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Exploring Innovations in Aquaculture: A Comprehensive Investigation of Smart Fish Farming Techniques

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Abstract

Aquaculture, or fish farming, is a crucial industry for satisfying the rising demand for seafood on a global basis. However, issues with disease identification, feed optimization, environmental effect, and water quality control frequently confront conventional agricultural practices. Combining artificial intelligence (AI) and Internet of Things (IoT) technology offers a viable way to overcome these obstacles and improve the sustainability and effectiveness of fish farming methods. IoT sensors deployed in aquaculture facilities enable real-time monitoring of crucial parameters such as water temperature, pH levels, dissolved oxygen, and ammonia concentrations. These sensors collect vast amounts of data, which, when combined with AI algorithms, can provide valuable insights for farm management. AI algorithms can analyse the data to predict trends, identify anomalies, and optimize operational processes. Predictive analytics for managing water quality is an essential application of IoT and AI in fish farming. AI systems may anticipate any problems with water quality before they arise by evaluating recent sensor readings and previous data, giving farmers the opportunity to take proactive preventive action. Additionally, AI-driven feed optimization systems can modify feeding schedules and amounts to minimize waste and maximize growth by analysing fish behaviour, ambient factors, and dietary needs. AI-based disease detection systems are able to investigate physiological data and fish behaviour to identify signs of illness at an early stage. This allows for rapid diagnosis and lowers the likelihood of disease epidemics. IoT-enabled environmental monitoring systems may also measure variables like water flow and weather, which can assist farmers in reducing risks and adapting to changing environmental circumstances. Given that this study proposes an innovative approach for overseeing aquaculture, it was thought necessary to offer a thorough background scenario in order to frame the important concerns.

Introduction

The industrialization of aquaculture has been aided by the vast amount of information that has been produced in this field. Since many parameters in today's aquaculture systems need to be managed, industrialization is closely linked to the adoption of technology. Certain procedures need for specialized equipment and facilities that have been created via extensive study and creative thinking. Technological developments have typically helped to modernize aquaculture since many goods that were not created with agricultural systems in mind have found use in this field. Certain technical innovations are designed for use in aquaculture. Water redistributing systems, automated time-controlled feeding systems, clean up systems, and semi-submersible cages are a few examples. These developments call for specialized technical uses grounded in solid scientific knowledge. Aquaculture system development may proceed with confidence because of the technology's obvious advantages. The following stage will enhance automation, simplify administration, and assist decision-making processes through the use of computer programs and artificial intelligence (AI).

Equation-based empirical, statistical, and mathematical models have been utilized by researchers studying fish populations to analyse various aspects including the length-weight connection, condition coefficient, food selectivity index, food conversion ratio, and specific growth rate. These measurements are frequently used to evaluate the health of cultivated fish and the results of system changes intended to increase production effectiveness. Beyond the scope of statistical formulae or models, there exist qualitative components that comprise biological or environmental complexity. Applying artificial intelligence (AI) is beneficial in these circumstances and calls for creating methods to replicate or automate the brain's computational functions in order to exert control over cultural systems. The two primary areas of artificial intelligence (AI) that simulate human intellect in machines to some degree are fuzzy logic and artificial neural networks (ANN). In order to simulate the mechanisms by which motor nerves transmit signals from the brain to effector organs for action and sensory nerves transmit sensations detected by sensory receptors to the brain as electrical impulses, neural network models attempt to mimic the fundamental operations of the central nervous system. A basic form of such neural processing is termed an Artificial Neural Network (ANN). It's essential to recognize that these systems' complexity pales in comparison to the human nervous system. Describing the human brain as one of the most intricate entities in the universe is likely not an exaggeration. Neurons serve as interconnected processing units vital for various facets of brain function. Output is produced at the other end of the network by data provided at one end. Layers of neurons are located between these ends. Though they are inspired by brain neurons, artificial neural networks (ANN) do not replicate the workings of neurons. Compared to their counterparts who are biologically neurotic, they are far simpler and far less in number.

The purpose of artificial neural networks (ANNs) is to handle data and signal processing in systems where knowledge is represented by parameters in dynamic systems. The analytical devices within a hatchery system can detect chemical changes, which are then relayed to a central command system (computer programs). The aquatic life (a biological entity), non-biological materials (such saltiness, pH, dissolved oxygen, and humidity), and fish waste are all under the control of this system in the hatchery. The central command system uses these inputs to transmit motor routes, or signals, to regulators (such air purifiers and water flow control devices), telling them to modify their operations in accordance with pre-set algorithms. Artificial neural networks (ANN) will be incorporated into complex smart models as aquaculture develops in the twenty-first century, requiring a large amount of computer processing power enabled by specialist software.

Aquaculturists recognize that the physiological rates and metabolic outputs of cultivated species (such as ammonia levels, pH, and growth) can be regulated by adjusting ambient factors and inputs to the system (such as saltiness, feeding rates, dissolved oxygen concentrations, and population density). These measurements are crucial for commercial aquaculture facilities to minimize their environmental impact, while simultaneously optimizing efficiency, albeit at the cost of increased labour and utility expenses. Anticipated benefits of implementing aquaculture process control systems include enhanced process efficiency, reduced energy and water wastage, decreased labour costs, minimized stress and illness among the fish population, improved accounting practices, and a better comprehension of the aquaculture procedure (Lee, S., et al. 2019). A restricted number of Artificial Intelligent systems that are now on the market have limited uses, and they are built using a tried-and-true process for putting in place intuitive and inferential management systems.

Process control technology is being used to aquaculture in industrialized nations for a variety of socioeconomic reasons, including as climatic variability, high labour costs, greater competition for land and water resources, and bureaucratic regulations. These factors are propelling the aquaculture industry towards the adoption of offshore cages and pens, alongside extensive recirculating water filtration systems (Murray, F., & Bostock, J 2018; Smith, J. 2020; Jones, A., & Brown, C. 2019). High-performance automated control systems are expected to achieve two main objectives: (1) reducing the volume of pollutant-laden effluent and high-quality make-up water required for land-based recirculation systems, and (2) cutting down on labour costs associated with on-site supervision and typical feed waste in offshore aquaculture operations (Pauly, D., & Macara, J. 2020).

The integration of automation and computerized monitoring in aquaculture represents a recent advancement. This innovation encompasses various areas, including environmental monitoring and control (Pillay, T. V. R. 2018; Boyd, C. E., & Tucker, C. S. 2018; Costa-Pierce, B. A. 2018; Pauly, D., & Macara, J. 2020), feed management (Barrows, F. T., Gaylord, T. G., & Sealey, W. M. 2016), filtration systems (Tacon, A. G. J., & Metian, M. 2008; Beveridge, M. C., Clay, J., Folke, C., & Lubchenco, J. 2000; Phillips, M. J., Hough, C., & Mc Gladdery, S. E. 2009), vision systems (Becker, C. D., & Losordo, T. M. 2003; Boyd, C. E., & Tucker, C. S. 2012), and integrated systems management (Jones, A., & Brown, C. 2019, Costa-Pierce, B. A. 2018; Costa-Pierce, B. A. 2011). An exemplary instance of AI-based system implementation in aquaculture is the control of solar thermal water heating systems. The system comprises a solar collector unit for daytime hot water provision, an auxiliary biogas heater for night time and overcast conditions, a storage tank for maintaining high water temperatures, and a thermostatic valve to control hot water flow into the pond. This aquaculture system's fundamental operations can be illustrated through three levels of AI integration. Initially, data on air temperature, pond temperature, and errors are input into the first layer. The hidden layer then utilizes this information to perform various logical calculations, while the output layer adjusts water supply based on weather conditions and time of day.
This trend toward automation and intensification is happening in tandem with the growth of other commodity markets that are agricultural in nature and have many traits in common with intensive aquaculture systems.

Certain computer systems are even capable of reproducing the movements of recognized process specialists (Vasquez, M. & Liu, C. 2017). Process specialists must create explicit rules (such as "if" and "then" statements) or pictorial information (such as flow charts or logic trees). This calls for the laborious process of formalizing expert knowledge into rules for a process and then comparing the expert system's output to the expert's conclusions. method specialists with a lot of expertise sometimes find this method adversarial, especially when the results of their previous rules conflict with this approach. To fine-tune or modify the rules, the procedure calls for a patient expert and an even more patient computer programmer. The capacity of a process expert to swiftly disseminate insight across the aquaculture business is the most important outcome of a knowledge-based expert system.
AI helps decision-support systems by emphasizing experience learning and interactive problem-solving in knowledge-based systems. The aquaculture sector will undoubtedly flourish with fewer risks and greater profit without cost inflation if knowledge that encompasses the pragmatics and semantics of real-world problem-solving sets is used.

Some aquaculture companies that are driven toward technology-intensive culture utilize an artificial intelligence tool known as the "Expert System" (ES). It is a type of computer software that, by imitating experts, can assist in solving specific difficulties related to aquaculture. ES helps farmers adopt the best approach to address their captive stock-related issues by storing a wealth of knowledge and experience from experts and practitioners in that field. This uses a systems approach to apply particular information, going beyond general thinking. The authors of (Noraini Hasan, Shafaf Ibrahim, Anis Aqilah Azlan, 2022) gathered a total of 90 images for the three classes of white spot (30), red spot (30), and healthy (30). They only used the CNN model, which had a 94.44% accuracy rate.
The authors of (Md. Rashedul Islam Mamun, Umma Saima Rahman, Tahmina Akter, 2023) collected a total of 1382 photos for each of the four classes—White Spot, Black Spot, Red Spot, and Fresh Fish—in order to create an accurate model. Deep learning performs better than machine learning in the classification of images. To find the affected area in this study, the scientists employed a segmentation technique. Performance is also measured using two ensemble approaches and nine widely-used classification algorithms with the use of performance assessment matrices. The VGG16 and VGG19 ensemble models obtain the maximum accuracy of 99.64%, while the pre-trained model ResNet-50 outperformed Random Forest with an accuracy of 99.28%.

Food and Agriculture Organization of the United Nations (2018) emphasized the significance of using case-based reasoning (CBR) as a fundamental part of a decision-support system to collect, store, and reuse information. CBR is a type of reasoning where a new problem is addressed by looking at previous solutions to a problem that is similar to it. This four-step approach consists of a problem description, a solution, and an outcome: 1. Retrieve: a brand-new issue that is explained as a query case. 2. Reuse: Taking up this case, one may either reuse it straight or modify it to match the query case in a different way. 3. Revise: Applying the solution and having it reviewed by a domain expert are common ways to evaluate the solution. 4. Update it to a case base in order to retain the knowledge gained from the upgraded problem-solving experience.

AI tools serve as a foundation for decision-support, emphasizing experiential learning and interactive problem-solving inside a knowledge-based system. This approach makes use of information that encapsulates the pragmatics and semantics of real-world problem-solving environments, with particular relevance in aquaculture.

What are the reasons for the utilization of AI in modern aquaculture?

1. Before the advent of Knowledge Management (KM) tools and collaborative workspaces, individuals had to rely on accessing centrally maintained and regulated databases. In contrast, the development and dissemination of new information relied on the gradual productivity of a small number of individuals inside a core team. The process may be made faster and simpler by designing AI systems so that stakeholders can meaningfully contribute to the generation of new information from their experiences and combine it with knowledge derived from scientific experiments. This also eliminates the requirement for databases under central control. Artificial intelligence (AI) systems are flexible enough to adjust to new knowledge that may surface from tests carried out in novel ways under variable circumstances.

2. Within a research institute or company, knowledge bases allow individuals to quickly provide feedback, acquire new knowledge, collaborate, and, when necessary, create and modify new knowledge. Participants are the ones who gain most from using these tools.

3. Knowledge bases provide a thorough background on a subject by organizing questions according to "what, why, who, where, when, and how."

4. While acknowledging their valuable support, it's noteworthy that certain information repositories, such as wikis, operate independently of the IT department. This is particularly beneficial as many stakeholders in the aquaculture industry may not possess advanced technical skills, allowing for swift creation of

knowledge bases by the users themselves. Subsequently, these users can leverage Knowledge Management (KM) tools to both contribute to and access critical information within the knowledge base.

Using AI-powered applications in water quality control systems

Controlling the standard of water in aquaculture:

Maintaining high-quality water is essential for the successful cultivation of any aquatic species. Optimal water quality varies for each species and must be closely monitored to ensure optimal health and growth. The quality of water within the production systems significantly affects the health of organisms and the overall cost of bringing products to market. Aquaculture operations routinely monitor various parameters such as temperature, dissolved oxygen, pH, alkalinity, hardness, ammonia, and nitrites, among others. The growth of aquaculture stock is heavily influenced by water quality, which directly impacts productivity and financial outcomes. When evaluating the quality of water, saltiness, pH, oxygen concentration, and water temperature are important variables to take into account.

Automation is necessary for maintaining quality of the water:

Maintaining quality of the water is a crucial aspect of aquaculture, and it usually calls for human intervention if a parameter changes in a way that lowers the quality of the rearing medium. Automation made possible by the creation of an AI system would allow for the reduction of human intervention, which would save money and provide a prompt solution to the issue.

The temperature, dissolved oxygen content, salinity level, and pH level of the fish tank's water are all measured using four input boxes that make up the user interface. The four buttons are coded with logic to verify that the four parameters are at their optimal settings. This serves as the software's "brain," doing logical computations to ascertain whether the levels are inside or outside of the ideal range.

A system for managing water quality that uses artificial neural networks:

Under some circumstances, the robot might be able to alert the hatchery operators to the need for action, but even with the information it gathers, it might not be able to solve the issue. Think about the fish stocking density in an incubator tank. A computer's image detector may be connected to a single webcam sensor, and it will use the sensor's colour, shape, and artificial intelligence (AI) to identify the species and quantity of patients that have received treatment. To obtain the values, the software program communicates with the hardware. In addition to offering remedial alternatives, the application triggers an AI-powered device to carry out the required corrective actions instantly when the values go outside the range. Important water quality metrics including salinity (10–30 ppt), dissolved oxygen (5–6 mg/L), pH (6.5–9), and temperature (25–32°C) are stored in our hatchery using a customized software prototype made for Asian sea bass breeding. These criteria are embedded into the "brain" of the system, allowing it to decide if recorded values are within the given range. An alarm system may be incorporated with the program to rapidly notify hatchery workers of any deviations. Additionally, employees may have color-coded each parameter and values that are above the threshold range to help with the rapid detection of problems with the quality of the water.

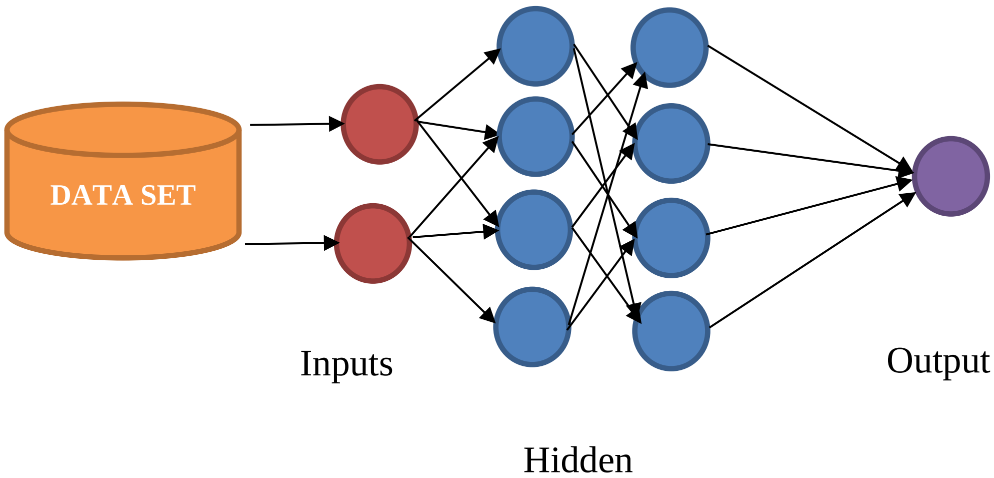

Figure 1. Artificial neural network

Real-time data is gathered by monitoring elements like pH level, dissolved oxygen, turbidity, ammonia, total dissolved solids (TDS), and temperature for the purpose to keep a lid on the water quality in aquaculture. Applying this technology has a number of advantages, one of which is improved pond water quality monitoring. When water quality drops, it instantly alerts farmers so they may take appropriate action. Our objective is to create a cheap, versatile, easy-to-configure fishpond water quality monitoring system by utilizing the Internet of Things (IoT) and Arduino platforms.

A. Temperature Sensor

The ideal temperature range for fish development in warm water is typically 25°C to 32°C (Source: World Health Organisation). The water's temperature is still within the typical range right now. For warm-water species, growth usually stops at 20 degrees Fahrenheit, whereas for cold-water species, it stops at 10 to 15 degrees Fahrenheit. Aquaculture has particular temperatures to be reliably maintained, thus steps like minimizing the amount of direct sunlight, raising aeration, and replacing the water once a day are required.

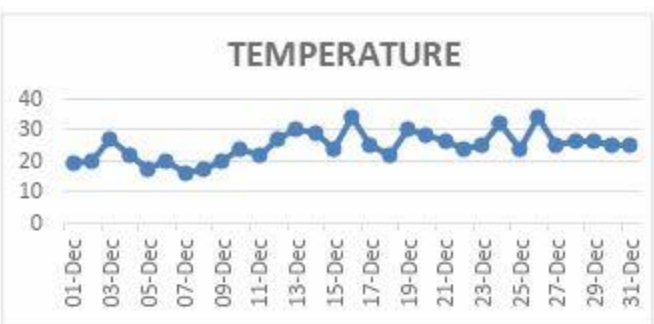

Figure 2. Temperature graph

B. pH Sensor

Although fish cannot survive in water with a pH below 4 or higher than the critical pH of 11, the pH range that is frequently suggested for aquatic habitats is between 6.5 and 9 (Source: World Health Organisation). The pH levels that are 4-6 and 9–10 considerably decrease growth. Techniques like doing partial water changes, using clarity defence chemicals, and using pH reduction kits are frequently used to control pH levels in aquaculture environments.

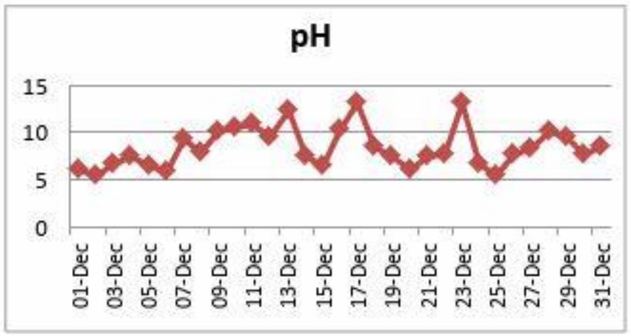

Figure 3. pH graph

C. Dissolved oxygen

Dissolved oxygen concentrations should ideally range from 5 to 6 mg/L (Source: World Health Organisation) for healthy fish development and activity. Fish raised in aquaculture cannot live when concentrations fall below 3 mg/L. In order to keep a pond healthy, dead plants and animals must be removed, fresh water must be added to the pond on a regular basis, and vegetation near the bank must be trimmed back to allow more sunlight to enter the pond.

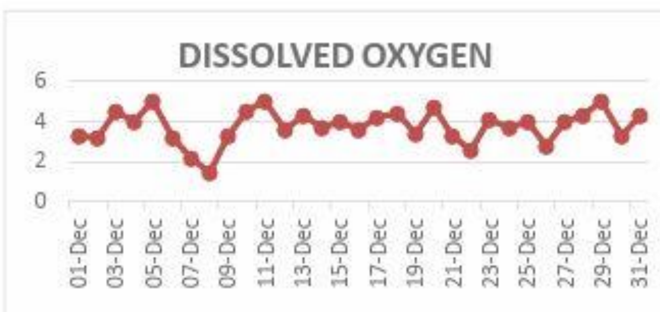

Figure 4. Dissolved Oxygen graph

D. Turbidity Graph

A fishpond's turbidity should ideally range from 30 to 80 (Source: World Health Organisation); anything less than that is deemed undesirable. In order to efficiently treat low turbidity levels and remove suspended clay particles from muddy ponds, materials like calcium carbonate, aluminium sulphate, and calcium sulphate can be used.

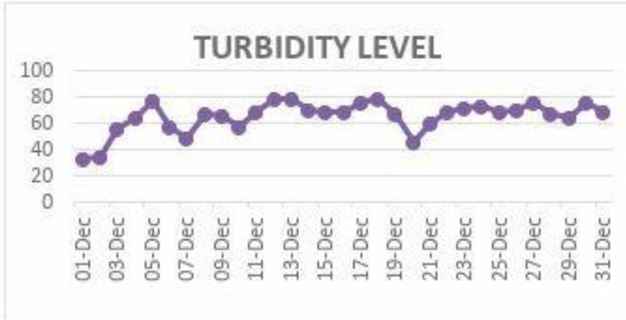

Figure 5. Turbidity graph

E. Ammonia graph

Ammonia concentrations in a fish pond usually vary from 0.1 mg/L to 2.0 mg/L (Source: World Health Organisation), which can be fatal. Reducing the feeding rate, adding bacterial supplements, supplementing the bacteria with fertilizers, deepening the pond, adding organic carbon sources, and using ion exchange materials are some strategies that may be used to efficiently regulate ammonia levels.

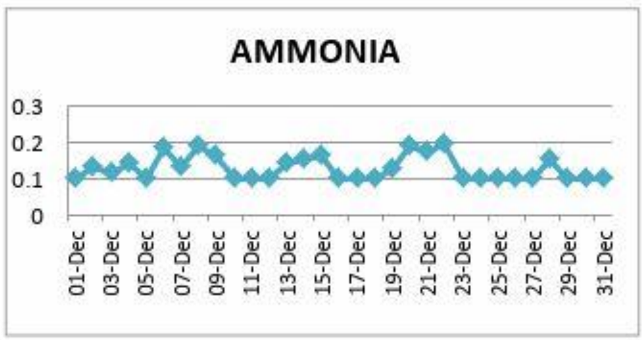

Figure 6. Ammonia graph

Additionally, we will explore the potential applications of aquaculture in addressing global challenges such as climate change, biodiversity loss, and food insecurity. By integrating aquaculture with other sustainable practices, such as aquaponics and agroforestry, we can create synergies that benefit both the environment and local communities.

Fish in aquaculture ponds live in a very complicated environment, thus maintaining their health is crucial for the long-term production of healthy fish. Carp productivity is frequently hindered by their susceptibility to many illnesses, especially in intensive aquaculture. Typically, high stocking density, over or underfeeding, a dirty pond, and the use of extraneous inputs are the main causes of stress in fish, which increases their susceptibility to illnesses. Additionally, this method encourages pathogen growth and proliferation in the environment. The estimated overall economic loss (in Indian rupees) and the estimated loss of fish output (percentage of total production) in Assam were calculated to be approximately 10.8% (30,770.00 per hectare) and may be comparable in other states as well. By using Computer Vision-Based Disease Diagnosis, which improves computer vision algorithms to precisely diagnose fish diseases using visual cues acquired by cameras, this predicted economic loss could be decreased. Creating deep learning models that accurately identify and measure disease symptoms is one way to do this.

Intelligent fish feeding system using Artificial Intelligence

The hardware and computational components make up the two aspects of the proposed research project. The gear includes an Arduino, a personal computer, a food dispenser, a fish tank, and a webcam. The planned feeder and smart feeder are the two main feeding algorithms that make up the computational portion. By releasing food according to a prearranged schedule, the programmed feeder is used to entice fish and introduce them to the system. The smart feeder is employed to response to fish behaviour as shown as in Fig 7.

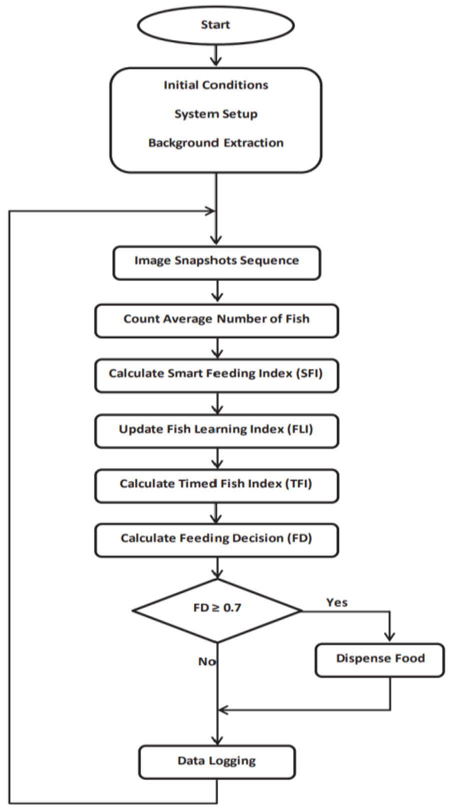

Figure 7. Feeding Algorithm Flowchart

Hardware Setup

1. **Automatic dispenser:** A horizontal, cylindrical food container with an adjustable gap at one end is the automated dispenser. A stepper motor is attached to the container. A tiny amount of food is deposited into the tank by spinning the container 360 degrees.

2. **Webcam:** The tank's feeding area is covered by a webcam that provides a top-down view of the fish's movements. The system's affordability is guaranteed by the usage of the webcam.

3. **Interface Circuit:** The software algorithm is able to control the automatic dispenser in response to the fish's movements since it is connected to an interface circuit.

Software Setup

1. **Graphical User Interface (GUI):** The Arduino controller and webcam can be chosen by the user via the interface.
2. **Automatic Background Extraction:** As soon as the software recognizes hardware peripherals, background is removed.
3. **Fish counting**: The algorithm takes a series of sequential pictures of the feeding area at predefined intervals of time. To count the number of fish in the feeding region, the image is removed from the backdrop using blob analysis.
4. **Smart Feeding Index (SFI):** Fish activities and the amount of time since the last feed are the two elements that determine the smart feeder index. The reason there are more fish at the feeding location is either that they are asking for food or that food has recently been dropped.
5. **Timed Feeder Index (TFI):** The purpose of the timed feeder is to train fish on the new feeding system by stimulating them with food signals four times a day, at 9:00, 12:00, 15:00, and 18:00, according to a prearranged schedule. Once the fish learning index reaches a predetermined threshold, the timed feeder is switched off.
6. **Fish Learning Index (FLI)**: After being weighted using the fish learning index, the two feeding indices (SFI and TFI) are combined into a single feeding probability.
7. **Feeding Decision:** The FLI value is used to make feeding decisions. A feeding signal will be sent to the Arduino to activate the feeder if the FLI value rises beyond a predetermined threshold.

Handling illnesses in Fish

1. Effective management techniques are necessary for a healthy health management program at every level of aquaculture operations.
2. As treating a sick fish in isolation is more challenging than treating land animals, prevention is always a better strategy for controlling the disease outbreak in aquaculture than treating the illness itself.
3. Fish health can be managed by taking preventive steps, particularly in the winter, such as keeping the water's overall alkalinity at a healthy level, controlling its depth, and preventing overfeeding.

A comprehensive IoT framework that integrates various sensors for water quality monitoring, fish behaviour analysis, and disease detection. The framework will provide a holistic view of aquaculture conditions and enable proactive disease management. Enhance computer vision algorithms to accurately diagnose fish diseases from visual cues captured by cameras. This includes developing deep learning models that can classify and quantify disease symptoms with high accuracy.

Conclusion

The research offers an intelligent aquaculture system that maximizes the application of current information, resources, and technology to improve production effectiveness while reducing inputs and costs. The aquaculture industry may benefit from utilizing the internet and digital technologies that several countries, including India, have made significant advancements in. It acts as an example of how cutting-edge methods may be used to aquaculture, one of the increasingly significant seafood producing systems. Significant developments in instrumentation technology over the last few decades have made it possible to use sophisticated devices like those made available by YSI for continuous multi sensor water quality monitoring. These sensors can now be combined with wireless communication systems to form a single sensor network platform that can be used locally or remotely via a mobile phone to monitor aquaculture water quality parameters (such as temperature, salinity, pH, and dissolved oxygen) in real-time and digitally. This integration requires independent hardware design and operational programming for corrective actions, managed by a neural network linked to robotic systems. Moreover, aside from monitoring and controlling water quality, this sensor-digital combination facilitates information sharing among farms through shared devices and applications, thereby enhancing the utilization of cloud computing for comprehensive data analysis from diverse sources.

The anticipated next phase involves integrating AI with robots, marking a significant and captivating advancement in robotics. Artificial intelligence stands at the forefront of this field, where a computer's AI system gathers information through sensors or human input. Using this information, the computer executes various actions based on a predefined program, predicting the most suitable action. However, it's important to note that the computer can only address issues it's designed for and lacks autonomous analytical capability. Robot software consists of directives outlining tasks for mechanical devices or robots and guiding their movements accordingly. The programming of a robot intended for aquaculture operations is based on the concept of information flow, where changes in one variable (such as dissolved oxygen) should prompt corresponding changes in others (like dissolved gases in water or fish survival). Employing artificial neural networks (ANN), the robot mechanically responds to these changes to find a solution. The system can be operated using various devices, including tablet computers, desktop computers, and mobile phones running the Android operating system. With mobile phones becoming increasingly ubiquitous across all sectors of society, even in remote areas, managing aquaculture as a primary or secondary food production system is facilitated by this versatile tool.

Addressing biofouling is another critical task integral to fish farming. It's widely understood that biofouling reduces water exchange within marine cages, hindering the ingress of oxygen-rich water. Consequently, fish growth is stunted, illnesses become more prevalent, and mortality rates increase. Moreover, biofouling adds weight to the cage and shortens its lifespan. Currently, significant human effort is required to maintain biofouling-free cages. However, robots can efficiently carry out net cleaning tasks, alleviating this burden.

Conflicts of Interest

The writers have disclosed no conflicts of interest.

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