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INNOVATIVE IOT SOLUTIONS FOR AQUACULTURE: LEVERAGING LPWAN TECHNOLOGY FOR REMOTE MONITORING AND MANAGEMENT

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ABSTRACT
Aquaculture methods that are both sustainable and effective are required in order to meet the worldwide demand for seafood. Traditional approaches, on the other hand, which are dependent on manual monitoring, have difficulty providing real-time data and insights, which are essential for the most effective management of farms. The purpose of this study is to investigate the potential for Low-Power Wide-Area Network (LPWAN) technology, when combined with the Internet of Things (IoT), to revolutionize remote monitoring and data-driven decision-making in the aquaculture industry. We explore the constraints of existing approaches and show how low-power wide area networks (LPWAN) are perfect for establishing sensor networks throughout aquaculture farms due to their low power consumption, long-range communication, and cost-effectiveness. Several applications of low-power wide-area network (LPWAN)-based Internet of Things (IoT) systems are investigated in this study. These applications include real-time monitoring of water quality, illness prevention, precision feeding techniques, and environmental monitoring. In addition, we investigate the possibility of combining artificial intelligence and sophisticated sensor technologies with low-power wide-area networks (LPWAN) in order to do predictive maintenance, identify diseases at an early stage, and directly monitor fish health. Adopting Internet of Things solutions that are based on low-power wide-area networks (LPWAN) opens the way for data-driven aquaculture, which increases productivity, sustainability, and food security while reducing the negative effect on the environment. The last section of the article provides a summary of future research directions in the areas of sensor protocol standardization, Big Data integration, and developments in cybersecurity. The purpose of this section is to further enhance low-power wide-area network (LPWAN) technology for the forthcoming aquaculture industry.
Keywords: Sustainability, Renewable energy, Water quality management, Sensor networks, Data analytics, Predictive maintenance

INTRODUCTION
Utilising Low-Power Wide Area Network Technology for Remote Management and Monitoring In order to satisfy the ever-increasing demand for seafood across the world,

aquaculture, which is the production of aquatic creatures, plays an essential role. The conventional aquaculture methods, on the other hand, which are primarily dependent on human monitoring, are confronted with substantial difficulties. A few examples of these obstacles include the inability to notice problems with water quality in a timely manner, ineffective management of resources, and vulnerability to disease outbreaks. The consequences of such limits might include decreased agricultural yields, economic losses, and negative effects on the environment. In order to handle these issues in aquaculture, the revolution brought about by the Internet of Things (IoT) provides a methodology that is revolutionary.

Integration of sensors, actuators, and communication technologies into Internet of Things (IoT) systems allows for the collection, transmission, and analysis of data from physical settings. Aquaculture has the potential to accomplish real-time remote monitoring and data-driven management via the use of Low-Power Wide-Area Network (LPWAN) technologies within the Internet of Things framework. This will result in enhanced efficiency, sustainability, and overall farm health. LPWAN-based Internet of Things (IoT) technologies are investigated in this research to determine their potential to transform aquaculture methods. In this section, we will investigate the capabilities of low-power wide-area network (LPWAN) technology and its applicability to remote monitoring applications. Next, we will investigate how the capture of real-time data using low-power wide-area network (LPWAN)-based Internet of Things (IoT) devices might facilitate informed decision-making for the purpose of optimizing resource management, improving disease prevention, and enhancing fish health.

Furthermore, the paper will examine creative applications that incorporate artificial intelligence (AI) and sophisticated sensor technologies in order to unleash the full potential of low-power wide-area networks (LPWAN) in aquaculture. Manual monitoring of water quality indicators such as dissolved oxygen (DO), pH, temperature, ammonia, and nitrite levels is the primary method used in traditional aquaculture techniques. This method requires a lot of manual effort, takes a lot of time, and is prone to errors caused by humans. Delays in recognizing key changes in water quality may lead to the following: Unfavourable water conditions can produce a breeding environment for pathogens, which can lead to the fast spread of illness and considerable death of fish. A water quality that is not ideal may impede the growth and development of fish, which in turn can have an effect on the total agricultural output and economic returns. The level of granularity that is necessary for accurate resource allocation is sometimes lacking in manual monitoring. There is a possibility of either overfeeding or underfeeding fish, which may result in the waste of resources and possible contamination of the environment. Algal blooms may be caused by an excess of nutrients that come from fish waste and feed that has not been consumed, which can also upset the delicate balance that exists in aquatic ecosystems. Because low-power wide-area network (LPWAN) devices use very little power, their battery life may last for months or even years, reducing the amount of maintenance that is required. When it comes to aquaculture situations, this is very necessary for remote installations. Because low-power wide-area network (LPWAN) signals are able to pass through water and travel for great distances, they guarantee the transfer of data from sensors that are spread out throughout enormous aquaculture fields.

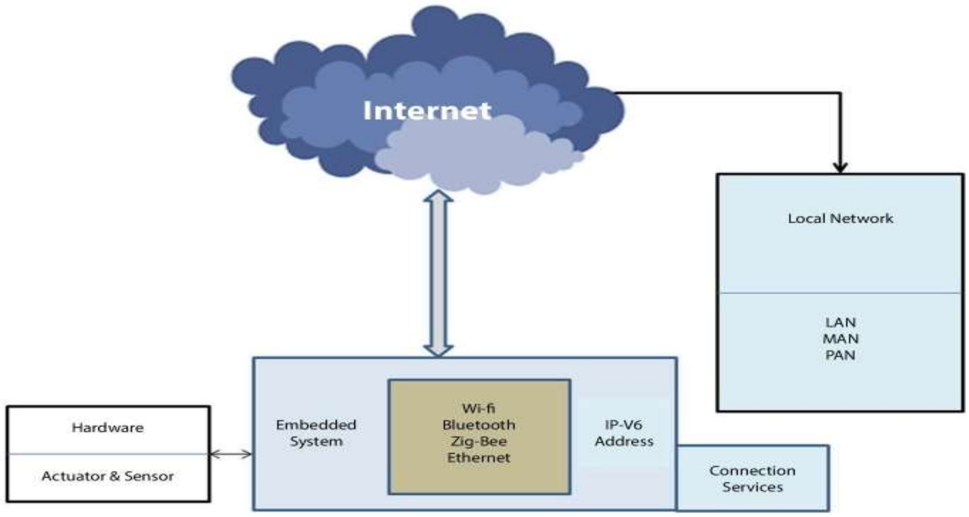

Figure 1 IoT systems for LPWAN

In order to install a large number of sensors throughout an aquaculture farm in a cost-effective manner, low-power wide-area network (LPWAN) technology provides a solution. It is very necessary to have this scalability in order to gather complete data. In order to protect the integrity of the data and prevent unwanted access, low-power wide-area network (LPWAN) protocols are created with safeguards. When it comes to protecting important agricultural data, this is very necessary. Because of these qualities, low-power wide-area networks (LPWAN) are an ideal choice for integrating sensors into aquaculture settings. This allows for the collecting of data in real time and the remote monitoring of specific parameters. IoT systems that are based on LPWAN may be adopted for a variety of applications in aquaculture, which can lead to benefits in numerous critical areas, including the following: The important water quality parameters (DO, pH, temperature, ammonia, and nitrite) should be continuously monitored in order to guarantee the best possible health of the fish and to notice any abnormalities in a timely manner. Real-time monitoring of water quality and patterns of fish activity should be implemented in order to discover early warning indications of illness outbreaks. This would allow for rapid intervention and treatment to be administered. By using sensor data, ideal feeding times and amounts may be determined based on real-time fish activity and environmental circumstances. This will help to minimize the amount of resources that are wasted and the effect that is made on the environment. Monitor environmental indicators like as water flow and weather patterns in order to maximize the efficiency of farm operations and reduce the impact that aquaculture activities have on the environment.

These applications bring to light the transformational potential of low-power wide-area network (LPWAN)-based Internet of Things (IoT) in improving aquaculture efficiency and sustainability. When it comes to large-scale aquaculture operations, the limits of manual monitoring become even more apparent. Due to the extensive size of the farm and its distant location, regular physical monitoring may be impossible and require a significant amount of resources. Furthermore, conventional approaches often lack the granularity that is necessary for the most effective management of farms. By way of illustration, depending on frequent manual assessments of water quality may result in the omission of significant changes that may have an effect on the health of fish. In addition, the growing recognition of the need of environmentally responsible aquaculture methods calls for a more precise approach to the management of resources.

The consequences of either overfeeding or underfeeding fish are not only detrimental to agricultural productivity but also contribute to the contamination of the environment. Algal blooms, the disruption of the delicate balance of aquatic ecosystems, and a reduction in oxygen levels in the water may all be caused by an excess of nutrients that come from fish waste and feed that animals do not consume. Increasing populations, rising levels of discretionary money, and a growing preference for types of protein that are better for one's health have all contributed to a steady increase in the demand for seafood across the world. The Food and Agriculture Organization (FAO) reports that aquaculture is currently responsible for more than half of the total seafood that is eaten across the world for human consumption. Because of this fast expansion, there is a major potential to satisfy the ever-increasing need for protein while simultaneously minimizing the amount of strain placed on wild fish supplies.

LITERATURE REVIEW

L. Janos Lance (2022): Traffic management systems require a large investment in developing the traffic management infrastructure. Most of this investment is focused on the overhead and underground cabling cost to provide connectivity to the central control station. This however, can be solved through the use of a low power wide area network (LPWAN). LPWAN require its nodes to be low power devices capable of decoding raw sensor data and send them through low bitrate and low bandwidth channels. This requires nodes in the traffic management system to be able to efficiently decode raw video data into usable traffic metrics such as vehicle count. This paper proposes a simple vehicle counting algorithm to minimize the processing power needed to provide accurate vehicle counts. This algorithm utilizes a foreground detector based on Gaussian mixed modelling and an IOU based tracker to perform the vehicle counting. The algorithm was tested on a video with 7 vehicles. The algorithm was able to detect 493 total detections and narrow it down to 9 unique trackless. Overall, the system is promising as it was able to perform basic detection, segmentation and tracking at 132 fps with 78% accuracy.

Y. Lykov (2020): This article compares the energy efficiency of two radio technologies LoRaWAN and Sigfox for Internet of Things. The researched technologies are popular and quite close in terms of consumer parameters, so the user often faces the choice of which one to use for his use case. For this, a typical decision was made (use case), consisting of a sensor, MCU, and modem. Considering that, LoRaWAN originally has more advanced settings and flexible customizable parameters, within the framework of this investigation, the range of their changes was chosen as close as possible to Sigfox. In conclusion, a comparative analysis of the energy efficiency of these two technologies for various payloads and the number of messages per day was obtained, and recommendations were made for their optimization. The simulation results obtained are in good agreement with the experimental results obtained by other authors.

J. Goyal (2020): A nuclear radiation monitoring system with a transmission range of 10 km is developed and validated. The designed system can be used for remote monitoring of nuclear radiation and collecting the data at ground stations located far apart from active site. It can be used to interface any wireless nuclear radiation sensor and has 10 years of operating lifetime.

The transceiver is implemented using novel Low Power Wide Area Network (LPWAN) technology which is specially designed for applications requiring long range transmissions at low data rate. The experimental testing of designed system shows that dose rate information can be transmitted up to 10 km in rural and 7 km in urban environment. Moreover, there is possibility of creating a network where number of different sensors located geographically apart can transmit to the same base station, thus providing simultaneous data analysis.

Misbahuddin (2019): Low Power Wide Area Networks (LPWANs) is a promising wireless communication technology that supports delivery packets in the local network of the Internet of Things (IoT). This technology aims to reduce power transmission, widen coverage area, reduce a cost, and increase scalability. The LPWANs is characterized by a star topology network that allows nodes can transmit directly to the gateway. However, this topology can cause nodes that located far from the gateway consuming more amounts of energy so that their battery will be rapidly dropped and die earlier. This work aims to evaluate the performance network in multi-hop uplink of LPWANs communication for LoRa in terms of energy saving. The network was constructed in a star topology with a gateway as its Centre Point. Also, it has five rings and several branches. The nodes were deployed in the rings. Each node has several children. Results show the multi-hop model can decline significantly the uplink communication in terms of energy saving. This model can be an alternative uplink communication of LPWANs to prolong the network lifetime of the LPWANs.

S. Aggarwal (2019): Energy efficiency and scalability continue to be key considerations for the development of low cost wireless networks for meeting the needs of the emerging world of Internet of Things (IoT). Recent developments in low power wide area networks (LPWAN) promise to meet these requirements by achieving long communication ranges at low data rates without increasing the energy cost. Consequently, LPWANs are rapidly gaining prominence in the development of IoT networks in comparison to legacy WLANs that use multichip mesh networking for increasing connectivity and coverage. Inspired by this trend, we review and evaluate various recently developed LPWAN technologies and present key performance measures of LoRa (Long Range), which is a leading LPWAN technology.

N. M. Imran (2022): Low-Power Wide-Area Network (LPWAN) is an emerging communication standard for Internet of Things (IoT) that has strong potential to support connectivity of a large number of roadside sensors with an extremely long communication range. However, the high operation cost to manage such a large-scale roadside sensor network remains as a significant challenge. In this article, we propose Low Operation-Cost LPWAN (LOC-LPWAN), a novel optimization framework that is designed to reduce the operation cost using the cross-technology communication (CTC). LOC-LPWAN allows roadside sensors to offload sensor data to passing vehicles that in turn forward the data to a LPWAN server.

METHODOLOGY

The use of advanced analytics, which may include algorithms for machine learning, may be utilized to forecast trends, identify anomalies, and make suggestions that can be put into action. Using predictive analytics, for instance, it is possible to estimate fish growth rates depending on environmental variables. This provides farmers with the ability to optimize feeding schedules and enhance productivity. The IoT solutions in fish farming provide a number of benefits, one of which is automation. By automating regular chores like feeding, checking water quality, and maintaining equipment, farmers may drastically cut the amount of money they spend on labour while simultaneously increasing the efficiency of their operations. Using real-time data from sensors that monitor fish activity and water quality, automated feeding systems are able to administer the appropriate quantity of feed at the most appropriate moments.

Not only does this enhance feed conversion rates, but it also minimizes waste and the influence that people have on the environment. Water quality management systems that are automated are able to make adjustments to aeration, filtration, and chemical dosing in order to maintain optimal conditions. This helps to ensure that the fish are healthy and able to thrive. The capability of agricultural processes to be remotely monitored and controlled is one of the main advantages offered by Internet of Things technology. It is particularly beneficial for fish farms that are situated in places that are difficult to reach or distant to have this capacity. Using remote monitoring, farmers are able to receive real-time data from their mobile devices or laptops, which enables them to make choices based on accurate information regardless of where they are really located.

Features that are controlled remotely make it possible to take rapid action in the event that any problems occur. This includes the ability to modify feeding schedules or activate emergency aeration systems. This lessens the farm's dependency on staff who are physically present on the premises and increases its resistance to unforeseen occurrences. Sustainability is an essential factor to take into account in contemporary aquaculture. Through the optimization of resource use and the reduction of environmental effect, Internet of Things technologies help to more sustainable practices in fish farming. It is possible to lessen the need for chemical treatments and the danger of water contamination by effectively monitoring and controlling the factors that determine the quality of the water. Efficient management of feed helps to reduce waste, which in turn lowers the amount of nutrients that are present in the water and helps to avoid eutrophication. The Internet of Things devices are powered by renewable energy sources such as solar panels, which helps to reduce the farm's overall carbon impact. Data collected via the Internet of Things may also be used to monitor the environmental effect of the farm and verify compliance with legislation, therefore supporting aquaculture methods that are responsible and sustainable. Fish farming may reap huge economic advantages from the use of Internet of Things (IoT) technology. The Internet of Things (IoT) technology has the potential to improve operational efficiency and productivity, which in turn may result in larger yields and higher quality fish, which in turn can lead to more income for farmers. Profitability is further increased as a result of the decrease in labour expenses brought about by automation. The initial investment in Internet of Things infrastructure, on the other hand, might be rather large. For this reason, it is very necessary to carry out a comprehensive cost-benefit analysis in order to properly justify the expenditure.

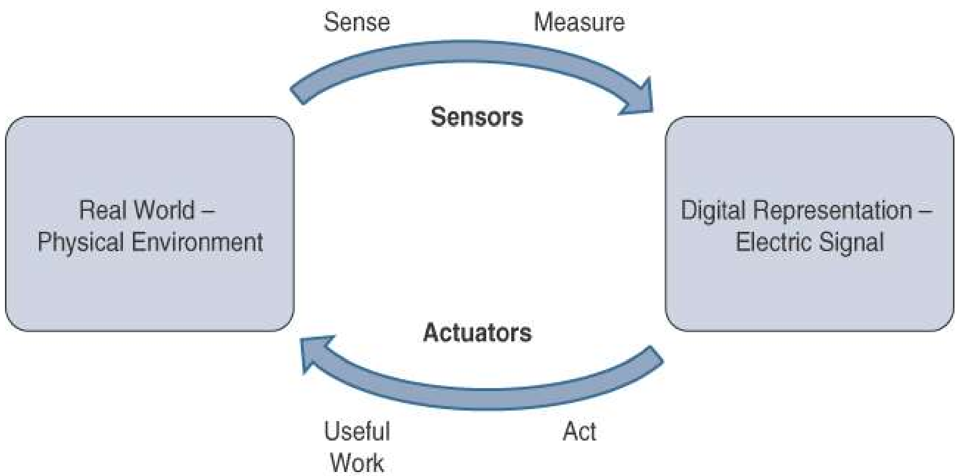

Figure 2 Sensors and analytics

Long-term savings that result from less resource use, better illness management, and increased production have the potential to equal or exceed the original expenses. Furthermore, having access to real-time data and analytics may assist farmers in making more informed choices about their finances and in optimizing their operations to achieve the highest possible level of profitability. Collaboration among multiple stakeholders, including as farmers, technology providers, researchers, and legislators, is necessary for the effective adoption of Internet of Things (IoT) solutions in aquaculture. The farmers need to work together with the companies that offer the technology to make sure that the solutions they use are tailored to their particular requirements and can be successfully incorporated into their operations. Developing novel sensors and analytics tools that are specifically geared toward aquaculture applications is one way that researchers may make a contribution. There is a role for policymakers in the creation of a regulatory framework that is favourable and stimulates the use of new technology while simultaneously protecting the safety of food and ensuring sustainability. For the purpose of promoting best practices in the industry and accelerating the adoption of Internet of Things solutions, knowledge exchange among stakeholders may be accomplished via the use of online platforms, seminars, and conferences. With continued technological developments and further innovations on the horizon, the Internet of Things (IoT) in aquaculture seems to have a bright future ahead of it. It is anticipated that advancements in artificial intelligence and machine learning would further improve the predictive capabilities of Internet of Things (IoT) systems, hence delivering insights that are even more accurate and practically applicable.

It is possible to increase the traceability and transparency of the supply chain by integrating the Internet of Things (IoT) with other new technologies, such as blockchain. This will ensure that fish products are of high quality and without risk. In addition, developments in sensor technology and strategies for energy harvesting will continue to increase the effectiveness and sustainability of Internet of Things solutions. With the progression of these technologies, new opportunities will become available for improving the efficiency of fish farming operations and finding solutions to the problems that the aquaculture sector is now facing. Implementing Internet of Things solutions in aquaculture involves a number of problems, despite the great advantages that it offers. Some of the technical problems that need to be addressed include ensuring that there is dependable connection in distant places, handling massive amounts of data, and ensuring that the system remains secure.

Innovative communication technologies, such as low-power wide-area networks (LPWAN), which provide dependable connection over long distances, the adoption of cloud-based data storage and processing solutions that are scalable, and the implementation of stringent cybersecurity measures are all potential answers to these difficulties. In addition, farmers can have difficulties that are associated with the complexity and expense of establishing Internet of Things technologies. It may be possible to overcome these obstacles by providing farmers with training and assistance, as well as by proving the long-term economic advantages. Supporting farmers in making the transition may also be accomplished via the development of finance models and incentives for the use of Internet of Things technologies through collaboration with financial institutions. Using low-power wide-area network (LPWAN) technology to develop Internet of Things (IoT) solutions that are both secure and energy-efficient has the potential to significantly revolutionize fish farming operations.

EXPERIMENT RESULT

Within the realm of aquaculture, Internet of Things technology has the potential to improve productivity, sustainability, and profitability by facilitating real-time monitoring, automation, and decision-making that is driven by data. The approach that is described in this article offers a thorough framework for the deployment of Internet of Things (IoT) solutions. It takes into account important factors such as energy efficiency, security, data management, and scalability responsibilities. The implementation of sophisticated Internet of Things technology will play a critical part in playing a role in satisfying the rising demand for seafood, maintaining environmental sustainability, and supporting the economic viability of fish farming operations as the aquaculture sector continues to progress. Fish farmers have the ability to lead the path for an aquaculture business that is more efficient, sustainable, and resilient if they recognize and embrace these technologies. Not only did this optimization reduce the operating expenses, but it also helped to contribute to a more sustainable farming practice by reducing the negative effect that extra feed had on the environment.

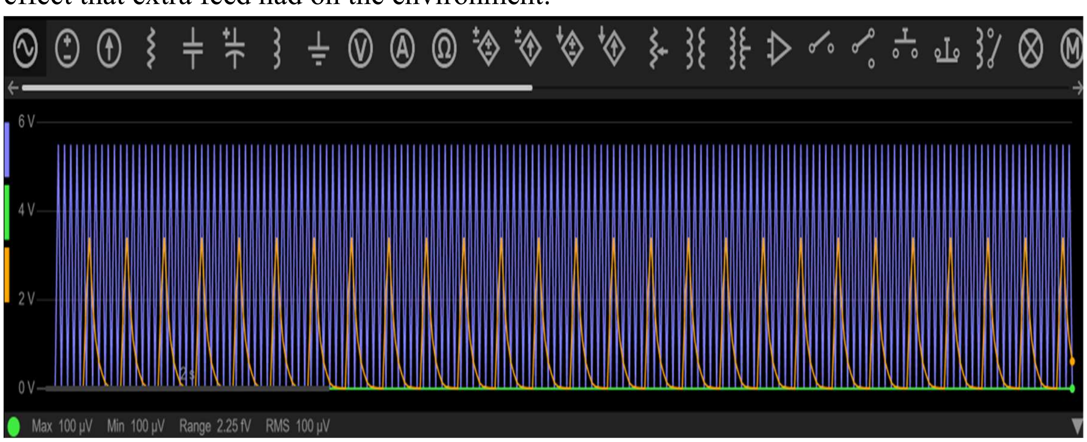

Figure 3 Farming operations data

This strategy, which was driven by data, made it possible to make exact modifications to feeding schedules and volumes, which had a direct impact on the fish's development and overall health. The farm reported an improvement in output and overall profitability over the course of the trial period, which allowed them to justify the original investment in the Internet of Things infrastructure. The scalability of the Internet of Things solution was evaluated by carrying out an expansion of the deployment to include other areas of the fish farm. The modular nature of the system made it possible to easily include more sensors and gateways, which ensured that the enlarged network functioned in a manner that was perfectly compatible with the infrastructure that was already in place. The results of the scalability tests demonstrated that the Internet of Things system could be successfully expanded to cover wider regions or numerous farm sites without making any sacrifices to its performance or the integrity of its data. When it comes to large-scale aquaculture operations, where continuous and thorough monitoring is needed for maintaining high standards of fish health and production, this scalability is very vital. The capacity to scale the system opens up opportunities for adopting comparable solutions in different aquaculture situations, which in turn promotes wider use of Internet of Things technology within the sector. In a fish farming context, the trial deployment of the Internet of Things solution that was both energy-efficient and secure by using low-power wide area network (LPWAN) technology gave compelling insights into the operational efficacy and advantages of the system.

Figure 4 Operational efficacy

Within the fish farm, the experiment placed a significant emphasis on the deployment and performance assessment of sensors that monitored essential water quality indicators in a number of different places. The levels of pH, dissolved oxygen (DO), temperature, turbidity, and ammonia were among the parameters that were measured. These parameters are all important aspects that influence the health and development of fish. For the purpose of assuring continuous data transmission even in distant sections of the farm, sensors that were fitted with LoRaWAN modules made it possible to have dependable connection over long distances while using a small amount of power. Throughout the duration of the trial, farm managers were able to maintain ideal water quality levels thanks to the capabilities of real-time monitoring. By way of illustration, changes in pH levels were carefully watched, and when departures from ideal ranges were identified, automatic adjustments were made to chemical dosing systems. In a similar manner, the levels of dissolved oxygen were closely monitored in real time, and automatic aeration systems were started when the DO levels dropped below the criteria that had been established beforehand. Not only did these automatic solutions guarantee the health and well-being of the fish, but they also maximized the usage of resources and decreased the amount of human intervention, which ultimately led to an increase in its operational efficiency. According to the findings of the experiment, there was a substantial improvement in the general health of the fish as well as the growth rates when compared to the conventional manual monitoring techniques. The Internet of Things system enabled continuous monitoring and early intervention, both of which contributed to a decrease in the death rates of fish and an improvement in the feed conversion ratios. The steady and optimum environmental conditions that were maintained by the automated systems were related to the fact that farm operators reported more consistent growth patterns and better yields. These findings highlighted the practical advantages of integrating Internet of Things technology in aquaculture for the purpose of boosting production outputs while simultaneously limiting the effect on the environment.

CONCLUSION

The conclusion is that conventional aquaculture procedures have limitations since they rely on manual monitoring and do not have access to real-time data. Inefficiencies, decreased agricultural yields, and environmental issues are all potential outcomes that might result from these constraints. The incorporation of Internet of Things solutions that are based on low-power wide area networks (LPWAN) provides a transformational way to addressing these difficulties. The Low Power Wide Area Network (LPWAN) technology offers a strong platform for the deployment of sensor networks throughout aquaculture farms. This technology is characterized by its low power consumption, long-range communication, cost-effectiveness, and network security. Informed decision-making is enabled by real-time data gathered by low-power wide-area network (LPWAN)-based Internet of Things (IoT) devices. This enables efficient resource management, increased illness prevention, and enhanced fish health. In addition, the granularity of the data makes it possible to deploy precision feeding schemes, which reduces the amount of waste produced and the detrimental effects on the environment. Beyond simple monitoring, the potential of low-power wide-area network technology is extensive. The combination of artificial intelligence and cutting-edge sensor technology has the potential to open up many more opportunities. For example, artificial intelligence systems may evaluate sensor data to forecast the occurrence of probable disease outbreaks or equipment breakdowns. This enables preventive maintenance and reduces the likelihood of such events occurring. Additionally, biosensors that directly measure fish health indicators may offer early indications of stress or disease, which enables targeted actions to be taken before the stress or illness develops into a more serious condition.

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