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REVOLUTIONIZING AQUACULTURE THROUGH ARTIFICIAL INTELLIGENCE

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This article delves into the transformative impact of Artificial Intelligence (AI) on aquaculture, emphasizing global food security and sustainability. Smart aquaculture, driven by AI, addresses challenges through applications such as automated feeding, remote monitoring, and disease prevention. Emerging technologies like drones and blockchain further amplify industry efficiency. Despite existing limitations, future prospects centre on data sharing, adaptability, affordability, and ethical considerations. As AI becomes integral to aquaculture, it propels the industry toward a more sustainable and resilient future.

The imperative to achieve global food security, as meticulously outlined by Jorgensen and Costanza (2016), is underscored by the United Nations Sustainable Development Goal (SDG) 2. Food security, meticulously defined by the Food and Agriculture Organization (FAO, 2008), emphasizes the dire need for both physical and economic access to sufficient, safe, and nutritious food. Despite the collective efforts invested in addressing this challenge, a staggering 690 million people worldwide continue to endure the harsh reality of hunger (FAO, 2020).

With the global population projected to burgeon to 9.7 billion by 2050 (Gerland *et al.*, 2014), the demand for food intensifies, exerting significant pressure on traditional food production systems (Lewis and Nocera, 2006; Chen *et al.*, 2016). Amid this burgeoning demand, aquaculture emerges as a critical protagonist, playing a pivotal role in providing high-quality proteins (Nash, 2010; Gui *et al*., 2018).

Experiencing unprecedented growth, aquaculture surpassed wild fisheries production in the pivotal year of 2013 (FAO, 2020). The advent of the Fourth Industrial Revolution (4IR) introduces transformative technologies, with Artificial Intelligence (AI) positioned strategically to address inherent structural weaknesses in global food systems (Liao *et al.*, 2018).

Aquaculture, intricately involving the cultivation of aquatic animals and plants for commercial purposes, confronts traditional challenges that not only limit production but also necessitate significant labour inputs. Among these challenges are intricacies related to water quality management, disease detection, and precise monitoring of factors such as leftover food and fish count.

Smart aquaculture signifies a profound paradigm shift, strategically leveraging intelligent and automated systems to surmount age-old challenges. This transformative trend harmonizes seamlessly with sustainable development goals, integrating modern technology to enhance efficiency while concurrently minimizing environmental impact. The transition to smart aquaculture is not merely a necessity; it represents a transformative leap towards a more sustainable and resilient food production system.

In the past 50 years, applications of science and the introduction of new technologies have propelled the rapid development of aquaculture. Improved reproductive technologies, live feeds, selective breeding, and advancements in disease management have significantly contributed to the growth of the aquaculture industry (Burnell & Allan, 2009; Weber & Lee, 2014).

Artificial intelligence refers to the simulation of human intelligence through machines programmed to think like humans and mimic their actions (Russell and Norvig, 2016). The goals of AI include learning, reasoning, and perception (Copeland and Proudfoot, 2004). It encompasses machines exhibiting characters associated with a human mind, such as learning, problem-solving, rationalizing, and taking actions to achieve specific goals.

The advancement of AI techniques offers promising solutions for optimizing fish farming practices and ensuring sustainable aquaculture. By leveraging AI, fish farmers gain valuable insights into fish growth patterns, feeding behaviour, and environmental factors affecting fish health.

Applications of AI in Aquaculture:

1. Automated Feeding Systems:

Transformative Impact:

The AI-driven automated feeding systems, intelligently adapt feeding schedules based on historical data. Machine learning algorithms process information on fish behaviour, growth rates, and environmental parameters, minimizing feed wastage and ensuring optimal nutrition. This promotes healthier and more sustainable growth, contributing significantly to precision farming tailored to specific aquaculture sites. (Li *et al.*, 2019; Wang *et al.*, 2021).

2. Remote Monitoring and Maintenance:

Paradigm Shift:

Integration of AI into remote monitoring systems, represents a transformative leap in aquaculture management. Sensors and cameras continuously collect data on water quality, temperature, and equipment status, processed in real-time by AI algorithms. This allows farmers to remotely detect anomalies, facilitating prompt interventions and enhancing overall operational efficiency. (*Sun et al.*, 2018; Garcia *et al.*, 2020)

3. Growth Statistics Analysis:

Data-Driven Precision:

AI's pivotal role in growth statistics analysis, involves dynamic monitoring and interpretation of diverse metrics related to aquatic organisms. Machine learning models predict growth trajectories based on factors like water quality, feeding patterns, and genetic influences. This data-driven precision fosters personalized aquaculture practices, enhancing overall productivity and economic viability in a sustainable manner. (Xu *et al.*, 2019; Liang *et al.*, 2020)

4. Temperature Optimization:

Stable Thermal Environment:

AI systems optimizing water temperature, analyse historical data and seasonal variations. Tailored to the specific requirements of aquatic species, these systems ensure a stable and favourable thermal environment, critical for metabolic processes, growth rates, and overall health. This AI-driven temperature optimization minimizes stress and maximizes productivity, contributing to the creation of ideal conditions for aquaculture. (Nguyen *et al.*, 2017; Zhang *et al.*, 2021)

5. Water Quality Management:

Proactive Approach:

AI-powered sensors for water quality management, continuously monitor parameters like oxygen levels, pH, and salinity. Upon detecting deviations from optimal conditions, AI systems trigger automated responses, such as adjusting aeration or activating water treatment processes. This proactive approach prevents stress and diseases among aquatic organisms, ensuring a consistently healthy environment and promoting sustainable production practices. (Wu *et al.*, 2018; Chen *et al.*, 2019)

6. Consistent Aeration:

Optimized Oxygen Levels:

AI ensuring consistent aeration, dynamically adjusts aeration systems based on real-time data. Optimal oxygen levels are vital for the survival and growth of aquatic organisms. AI algorithms consider factors such as stocking density, water temperature, and oxygen consumption rates to determine precise aeration requirements. This automation not only improves the well-being of cultured species but also optimizes energy consumption, making aquaculture operations more resource-efficient. (Guo *et al.*, 2016; Kim *et al.*, 2020).

7. Smart Sensors Implementation:

Transformative Environmental Monitoring:

The integration of smart sensors into aquaculture systems, signifies a transformative leap in environmental monitoring. Equipped with advanced AI algorithms, these sensors precisely measure critical parameters such as oxygen levels, salinity, and temperature. The real-time data streams generated provide aqua culturists with a detailed understanding of the aquatic environment, enabling informed decision-making in real time. The AI-driven analysis goes beyond basic monitoring, offering insights into dynamic changes and potential stressors, fostering a resilient and sustainable aquaculture ecosystem. (Chen *et al.*, 2020; Svendsen *et al.*, 2020)

8. Disease Detection and Prevention:

Proactive Disease Management:

AI's role in disease management, transcends traditional diagnostic approaches. Through sophisticated image processing and machine learning techniques, AI systems identify subtle patterns and deviations in fish behaviour and appearance. This proactive approach enables the aqua culturist to detect potential issues before they escalate into full-scale outbreaks, contributing significantly to disease prevention. Safeguarding economic viability and promoting ecological sustainability, AI minimizes the need for antibiotics or other treatments. (Hitesh *et al.*,2018; Kelly and Renukdas, 2020)

9. Biomass Detection of Fish:

Precision in Population Assessment:

The application of AI and machine vision in biomass detection, revolutionizes the precision and depth of fish population assessment. Machine vision algorithms accurately gauge fish size, weight, and other crucial biological metrics, providing a non-invasive and ethical means of assessing biomass. Utilizing this data, aqua culturists can optimize feeding regimes, monitor growth trajectories, and tailor management practices for specific species. The granular insights provided by AI-powered biomass detection contribute to more efficient and sustainable aquaculture practices. (Su *et al.*, 2020; Zhao *et al.*, 2021).

10. Predictive Analytics and Big Data:

Anticipatory Management:

The fusion of AI, predictive analytics, and big data, propels aquaculture into anticipatory management. AI algorithms, fuelled by extensive datasets and environmental variables, forecast future outcomes and trends. This forward-looking approach enables aqua culturists to proactively adapt to changing conditions, optimizing resource allocation, refining stocking densities, and implementing strategic interventions. This data-driven decision-making enhances operational efficiency and positions aquaculture systems to thrive in a dynamic and evolving industry landscape. (Mair *et al.*,1997; Chen *et al.*, 2020)

Emerging Technologies

1.AI with Drones:

Cost-Effective Monitoring:

AI-equipped drones, leveraging cloud computing, offer cost-effective monitoring of aquaculture sites (Chen *et al.*, 2020). They play a crucial role in checking for holes and damages in cages, collecting valuable data, and providing insights for improving overall operational efficiency. These aerial systems, when coupled with AI, not only enhance monitoring capabilities but also contribute to precision farming practices in aquaculture. Drones, armed with sensors, efficiently gather and analyze a range of water quality data, encompassing turbidity, temperature, dissolved oxygen, and even fish heart rates—all conveniently accessible via a smartphone connected to the drone Drones play a crucial role in aquaculture by gathering unique and hard-to-obtain data, contributing to the creation of algorithms that enhance technology and boost the efficiency of aquaculture production. Drones can detect early signs of issues, enabling prompt intervention and minimizing the environmental impact of aquaculture operations. This integration exemplifies the intersection of cutting-edge technology and environmental stewardship in smart aquaculture practices.

2.**AI with Robotics for Labor-Intensive Tasks:**

Automating Routine Operations:

The integration of AI-driven robotics, signifies a paradigm shift in automating labour-intensive facets of aquaculture management. Equipped with AI algorithms, these robotic systems undertake tasks such as feeding, pond cleaning, and fish behaviour monitoring. Precision and adaptability enhance operational efficiency, reduce labour costs, and minimize human intervention in sensitive aquaculture ecosystems. Deploying these robotic solutions for precise and consistent execution of routine tasks allows human operators to focus on strategic decision-making and higher-level management. This transformative application of AI contributes to the sustainability and scalability of aquaculture operations. (Osaka *et al.*, 2010; Antonucci and Costa, 2020)

3. **Augmented Reality (AR) and Virtual Reality (VR):**

Interactive Simulation and Monitoring:

The integration of AR and VR technologies, introduces a multi-faceted dimension to aquaculture operations. Beyond visualizing data, these immersive technologies actively contribute to real-time monitoring and issue detection. AR and VR enable visualization of fish behaviour, detection of anomalies in nets, and simulation of environmental scenarios. These technologies find applications in education and training, offering realistic and interactive simulations for aquaculture practitioners. The synergy of AI with AR and VR enhances decision-making, improves operational efficiency, and cultivates a culture of continuous learning within the aquaculture industry. (Xi *et al.*, 2019; Jung ,2019).

4. **AI with smart phone**: In fish farming, using AI with smartphones is changing how we get and understand data. Smartphones, with AI, can quickly tell us about water quality, temperature, and fish health. This helps farmers act fast and run things better. Also, AI on phones helps spot and handle fish diseases early, so farmers can manage things well without using too many antibiotics.

4. **Blockchain for Traceability:**

Revolutionizing Supply Chain Integrity:

The implementation of blockchain technology, revolutionizes traceability and transparency in the aquaculture supply chain. As a decentralized and tamper-proof ledger, blockchain ensures secure and immutable records of transactions. This technology enables end-to-end traceability of aquatic products, addressing concerns related to food safety, fraud prevention, and supply chain integrity. Establishing a verifiable and transparent system, blockchain builds consumer confidence and facilitates accountability throughout the aquaculture supply chain. This application fosters a culture of responsible and sustainable practices within the aquaculture industry, extending beyond mere traceability. (Drescher ,2017; Altoukhov ,2020)

Limitations of AI in Aquaculture

The effectiveness of AI systems in aquaculture is contingent on the reliability of data and sensors used (Altoukhov, 2020). Inaccurate or incomplete data can lead to erroneous outcomes.AI may struggle to handle unexpected scenarios requiring human intuition, judgment, or adaptability, such as sudden environmental changes or disease outbreaks (FAO, 2020).The adoption of AI in aquaculture may face barriers, particularly for small-scale farmers, due to high costs associated with components, installation, and maintenance (Altoukhov, 2020).The integration of AI raises ethical concerns, including the impact on human labour, data ownership, privacy, and potential risks of AI malfunction or misuse (FAO, 2020).

Future Prospects and Technologies in AI-driven Aquaculture

Future developments should focus on establishing reliable data-sharing mechanisms among aquaculture stakeholders, enabling improved AI algorithms (Altoukhov, 2020).Research and innovation should target the development of AI systems capable of adapting to unforeseen challenges, enhancing the resilience of aquaculture operations (FAO, 2020).Efforts should be directed towards making AI technology more accessible and affordable for a broader range of aquaculture producers, ensuring widespread adoption (Altoukhov, 2020).Future AI implementations should prioritize ethical considerations, addressing concerns related to labour impact, data privacy, and social implications (FAO, 2020).

Conclusion

The integration of Artificial Intelligence into aquaculture practices heralds a new era of efficiency, sustainability, and innovation. From optimizing feeding schedules to proactive disease management and anticipatory analytics, AI-driven solutions empower aqua culturists to navigate the challenges of a growing population and evolving environmental dynamics. As drones, robotics, AR, VR, and blockchain converge with AI, the future of smart aquaculture holds promise for a resilient, eco-friendly, and productive industry. To ensure the responsible implementation of AI in aquaculture, addressing challenges such as reliable data, affordability, and ethical considerations remains imperative. As the aquaculture sector embraces these technological advancements, the journey towards global food security and sustainable development takes a significant leap forward.

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