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Digital Technologies Shaping the Future of Marine Aquaculture

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Abstract – The decrease in natural fishing resources has prompted the adoption of marine aquaculture as a key strategy to sustainably and ecologically support the expansion of the sector. The aquaculture industry is increasingly adopting novel digital initiatives, including the Internet of Things, big data, cloud computing, blockchain, and artificial intelligence. These technologies are being used to solve challenges in agriculture, enhance farming productivity, and bring about modernization in fisheries. This study presents the foundational framework for the potential integration of novel digital advancements within the domain of marine aquaculture. This study examines the outcomes of implementing several novel digital advancements within the marine aquaculture context. Additionally, it explores the advantages and disadvantages connected with the use of these technologies. Furthermore, this page enumerates the many applications of contemporary digital technology in undersea aquaculture systems. In summary, this article aims to define and characterize the primary obstacles posed by emerging digital advancements in this marine aquaculture production process. The objective is to provide a scholarly resource that may facilitate the widespread adoption of these novel digital advancements within the domain of marine aquaculture.

Keywords – Marine Aquaculture, Deep-Sea Aquaculture, Fishery Technology, Marine Population, Marine Fishery Production, New Digital Technologies.

I.INTRODUCTION

Aquaculture, sometimes referred to as aqua farming, is a rapidly expanding sector in animal food production globally. **Fig. 1** shows that China is a global leader in the production of aquaculture. It is fundamental to note that the origins of this type of farming may be traced in China about four thousand years ago, when the cultivation of carp marked its inception. In a significant development, the utilization of farmed fish has surpassed that of wild-caught fish, marking a notable milestone. Furthermore, projections indicate that by the year 2030, aquafarming is expected to account for about 70% of global fish consumption [1]. Shellfish, crabs, and seaweeds are cultivated via the practice of aquaculture, serving as valuable sources of vital nutrients for human consumption and as reservoirs of bioactive compounds used in the pharmaceutical industry.

The increasing consumer demand for seafood has negatively impacted the fisheries' capacity to sustainably meet their own needs. As a result, there is a need to explore innovative uses of both current and developing technical techniques. Fortunately, there exists ample potential for enhancing the technologically-enabled sustainable production of this protein source. It is projected that the global populations will be more than 9 billion by the year 2050, hence requiring a substantial augmentation in annual food production from the present 8 billion 400 million tons to 13 billion 400 million tones. When tried-out in a sustainable manner, aquaculture has the potential to provide a higher quantity of nutritious proteins and nutrients compared to the majority of animal proteins. Fish is known for its high content of omega-3 fatty acids, which have been shown to decrease the risk of cardiovascular illness and serve as a dependable source of protein. According to de Medeiros et al. [2], there exists a positive correlation between the red meat consumption and the probability of contracting cardiovascular diseases and colon cancer. Conversely, a diet rich in fish has been shown to be inversely related with the risk of both aforementioned illnesses.

The potential risk may be mitigated by refraining from consuming red meat. Inexpensive and middle-income households might potentially get advantages from the cost-effectiveness associated with cultivating freshwater fish, especially within pond environments. The flourishing of aquaculture in Asia may be attributed to the increasing disposable incomes in the region. According to Garlock et al. [3], Asia accounted for approximately 90% of the global production of aquaculture in the previous year. In this particular case, carps are considered to be the most extensively cultivated fish, both inside China and other regions throughout the globe. In 2017, the global aquaculture production consisted of 38 different species of carps, contributing to a significant proportion of 25% of the total output. This amounted to a substantial quantity of 28 tones, with a corresponding economic value of US$61 billion.

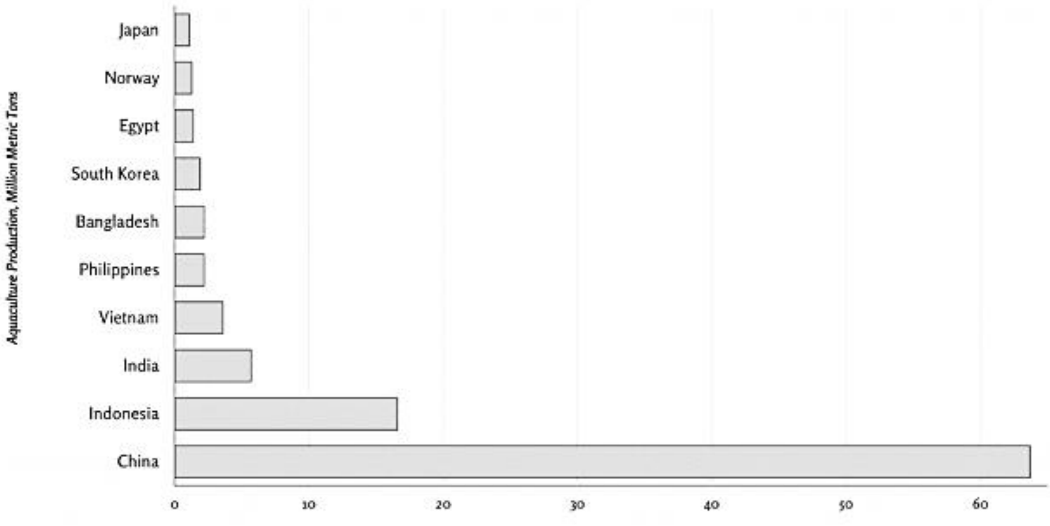

Fig 1. The Global Production of Aquaculture

The inception of marine aquaculture and fisheries informatization in China may be traced back to the year 1978, when first efforts were undertaken. With the escalation of overfishing and marine pollution, China saw a transition in its marine fisheries policy from a focus on traditional fishing practices to the adoption of aquaculture. Since 2003, efforts have been made to enhance and optimize the information network and database of marine fisheries. Rowan [4] have the potential to predict and use information services for aquaculture data by using information mining techniques for example neural networks and machine learning. Furthermore, the integration of sophisticated advancements such as sensor engineering, radio frequency identification, and machine vision has facilitated the development of intelligent aquaculture facilities capable of monitoring water quality, implementing intelligent feeding strategies, autonomously cleaning themselves, and even autonomously capturing aquatic organisms.

In recent years, more factors for example mechanical power, fisheries labor and aquacultural area have shown enhanced efficiency. However, it is noteworthy that this progress has not been accompanied by a commensurate rise in investment or overall efficiency. Insufficient financing for research and development has been identified as a contributing factor to the comparatively lower effectiveness of fishing technology in comparison to other domains within agriculture. The aquaculture industry chains imperfections and the inadequate execution of a bearable development plan have emerged as the main obstacles during China's pivotal shift from analogue aquafarming and processing methods to brilliant aquafarming and processing methods.

The integration of modern technology has promise for enhancing the supply chain of marine aquaculture, raising the marine aquaculture sustainability, improving the bionomical ecosystem of marine aquaculture, and overcoming the existing snarl in marine fishery. Prominent instances of state-of-the-art data-driven advancements include big data analytics, IoT, blockchain, cloud computing technology, and artificial intelligence. The Internet of Things (IoT) enables the collection of information. The use of big data technology enhances the quality and effectiveness of information. Cloud computing is used for the execution of data management and operational tasks. Artificial intelligence systems are responsible for processing data, which is then encrypted via the use of blockchain networks. The interconnection between the five types of digital technology is inherent and cannot be separated.

In this article, an overview of the present situation of marine fishery equipment development is provided, exploring the impact and use of emerging digital technologies, and delineates the fundamental framework governing the interplay between these technologies. This paper proposes suggestions for the development of a contemporary modernization framework for marine aquaculture, with a focus on assessing the advantages and disadvantages linked to the employment of emerging digital advancements within the sector. This is how the article is organized: Section II presents a discussion of the novel digital technologies to be employed in aquaculture. Section III focuses on the applications of new digital technologies in marine aquaculture, such as IoT applications, big data applications, AI applications, and the blockchain applications. Section IV presents a discussion of the new digital technological application in deep-sea aquaculture facilities. Lastly, Section V presents a conclusion as well as directions for future research.

II.NEW DIGITAL TECHNOLOGIES

The ability to gather data, exchange data, examine data, secure data, forecast data, and optimize decision-making processes are facilitated by a set of five emerging digital technologies constituting the IoT: big data, blockchain, cloud computing, and artificial intelligence. One potential benefit of emerging digital technologies is their ability to enhance total-factor productivity by fundamentally transforming established industries on a global scale and along the whole value chain. However, the integration of emerging digital technologies has the potential to foster the development of novel industries, business models, and modes of operation. Consequently, this may lead to transformative effects across many fields of study, different organizational levels, and whole systems.

Simultaneously, the swift amalgamation of emerging modern technologies and marine aquaculture has not just expedited progress in domains such as research and development for intelligent fishing vessels, seafood supply supervision and marine data management, but it has also laid the groundwork for more comprehensive exploration of marine aquaculture. Aquaculture, a method involving the captive rearing of juvenile animals followed by their subsequent maturation in marine habitats, has been a longstanding activity for over a century. Certain species, such as the Japanese flounder (Paral ichthys olivaceous), have shown superior performance compared to other species. However, there have also been instances of unsuccessful outcomes in the fishery, mostly attributed to insufficient understanding of the factors that impact recruitment and decline.

The scope of interest in ranching has expanded to previously unexplored places and has been extended to include a broader range of species, owing to the accumulation of information about the factors that contribute to the success of ranching endeavors. Several nations, including Norway, the United States, Australia, and China, have initiated stock enhancement initiatives for a range of species. The first international conference on Stock Enhancement and Sea Ranching took place in Norway in 1997. Subsequently, a second conference has been planned for January 2002 in Kobe, Japan, with the aim of fostering a more productive exchange of information. If the availability of suitable habitat is enough and fishing activities are well regulated, sea-ranching might potentially serve as a feasible approach to enhance catch rates.

The use of Artificial Intelligence (AI) in diagnosing fish illnesses has emerged as a promising subject, using improved techniques to diagnose diseases based on the analysis of fish behavior and exterior characteristics. The grouper that was raised in cages had three separate abnormal visual characteristics, which were categorized using a two-step method of image analysis as described by Zhang, Li, Yin, Zhang, and Grzegorzek [5]. This method included the use of deep learning techniques and a convolutional neural network. The most optimal classification model among the four models examined in the research had a mean rate of accuracy of 98%. The initial investment required for implementing complex AI systems in fish farming is very substantial.

However, the decreasing costs and emerging techniques associated with these systems have the potential to make them accessible to even the most modest-scale farms. He, Zhan, and Xie [6] have proposed a methodology aimed at facilitating timely response and effective management strategies for artisanal farmers in the face of disease epidemics. This methodology focuses on early detection of disease outbreaks. Underwater sensors and cameras are used to record images, which are then sent to a third-party entity through cloud technology for the purpose of analysis and evaluation. Subsequently, an AI model that has undergone training will undertake the task of categorizing and analyzing the data. Using contemporary networking methods, it is feasible to evaluate the efficiency of several agricultural establishments during a 24-hour period, with prompt results obtained in a matter of minutes.

Current research in the field of aquaculture AI has also placed emphasis on the development of feeding techniques with enhanced efficacy. Xiaorui, Jiamin, and Longji [7] used a support vector machine model and artificial neural networks to develop a biomass prediction method that incorporates real-time water quality data in order to determine the ideal feeding levels for shrimp cultivated in a recirculating aquaculture system (RAS) facility. The findings represent an average error of 3.65%, suggesting a significant improvement compared to manual feeding methods. The use of artificial intelligence in aquaculture may also be effectively utilized in the domains of biomass monitoring and stockpile management. Gonçalves et al. [8] presented a study in which they revealed the use of a shift invariant for the purpose of fingerling counting.

The flexibility of the model enabled it to effectively predict the movements of juvenile fish, whereas the AI approach relied on a collection of photographs to achieve precise fish enumeration, even in scenarios where many individuals were in contact or overlapped. The inclusion of temporal information in the model led to an overall F-measure of 97.89, which is calculated as the harmonic mean of accuracy and recall, with a value of 1.0 indicating optimal performance. Pai, Mehrotra, Verma, and Pai [9] utilized deep learning approach identified as "semantic segmentation" in relation to about nine thousand time-lapse images to effectively detect and track scallop within the lantern nets. This methodology enabled the comprehensive observation of scallop growth and behavioral patterns over a specified duration.

III.APPLICATIONS OF NOVEL DIGITAL ADVANCEMENTS WITHIN MARINE AQUACULTURE

IoT Applications

In the realm of marine fisheries, fishing processing, circulation, and management, the use of IoT in fisheries might be considered a subsidiary technology within the broader domain of agricultural IoT. The principal applications of this technology include the surveillance of fish behavior, the acquisition of data on aquaculture products, and the monitoring of the surrounding ecosystem.

The predominant approach used by fishing fleets to collect information on seafood from an aquaculture standpoint involves retrospectively attaching RFID tags. Users have the capability to transmit sensor data related to storage, aquaculture, transportation and fishing to an RFID reader via a detector network. In addition, it is possible for anyone to physically grasp the radio frequency identification reader and perform a skimming operation on the label in order to input the relevant data. There are several problems that continue to hinder the implementation of RFID-based supply chain applications in an academic context. These challenges include the limited acceptance of intelligent devices, the high costs associated with installation, and the presence of significant constraints.

In order to comprehensively analyze the marine fishing production supply chain, it is important to get data pertaining to both the production facilities and the production environment. The nautical information platform, BlueNavi, was built by Liu as a service- oriented architecture, according to Aljazzaf, Capretz, and Perry [10]. This platform enables users to remotely access information stored in distant information centers. Additionally, users may get local data via devices connected to workstations even while offline. The present study aims to examine the concerns pertaining to the geographical positioning and connectivity challenges encountered by marine fishing facilities. Bagdasaryan, Bagdasaryan, Belyanin, Nikolaev, and Pavlyukova [11] proposed the integration of radio frequency identification with the BDS with the purpose of enabling simultaneous monitoring of the whole transportation and strategies process of seafood. This integration allows for the simultaneous collection of comprehensive production and transit data.

Use of IoT in fishing industry has the potential to significantly decrease expenses, enhance efficiency, and optimize various operations such as automated identification, location tracking, monitoring, and management. The challenge associated with the monitoring and transmission of marine data has been somewhat mitigated with the expansion of underwater Internet of Things (IoT), Long Range (LoRa) technology, optical telemetry, and sound telemetry. Nevertheless, the use of advanced technology for example global positioning systems, RFID and boat detection systems (BDS) has the potential to enable the comprehensive collection of marine fisheries data. Furthermore, enhancing the distribution chain governance system of the seafood field supplies essential data for assuring customer safety but also contributes to the accumulation of information used in the management of marine fisheries.

Big Data Applications

In the context of big data integration into marine fishery, it is essential to effectively arrange and store the acquired data, while also using data fusion and mining techniques for comprehensive analysis. Scientific visualization is used to provide reconstructed multidimensional data with pertinent knowledge to end-users. The comprehension, implementation, and decision-making regarding marine fisheries production processes would be facilitated by the use of this information. Big data on marine fisheries may be obtained from several sources for example Internet of Things, World Wide Web, expert databases, and fishery management systems. Accessing professional databases is a straightforward process, characterized by its efficiency and reliability, since these databases provide speedy and authoritative information retrieval. This technology may be used for the purpose of assessing and visually representing data pertaining to the quality of water in aquaculture systems, as well as elucidating the overall advantages associated with the aquaculture business.

The examination of water quality in aquaculture demonstrates the significance of a superior aquaculture environment in order to optimize productivity and uphold stringent requirements. The water quality is a crucial factor in the cultivation of aquatic organisms. Every species has a distinct ideal water quality that must be preserved to provide the most favorable conditions for growth and survival. The survival of an organism and the financial implications of product commercialization are contingent upon the caliber of water used in the production procedures. In the aquaculture industry, many water quality parameters are regularly assessed, including temperature, dissolved oxygen levels, pH, alkalinity, hardness, ammonia concentration, and nitrite levels. The monitoring of carbon dioxide levels, chlorides, and salinity is contingent upon the specific kind of farming system being used.

The levels of alkalinity and hardness exhibit a somewhat stable pattern, whereas the concentrations of dissolved oxygen and pH show diurnal fluctuations. The development of a consistent methodology for evaluating water quality that is suitable to the specific circumstance is of utmost importance. It is important to ascertain the critical thresholds for the species under cultivation and develop a contingency strategy to promptly address any potential issues that may occur. Certain species that are commonly grown have preferences for certain water quality conditions, as shown in **Table 1**.

Marine fish, in particular, exhibit sensitivity to fluctuations in water quality. This sensitivity arises due to the impact of variations in variables for example soluble oxygen and potential of Hydrogen, which hinder the proper development of fish. The analysis and foretelling of water standard data play a key role in the detection of biological anomalies, prevention of infections, and mitigation of related hazards in aquaculture. In order to evaluate the suitability of a culture pond for fish production in inland marine fishery, it is necessary to investigate several environmental aspects present inside the pond. The use of interconnected sensors inside a pond enables farmers to effectively observe and assess several parameters like salinity, oxygen levels, pH, oxidation reduction potential and temperature. The use of big data enables farmers to analyze the correlations among environmental variables in order to assess the suitability of a pond for white shrimp cultivation. In cases where the pond is deemed unsuitable, farmers may employ this data to enhance water quality by making targeted adjustments to specific parameters, should a drop occur. The offshore marine aquaculture setting is subject to continuous exposure to external factors, resulting in water quality metrics that often exhibit non-linear, dynamic, changing, and complex fluctuations.

Table 1. Typical preferences for water quality conditions

Species	**Nitrite (mg/L)**	**Ammonia (%)**	**Alkalinity (ml/L)**	**pH**	**Dissolved Oxygen (mg/L)**	**Temp ºF**
Tropical ornamentals	0-0.5	0-0.03	50-250	6-8	4-10	68-84
Tilapia	0-0.6	0-0.03	50-250	6-8	3-10	75-94
Trout/Salmon	0-0.6	0-0.03	50-250	6-8	5-12	45-68
Walleye/Perch	0-0.6	0-0.03	50-250	6-8	5-10	50-65
Hybrid striped bass	0-0.6	0-0.03	50-250	6-8	4-10	70-85
Carp/Catfish	0-0.6	0-0.03	50-250	6-8	3-10	65-80
Baitfish	0-0.6	0-0.03	50-250	6-8	4-10	60-75

The prevalence of incomplete or erroneous data is pervasive within the field of marine aquaculture. The task of upholding the dependability of statistical data in the field of marine aquaculture presents significant challenges, since even little alterations might compromise the outcomes of data analysis and predictive models. Relying only on big data analysis is inadequate in effectively managing the ever-changing marine environment and ensuring the preservation of data integrity. Therefore, in this context, the study and prediction of water quality indicators need the use of artificial neural networks (ANNs), deep learning, and other methodologies.

From a cost-benefit analysis standpoint, it is widely acknowledged that aquaculture farmers allocate substantial financial resources towards the procurement of antibiotics and chemicals for the purpose of mitigating disease outbreaks. These outbreaks have been shown to exhibit a significant association with the agricultural environment. The sustainable growth of marine aquaculture necessitates the use of big data analysis to assess loading capacity of the aquafarming environment and evaluate the associated costs. Currently, scholars have the ability to investigate the correlation between marine fishery and ecosystem components via the use of diverse models, indicators, and methodologies. To optimize the societal, economic, and environmental advantages derived from shellfish of bivalve aquaculture in Saldanha Bay, South Africa. Ferreira [12] employed the ecological model EcoWin. This model, renowned for its efficacy in aquaculture management, facilitated the integration of extensive ecological data and incorporation of pivotal ecological parameters.

Consequently, the researchers conducted an assessment of loading capacity of bivalve shellfish cultivation in Saldanha Bay. In addition, Dewi and Purwanta [13] proposed a method for effectively managing the expenditures associated with marine fisheries farming via the use of a sophisticated big data analytical algorithm. This approach has promise for significantly improving the overall efficiency and effectiveness in the management of these financial resources. The study's findings revealed that the technique exhibited enhanced stability in effectively controlling the financial aspects of marine fisheries production, as well as facilitating the implementation of cost management methods in this domain.

The organization, integration, and visualization of marine fisheries big data play a crucial role in facilitating the monitoring of the aquafarming environment and informing making decision applications. This is due to the dynamic, diverse, extensive characteristics and multidimensional of such data. The use of a big data platform, facilitated by the implementation of collection automation and visualization techniques using frameworks such as JPA and SpringBoot, has the potential to help experts and users in effectively managing the many water quality aspects in aquaculture. Significant progress has been made in the visualization of marine data as a consequence of developments in marine environment simulations and information representation. Consequently, there is a growing need for real-time capabilities in this process.

Su, Cao, Lv, Liu, and Li [14] developed a software application that utilizes a three-dimension rendering approach and the Delaunay approach to visually represent marine hydrological environmental data. This software is capable of displaying a dimensional area that originates from a single dimensional point in the ocean, using measured marine hydrographic data. The curriculum demonstrates proficiency in effectively and straightforwardly modeling the characteristics and dynamic ways of marine water ecological factors. In order to foster the sustainable growth of marine fisheries, the establishment of a reliable and comprehensive geographic database is necessary to facilitate effective future planning endeavors. Clawson et al. [15] conducted a comprehensive data collection and compilation effort to create a worldwide database of standardized marine aquaculture areas. The study focused on gathering extensive data on marine aquaculture fields from 73 nations that exceeded a production threshold of five hundred tons for a single marine fishery species in the year 2017. The researchers then conducted an analysis and cartographic representation of worldwide marine fishery by use of R version 4.0.2, and visually depicted the geographical distribution of marine aquaculture sites on a global scale.

Farmers possess the capacity to evaluate factors such as the quality of aquaculture water and the sustainability of aquaculture practices, utilizing huge data quantify and analyze marine aquaculture production. This capability enables the development of appropriate aquaculture strategies, ultimately leading to enhanced production efficiency. Marine ecosystems are well recognized for their inherent complexity, necessitating the careful examination of temporal and geographical dimensions, alongside socioeconomic considerations. Furthermore, several information systems in the sector of marine fishery have the capability to gather a significant amount of data on the environment of marine fishery. Moreover, the visual representation of this data may be beneficial to farmers, enabling them to effectively monitor the various aspects of the sector.

AI Applications

Through the use of IoT and the analysis of substantial datasets, it becomes feasible to amass a significant volume of information pertaining to marine fisheries. Nevertheless, AI has the potential to use the acquired data in order to provide evaluations, analyses, and conclusions that are not only more precise but also timelier. Information mining and learning machine are fundamental concepts in the field of AI, serving as theoretical foundations that allow computers to acquire knowledge from previous instances and provide precise forecasts, therefore replacing human capabilities. AI is now used in several applications within marine aquaculture, including classification, water quality forecasts and fish identification, feeding decision making, and fish biomass detection, among others. The quantity and intricacy of factors that might impact environmental circumstances and water quantity in marine fishery are expanding, concurrently with the rising need for environmental sensing tools. Therefore, the incorporation of AI models is essential for the purposes of forecasting and analysis.

The prioritization of automating the monitoring of water quality, fish stock, and other environmental elements has resulted to the advancement of AI-powered systems. These gadgets possess the capability to identify the existence of pathogenic microorganisms, alongside monitoring alterations in water temperature, salinity, and oxygen concentrations. AI-based systems may be used to monitor fish populations and follow their movements, hence aiding in the early detection and prevention of potential hazards. AI has the potential to enhance the management of aquaculture resources, as well as facilitate monitoring processes. AI-driven systems have the potential to be used for the purpose of predicting resource needs and offering suggestions for optimum utilization.

The use of AI may be helpful in the development of models aimed at evaluating the potential impact of climate change on aquaculture supply. Several aquaculture firms have already used AI-based solutions, and it is anticipated that the range of potential applications will continue to grow. AI has the potential to enhance the long-term sustainability of aquaculture operations via improved monitoring accuracy and resource management efficiency. In addition, this might potentially provide cost savings and enhance productivity for aquaculture operations. The use of AI within the realm of aquaculture management is anticipated to expand in tandem with the advancement of this technology. The utilization of AI has the capacity to profoundly revolutionize the aquaculture industry, enhancing its resilience over an extended period of time, contingent upon the allocation of enough financial resources towards its advancement.

The dependence on automated visual equipment for data collection is essential due to the distinctiveness and intricacy of marine species. The foundation of aquaculture management, scientific aquaculture, and density control is on the accurate identification and classification of fish. Extensive efforts have been dedicated by researchers to investigate various aspects related to fish, including the identification of fish species, determination of fish age, identification of fish illness, identification of fish sex, classification of fish species, and recognition of deceased fish. These research endeavors aim to offer valuable technical assistance in the realm of intelligent aquaculture production management. Simultaneously, due to the continuous movement of fish, the use of machine vision often leads to frequent occurrences of inaccurate identifications. The development of PelagiCam was motivated by the need to facilitate the collection of legitimate information for effect assessment of structures that float in marine environments and to mitigate potential biases in monitoring other fish species on aquaculture facilities. This device was designed to enable remote monitoring of the free biomass present on fish firms. In addition, the use of unmanned aerial vehicles (UAVs) for observation might potentially provide an effective means of facilitating fish locomotion in aquatic environments. This approach has promise in terms of gathering significant data for the surveillance of diverse fish species inside marine enclosures.

The tool in **Fig. 2** aims to maximize feeding rates while concurrently reducing wastage. Scientific aquaculture is well recognized for its stringent feeding requirements. Insufficient food availability may impede the aquaculture process, resulting in prolonged growth duration for fish since they are unable to attain their maximum growth potential. As a result, the expenses and risks involved with aquaculture would increase. Nevertheless, over use of feed has the potential to deteriorate the water quality in aquaculture systems and contribute to the process of eutrophication. This implies that it does not facilitate the enhancement of fish well-being or the stimulation of their development. The conventional approach to feeding fish in aquaculture, which relies on practical experience, has been replaced by a more informed and data-driven technique known as machine feeding. This new approach takes into account several parameters including fish behavior, feed allocation, and environmental circumstances such as temperature and seasonal variations when determining the feeding strategy. A innovative decision-support tool has been created to enhance feeding rates and reduce waste in the aquaculture of seabass and seabream, as seen in Fig. 2.

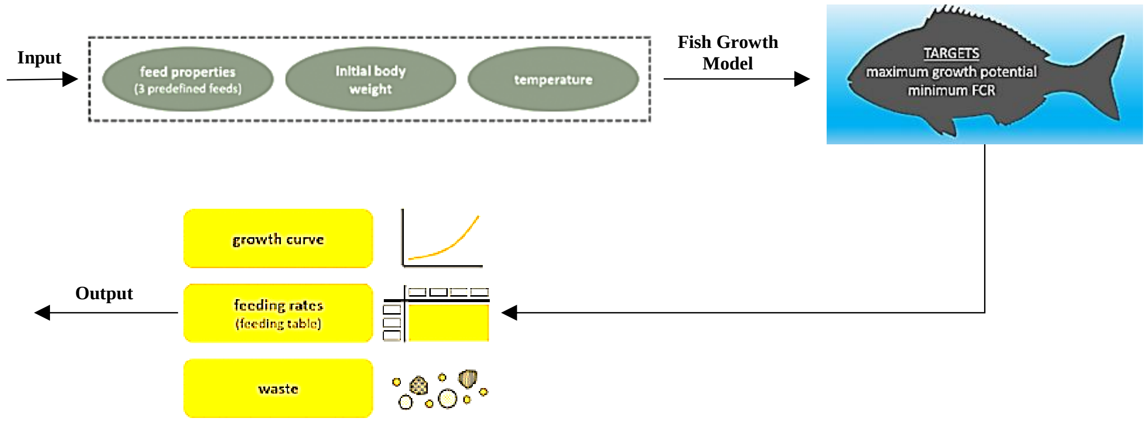

Fig 2. A Novel Tool Designed to Enhance Decision-Making Processes in The Field of Seabream and Seabass Aquaculture

The effective implementation of aquaculture operations, such as sorting, feeding, and yield estimation, is contingent upon the accurate detection and assessment of fish biomass. Hence, the use of a blend of machine sight and machine studying techniques for fish bio-fuel identification has the potential to improve detection effectiveness and provide more precise assessments of fish dimensions, mass, quantity, and other biological data. These techniques are characterized by their sustainability, lack of harm, and absence of interaction with fish. Furthermore, they are reasonably affordable in terms of cost. The culinary practice of fish preparation often included a sequential process carried out by a team of individuals. The aforementioned approach is characterized by its arduous and time-intensive nature, hence rendering it uncertain as to whether the fish in question will really possess a state of freshness. The use of machine learning was first employed by Zhao et al. [16] in the context of fish-cutting operations.

The acquisition of fish head images, using a charge-coupled device (CCD) camera, resulted in the production of two-dimensional Gaussian smoothed photos that exhibited enhanced edge detail. In order to ascertain the optimal locations for making incisions on the fish's head, a multiple regression technique was used, using the variables derived from the enhanced photographs. The use of artificial intelligence should be considered for the purpose of categorizing and segmenting fish, as well as assessing their freshness in relation to the previously indicated biomass. Sathiyamoorthy [17] suggested a fish categorized system that utilizes machine sight technology. The methodology used in this study involves the measurement of the fish's outlines, followed by the utilization of a SVM model to build a link between the fish body mass and its geometrical properties. This technique allows for a grading rate of three fish each second. In their research, Jayasundara et al. [18] used the big yellow croaker as a subject of investigation, whereby they developed a computerized grading line based on the fish's model. By leveraging the sensory index features, this methodology demonstrates the capability to categorize the quality of large yellow croakers by the extraction of the fish's physical attributes, followed by the development of a classifier, and then extracting the measure of freshness.

The expansion of AI in marine fisheries and aquaculture presents many challenges that must be addressed. One example of the potential benefits of optical technology in the field of fishing is its ability to improve the effectiveness of standard artificial fishing measuring methods. Additionally, the use of optical technology may contribute to the protection of fish bodies and enhance worker productivity. This is achieved via the use of optical technology for assessing biomass and recognizing fish. Fish photographs obtained using visual light imaging techniques need further processing due to the inherent limitations of underwater visibility and the complex environmental conditions. The present state of study continues to encounter several obstacles, including those pertaining to the overlapping bodies of fish, limited resolution, and the presence of a small, indistinct contour around the target fish. In order to fully harness the potential of smart data analysis and its succeeding forecasting of water quality, it is imperative to solve the issues associated with quick deterioration and expensive water quality sensors in saltwater. Although real-time performance and efficiency are already commendable, these obstacles hinder the technology from achieving optimal functionality. The use of intelligent feeding strategies has the potential to minimize feed wastage and enhance labor efficiency. However, the successful automation of feeding processes needs the establishment of robust models capable of monitoring fish growth, estimating biomass, and analyzing eating behaviors in the presence of environmental disturbances and sensor imprecisions.

Blockchain Applications

The blockchain is an emerging technological innovation that enables the implementation of distributed systems. The decentralization of control and the establishment of secure data and resource sharing among all nodes within the Internet of Things (IoT) network offer numerous potential advantages for marine fisheries. These advantages encompass enhanced transparency in funding for marine conservation, reduced plastic pollution, improved traceability of seafood, secure management of farming data, and the promotion of sustainable fisheries management.

According to Larissa and Parung [19], the application of the blockchain technology within the marine sector has promise in mitigating fraud, minimizing food waste, and reducing the occurrence of diseases associated with the consumption of inadequately cooked or expired goods. The COVID-19 pandemic's worldwide dissemination highlights the need of addressing supply chain issues, with blockchain technology poised to contribute significantly in this regard. As argued out by Kouhizadeh, Saberi, and Sarkis [20] digital technologies provide significant promise for addressing these challenges. However, the integration of novel digital technologies by stakeholders throughout agri-food systems has exhibited a somewhat sluggish pace of adoption. The existing data has significant untapped potential; yet, its accessibility is hindered due to its confinement inside isolated repositories. The economic challenges associated with unlocking the value of data are many. One such challenge is the hesitancy of stakeholders to participate in data initiatives owing to the uncertainty surrounding potential returns. Additionally, the private sector's capacity to meet the transparency requirements necessary for data use varies, thus complicating the process.

The comprehensive realization of the potential benefits arising from the automated collecting and analysis of data using ICT-based methods, as well as the adoption of precision technologies, can only be achieved by taking into account the whole of the agri-food system, including its various dynamics and responsiveness. In this manner, primary producers have the ability to adjust and respond to evolving market needs by integrating feedback and learning mechanisms into their operational processes. Consequently, this adaptation has an impact on the products supplied by feed suppliers. The use of digitalization in aquaculture operations enables the collection of various data, including production statistics, quantity, quality, and composition of primary products. This information may be utilized to inform the aims of processors in the immediate and medium term via feed-forward processes. Consequently, the use of waste reduction measures leads to enhanced system efficiency and expansion of the supply chain in relation to power consumption, waste management, and overall balanced. Moreover, this approach results in the production of valuable by-products. The integration of digital technologies, exemplified by the utilization of robots within the upcoming industry 5.0 framework that prioritizes human-centric solutions, is increasingly intertwined with human cognitive processes for the purpose of problem-solving. This trend can be traced back to the inception of Agriculture 4.0, which facilitated real-time optimization in the production of novel products and services.

Consumers possess valid grounds for exercising caution towards seafood due to its geographical origin. Hence, it is imperative to prioritize the protection of fishing grounds, since they serve as the foundational component of the whole supply chain. Ouariti and Bennouri [21] advanced a blockchain centered on fisheries system in order to safeguard the honesty of aquaculture information. The primary objective of the design segment is to ensure a good facility where fishermen may save a substantial amount of original data linked to marine farming. Smart contracts are designed to automate various activities within the fisheries industry in order to minimize the occurrence of human errors and reduce external intervention. Zhang, Liu, Jiong, Zhang, Li, and Chen [22] developed a novel traceability system for frozen aquatic products (BIOT-TS) by using blockchain and IoT technologies. This system aims to resolve the challenges associated with attributability management in the existing cold chain strategy procedures.

The issues included in this context are to inadequate safety performance, ineffective centralized information administration, and the easy manipulation of attributability information. Hang, Ullah, and Kim [23] proposed the application of the blockchain technology as a means to effectively monitor and manage the data collected across the commercial fish industry. The immutability of the digital ledger and the use of information saved on the chain as evidence of an issue's presence guarantee the utmost degree of quality and safety subsequent to problem identification. In order to enhance the management of the fishing distribution chain in a decentralized and reliable manner, many frameworks, applications, and schemes have been proposed. Examples include Shrimpchain, the Ethereum Blockchain, and Fishcoin. These solutions aim to provide transparency, traceability, security, privacy, and trustworthiness.

The studies and applications discussed above have significant implications for the supply chain, benefiting both upstream enterprises and downstream consumers. Suppliers may enhance their ability to meet consumers' expectations by implementing strategies such as improving the quality and safety standards of aquaculture practices, as well as establishing a streamlined method for tracing the origin of seafood products. The use of genuine seafood labels enables processing facilities to enhance the efficiency of their manufacturing and processing operations, reduce waste and expenditures, and enhance their control over seafood quality. Organizations that specialize in the integration of storage and transport services have the potential to enhance product delivery efficiency and optimize temporary inventory management and selection processes. Consumers have the ability to promptly express their concerns on seafood-related matters, therefore safeguarding their rights and interests. Nevertheless, according to Garrard and Fielke [24], after conducting interviews with many Australian prawn growers, it was contended that blockchain technology would not provide substantial benefits to the aquaculture industry. An problem arises in the prawn supply chain because participants lack a reliable means to assess the accuracy of information given by other parties. However, it is important to note that as now, there exists no infallible technique for the identification and monitoring of seafood. Hence, the storage of seafood data is detached from the supply chain. Ensuring a reliable and consistent supply of seafood, whether at the stage of production or processing, is a considerable challenge.

One primary challenge associated with the use of blockchain technology in marine fisheries is its dependence on external factors and technological infrastructure in order to achieve optimal effectiveness. In contrast to terrestrial Internet of Things

(IoT), the marine IoT exhibits a much lower quantity of nodes. Similar challenges will be encountered in the respective domains of blockchain and IoT technologies. One potential solution to address the problem at hand is optimizing the consensus mechanism by implementing measures such as decreasing the required number of nodes for the confirmation of consensus and weight ratio refining between common and critical knots. Hence, the enhancement of fishing data security will be significantly augmented if the challenges associated with Internet of Things in offshore sea fisheries can be effectively addressed. An additional challenge emerges due to the absence of a mechanism to authenticate the precision of data being appended to the blockchain. Despite the potential of digital ledger applications to collect information on marine aquaculture and track their journey from marine aquaculture to consumer purchasing, there is a lack of certainty on the authenticity of the commodities or technology used in this process. Consequently, several policy obstacles have to be surmounted prior to the widespread use of this technology.

IV.NEW DIGITAL TECHNOLOGICAL APPLICATION IN DEEP-SEA AQUACULTURE FACILITIES

The establishment of a continuous and reliable supply of fish products has been made feasible by the practice of marine fish farming, which utilizes the inherent characteristics of the deep-sea environment. Nevertheless, the cultivation of typical artificial culture in open water encounters challenges due to the presence of wind and waves.

According to Chen and Gao [25], Chinese patent applications in the field of aquaculture facilities have primarily concentrated on various aspects such as water quality monitoring, pond water level control, feed storage and feeding, fish detection technology, signal monitoring, communications technology, early warning and aquaculture water devices. The achievement of precise feeding in marine aquaculture is made possible through the integration of various technologies such as big data analysis, sensors, underwater robots and fish growth models. This combination enables early warning, prediction of water quality and real-time monitoring. Additionally, the automation of marine aquaculture is facilitated through the implementation of the vision of machine and other screening and grading technologies for finished fish. Let us examine the scenario of aquaculture vessels: In order to address the need for efficient and automated control of numerous aquaculture tanks on a deep marine aquaculture vessel with a capacity of 100,000 tons, Jiang, Wang, Lin, Weng, and Lu [26] developed a centralized automatic feeding system. This system allows for remote control, operates at predetermined and consistent speeds, and is capable of diagnosing faults.

The application of automatic feeding models has the potential to alleviate the impact of vessel rolling and pitching on the precision of weighing sensors, as well as the effect of aerial conveyance within pipelines of distinct lengths on the efficiency of output feed throughput and the rate of crushing. The suite of vessel control systems developed by Otieno and Shidavi [27] enables centralized monitoring and presentation of several aspects of aquaculture, including production management, dissolved levels of oxygen, water exchange and other related operations. The use of this technology on operating boats amounted to a vital decrease in staff workload, mitigated the risk of human error, and ensured a consistent increase in aquaculture production. In their study, Liu, Bi, Xu, and Zhao [28] aimed to enhance the efficiency of dynamic of an aquaculture load. This was achieved by the development of a bright aquaculture vessel equipped with several functionalities such as evaluation of the aquaculture load, processing, fish-sucking operation, refrigeration and aquaculture. In the process of building deep-sea cages, it is important to consider other factors such as the maintenance of the net coat, the effective capture of fish, and the ability to survive the challenging conditions of wind and waves.

Busaeri, Hiron, Andang, and Taufiqurrahman [29] undertake a comparative analysis of two contemporary fish feeder machines in order to provide a benchmark for the assessment of future designs. Two fish feeder systems were put inside a functional marine farming enterprise in order to guarantee their sustainability and effectiveness. Machine A utilizes solar energy to activate the gate at the designated time, while concurrently dispensing fish feed into an automated feeder. The equipment controlled by B's programmable logic controller (PLC) is at the forefront of technological advancements. The device has the capability to be programmed to operate on a 24-hour schedule and is directly powered by the electrical grid. The findings of this study indicate that both machines have a design that is unwieldy and are manufactured using materials that possess inadequate resistance to water and high temperatures. Hence, a recent study proposed an innovative design for an automatic feeding apparatus capable of accommodating a maximum load of 5 kg, and driven by a pair of direct current (DC) motors. The device is capable of projecting 500 grams of pellets to a height of 4.75 meters within a time frame of less than one minute.

Walsh, Nguyen, Strebel, Rhodes, and Davis [30] describe an architectural framework for an automated fish feeder that utilizes the Internet of Things (IoT) technology. The operation of the system is facilitated by an Arduino microcontroller, which establishes communication with the user through Wi-Fi connectivity and a graphical user interface (GUI) accessible via any Android smartphone. The feeding process may be seen by owners via the use of Android smartphones, allowing for the configuration of different variations of time based on the specific species of fish. The system comprises a dispatch container and a storage container. The system exhibits adaptability and was designed with the constraint of limited sea area in consideration. However, due to disadvantages in internet connectivity in some regions, especially in rural places, it may not always be feasible to use this approach in the context of offshore aquaculture in Indonesia.

Upon examining the practices used by other prominent global powers in the realm of marine aquaculture, it becomes evident that their operations exhibit a higher level of efficiency. This may be attributed to their prior engagement in comprehensive research and development endeavors pertaining to marine aquaculture equipment. According to a reliable source, Ocean Farm 1, recognized as the first offshore fish farm globally, has the capacity to yield around 1.5 million salmon annually. NORDLAKS, a Norwegian company, has successfully designed and implemented a fish farm called Havfarm 1, which has the appearance of a ship. This innovative fish farm utilizes a multi-network architecture to effectively house and manage a substantial quantity of salmon, amounting to 10,000 tons. The marine farm known as the "Jostein Albert" has the capacity to accommodate up to 10,000 tons of salmon simultaneously.

Its maximal density, which is equivalent to 25 kg per 1000 L of water (with a composition of 2.5% salmon and 97.5% water), is similar to that of other aquacultural farms. It is noteworthy that both products were conceived in Norway but manufactured in China. As a result, the construction of this facility in China was significantly identified as a vital milestone in the progression of offshore aquafarming inside the nation. The development of improved unified large-scale aquafarming facilities has mostly been led by strong nations in the sector of marine aqua-farming. However, there has also been progress in the development of smaller-scale stand-alone equipment, like net cleaners and feeders.

In the aquaculture business, there has been a notable increase in the automation of several phases in the processing line, such as quality checking, boning, slicing, sorting, and packaging. However, it is essential to guarantee hygienic conditions throughout the whole of the manufacturing process. The use of machine vision and convolutional neural networks (CNNs) has been employed for the autonomous cleaning of fish bodies during processing. This technology enables the identification of residual fish blood on the surface after the completion of the cleaning process by the robot. The use of a genetic algorithm (GA) may be advantageous for the autonomous fish body cleaning robot. When used in conjunction, they have the potential to facilitate the detection and elimination of undesirable fish bodily excretions throughout the production process. The aquaculture industry necessitates a sophisticated supply chain that heavily depends on computerized record-keeping systems to ensure traceability. The assurance of data integrity within a complicated supply chain cannot be solely reliant on machine learning techniques.

Thus, Parreño-Marchante, Alvarez-Melcon, Trebar, and Filippin [31] provided resources to enhance the quality of products of aquaculture via the use of barcodes that are traceable and data encrypted technologies inside the Internet of Things. The aquaculture link is regulated by Wang et al. [32] via the implementation of Hazard Analysis and Critical Control Points (HACCP), hence facilitating the establishment of a blockchain-based supply chain monitoring system that ensures the presence of verifiable audit trails. Currently, the focus of traceability initiatives in aquaculture products mostly lies in the latter phase of the supply chain, namely in the retail sector. The implementation of traceability and information-sharing systems will be established, with the government undertaking real-time monitoring of various data sets including environmental data, production data, processing data, logistics data, and sales data pertaining to nautical commodities. In pursuit of this objective, the use of blockchain technology serves a dual function. Firstly, it enables consumers to evaluate the equitable nature of aquaculture product pricing. Secondly, it ensures the integrity and genuineness of the associated data.

V.CONCLUSIONS AND FUTURE RESEARCH

This paper provides an in-depth analysis of the present condition of emerging digital technology. It explores the utilization of this initiative in instantaneous marine aquafarming by scholars in China and other regions. Additionally, it emphasizes the pivotal role and notable challenges associated with the implementation of this advancement in marine aquaculture context in China. The wireless connection and advancement of the Internet of Things (IoT) facilitates the uninterrupted determination of water quality in marine aquafarming. The obtained information is promptly evaluated in actual time and sent to terminal devices. Fisheries managers now have affordable access to a substantial amount of information pertaining to marine aquaculture, owing to the widespread availability of easily available online resources. The marine aquaculture environment has distinctive characteristics such as climate, topography, and biological diversity, which may potentially expose marine sensors to corrosion and hinder their efficacy in carrying out underwater communication tasks. Consequently, there is an ongoing accumulation of data pertaining to aquaculture, although with a significant portion being characterized by incompleteness or inaccuracy. Consequently, the enhancement of systems of machine learning and data mining necessitates addressing the inherent issue posed by missing data.

Significant advancements in technology are now being seen across several domains of aquaculture monitoring and management, which are centered on artificial intelligence. Technological improvements have facilitated the study of fish and shrimp by enabling stereoscopic observation, which allows for the examination of their size, shape, location, and activity. To facilitate video recording in environments with limited lighting or reduced visibility, "Sonar cameras" use a mechanism that transforms sound echoes into visual representations. The use of autonomous vehicles equipped with raising and lowering sensors presents a potential application for generating three-dimensional data profiles of water quality inside enclosed spaces and large containers. In spite of the more stable conditions found in indoor recirculating aquaculture systems (RAS) and underwater net-pen production settings, equipment put in open ponds may encounter further environmental challenges in the future. The reviewed articles present a thorough examination of the current and prospective use of artificial intelligence in the field of aquaculture. The scholars provided a description of the transition of several machines from human-operated to mechanized and automated, ultimately attaining sentience. Significantly, the scholars highlight the rapid advancement of autonomous robots in the net-pen farming sector, emphasizing their potential to enhance biosecurity via the use of unmanned machinery. Furthermore, apart from the collection and disposal of mortalities, uneaten feed, and accumulated waste, these machines possess the capability to effectively cleanse nets, a crucial aspect in maintaining sanitary conditions. Certain surgical procedures may now be deemed too costly; however, it is anticipated that this situation may undergo transformation in the coming years.

CRediT Author Statement
The author reviewed the results and approved the final version of the manuscript.

Data Availability
The datasets generated during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interests
The authors declare that they have no conflicts of interest regarding the publication of this paper.

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