infections that are harmful and remedied to prevent further loss.

14. **AI Based Fish and Shellfish Seed Screening:** Screening of fish and shellfish juvenile (seed) is a complex process that involves skilled labour and is a time-intensive process. It is an important determinant of culture so utmost priority is required. The Kindai University's Aquaculture Research Institute, Japan uses Microsoft Azure ML based studio in order to screen and remove any odd-shaped fish seed from rearing cage.

15. **AI in the Conservation of Endangered Fishes:** Anthropogenic activities, along with pollutants, are causing a reduction in the aquatic animal population rapidly. Although many conservation efforts are made so far but they are proving themselves insufficient and involve human efforts in large amount to monitor and study them. Through the principles of vision cameras and sensors, AI drones can be assigned these jobs; they'll analyze their habitat faster and accurately in less time and effort. Fish like Sharks, Humpbacks, and other large fishes can be fitted with transmitters to study their movement and behaviour more easily and helps conserve the better (Chrispin *et al*., 2020).

16. **Advantages and Challenges to AI in Fisheries:** AI can be useful in every aspect of fisheries ranging from the capture of the fish till it reaches finally on the table. Due to easy traceability, AI can have its applications in both aquaculture and processing units as well. It will save time and also maintain the accuracy of work thus will save wastage of inputs. Farms based on AI infrastructure can be maintained and managed with nearly 95% accuracy in operations (Chrispin *et al*., 2020). Even though AI has multiple use and advantages in the fisheries sector there are some challenges to it as well. Initially setting up of AI infrastructure requires huge capital which might push off investments. And complete automation is yet to be achieved and made available. People who are dependent on fishery activity for sustenance will suffer as AI will replace manual labor.

    The following shortcomings are discovered in the application of DL in aquaculture: First, big data sets need to be collected for DL model training, verification, and testing, which necessitates the development of cameras or sensor equipment to gather data in different scenarios. Secondly, since the majority of DL-based aquaculture problems involve supervised learning, labeling the corresponding sample data is needed. More experts are usually required to take part and manually mark the target category.

    Any novel technology or system has to go through some form of user training prior to its implementation. Depending on the educational level of the users, this process may take a while. Most of the aquaculture enterprises tend to be situated in less educated rural areas. This, however, hasn't slowed down the development of innovative technologies. This implies that even among potential users of technology that are less educated, the approach of information dissemination and technique demonstration could facilitate adoption. Consequently, for successful adoptions of innovations, three key concerns need to be resolved (Van Henten, 2020): First and foremost, acknowledging that the advancement of technology is bringing a new discipline into the technical market, one that requires extensive knowledge in robotics and AI. Secondly, since new technology is data-intensive, integrating it into the data infrastructure of the future farm can be challenging. Thirdly, selecting appropriate technologies to meet farmers' demands and educating them on how to operate higher-tech equipment are crucial success factors for implementing new technologies.

VI. CONCLUSIONS

Technology advancement is now vital for the aquaculture sector to preserve wild fish stocks, regulate fish prices, and boost output in response to the present population rise. Population growth exerts more pressure on wild fish stocks by driving up fish prices as a result of increasing demand and an inadequate supply of seafood. R&D on technology might reduce the decline of wild fish species, boost social welfare, and ease poverty. Although aquaculture is beginning to see the profound effects of recent information technology developments, this sector still has a lot of room for growth in comparison to the considerably wider deployment of IT in the manufacturing and agricultural sectors. However, we believe that the pace of aquaculture growth will rise dramatically owing to the continual implementation of information technology. To sum up, novel technologies are vital to the future development of aquaculture and should be taken into consideration in all aspects.

In light of issues like the depletion of wild fish stocks, marine pollution, and a decline in the number of workers engaged in the sector, aquaculture revolution needs to shift from traditional mode to digital intelligent farming system. In order to liberate the traditional labour force, current emerging technologies, like AI and robotics, will progressively contribute in every step of aquaculture production which will in turn achieve multi-scene all-weather real-time monitoring of the environment, data analysis, and intelligent decision-making.

The chapter provides a detailed introduction to the use of intelligent measurement and control, feeding, surviellance, and harvesting equipment in intelligent fish farms. Further issues need to be resolved regarding the robustness and service life of sensors, the accuracy of analysis and decision-making models, the reliability of data transmission based on IoT technology. In future, sound infrastructural development and strong government policy backing are crucial for the rapid development of intelligent fish farms. In an effort to ensure an environment friendly functioning of intelligent fish farms, the government should support aquaculture enterprises to upgrade, adopt cutting-edge technology, and employ high-tech skilled workers vis-à-vis regulating the standards of aquaculture sustainability indicators.

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