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Application of Artificial intelligence in aquaculture

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Introduction

Artificial intelligence (Ai) is transforming aquaculture into a high-tech, sustainable industry by optimizing production and reducing costs through real-time monitoring. Artificial intelligence has become increasingly relevant in aquaculture research and production in recent years with start-ups and established companies developing new Ai-based applications for the industry. Artificial intelligence can be defined as the simulation of human intelligence in a machine that can learn, solve problems, reason, make decisions, understand language, and even recognize faces (Zhang and Lu, 2021). Artificial intelligence has become remarkable in the aquaculture industry because it delivers optimal and creative solutions in numerous application areas that can surpass the disadvantages of conventional techniques.

Aquaculture

Aquaculture has speedily emerged as a vital contributor to the global seafood supply, now accounting for more than half of the seafood consumed worldwide (Anderson et al., 2017). Aquaculture is relied on by an estimated 1 billion people, providing food, livelihoods, and revenues for billions worldwide (Ahmad et al., 2021). According to FAO 2024 global fisheries and aquaculture production surged to 223.2 million tonnes, with 185.4 million tonnes of aquatic animals and 37.8 million tonnes of algae. In 2022, global

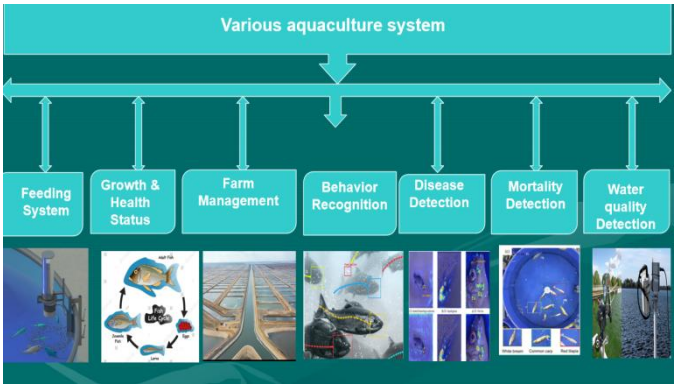

Fig. 1. Ai applications in aquaculture

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aquaculture production reached 130.9 million tonnes, valued at USD 312.8 billion, 59 percent of global fisheries and aquaculture production (FAO, 2024).

India is the second largest fish producing country in the world and accounts for 8 percent of the global production. The total fish production dSSSuring FY 2023-24 is estimated at 18.40 MMT with a contribution of 13.91 MMT from Inland sector and 4.49 MMT from Marine sector. The annual average growth rate in the Fisheries sector has been 6.30% over the last five years.

Applications of Artificial intelligence in the Aquaculture Industry

Artificial intelligence (Ai) is revolutionizing the aquaculture industry by introducing innovative solutions to enhance productivity, efficiency, and sustainability. Aquaculture is being significantly changed by Artificial intelligence, which is helping to make farming smarter, more resourceful, and more sustainable at different stages. Advanced monitoring technologies have revolutionized aquaculture management. Sensors and Internet of Things (IoT) devices continuously track essential parameters such as water quality, temperature, pH levels, and oxygen concentration (Prapti et al., 2022).

Water quality analysis

Using Artificial intelligence, real-time assessments and predictions of key water properties, such as temperature, pH, dissolved oxygen, and ammonia, are possible. The combination of sensors and machine learning enables the detection of anomalies earlier, allowing the system to send signals to the farm manager immediately. This approach reduces the risk of fish kills and promotes quality environments in aquatic systems (Bibri et al., 2024; Capetillo-Contreras et al., 2024).

Population monitoring and species identification

Using Artificial intelligence, cameras, and drones are used to track fish underwater to determine the species present. Classification systems use the physical characteristics and movements of fish, including their size, colour, and movements (Congdon et al., 2022; Alam et al., 2024). Automating this process helps to more accurately assess current stocks, reduce human errors, and protect endangered species (Gebremedhin et al., 2021; Ullah et al., 2024).

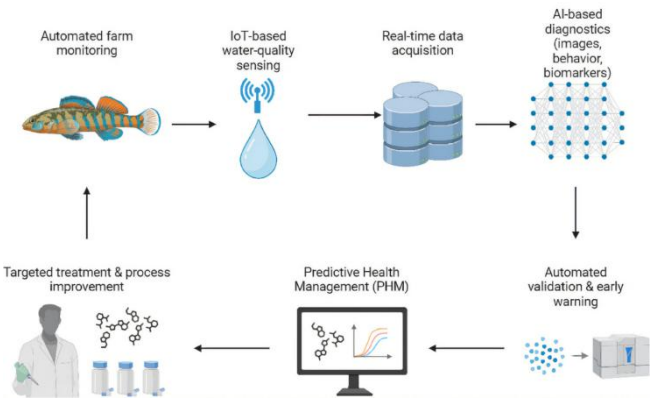

Fig. 2. Benefits of AI in fish health management (Mustafa et. al, 2025)

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Disease detection and management

Tracing diseases early is crucial in aquaculture. Artificial intelligence models look at images and movement patterns to detect health problems early and help stop their spread. Convolutional Neural Networks (CNNs) have emerged as a highly accurate, automated, and non-invasive tool in modern aquaculture to identify visual signs of fish diseases from images. These advanced systems can analyse external symptoms—such as bacterial red disease, gill issues, and white spots—often surpassing traditional, time-consuming manual inspection methods.

Optimization of production processes

Artificial intelligence utilizes models to determine the optimal times to harvest and feed fish based on genetic, environmental, and nutritional history information. Thanks to these models, feeding systems use less food, waste is reduced, and the products produced are of higher quality. Artificial intelligence utilizes various information, including temperature, stocking density, feed composition, and lighting cycles, to advise users on the optimal daily actions for achieving better biomass results.

Supply chain and logistics optimization

Artificial intelligence assists in supply chain tasks by providing more accurate demand forecasting, optimizing routes, and managing cold zones in logistics. Using machine learning, past sales, and seasonal trends are examined to predict future sales, which helps the business avoid excessive stock losses (Elufioye et al., 2024; Galaz et al., 2021. In addition, using Artificial intelligence and blockchain makes it possible to trace the entire process the fish undergoes, from where it is farmed to when it is sold.

Sustainability and adaptation to climate change

Artificial intelligence is helping to protect the environment by identifying the effects of climate change on water. It forecasts changes in water temperature, salt levels, and acidity and suggests when and how fish will migrate and reproduce. Applying these findings facilitates the design of adaptive strategies and reduces the CO2 footprint from aquaculture, thereby helping aquaculture align with global climate goals (Goodwin et al., 2022; Mugwanya et al., 2022; Parab et al., 2023; Ditria et al., 2022; Fu et al., 2024).

Industry-specific challenges and opportunities

Although there are benefits, the use of Artificial intelligence in aquaculture is limited by high costs, inadequate facilities, and insufficient digital training for those involved. A challenge in adoption is that hardware systems do not use consistent data formats for

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integration. A significant number of aquaculture businesses lack the expertise to handle the results generated by Artificial intelligence or operate sophisticated computer systems. Due to these challenges, interfaces and training courses should be designed in a manner that allows everyone to follow them. The use of low-cost sensors and cloud-based analytics is making it easier for more people to utilize Artificial intelligence.

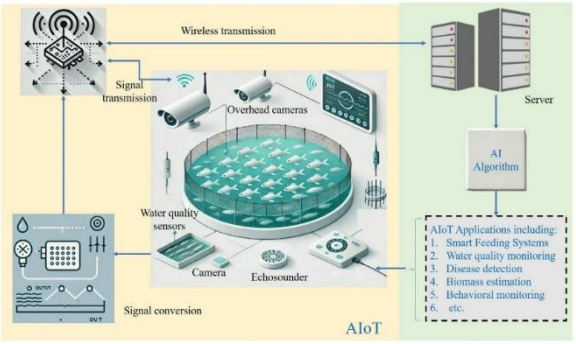

Fig. 3. The artificial intelligence of things and its aquaculture applications (Yo-Ping Huang, 2025)

Data-driven Decision Making

In modern aquaculture systems, sensors, cameras, and other monitoring devices are deployed to collect real-time data on a wide range of parameters. These include water quality parameters such as temperature, pH levels, dissolved oxygen, salinity, and ammonia levels are continuously monitored to ensure optimal living conditions for the aquatic species (Ubina and Cheng 2022). AI plays a crucial role in optimizing aquaculture operations by determining the ideal feeding times and quantities based on fish behaviour and growth data, which reduces feed waste and boosts growth rates (Li et al., 2020).

Improving Feed Efficiency

Ai significantly contributes to optimizing feed efficiency in aquaculture by analysing data on fish growth rates, feeding patterns, and nutritional requirements. Smart feeding systems powered by AI adjust feed portions and schedules to ensure that each fish receives the optimal amount of feed. This not only improves growth rates but also reduces waste and minimizes environmental impact.

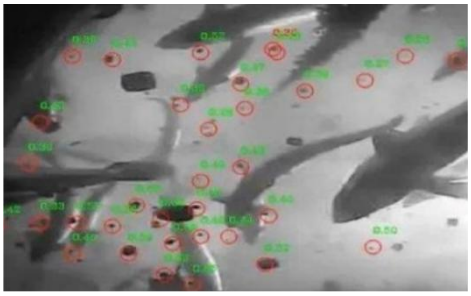

Fig. 4. Uneaten feed detected by AKVA observe system (Minapoli, 2021).

Sustainable Feed Formulation

Ai optimizes feed recipes to meet the specific needs of fish species while minimizing environmental impacts. This approach contributes to a more sustainable and efficient aquaculture industry. Ai enables the creation of customized feed formulations based on the precise nutritional requirements of different fish species and growth stages (Mandal and Ghosh 2024). Different fish species

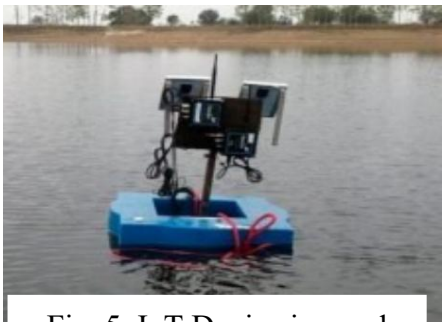

Fig. 5. IoT Device in pond (Niswar et al., 2018).

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have varying nutritional needs, and Ai algorithms analyze data on species-specific requirements, such as protein, lipid, and carbohydrate levels, to develop feeds that meet these needs effectively. As fish progress through different growth stages, their nutritional requirements change. Ai systems adjust feed formulations to cater to these evolving needs, ensuring optimal growth and health at each stage of development.

Monitoring and Control Systems

Ai-based monitoring systems are transforming aquaculture by enabling continuous and precise surveillance of aquaculture facilities. These advanced systems leverage Ai algorithms and various technologies, such as drones and automated control systems, to enhance the health and productivity of aquatic species while ensuring optimal environmental conditions. Ai-powered monitoring systems utilize a range of devices to continuously observe and analyze the conditions within aquaculture facilities.

Advantages and limitations of Artificial intelligence applications

Artificial intelligence enables high accuracy and instant analysis, reducing potential human errors. Artificial intelligence can enable businesses to make faster decisions and improve resource utilization (Zhang and Lu, 2021; Gupta et al., 2021). Although deep learning models can predict results with great accuracy, their complex results often cause users to doubt the decisions. Now, regulatory agencies are demanding greater transparency from companies, particularly in Artificial intelligence decisions involving animals or environmental safety.

Future research directions

Future research in Ai-aided aquaculture should focus on explainable Ai (XAi), federated learning for data privacy, the integration of multimodal datasets (e.g., sensor, image, genomic), and the development of hybrid models. Additionally, affordability, accessibility, and user-friendly interfaces should be prioritized to facilitate adoption among smallholder farmers and in developing regions (Ullah et al., 2024; Rashid and Kausik, 2024). Moreover, interdisciplinary collaboration is crucial for bridging the gaps between aquaculture experts, data scientists, and policymakers. Research into the ethical implications, data ownership, and ecological impact assessments will become increasingly important as Artificial intelligence systems assume more autonomous roles in the industry. Pilot projects and case studies documenting real-world deployments of Artificial intelligence systems in aquaculture, particularly in diverse geographical contexts, are also necessary to inform best practices, policy, and investment decisions in the sector. While many future directions are proposed, a lack of interdisciplinary collaboration often hinders practical innovation and field application.

Conclusion

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Artificial intelligence has emerged as a transformative force in the aquaculture industry, offering solutions to longstanding challenges and paving the way for a more sustainable and efficient future. Through advancements in machine learning, computer vision, and predictive analytics, Ai enables precise monitoring, optimal resource management, and proactive decision-making, significantly enhancing productivity and sustainability in aquaculture operations. The use of artificial intelligence in the aquaculture industry relates to the economic impact, environmental gains, and conservation. Artificial intelligence is used in aquaculture to track fish, diagnose fish diseases, examine water quality, enhance production, and efficiently utilize resources and sustainability. Underwater captured images are analysed by artificial intelligence to determine the type of fish and population growth. Artificial intelligence can be used in the early detection of diseases affecting fish and aquatic plants, helping to minimize potential production losses and improve the overall health of aquatic organisms.

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