Evolving Towards the Future: Internet of Things (IoT)-Based Precision Aquaculture System

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Abstract— − *Humans and technology have been developing continuously from the prehistoric period to the present and it has evolved into a key component for assisting with daily tasks in today's world of technology. As an approach to fulfilling nutritional needs and a variety of other necessities, civilizations established agriculture millennia ago.*

Aquaculture is yet another important concept in agriculture, where farmers cultivate fish in ponds and tanks for human consumption. Aquaculture, or fish farming, has long been recognized for its significance by agriculture, which has its roots in satisfying human needs and it is only one of the many industries that are undergoing advancements driven by modern technologies. As technology continues to evolve, IoT-based aquaculture systems are gradually replacing traditional fish farming techniques. By applying Internet of Things (IoT) and AI-based technologies, the system enables fish farmers to accurately monitor the growth and wellbeing of fish as well as the water quality, temperature, and pH levels in fish tanks. This system, which is readily accessible through computers, tablets, and mobile phones, minimizes manual labor while significantly expanding aquaculture outcomes, resulting in advantages for the fishery's marketing industry.

The primary objective of this research project is to explore through the prospective benefits associated with implementing IoT and AI technologies in aquaculture and further this study explores artificial intelligence utilization in aquaculture worldwide, focusing on analytical models, AI-powered image recognition and vision-based algorithms for disease management and sustainable methods to improve awareness of the role that technology plays in strengthening efficiency and ensuring long-term sustainability for the aquaculture sector by examining certain scenarios and possible benefits.

Keywords— **Aquaculture, IoT and AI technology, Remote access, Solar power, multi-sensor**

I. INTRODUCTION

Aquaculture refers to the raising and harvesting process of aquatic organisms, and it is rapidly developing into a significant aspect of modern-day agriculture. It involves cultivating numerous species for human consumption while also preserving the health of the aquatic environment. These organisms include seaweed, shrimp, cockles, crawfish, mussels, and crabs, among many more. As the worldwide population keeps on expanding, the requirement for food has grown to previously unimaginable stages, expanding and resulting in cutting-edge approaches to meet the rising needs.

Seafood is essential in human diets because it provides significant proteins, minerals, and nutrients necessary for a healthy lifestyle. Given an overall initial sales worth USD 401 billion, fisheries output worldwide in 2018 surpassed 179 million tons. Aquaculture output accounted for 82 million tons with a value of USD 250 billion. Twenty-two million tons were utilized for non-food items including the manufacturing of fishmeal and oil, leaving 156 million tons for human use. Aquaculture provided 46% of total production, with 52% intended for consumption by mankind. China remains to be the largest seafood supplier in 2018, accounting for 35% of global fish productivity. (Food and Agriculture Organization of the United Nations,2020) As a result of an increasing need on seafood, fish farmers across the globe are embracing the challenge of continuing this required sector. To satisfy the rising demand, they are actively implementing efforts toward increasing production and efficiency.

Over the last five decades or so, aquaculture has benefited greatly from technological developments, which have allowed for higher productivity and sustainability. (Food and Agriculture Organization of the United Nations, 2020) The Internet of Things has significantly benefited aquaculture since it has allowed producers to utilize technology to their own gain throughout the whole production cycle. The aquatic industry could undergo an

extensive shift as a result of the combination between IoT and AI technology. This interaction has the potential to result in more effective resource usage, lower environmental impact, and greater welfare for the fish. IoT's real-time monitoring improves the reliability of AI models, resulting in enhanced decision-making and sustainable development.

The use of these technologies throughout a variety of industries comes with positive and bad effects. There is no denying that technologies including AI and IoT maximize productivity.

The scope of this research is to investigate the minimal adoption of IoT and AI technologies in Sri Lankan aquaculture and to assess their significant advantages and prospects. It highlights the hurdles and constraints preventing overall adoption whilst highlighting the significance of utilizing advanced technologies to efficient use of resources, sustainable growth, and living standards. However, there are also different challenges that need to be considered. Preservation of data and data encryption are of the highest priority due to the possibility for problems that might be exposed by greater interconnection as well as information interchange. Another barrier is the overall cost of installing IoT and AI devices, which involves infrastructure and technology breakthroughs. Yet, because of their benefits, such as higher output, resource efficiency, and precise decision-making, both AI and the Internet of Things are prospective technologies for strengthening precision the aquaculture industry and agricultural sustainability.

II. RELATED WORK

Agriculture has been transformed by IoT and AI technology, which resulted in more environmentally friendly approaches. Real-time data collection and analysis on environmental elements, agricultural production, and soil conditions is carried out via IoT equipment such sensors, controllers, and drones. These advancements have revolutionized traditional agriculture while also benefiting aquaculture.

Sri Lanka, an island nation in the Indian Ocean that is tropical and comprises 65,610 km2, has a robust fishing sector that contributes a substantial contribution to the country's economic growth. The local economy of coastal communities is nourished by fishing, which is a widespread vocation. Seasonal village ponds and tanks are the primary source of Sri Lankan inland aquaculture. Ornamental fish from the country's freshwater and brackish water ecosystems are in high demand overseas; significant gainers include France, Germany, the United States, the United Kingdom, Belgium, Japan, Spain, the Netherlands, and New Zealand. Popular ornamental fish species including the swordtail platy, molly, angels, goldfish, and zebra dominate the export market, accounting for around 60% of all fish exports. Moreover, widespread indigenous tilapia fish is a rich resource for both domestic consumption and potential export. (The World Bank Group, 2022).

The method by which data is gathered, processed, and applied in the aquaculture sector has been transformed by the combination of machine learning algorithms and data analysis methods with IoT devices. IoT sensors and devices provide enormous volumes of data, which ML algorithms may analyse to find relationships, trends, and patterns that may be applied to improve aquaculture operations. Aquaculture operators may enhance overall farm management techniques, optimize feed formulas, expect ideal harvesting periods, and acquire a deeper knowledge of the factors impacting fish health by utilizing ML and data analysis. These cutting-edge innovations hold an opportunity to reduce hazards and promote sustainable aquaculture practices, creating up prospects for a more productive and sustainable field. (Chiu et al., 2022)
However, the aquaculture sector encounters difficulties in managing water quality, tracking resources, and monitoring temperature increases, all of which have a significant influence on the overall well-being of aquatic life. Traditional methods of managing these resources are often lacking resulting in higher rates of fish loss and reduced productivity.

The PROTEUS project focuses on affordable cost, multiple capacities, adaptability with diverse technological procedures, and sensitivity with the objective to improve water monitoring technologies. Along with positive outcomes from biological pollution experiments and decreased sound features, its ability to monitoring the pH level, chlorine, and chlorides, nitrites and calcium in difficult conditions is explored. The project assures a low-cost, highly multiplexable multiparameter sensor device for live measurements with the possibility for increased sensitivity through use of transistor techniques. The project's influence on the real-world practice of monitoring the quality of water is emphasized, with a primary focus on practical, accurate, and sustainable solutions. The initiative has had a major and long-lasting effect on aquatic environmental monitoring. (Dupont, Cousin and Dupont, 2018).

According to the study, ‘An Integrated Wireless Multi-Sensor System for Monitoring the Water Quality of Aquaculture’ it demonstrates an overall structure for evaluating fish farm water quality utilizing a variety of sensors and tools. For temperature monitoring, the system has a pH Sensor, a Digital EC Meter, and a Resistant Sensor. Processing and data transport are handled by the Arduino UNO microcontroller and Raspberry Pi 3 CPU.

Guidelines for activities are given on a PHP website based on the water quality. For a thorough examination of the water quality, precise sensor readings are essential. (Lin, Tsai, and Lu, 2021)

In order to establish a healthy environment for the development of plants and fish, the paper on 'Comprehensive Review of Aquaponic, Hydroponic, and Recirculating Aquaculture Systems' suggests a method where aquaponics integrates hydroponics with aquaculture. A soilless technique called hydroponics has benefits including quick plant development and maximizing elements like distance, efficiency, and quality of production. To monitor and manage the aquaponics system, the suggested system makes use of hardware elements and Internet of Things technologies. The suggested method intends to produce consistent plant growth rates, efficient production, and reduced water usage. Aquaponics demonstrated faster plant growth rates than conventional techniques for a variety of plants, including spinach, yard beans, French beans, red beans, and bitter guard. Through a mobile application, the system's interaction with the user enables surveillance and management. (Rajalakshmi, Manoj and Manoj, 2022)

Yet another study discovered an approach to recognize and maintain the ideal environment of a freshwater shrimp farm within control. To monitor and regulate important parameters, it utilizes a wide range of detectors and an automated monitoring system. The system consists of an electrical conductivity meter to measure salinity, a Temperature Sensor, a salinity sensor to evaluate aquatic environment, a pH sensor to assess pH levels, an oxygen concentration sensor, a light exposure sensor to control shrimp behaviours, and a dissolved oxygen sensor. Data is gathered and handled using Arduino software, and the hardware resources are linked to an Arduino board. The information is then sent to a Mobile application, which offers a simple user interface for keeping track of the shrimp farm, showing real-time statistics, and providing management. (Uddin et al., 2020)

A. Global aquaculture methods

IoT utilization in aquaculture has undergone an upsurge in demand over the past several years on a worldwide scale. The potential advantages of IoT in enhancing both the efficiency and the long-term viability of a country's aquaculture systems have been acknowledged by several nations across the world. The adoption of IoT in fisheries has accelerated throughout both industrialized and developing nations. These economies have recognized how analysis of data, and automation possibilities offered by IoT could impact the method by which aquaculture operates forward. Aquaculture analysts may collect accurate information on water quality, surrounding circumstances, and fish by using IoT devices. These technologies are being used in aquaculture and in several minor business operations as well.

IoT technology is also adopted by cooperatives and small-scale fish farmers throughout the world to increase production and profitability. These farmers could overcome obstacles like limited resources, rapidly changing climatic conditions, and market access by utilizing IoT solutions customized to their needs. They can remotely track and control their farms using IoT-enabled technologies, get timely notifications, and decide on smart choices to increase harvests.

Norway has been in the leading edge of using IoT in aquaculture and is among the global leaders in salmon farming. To gather real-time information on water quality, fish activity, eating habits, and health indices, they have set in place complex monitoring systems that utilize the use of sensors and underwater cameras. (Skjæran, 2022).

Aquacultures have a long history in Japan, which adopted I oT to advance the sector.

They apply IoT devices like sensors, drones, and self-driving underwater vehicles namely AUVs to observe fish movements, check water quality, and supervise feeding operations. Japanese aquaculture professionals can maximize feeding s chedules, regulate water quality better, and lower the da nger of diseases with the use of IoT technologies. (FutureIoT Editors, 2022) .

Chile has been using internet of things in aquaculture and is one of the key players in the cultivation of salmon field. They use IoT technologies to maintain tabs on fish farm characteristics including pH, salinity, temperature, and oxygen levels. IoT solutions for Chilean aquaculture aid farmers in preserving ideal water conditions, guaranteeing fish wellbeing, and stopping disease outbreaks. (Hanchett, 2020).

Singapore has employed advanced techniques, which include IoT, for the cultivation of aquaculture despite being a small country with few opportunities for traditional aquaculture. They are setting in place urban aquaponics systems which combine hydroponic plant culture with fish husbandry. IoT technology is employed in Singapore's urban the aquaculture industry to track and manage variables including water quality, fertilizer levels, and temperature. (Mok, Tan and Chen, 2020)

The Yield is an Australian company founded in 2014 focused on developing the Sensing Aqua Internet of Things (IoT) platform for the benefit of the oyster industry. The technology uses sensors to collect information about the climate, including salinity, water temperature, depth, pressure readings and tide levels. The Microsoft-powered Yield cloud platform receives this data, processes it using

artificial intelligence and advanced analytics algorithms, and produces three-day forecasts of local weather and best harvest times. For oyster farmers, who often suffer financial losses from heavy rains, The Yield's hyperlocal layouts are particularly useful. According to the predictive IoT system, harvest downtime will be reduced by 30%, bringing significant financial benefit to oyster farmers. Yield's advanced IoT prediction technology can even give a delicious coating to oysters.
Further an Indonesian firm named 'Jala' focuses on IoT hardware and software to monitor the water quality in shrimp farms. Their complete equipment measures and reports oxygen levels, humidity, temperature, the pH level, salinity levels, and overall solids dissolved through web or smartphone interfaces.

'Eruvaka Technologies', which was launched in 2012, provides surveillance methods for fish farms, including their solar generated 'Pond Guard' system. These sensors enable real-time monitoring of critical water parameters, allowing for preventive problems detection and up to 20% energy cost reductions.

'Sensaway, a Portuguese aquatic establishment, manufactures solar-powered sensors that are easier to maintain and operate than existing market versions. (Nanalyze, 2018)

These instances show how several nations have adopted IoT aquaculture technology to increase productivity, sustainability, and profitability. They seek to improve production methods, reduce environmental effects, and guarantee the welfare of aquatic species by utilizing real-time data and smart monitoring systems. The technological environment of a nation is influenced by factors like supplies, infrastructure, and financial conditions.
For instance, Sri Lanka, as a third world nation adopting hydroponics technology can significantly contribute to economic progress and transform traditional living methods. This technology increases food production capacity, reduces import reliance, and promotes self-sufficiency. By expanding and upgrading the agricultural sector, Sri Lanka can boost its economy, food safety, and sustainable development.

III. METHODOLOGY

The decision to focus on specific sensors to satisfy the needs of the industry was made after a thorough evaluation of multiple publications and websites focusing on Internet of Things, or IoT, technologies in aquaculture.
Elements that affect water quality must be effectively monitored in aquaculture systems to guarantee the overall well-being of aquatic organisms. There are several sensors utilized, which includes conductivity, ammonia, turbidity, chlorophyll, oxidation, and reduction potential (ORP), total dissolved solids (TDS), carbon dioxide (CO_2) and Phosphate levels. These sensors are linked to provide a thorough monitoring system which allows to maintain the ideal water quality parameters necessary for aquatic life to become successful. They were discovered to be the most suitable choices for obtaining current data and monitoring critical aquaculture system features. (Zhuiykov, 2012)

A. Monitoring Water Quality through Sensors

Since water is a crucial component of the survival of fish a s well as other aquatic species, effective water quality mo nitoring is essential in aquaculture. The poor condition of the water is the most common issue faced when aquaculture results is unsuccessful. As a result, water quality monitoring is essential throughout operations. When it comes to providing their aquatic species w ith the best possible water conditions, fish farmers must overcome a number of obstacles. The implementation of IoT-based technologies in aquaculture, however, offers an acceptable way to overcome the difficulties and obtain plenty of advantages, Fish are raised through a variety of methods including aquatic, brackish and also saltwater eco-systems. Raising fish and aquatic animals in saltwater or marine environments is referred to as mariculture. (Food and Agriculture Organization of the United Nations,2020) Despite of the aquaculture technique used, aquatic life's health, development, and production is greatly influenced by the water quality.

Since slight modification can have a negative impact on the fish population, maintaining ideal conditions for the water continuously can be quite difficult for fish farms. Consequently, it is crucial to incorporate advanced monitoring systems that use sensors. Fish farmers can improve overall output by effectively managing possible problems by regularly monitoring water quality measures.
As an example, the application of the sensor platform from 'Libelium' is connected to IoT monitoring system. This platform incorporates innovative devices, such 'The Wasp Mote Plug & Sense! Nodes', that are made especially for checking the water quality in aquaculture. These nodes, which may be properly placed in fish farm ponds and include systems such 'Smart Water and Smart Water Ions', can encompass broad areas and offer thorough data. The system of sensors allows for live measurements of such essential water quality indicators as humidity, dissolved oxygen, pH levels, the compound ammonium and nitrogen levels. To store, analyse, and visualize this information, it is wirelessly delivered to an entry point, which links to a cloud-based platform. Using a dashboard that is easy to use on their tablets, PCs, or cell phones, fish farmers may access this data, enabling them to keep track of the water levels remotely and come up with wise decisions. (Libelium, 2018).

Effective control of water quality is essential for aquaculture, especially in countries with limited resources such as Sri Lanka where accessibility to power in rural regions may be constrained. This problem may be effectively solved through an installation of water quality monitoring even in remote areas by integrating a solar-powered sensors in IoT-based monitoring equipment. For this approach, a structure of a circuit that includes key parts like as sensors, microcontrollers, solar panels, batteries, and communication units needs to be applied. For the firmware process, a microcontroller should be set up to gather data, monitor its energy usage efficiently, and also to easily communicate the data to a selected web server or a platform which is programmed to transfer data simply towards a cloud-based system or database system. It has a lot of effectiveness and offers many benefits in a variety of applications to design a renewable sensor device for monitoring the condition of water. To optimize the advantages of solar power, these sensors must be environmentally friendly and suitable for low-power operation. A solar panel is also necessary for the system to take in sunlight and turn it into electricity for the sensors as well as other electrical parts. To store extra energy produced during bright hours for use during dark or nighttime circumstances, which involves a rechargeable battery, remains necessary. A form of communication component, such Wi-Fi or cellular connection, can be included to facilitate wireless data transmission. Finally, real-time data should be presented in a user-friendly interface or dashboard so that individuals may easily access and analyse it. An effective sensor system driven by solar energy may be built to monitor water quality, offering a cost-effective and sustainable option for the aquaculture industry. Operating expenses for standard monitoring systems powered by electricity will be decreased by solar energy.

Farmers in Sri Lanka could lower maintenance costs and power bills by utilizing the country's warm weather, which lowers the cost and accessibility of water quality monitoring sensors powered by solar may simply be adjusted up or down depending on the demands of various aquaculture systems. The adaptability of solar-powered sensors enables deployments depending on the scope and needs of the farm, whether it is a smaller fishpond or a bigger aquaculture plant. The deployment of IoT-based tracking devices is also consistent with Sri Lanka's objectives to modernize and improve its farming industry via the adoption of cutting-edge technologies. It fosters the financial well-being of rural communities that engage in fish farming, encourages a long-term development of aquaculture, and increases productivity.

B. A sensor for monitoring aquatic species development and well-being

It is essential to regularly monitor the development, well-being, and behaviours of aquatic life in aquaculture systems in addition to the water quality. In the past, fish farmers were dependent on manual methods of evaluation to determine the health and wellbeing of the aquatic organisms, which frequently led to handling of the fish, disruption of the aquatic environment, and even mortality.

Fish farmers may now simply and rapidly monitor the biological as well as developmental aspects of the fish by deploying wireless sensors created particularly for fish monitoring. These sensors can also notice changes in background, making it simpler to recognize and handle any difficulties. The habits, consumption patterns, and biological traits can be monitored through collecting data. Any unusual behaviours, food preferences or stress cause can be quickly identified, and corrective measures can be performed by continually monitoring the aquatic organism's health and physiological responses, the sensor-based system for monitoring offers immediate data on fish eating habits, behaviour, and biological traits. This data is crucial for comprehending the organism's overall performance, Farmers can customize feed utilize, avoid excessive feeding as well as underfeeding, and make sure the nutritional needs of the fish are satisfied by getting knowledge into the behaviour of the fish.

Furthermore, risk reduction and climate adaptation depend heavily on these sensors' capacity to recognize environmental changes.

Aquaculture operations can predict and adapt to changes in the water's conditions by maintaining a close eye on variables like humidity and levels of oxygen. In addition to reducing discomfort on the fish and fostering a more stable and beneficial environment for their growth, this enables greater supervision over the farming settings. One of the main benefits of this sensor-based technique is that it causes the least amount of disturbance to aquatic life and does not require having access to the ponds or fish tanks for evaluation. In order to provide a non-intrusive monitoring option, the sensor serves as a waterproof camera that is placed above the water's surface. The required indications and insights into the development and health of the fish are then extracted from the acquired data utilizing automated analysis performed by specialized algorithms. By establishing an alarm system which provides real-time notifications to fish the controllers whenever unexpected behaviours, health concerns, or environmental changes are noticed.

IV. THE POSSIBLE ADVANTAGES OF IOT AND AI IN AQUACULTURE

By shifting from outdated and unsustainable fishing techniques to more modern ones, Sri Lanka, as an emerging economy, could speed up its economic

development. The country could experience a variety of benefits and open new development potential by implementing cutting-edge technology and methods in the fisheries industry. The nation's economy can be more diversified and less dependent on traditional industries by making investments in the latest innovations like IoT in aquaculture.

Increased opportunities for entrepreneurship, employment growth, and economic development may result through this. The practical use of innovative technologies, such as IoT, in aquaculture could attract investment from abroad since it displays the nation's dedication to technological innovation and sustainable growth. Growth in the economy could be sped up by higher foreign direct investment by introducing fresh investment capital.

Exporting fisheries products from Sri Lanka to foreign markets also has tremendous possibility. The nation may improve the quality of products, transparency, and sustainability by implementing IoT in aquaculture, boosting its ability to compete in the global marketplace and producing foreign exchange revenues.

Poverty Reduction and Rural Empowerment; Aquaculture holds an opportunity to be adopted in Sri Lanka's rural regions, especially when combined with IoT technology. Particularly in coastal and rural populations that primarily rely on standard fishing techniques, this can generate employment opportunities, improve livelihoods, and lessen poverty.

Strengthening Industrial Sustainability and Efficiency; Aquaculture systems built on the Internet of Things allow for accurate surveillance, technology, and decision-making based on data. This might result in higher production, lower costs, and better resource management, thus improving the aquaculture industry's overall effectiveness.

The development of IoT-based aquaculture necessitates a staff with advanced technological and data analytics skills. Sri Lanka may establish a pool of qualified individuals capable of encouraging innovation and technical breakthroughs in the fishery industry by launching programs of training and educational opportunities.

V. Future work

There is an increased likelihood toward employing an exact sensor in the setting of future work in order to advance the current study. Although the findings and conceptual frameworks applied in this study were previously accessible, using an actual sensor would provide an opportunity to collect data directly and evaluate their findings. The addition of a real sensor supplies an enormous opportunity for overcoming the gap between theories and concrete evidence.

VI. Conclusion

The primary goal of this study is demonstrating the possible advantages of IoT and AI technologies which could potentially be implemented in Sri Lanka. Sri Lanka, an island nation with a rich agricultural heritage, has the opportunity to leverage its aquatic resources and develop from the oceans. By embracing aquaculture as a means of economic prosperity, Sri Lanka can break free from traditional agriculture constraints and address pressing issues like malnutrition, particularly among children. By starting at the grassroots level, Sri Lanka can lay the foundation for a brighter future, harnessing the vast potential of its aquatic resources to improve financial prospects and well-being. Although Sri Lanka utilizes IoT and AI technologies sparingly, it offers enormous potential to advance several industries.

Sri Lanka can increase effectiveness, productivity, and breakthroughs in agriculture, industry, healthcare, transportation, and other sectors by implementing these technologies. Adoption of these technologies can result in better resource management, better decision-making, additional interaction, and a better standard of living for citizens. Recognizing and enhancing infrastructures skills, and regulatory systems is critical for Sri Lanka to maximize its potential.

The paper points out the value of choosing appropriate sensors for setting up in Sri Lanka's setting while acknowledging instances of other nations wherein these advances have been effectively adopted. It's crucial to remain aware that this study has certain boundaries.

IoT and AI are generally discussed in terms of the benefits they offer; as a result, not all of the possible drawbacks or difficulties that arise from their adoption could be addressed.

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ACKNOWLEDGMENT

I would like to express my sincere gratitude to Dr. Charith, his guidance and expertise turned out to be of great assistance when creating the study. I also like to convey my sincere appreciation to Madam Chamodhi, for helping me with this paper. Additionally, I would like to acknowledge my brother for all his support and guidance throughout this paper. On a final note, I would like to express my heartfelt thanks to my friend who, despite the brief period available, provided me advice and support during this study.

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