RESEARCH ARTICLE

Detecting Fish Movement Behavior Based on Constant Temperature and pH Using the IoT and Real-Time Object Detection Model

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Abstract

This paper introduces a novel approach to water quality monitoring utilizing fish behavior as an indicator of aquatic environmental conditions. The proposed system integrates advanced technologies, including computer vision, sensors, and data analytics, to track and analyze the movement patterns of fish in real-time. Deployed sensors measure key water quality parameters such as temperature, pH, dissolved oxygen, and turbidity, while cameras capture fish activities within the monitored water bodies, then the livelihood of the fish will be affected. With problems that arise, solutions can be prepared by analyzing key components. Two components consist of a system that can automatically set fish feeding and the second component is water property measurement and level monitoring using the sensor module and electrical equipment with automatic video recording equipment installed, in observing the behavior and livelihood of aquatic animals. It has a communication connection in the form of the Internet of Things. We have developed a system that allows devices to measure temperature and pH in water and to display via the Internet for use in online data tracking and automatic installation of video recording equipment. By correlating observed fish behaviors with concurrently recorded water quality data, the system establishes meaningful relationships that enable the continuous assessment of the aquatic environment. From the results, it was known that the best conditions for the fish to survive. The project can be used as a prototype for creating an automatic fish tank that can adjust various parameters within the water if it is not appropriate for the well-being of aquatic animals. This innovative approach contributes to the advancement of environmental monitoring systems, fostering a deeper understanding of the dynamic interplay between aquatic ecosystems and water quality parameters.

1. Introduction

The issue of water sources for aquaculture arises from inappropriate pH and temperature levels, which are crucial for the survival of aquatic organisms. Unsuitable pH levels can lead to abnormalities, stunted growth, reproductive issues, or even death in aquatic animals. Monitoring water temperature is equally vital, as fluctuations, whether too high or too low, can negatively impact the aquatic environment. Therefore, careful attention must be paid to maintaining optimal pH and temperature levels in aquaculture settings to ensure the well-being and productivity of aquatic species (Matarneh et al., 2024).

The optimal water conditions for fish are contingent upon the particular species being housed. Each fish species exhibits distinct preferences regarding water temperature, pH, hardness, and other quality parameters. Nonetheless, adhering to some general guidelines can facilitate the establishment of a conducive environment for the majority of typical aquarium fish. Tropical fish, for instance, typically flourish in water temperatures ranging from 24°C to 28°C, while maintaining a

pH level within the 6.5 to 7.5 range is conducive for most freshwater fish (Lopes et al., 2020). Some fish species may have specific pH preferences, so it is essential to research the requirements of the particular fish you are keeping. It is crucial to research the specific needs of the fish you intend to keep and to regularly monitor and test the water parameters to ensure a healthy and stable environment. Different fish species may have unique requirements, so tailoring the aquarium conditions to match their natural habitat is key to their well-being (Saad et al., 2020).

Understanding the behavioral patterns of fish, particularly concerning temperature and pH, is pivotal in comprehending their ecological preferences, reproductive habits, and overall health. Various aspects of fish behavior, in relation to temperature and pH, shed light on these dynamics. Different fish species exhibit distinct temperature preferences rooted in their native environments. Observing the pathways fish navigate in response to temperature gradients aids in deciphering their thermal needs. Moreover, fish frequently modulate their activity levels in accordance with temperature fluctuations (Nyanti et al., 2020). Observing the paths fish take throughout different times of the day or in varying temperature conditions aids in comprehending their diurnal and seasonal activity patterns. pH levels can influence the availability and palatability of food sources, prompting fish to exhibit specific paths or foraging behaviors in response to pH variations. Understanding the interplay between fish behavior paths and temperature and pH is vital for effective fisheries management, aquaculture practices, and conservation endeavors. Monitoring these parameters alongside behavioral observations facilitates the creation of optimal conditions for fish health and productivity. Advanced technologies such as telemetry, sensors, and underwater cameras contribute to comprehensive studies on fish behavior concerning environmental variables (Kori et al., 2018).

Observing the behavior of aquatic animals during daily life can provide information for behavioral analysis of aquatic animals that can provide a sense of the living system within the reservoir. From the above issues, the organizers are interested in making a device that can measure temperature and measure pH in water to be displayed via the Internet to be used to track data online (Liu et al., 2024) and installation of movie recording equipment automatically. It is convenient to receive information to a device that will help prevent and lead to solutions for those who want to use it further. The analysis of living organisms provides insights into understanding the goals of their behavior to be achieved. Computer observation and image comparison contiguous frames from video must be compared by the modern technology. It can be of various types, such as video surveillance or monitoring the behavior of an interested creature. This provides insights into understanding the goals of their behavior. By dividing between the parts

that cause the opportunity to be achieved. Behavior can be tracked and analyzed for this goal (Zhao et al., 2019). Crawling involves aggregating content tailored to the needs of the target audience, triggered either by specific segments of the video or by particular behaviors exhibited by the target audience.

2. Related work

2.1 Properties of pH and Temperature in Aquatic Animal Farming

The pH value (Potential of Hydrogen) indicates the amount of hydrogen ion concentration in the water. It represents the pH of the water, ranging from 0-14, with a pH value of 7 indicating neutral water conditions. High pH values more than 7 indicates an alkaline water condition and a pH value lower than 7 indicates an acidic water condition. In general, the pH value in water sources depends on the terrain and the environment in many ways, including soil and rocks. A pH value that is too high or too low will not be beneficial to aquatic animals (dos Santos et al., 2020). The pH value suitable for raising aquatic animals is shown in Table 1.

Table 1. Web extraction experimental result.

pH	Extracting Method
under 4	Aquatic animals can die
4.0–6.0	Growth is slow, reproduction is disrupted
6.5–9.0	Suitable for aquaculture
9.0–11.0	Not suitable for living in for a long time
more than 11.0	The water conditions are toxic

2.2 Internet of Things (IoT)

The Internet of Things (IoT) is a vast network that interconnects various devices and technologies, facilitating seamless communication between devices and the cloud, as well as among the devices themselves. This connectivity has been made possible by the availability of affordable computer chips and high-bandwidth telecommunications, resulting in billions of devices being connected to the internet (Manzar et al., 2022).

2.2.1 Micro Controller

A micro Controller is a compact control device that possesses capabilities similar to computer systems. It integrates the CPU, memory, and ports—the essential components of a computer system—within a single circuit. This integrated design allows for versatile applications through the creation of circuits tailored to various tasks. By programming commands to control Input/Output pins, the micro controller can execute specific functions. It serves as a versatile system capable of managing an array of devices, suitable for both digital and analog applications. In the contemporary era, Arduino stands

out as a readily available micro controller board, derived from ATMEL's ARM family Controller. The notable advantage of this micro controller board lies in its open-source nature, allowing for extensive use and development. Additionally, the incorporation of a Boot Loader to the ARM facilitates the seamless uploading of code to the board. The development of software for Arduino board control is typically carried out using C++.

2.2.2 Sensor

A sensor is a device crafted to perceive a physical quantity, employing diverse operational principles depending on its type. It produces a signal that corresponds to the quantity of the object being detected. This is accomplished by converting the input signal, which is defined by physical properties, into an output signal with electrical properties.

Sensor DS18B20 is a temperature sensor that can measure -55°C to 125°C, error +/-0.5 °C (in the range between -10°C to 85°C) can be used in a variety of research work, whether it is finding the coldness value in refrigerators, mushroom cultivation plants, medical freezers, fish farming, to anything that needs to measure temperature or high humidity or in water (Manjakkal et al., 2021). Analog pH meter Sensor is a sensor used to measure the acidity - alkalinity in liquids. There is an acid-base measurement range that the sensor can measure at 0-14. The measured value is an analog value in the form of voltage. The device is shaped like a bar made from epoxy. The round glass bulb sensor at the end is a glass electrode and there is a reference electrode like a wire inside the device.

2.3 Motion Detection Technology

Object Detection serves as a pivotal technology in the field of computer vision, with its primary aim being to accurately identify and locate objects of interest within both images and videos. This task necessitates not only recognizing the inherent nature of the object but also precisely defining its spatial coordinates within the visual content. The spectrum of objects that Object Detection can discern is vast, encompassing everything from individuals and animals to inanimate entities. The development of Object Detection methodologies has been driven by the imperative need to empower machines with the ability to systematically scan and identify such entities within the vast expanse of visual data found in images or video streams (Qiao et al., 2021).

The primary objective of Object Detection is to pinpoint the location of objects of interest in an image or video. This involves determining the nature of the object and specifying its position within the visual content. Objects can range from individuals to animals or inanimate entities, and this method has been developed to enable machines to systematically search for such entities in pictures or videos (Chen, 2023). A key feature of object detection is its ability to calculate the trajectory or movement path of the detected objects, providing valuable information about their spatial dynamics.

Fiji (imageJ) Open-source plug-in algorithm of the imageJ program can calculate Fraction Area or proportion of area (Schindelin et al., 2012). And the measurement area can be found in the program. An efficient object tracking and tracking algorithm based on image sequence analysis or picture frame. It examines the spatial and temporal changes of objects during a sequence of frames, without having to pre-train to know anything first. It will start processing from the image in the frame, tracking objects in real-time using Hungarian assignment to calculate relationships between objects and processing by using YOLO's algorithm by dividing the image into sized boxes (Redmon et al., 2016), $N \times N$ and using an algorithm to calculate the possibility of that channel, whether it is an object in the dataset or not, and Single Object Tracking aims to track a specific target object throughout the video recording. The object tracking algorithm starts by defining the boundary of the target object in the first frame. Then find the same object in the remaining frames. The object tracking results are quite accurate and can track objects even if they partially overlap. But if the object is overlapped by more than 70%, it will cause loss in tracking. There are also limitations on Transitions between frames that create distance between objects. The clutter of the background affects the total loss value. The value can be found either in area units such as square millimeters or in pixel units of the image. Various values can be prepared in statistical form (Diwan et al., 2022) by measuring the length of the cell or measuring the density of images and displaying them in bar charts or histograms.
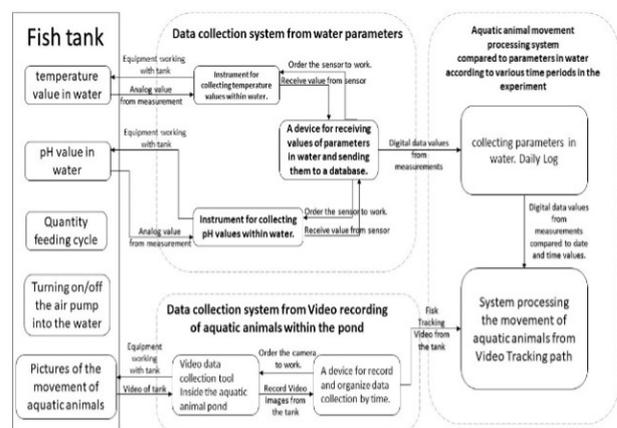

Figure 1. System architecture.

3.   Materials and Methods

Creating steps for conducting research, the researcher designed a monitoring system to assess the water quality of fish in the experimental tank. This system will involve reporting crucial parameters and capturing images depicting the movement behavior of fish in the tank (Pasha Mohd Daud et al., 2020). Additionally, the researcher developed a sensor system capable of real-time measurement of pH and temperature within the water. Simultaneously, a system for imaging the movement of fish within the water was also created.

The system architecture for detecting fish movement behavior is illustrated in Figures 1 - 4.
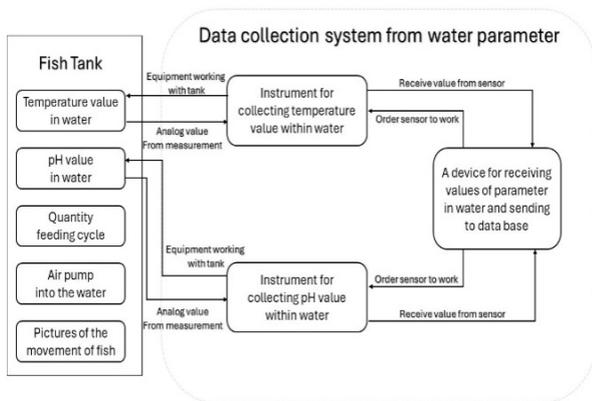

Figure 2. System architecture: Data collection system from water parameter (Part I).
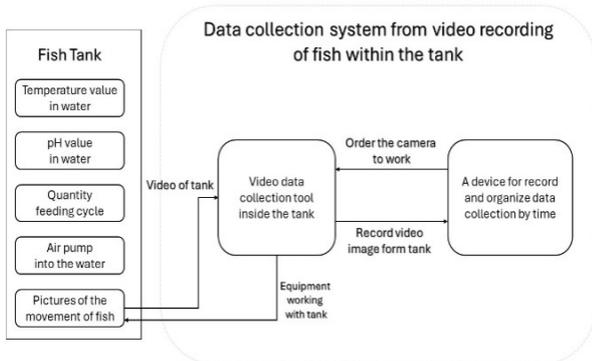

Figure 3. System architecture: Data collection system from video recording of fish within the tank (Part II).

The data storage system and data recording process have been developed. That can check data in real time and can analyze data on the movement of fish within the tank by correlating the data to develop a process for analyzing behavior from fish movement behavior and the quality of water in the pond from movement path data (Ismail et al., 2022) of fish and it can be developed to create a model for classifying water quality to find relationships from fish movement behavior by referring to the results of experimental data, movement distance and movement speed values.
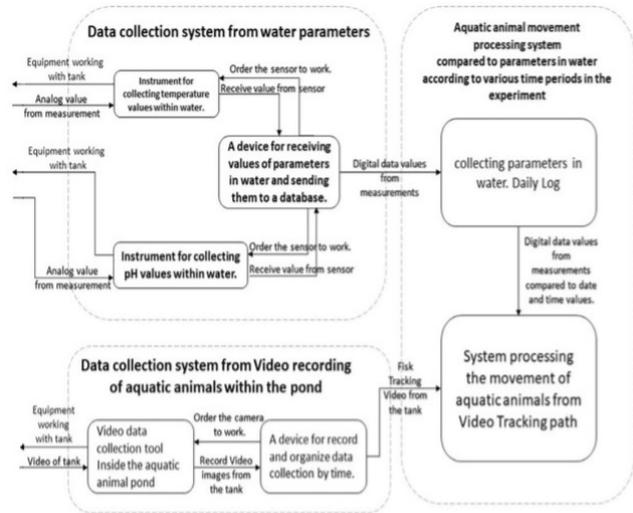

Figure 4. System architecture: Fish movement processing system compared to parameters in water according to various time periods in the experiment (Part III).

3.1   Creation of Systems and Equipment

This research involves the design of both the layout and operation of a water quality monitoring system centered around fish behavior and movement. The development includes a recording system for aquarium animations, pH levels, and water temperature, utilizing sensors to transmit values via a wireless network. The aim is to measure water parameters at different experiment levels. The process entails creating equipment for data collection, encompassing information on dynamic parameters and video animations of fish in tanks. To achieve this, the utilization of a micro controller and sensor devices becomes essential for measuring changing parameters, specifically pH and temperature in the water.

3.1.1   Designing a System and Organizing the Functions of Data Collection Equipment

The data collection system for water parameters is tasked with storing information acquired from the water parameter measuring sensor (see Figure 5). This includes the temperature and pH values of the water. To ensure accuracy, adjustments are made by calibrating these values against standards within the water, involving the calibration of equipment. The pH value is standardized using a pH Buffer Solution, and the temperature sensor is calibrated to a standard using a Water Thermometer device. Additionally, the connection

settings of the microcontroller with the device and the internet are adjusted to optimize performance.

Figure 5. pH accelerator in water and water thermometer experiment setup.

3.1.2 Instrument for Collecting Temperature Values Within Water

This system gathers temperature data in the water by converting it through the resistance of a resistor within the circuit immersed in the water, measuring the resulting change in electric current within the resistor circuit. The temperature sensor (see Figure 6), resembling a small wire bottle, experiences a variation in its resistance value when the temperature changes. Consequently, the sensor transmits the altered electric current value (Nanyanzi et al., 2021) and then the data are extracted based on the rules defined in the wrapper configuration file.

Figure 6. Water temperature sensor experiment setup.

3.1.3 Instrument for Collecting pH Values Within Water

It functions to collect information on the pH and alkalinity within the water using the principle of Assembly of the device with an electrode (glass probe) made of special glass that is sealed at the tip, as shown in Figure 7. Inside the glass is a standard acid solution, usually 0.1 Mole HCl, along with an internal reference

electrode. This instrument works like a voltmeter, able to measure small changes in voltage (also called potential difference). On the millivolt (mV) scale, the change in electric potential or voltage in water or solution is due to the loss of electrons corresponding to the loss of hydrogen ions (H+). The electricity in the solution is measured and compared to the voltage produced by the reference solution. The voltage difference between the two is used to calculate pH.

Figure 7. pH sensor experiment setup.

Analog pH Meter Sensor must be calibrated from the sensor to display a pH value in the range of 4-7-10, as shown in Table 2 Calibrating with pH buffer 12 times, 30 seconds each time, because 12 times is the number of measurements that will result in the starting Analog output value entering a state of fluctuation of values that have begun to stabilize (Khan et al., 2017).

Table 2. Web extraction experimental result.

pH / Trial	1	2	3	4	5	6	7	8	9	10	11	12	Average
4	450	450	450	451	450	450	451	457	457	457	450	450	3.9633
7	396	396	403	403	397	397	397	397	397	397	397	367	7.0464
10	345	345	345	345	350	351	351	351	351	345	344	350	10.0185

From Table 2, at pH 4, the average value was 451.92 millivolts. At pH 7, the average analog value was 397.83 millivolts. At pH 10, the average value was 346.25 millivolts. Take the average value to plot the graph. Create a pH calibration equation, as illustrated in Figure 8.
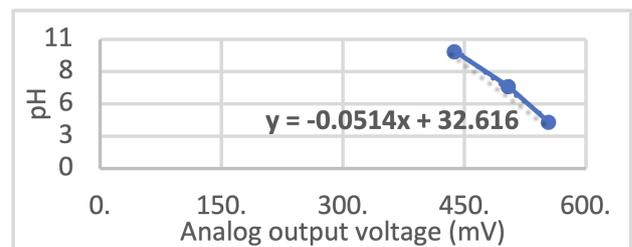

Figure 8. pH calibration equation graph from system of linear equations in two variables.

Table 3. pH sensor measurement compared with pH buffer solution.

pH / Trial	1	2	3	4	5	6	7	8	9	10	Average
4	4.00	4.06	4.00	4.06	3.84	3.86	3.84	4.00	3.95	3.99	3.96
7	7.06	7.00	7.34	7.34	6.94	6.94	7.04	6.88	6.94	6.94	7.04
10	9.94	10.0	10.5	9.70	10.0	10.0	9.89	9.94	9.94	10.0	10.01

Table 3 shows a total of 10 measurements in each period. The measured value was observed to be similar to the pH buffer solution, but there was an oscillation in the measured value near the actual value. Consequently, the average of each value was calculated to determine the measurement error. The averages were 3.9633 at pH 4, 7.0464 at pH 7, and 10.0185 at pH 10.

Table 4. pH measurement error of analog pH meter sensor.

pH	4	7	10
Error value	0.91%	0.66%	0.18%
Average error value		0.58%	

Table 4 shows the measurement error tests accuracy with pH buffer solution at pH 4 has a value of 0.91, at pH 7 it has a value of 0.66, at pH 10 it has a value of 0.18. Then the average error value was calculated, and the value was equal to 0.58%.

3.1.4　A Tool to Receive the Values of Water Parameters and to Send to a Database

The system operates by collecting data values from both temperature and pH sensors submerged in the water, as presented in Figure 9. The system design diagram is illustrated in Figure 10. These readings are then converted into digital format, enabling easy measurement and transmission through the internet network. At the core of the system lies the Micro Controller, specifically the ESP8266 type, which serves as the main integrated circuit (IC) on the module's board. However, it is worth noting that the ESP8266 IC lacks internal program storage space (flash memory), necessitating the use of an external IC (external flash memory) for program storage. The connection between the external IC and ESP8266 is established using the SPI protocol, while communication with Wi-Fi networks occurs in Serial format. Programming of the chip is accomplished using the Arduino Integrated Development Environment (IDE), providing a user-friendly platform for code development and integration (Jabbar et al., 2024).
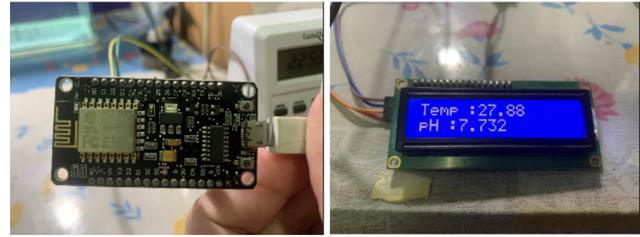
Figure 9. Micro Controller and LCD display experiment setup and monitoring.

Figure 10. System design diagram.

3.1.5　Recording System to Organize Data Collection According to Time

The system is designed to collect data from video files captured by the camera and store them in the local storage of the computer. The collected data is organized into daily logs based on the date and time of recording, or according to predetermined time intervals set during experiments under different conditions. To facilitate this organization, a recording program is utilized, which embeds the date and time information within the recording image, ensuring accurate timestamping for each captured video file.

3.2　Recording Datasets

The data collection process entails establishing correlations between fluctuations in water parameters and the average distance of fish movement within the tank. To conduct this experiment, a diverse population of aquatic animals, specifically Malawi colorless fish of different types and species, is cohabitated within the tank. These fish undergo rigorous quality checks and are provided with water feeding that complies with strict standards, ensuring their optimal condition for a period of two

months before commencing the experimentation phase. The objective is to gather data from the experiment conducted under various conditions. The system records and organizes data collection is shown in Figure 11.
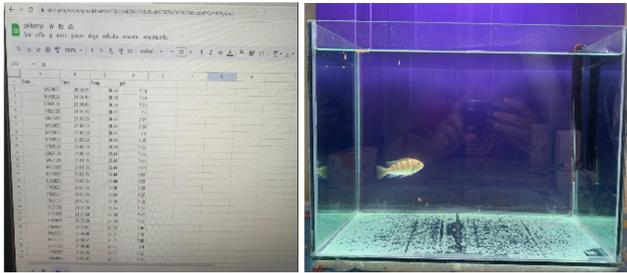

Figure 11. The system records and organizes data collection according to time and environment in the aquarium.

Data sets are collected from simulation experiments conducted in a fish tank with varying pH levels of 7, 4, and 9. The collected data includes pH measurements, water temperature readings, and animations depicting fish behavior within the tank. The simulation runs for a duration of 3 minutes. The design of the experimental results recording table can be explained in Table 5.

To generate an ample dataset for modeling the relationship between water parameters and fish swimming behavior within the tank, it is imperative to assess how changes in pH values impact the well-being of the fish. Throughout the data collection process and preliminary analysis for model development, the model's efficacy can be evaluated using the average swimming behavior as a key indicator. This evaluation aids in determining whether the water parameters, particularly pH values deviating from the optimal range, adversely affect the fish's health and behavior.

Table 5. Example of data recording.

Record Time (Minutes)	Temperature (°C)	pH
3	27	4
3	27	4
3	27	4
3	27	7
3	27	7
3	27	7
3	27	9
3	27	9

3.3 Development of a System for Processing Fish Movements Relative to Parameters in The Water at Various Times in The Experiment

The system analyzes fish movements in correlation with water parameters throughout different stages of the experiment. Its role involves processing animations by juxtaposing them with corresponding water parameters at specific time intervals. This comparison allows for the assessment of behavioral changes among the fish within the pond throughout the experiment. The Fiji (ImageJ) Realtime Object Detection Model is employed to compare fish movements captured in the animations with the recorded water parameters stored in the Daily Log (Manjakkal et al., 2021).

3.3.1 Feature Tools for Collecting Daily Log Parameters in Water

The system collects the data parameters sent from the micro Controller and store them in the Cloud Database that will record the values every 30 seconds to report the temperature in the water and the pH and alkalinity in the water according to the time that has been set. It stores values in the form of an .XLSX database file.

3.3.2 Feature Tools for Collecting Daily Log Parameters in Water

The system takes the Video Record file received from Local Storage and processes the movement by tracking the movement path or behavior of turning or moving the body in different parts by using Fiji(ImageJ) Object Detection. Model compared with parameters in water stored as Daily Log.

4. Results and Discussion

By processing the movement data and tracking the trajectory of fish (see Figure 12), we can determine the average distance covered by the fish within the tank over a three-minute period. This analysis provides insights into various parameters such as temperature and movement distance for all fish under different pH conditions. By observing how fish behave in water with varying pH levels, we can discern differences in their living behaviors, distinguishing between environments that may pose risks to their well-being and those conducive to their survival.
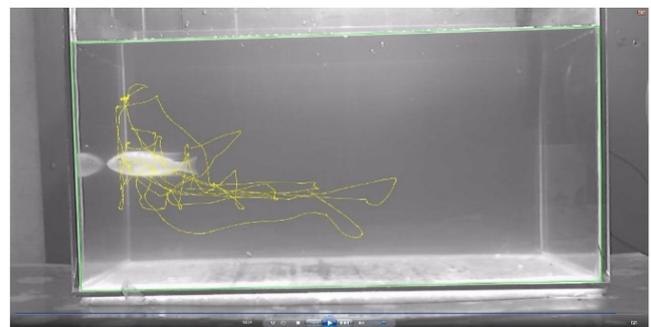

Figure 12. Image of fish movement paths in different water conditions.

Researchers have meticulously designed the experimental environment to ensure suitability across various scenarios and conditions. This involves consistently comparing equipment and tools to guarantee the accuracy and effectiveness of experimental values with each iteration. Additionally, researchers prioritize the welfare of experimental animals, providing proper care both before and after each experiment to maintain ethical standards and ensure accurate results (Winkler et al., 2023). To record the experimental results which are the final data values in the experiment, we obtain data on temperature, pH, and fish movement distance, which come out to measure the quality of water in various conditions in the experiment.

Table 6. Example of data recording.

Record Time (Minutes)	Temperature (°C)	Distance of movement (CM)	pH
3	27	266.182	4
3	27	2148.63	4
3	27	2217.74	4
3	27	500.21	7
3	27	87.93	7
3	27	312.24	7
3	27	594.76	9
3	27	1099.73	9
3	27	750.77	9

Table 6 shows the findings of a fish movement experiment conducted at different pH levels (4, 7, and 9) (Shreesha et al., 2023). In the pH 4 experiment, fish movement was observed consistently at distances exceeding 2,000 centimeters. From the 3 experiments, the average movement of the fish was 2342 centimeters. At pH level of 7, there was a difference in the movement of the fish in 3 experiments. There was a movement, greater than 500 cm and less than 100 cm. It can be concluded that the average fish movement was 300 cm. Despite the fluctuation in movement at pH levels 7 and 9, spanning between 500 and 1000 centimeters, pinpointing exact distances posed challenges. However, the average fish movement was estimated to be approximately 300 centimeters at pH 7 and 814 centimeters at pH 9. Notably, there were instances where movement distances were comparable between pH values 7 and 9. This suggests that certain fish species display a tolerance to alkaline conditions up to pH level 9, enabling them to navigate effectively under varying pH conditions.

5.   Conclusion

In this study, we present the development of a prototype system structure aimed at establishing an Internet of Things (IoT) system tailored for capturing motion pictures and monitoring aquatic animal behavior. Our primary objective is to investigate and comprehend the behavioral patterns of fish within aquaculture settings. The system is intricately designed to gather data on crucial water parameters that significantly influence the cultivation of aquatic animals. Moreover, it captures

the movements of aquatic species residing within the reservoir, providing invaluable insights into their behavioral dynamics. By leveraging this information, we can make informed assessments regarding the living conditions of aquatic animals, ultimately enhancing aquaculture practices. Our prototype serves not only as a tool for recording motion pictures but also as an advanced monitoring system that facilitates in-depth analyses of water parameters and aquatic animal behavior. This multifaceted approach is vital for obtaining a comprehensive understanding of the aquaculture environment, thereby supporting the sustainable and optimal cultivation of aquatic organisms.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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