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Technological innovations in aquaculture

with special reference to intelligent aquaculture

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Technological interventions in aquaculture have led to many fold increase in the aquaculture production of finfish and shellfish in several countries across the world. These technologies cover the fields of fish genetics, nutrition, health management, aquaculture system designs as well as the harvesting and marketing of the produce. However, a new intervention includes the application of artificial intelligence in aquaculture. This includes the collection of data on fish and the environment, transmitting it to the control centre followed by the data processing and decision making stages using cloud platform and internet of things. This technological innovation has paved the way forward for the development of an automated aquaculture system, thereby transforming this industry to the next level of production and sustainability.

Keywords: Aquaculture, Artificial intelligence, Big data, Internet of things

Fish is an important source of protein, and global aquaculture production has increased considerably over the last 50 years, supplying protein to the growing population. The global aquaculture production was 94.4 MT in 2022, of which marine aquaculture produced 35.3 MT, and inland aquaculture contributed approximately 59.1 MT (FAO, 2024). In India, the aquaculture production is estimated to be 10.23 MT, accounting for 10.8% of the world's aquaculture production (FAO, 2024). Traditional production systems have provided a foundation for the aquaculture industry's growth, offering a range of benefits from sustainability and resource efficiency to cultural preservation and economic development. However, the horizontal expansion of traditional farming exerts pressure on land-use and other natural resources. As technologies continue to evolve, aquaculture has gradually changed from traditional labour-oriented farming to automated systems, resulting in high production efficiency, high-end product quality, and sustainability. The certification programs in aquaculture towards sustainability have served as a major thrust for these innovations.

Technological interventions

The technological interventions that contributed to the growth of aquaculture at the present level include genetic improvement of farmed species through selective breeding and genetic manipulations, advancements in control of viral and parasitic diseases, advances in aquaculture diets, adoption of new species, designing better aquaculture production systems including tank-based recirculating systems. The prediction and assessment of the impact of aquaculture have also contributed largely to the development of aquaculture sector towards sustainability. The decreasing labour availability and increasing demand for fish, call for an innovative model of intelligent aquaculture (IA).

Artificial intelligence (AI) in aquaculture

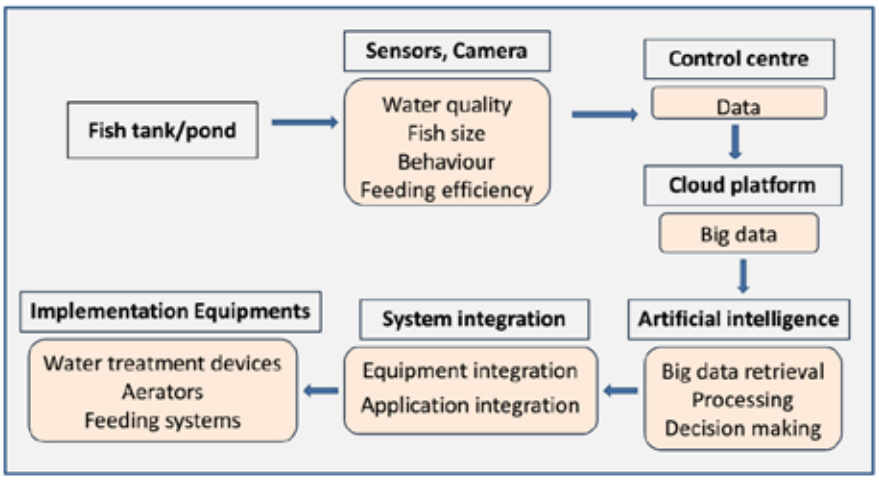
An intelligent production model employs sensor technology, Internet of Things (IoT), intelligent information processing model, equipment digitization, precision control and edge computing, big data and cloud platforms, as well as system integration. New technologies, from cloud computing to artificial intelligence, are not only revolutionizing communication, engagement, and transactions but also significantly transforming industries and driving their growth and development. IoT forms the basis of intelligent aquaculture. Both big data and artificial intelligence are crucial for intelligent operation of IoT, which is essential for precise aquaculture control. For a growing industry like aquaculture, these innovations can significantly impact its evolution.

How it works?

Intelligent aquaculture involves collecting information through various sensors, cameras, and other equipments for digital image acquirement; transmitting the data (information on growth, behaviour, and water quality parameters) to the control center; the processing of data and decision-making are executed on the data in cloud platform using AI. The response is sent to implementation equipment, enabling intelligent and automated processes to achieve sustainable intelligent aquaculture. Intelligent aquaculture could be employed in monitoring the water quality parameters, fish behaviour, and the prevailing climatic conditions to control water treatment and feeding protocols. An automatic fish divider can be used for counting, fishing, classification, and grading of animals.

Features of intelligent aquaculture system

- ***Sensor technology*:** A sensor is a device that detects physical input from its environment and transforms it into data that can be understood by humans or machines. Temperature sensor, dissolved oxygen sensor, humidity sensor, light sensor and CO_2 sensor can be utilized in aquaculture farms. There is an increasing demand for sensors which are reliable for their high accuracy, performance, multiple functions, portability, economic, and a long life. Integration of sensors with new technologies like nanotechnology, ultrasound, laser, microwave, biosensing, optical fiber, and integration with IoT promise a new era in aquaculture development globally. Computer vision is another area of sensor technology that reduces the human element with enhanced monitoring and increases yields and profit.
- ***IoT technology*:** IoT connects electronic devices like personal gadgets, home appliances, office machines, and industrial equipment to the internet. Intelligent equipment can automate aquaculture processes, thereby reducing the labour. However, complete unmanned operation in aquaculture is challenging due to its high-risk nature. Interconnected sensors, computers, tanks, and other equipment communicate and share critical data with a central command station, offering operators a comprehensive view of the entire fish farm.
- ***Intelligent information processing model*:** These models help to assess and envisage the data of individual fish. Recent advancements have provided satisfactory solutions for the identification of fish, its behavioural pattern, counting, sorting, as well as the assessment of size and quality. However, challenges remain such as models may not explain the underlying biological mechanisms, and extrapolating data afar the scope of the particular model can lead to large errors as the observed organisms (fishes) are sensitive and often in motion in uncontrollable environments.
- ***Big data and cloud computing*:** Big data is of high volume, and it requires technological and analytical tools to extract value. Cloud computing provides convenient, limitless, on-demand access to shared computing resources. AI systems rely on large datasets to generate meaningful insights for industries. Combining big data technology with cloud platforms addresses these challenges, particularly in data collection and storage for aquaculture. Various technologies, such as IoT sensors, industrial management systems, and traditional databases, gather data from production, processing, and sales. Storage and computing technologies manage aquaculture data, integrating heterogeneous sources before storing them in target databases for further analysis.
- ***System integration*:** This is a technology crucial for developing intelligent aquaculture. It works by linking the aquaculture equipments and the subsystems to create a unified IA system. The integration of equipment and application system forms the two types of system integration. In equipment system, integration combines various aquaculture equipment types and quantities, including aeration equipments, sensors, feeding systems, and mostly the water treatment devices. These are connected to an IoT platform for effective scrutinization and management, requiring standardized parameter designs for seamless integration. Application system integration integrates subsystems and expert knowledge bases within the IA framework, such as data processing systems and fish disease knowledge bases.



Intelligent aquaculture model

This integration resolves issues like data retrieval and communication between systems. Cloud computing offers an effective solution for integrating application systems.

Limitations of intelligent aquaculture model

However, there are some limiting factors in this field, such as high capital costs and high energy requirements, which need to be attended to advance the technology. AI technologies require trained manpower for their effective implementation in aquaculture. Lack of confidence in farmers regarding the reliability of the AI technologies is a major area to be addressed as they are the stakeholders to implement the technologies in field. The existing infrastructure is mostly unsuitable to adopt AI based technologies in aquaculture as the transformation from traditional to a new internet based system requires more efforts. Further, like any other sector, sustainable development requires that traditional aquaculture incorporate intelligent technology to realize automatic aquaculture production.

Future prospects of AI in aquaculture

The future prospects of AI in aquaculture are promising and transformative. The integration of AI in aquaculture holds the prospective to reform the industry by convalescing the efficacy, sustainability, and profitability while also addressing challenges such as disease management and resource optimization. AI systems can offer tailored recommendations for individual farms based on specific conditions and goals. It can also aid in achieving better management of the hatchery technologies such as breeding, seed production and larval rearing. As AI technology continues to advance, its applications in aquaculture are likely to expand, leading to even greater innovations and improvements in the sector.

In India, under *Pradhan Mantri Matsya Sampada Yojana* (PMMSY), Government has initiated schemes for the adoption of modern technologies such as AI, to boost aquaculture productivity towards attaining blue revolution. A digital platform, SISTA360 Platform was launched during 2023, to integrate AI for providing real-time data analytics. This aids in monitoring and managing aquaculture practices more effectively to develop this sector. A Digital Agriculture Mission was implemented to execute digital agriculture projects with the aim of knowledge sharing to empower the farmers. Similar platform could be given more emphasis in realizing sustainable aquaculture.

CONCLUSION

While AI presents significant opportunities for future development in aquaculture, achieving sustainable practices requires additional efforts. These include implementing renewable energy sources to conserve energy and enhancing water efficiency through advanced systems like recirculatory aquaculture systems, biofloc technology, and aquaponics. Entrepreneurs must prioritize integrating traditional aquaculture with intelligent technologies to automate production processes effectively. Moreover, effective policies and organizational frameworks play crucial roles in promoting the sustainable evolution of intelligent aquaculture models.

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