Journal of Industrial Engineering & Management Research
Vol. 5 No. 4
http://www.jiemar.org
e-ISSN : 2722-8878

Connecting Aquaculture to the Internet of Things A Model for Aquaculture Quality and Water Preservation

Saif AlMetwally[1], Mohamed H. Mourad[2], and Mohamed K. Hassan[3*]

[1,2,3] *Department of Industrial and Management Engineering, College of Engineering, Arab Academy for Science, Technology and Maritime Transport, P.O. Box 1029 Alexandria, Egypt*

Saif.almetwally@live.con
mmourad@aast.edu
mkhassan@aast.edu

Abstract — *Water, food, and energy are vital resources for humanity. This work introduces a system design, results, economic model, and solutions for an aquaculture smart system enabling monitoring and control of fish farming tanks' water quality. Reducing water usage, producing better quality food, reducing production costs, and optimizing the aquaculture water quality are the results of this research. System design and an economic model are presented together with the system data of the working prototype including calibration, verification, and validation. A mobile application was developed to observe and regulate the quality parameters of water. This research implements Internet of Things tools to monitor and control the parameters through embedded sensors for temperature, turbidity, pH, and water level/consumption. The system automatically intervenes online depending on the value of the measured parameters through a controller-predefined logic to set the parameters within acceptable limits. The verification and validation of results are presented by comparing the online and offline data measurements. The work also presents an economic analysis comparing financial indicators for traditional and smart farms including sensitivity analysis. The system implementation leads to a reduction in water consumption by 42%, and an 8% utilization of the actuators, leading to very low energy consumption and longer actuators' useful life. The system also produces higher-quality fish satisfying the EU standards due to the controlled living environment.*

Keywords — *Aquaculture, Food Quality, Water Preservation, Industry 4.0, Internet of Things (IoT), Smart Water Systems*

I. INTRODUCTION

The increase in the global population triggered the need for increased food production with lower amounts of water consumption. As fish provides a healthy protein; aquaculture has become a source of income for a considerable food industry sector. Nevertheless, aquaculture activities consume considerable amounts of water every farming cycle.

Industry 4.0, the acronym for the fourth industrial revolution was triggered by the developed modern technologies that have tremendous potential for changing people's lifestyles and food production methods.

A lot of work was done to manage the aquaculture environment. Among these efforts were the reduction of color, total suspended solids (TSS), and turbidity from actual aquaculture effluent using Neem leaves as a natural coagulant [1]. Other studies [2] employed hollow fiber membranes made of polyvinylidene fluoride (PVDF) to regulate the dissolved oxygen (DO) in the recirculating aquaculture system (RAS) denitrification process. Additional research [3] conducted tests on small-scale aquaponics subsystems that serve as a mechanical and biological filter to improve the water quality in aquaculture. Furthermore, the treatment of aquaculture effluent currently involves coagulation-flocculation, with biobased chemicals emerging as coagulants/flocculants [4].

The purpose of this research is to develop a smart system that can enable the monitoring and control of the crucial fish living parameters in aquaculture tanks. Implementing such a system should enable the real-time treatment and recycling of tanks' water leading to the objectives of using less water for fish farming and at the same time producing high quality food at affordable prices. Traditionally, aquaculture farms are manually monitored and controlled. The manual approach to aquaculture data collection and control has generally involved time-consuming on-site inspections and operator-activated monitoring devices [5]. Traditional pond fish farms are characterized by high water consumption. For example, a pond's annual filling and draining results in a total water consumption of about 45m^3 per kilogram of fish produced [6]. The novelty of the proposed system is that

Journal of Industrial Engineering & Management Research
Vol. 5 No. 4
http://www.jiemar.org
e-ISSN : 2722-8878

it is versatile, composed of low-cost technology that should not add much to the cost of food production, and at the same time is very efficient in keeping the tank parameters and water consumption under control. Smart models can be developed for almost any application that has IoT components. In an IoT environment, different devices are connected and communicated seamlessly, and the data are stored in a cloud environment. Wireless communication technologies and networks are used to connect the devices, no matter where the devices are [7-8].

There is a very fast development in technology, which greatly affects the life of mankind. They have been forced to change the way they consume resources, especially regarding food and water. Water is a vital resource of life for all living entities. As the freshwater amount is limited; it needs to be utilized most efficiently. To avoid wasting water in aquaculture systems; water quality must be monitored and controlled. IoT is one of the methods to be used for real-time observation and control of water specifications.

The current work introduces the design of a self-sensing system used in the monitoring and control of the aquaculture environment. The system is equipped with sensors to measure selected water quality characteristics namely; pH, turbidity, level, and temperature. The utilized IoT technologies in this system facilitate remote access to the aquaculture components. The data collected in real-time through the system can be used for analysis, improving resource utilization, producing higher quality fish, and maximizing profits.

Handling the water quality data remotely and in real-time facilitates improving the quality of water efficiently leading to the production of higher quality fish and hence higher profits for the farmer. The water quality can be measured at different times of the year to judge the seasonality effect on the aquaculture life and productivity.

The proposed system can make decisions to adjust the quality parameters to control the alkalinity, acidity, temperature, water level, and turbidity expressed in suspended solids, haziness, and cloudiness. These parameters are controlled within specification limits and the readings are stored on a cloud platform in real-time.

One of the objectives of the current work is the introduction of IoT capabilities to assess the opportunities and challenges for aquaculture development and to enable the adaptation of the system for small farmers to enhance food security in the world.

The paper also explores different literature that developed IoT applications introducing similar previous work. The proposed system concept and constituents are introduced together with the design schemas. Finally, the implemented model outcomes, discussion of the technical and economic feasibility study, and ideas for future work are also provided.

Industrial Developments: Big data, Cyber-Physical Systems (CPS), and IoT are tools that allow the development of smart machines [9]. These systems enable the machines to analyze the collected data and then control the variables accordingly in real time [10]. The introduction of advanced technologies due to Industry 4.0, such as advanced robotics, artificial intelligence, and Cyber-Physical Systems (CPS), contributed to reducing environmental pollution and other production wastes [11]. CPS provides the link between the real world and the simulated internet-based one. It involves smart machines and sensors that send feedback to the system, allowing it to remotely monitor and control the physical components.

Water as a Resource: The amount of water on earth is limited, and due to climate changes, keeping a balance between the demand and consumption of water is very challenging. As a scarce resource, it must be used efficiently and conserved for future populations [8]. Water resources management needs to guarantee that these resources are always healthy and can be consumed by living entities [9]. It is important to monitor and control the chemical substances found in the wastewater to avoid polluting the consumable water [10]. IoT is a great tool for gathering water quality data and exchanging them with interested stakeholders remotely [11]. Smart environmental management and utilization of resources can affect humans' lives in fields such as food and water consumption, and energy generation [16-19].

Fisheries: Aquaculture activities have been an old practice for human beings, which is documented in ancient history [20-23]. The Tilapia fish appeared in history a long time in the past. Aquaculture showed an increase over the last decade despite the reduction in capture fisheries. As a result, in 2020, 157 million tonnes of aquatic animals utilized for human consumption were produced, which is the second-highest amount ever [24-26]. Different aquaculture systems are highly important to the countries' fish production, followed by maricultural, including inland capture and natural fisheries [27-29]. Fish farming activities are widely popular due to the relatively high income they produce. It is considered one of the primary and oldest means of income for many countries. The development of the different fisheries systems and the researcher's interest led to the adoption of smart technologies such as IoT in aquaculture [22, 30].

Journal of Industrial Engineering & Management Research
Vol. 5 No. 4
http://www.jiemar.org
e-ISSN : 2722-8878

Recirculating Aquaculture Systems: The study was carried out on a Recirculating Aquaculture System (RAS). This is a closed aquaculture system that has the advantage of resource optimization, such as water, energy, land, and labor. Furthermore, the ability to control water characteristics, such as turbidity, temperature, dissolved gases, water level, and pH, improves the productivity of the system [30]. The tanks' size ranges from large concrete tanks constructed on the ground to smaller-sized plastic tanks.

Aquaculture IoT System: The introduction of IoT to aquaculture systems allowed monitoring of the water parameters to avoid any sudden changes in the environment. Most of the control efforts are manual control, for example, control of water pumps, and water heaters. These efforts lack the control of the most significant water parameters that have higher effects on the aquaculture environment. Some proposed frameworks monitor the water level only in real time, trying to utilize the lowest energy consumption level possible. Also to minimize the cost, these frameworks utilize the mobile networks to communicate with the controller. Continuous endeavors are going through observing the water quality but with constrained activities when the water characteristics are out of control. A few of these endeavors have begun to utilize cloud storage for accumulated information [31]. A few frameworks utilized Bluetooth innovation to communicate with a controller. In any case, that had the impediments of signal drops that cause information loss and slow communication.

An innovative system was introduced to effectively use the resources remotely. The system keeps track of the water quality parameters to enable continuous data monitoring and system improvement. Utilizing the IoT technology and the cloud capabilities paved the road for the development of a vast array of applications [32]. Other systems monitor water quality remotely by sensors that use low energy connected to central base nodes *for data collection. This data is compared with the nominal values, then send SMSs to the nodes in case values are out of the norm. In an attempt to monitor the water parameters such as pH, temperature, and turbidity a system monitors if the water parameters are not acceptable, then sends an alert message to the farmer. This system is considered a low-cost solution, but it does not automatically intercept [33].*

Others [34] introduced an aquarium model with a fish feeder timer and a heater using the IoT dashboard in a small fish tank, which is considered an elementary idea for the home aquarium with limited control and communication capabilities. An aquarium system utilizes an automatic feeder by connecting it to an Arduino controller and a water pump, which can also deliver messages and video streaming to a mobile phone. Another system obtains and controls the water level and lighting for the integrated aquaponics aquaculture system and monitors the soil's humidity using smartphones.

An integrated aquaponics aquaculture system was proposed that used sensors to monitor the water parameters, pH, dissolved oxygen, and temperature. However, no automatic control action was implemented. Others introduced an integrated aquaponics aquaculture system experiment with plastic containers for fish feed and automatically applied the feed supply three times per day.

Another approach implemented a remotely operated vehicle (ROV), to monitor the water parameters, turbidity, pH, and water level. The experiment recommended keeping turbidity under 400 Nephelometric Turbidity Units (NTU) and pH values from 6.5 to 9. The model used a camera to monitor fish health and send alert messages to a mobile phone. A fishery monitoring system [35] recommended using Arduino with temperature, pH, and water level sensors to monitor and send buzzer warnings to an LCD Display. Still, it lacked a management interface and wireless communications means. Another fish farming monitoring system proposed the use of a microcontroller with a pH sensor and ultrasonic sensor to display the values on an LCD and a water pump to keep the system's water level as desired. Monitoring and controlling a system’s temperature parameter using a temperature sensor and a heater only was proposed, which lacked other monitoring and control means. Also, the system implemented an LCD and LED indicators to give warnings and a sound buzzer. The researchers recommended the addition of a pH sensor and a dissolved oxygen sensor [36].

IoT Improved RAS: Utilizing IoT with the traditional RAS systems introduces many advantages. For example, effective control in real-time, which is preferred for close monitoring of critical parameters to enhance the quality of the fish’s living environment. Fast system interaction responds to unwanted conditions such as parameters going out of control. Compared to standard RAS, this system is more reliable and has lower operational costs. Finally, provides historical data that can be retrieved to allow for better farm audits and buyer monitoring of the fish farming quality.

II. MATERIALS AND METHODS

Table 1 illustrates the system components. The system contains sensors, hardware, control, and software.

Journal of Industrial Engineering & Management Research
Vol. 5 No. 4 e-ISSN : 2722-8878
http://www.jiemar.org

A. Sensing Elements

1) Temperature

To provide an acceptable farming environment, that affects fish growth rates, the temperature needs to be controlled. Sensing temperature means measuring how hot or cold the water in the aquaculture tanks. The measuring sensitivity of the temperature sensor (Table 1, component 1) was 0.01°C.

2) pH

Water acidity and alkalinity are measured using a pH sensor (Table 1, component 3). The sensor gives a value between 0 and 14 based on the water's hydrogen ions content. For the aquaculture of Tilapia fish to ensure acceptable survival and growth rates, the pH value should be maintained between 7 and 8. The pH sensor set includes a probe and module for signal preparation.

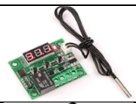
3) Turbidity

Water haziness or opacity can be measured by a Turbidity sensor (Table 1, component 5). The contamination of the water due to the suspended particles causes the amount of light transmitted through it to be decreased. The amount of the detected light is calibrated to indicate the water turbidity. For the Tilapia fish, the acceptable value measured should be under 50 NTU. In the case of high Total Dissolved Solids (TDS), filters can be utilized to control the TDS to avoid fish health issues that will be increased when a high concentration of suspended particles exists in water.

4) Water level

The water level is measured by an ultrasonic sensor (Table 1, component 7). The sensor sends waves to the tank water surface and detects the bounced waves back. This way the water overflow or shortage can be avoided.

TABLE 1. SYSTEM COMPONENTS

Component	Illustration	Component	Illustration
1. Temperature sensor Module		2. Water pump	
3. pH sensor module		4. Water filter	
5. Turbidity sensor module		6. Dosing pump	
7. Ultrasonic water level sensor module		8. Ceramic cartridge heater	
9. Angle solenoid water valve		10. 5V DC cooler fan	

B. Hardware

1) Water Filter Unit

To remove the contaminating particles from the water that causes the turbidity to increase, a water filter (Table 1, component 4) is used. The cartridge removes the waste of the fish, dirt, and any impurities. This improves the turbidity of the water.

2) Water Pump for Filter

The water pump (Table 1, component 2) is a device for moving water, it is used to provide pressure for water in the aquaculture system, to flow through the filtration unit.

3) Dosing Pumps

The system needed four dosing pumps (Table 1, component 6) to do the following:

Pump1: for increasing tank pH+. The pump sucks alkaline fluid through a hose into the tank to raise pH.
Pump2: for decreasing tank pH-. The pump sucks acidic fluid through a hose into the tank to reduce pH.
Pump3: for increasing tank water level LVL+, moving water through a hose to the main tank.
Pump4: for decreasing tank water level LVL-, moving water through a hose from the main tank.

4) Heater

The heater (Table 1, component 8) is used to heat the water. It has a ceramic cartridge heater to raise the temperature of the water rapidly.

5) Solenoid water valve

Based on the controller's received command, the solenoid water valve (Table 1, component 9) controls the water flow to the tank.

6) Cooler Fan

The fan (Table 1 component 10) is used to reduce the water temperature, using a fan that blows air to the water's surface. Its dimensions are 8x8x2.4 cm.

C. Control and Software

1) Controller

A controller is responsible for controlling the actuators and handling the sensors' data. The Arduino UNO controller was used and preferred over the Raspberry controller to prevent problems from the interaction with the module of the Wi-Fi. Raspberry controller has a quad-core processor of 1.2 GHz and 1 GB of memory. However, the Arduino UNO controller is lower in terms of cost and can gather the sensor data and execute the predefined logic [37, 38].

2) System Logic

The system logic diagram shown in Figure 1, illustrates the control flow. The diagram shows how the control processes are interlinked and the input and output of each sensor. It collects the values of the pH, temperature, turbidity, and water level sensors. The controller also operates the system actuators: increasing alkalinity or acidity through the pH control chemicals, the temperature is increased (by heating) or lowered (by fan), turbidity is lowered by filtration, and the water level is increased or lowered (by pumps and valves).

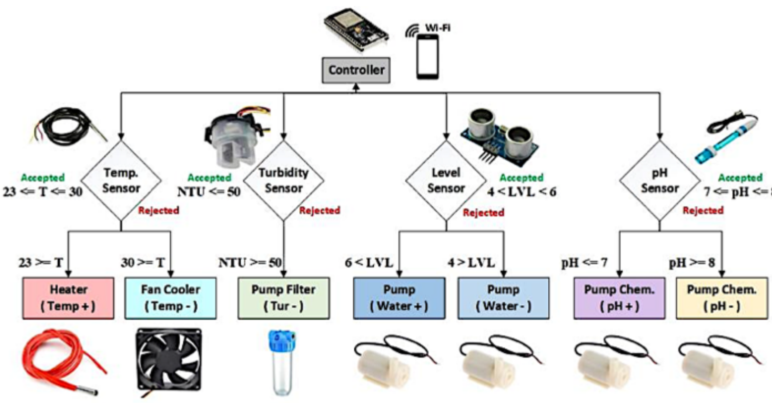


Figure 1. The system logic model diagram

3) Mobile Application

The developed application that displays the system's data is called "WaterQualityControl.apk©" and is kept on the cloud. Monitoring and controlling the system were carried out by a mobile application that was developed during the study introducing an easy interface that can be widely available on smartphones. The use of a graphical interface expands the system's capabilities through the use of mobile phones. An Android mobile application was developed to show the current sensor values, and units of each value, and automatically refresh's the values. The application can connect and disconnect the system [39].

122

Journal of Industrial Engineering & Management Research
Vol. 5 No. 4
http://www.jiemar.org
e-ISSN : 2722-8878

III. SYSTEM CALIBRATION, VERIFICATION AND VALIDATION

A. System Calibration

It is necessary to make sure that the sensors show the correct values as designed through the calibration process [40].

1) Calibration of the pH Sensor: The calibration of the pH sensor follows a three-point calibration process, to achieve high accuracy over the whole pH scale [41, 42]. The procedure calls for comparing the sensor reading to a known calibration solution of pH 4, pH 7, and pH10 until the reading is stable [43]. The three-point calibration process at 4, 7, and 10 is shown in Figure 2.

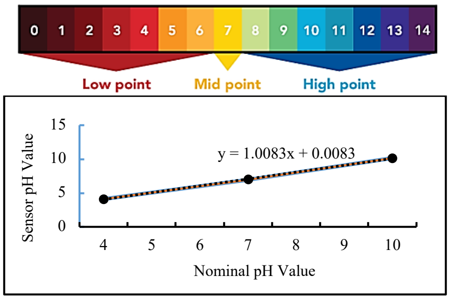


Figure 2. Three-point calibration at *pH* of 4, 7, and 10

The Figure shows the relationship between the standard calibration solution values (nominal values) and the sensor-measured values (actual values). The relationship between the nominal and actual pH values was calculated as $y = 1.0083x + 0.0083$ which was used in the software to calculate the actual pH value from the sensor readings.

2) Calibration of the Turbidity Sensor: Turbidity is the cloudiness or haziness of water caused by many individual particles that are generally invisible to the naked eye. The units of turbidity are called Nephelometric Turbidity Units (NTU). For calibration purposes, the turbidity levels are noticed visually, with increasing the level of turbidity the water becomes unclear and appears foggy and the values are compared to the FORMAZIN Turbidity Standard [44]. The calibration of the turbidity sensor starts with visually clean water, if the sensor voltage value is around 4.2 volts, then nothing needs to be done and readings should be good. But, if a different value appears, then adjustment for the potentiometer on the sensor board circuit is needed to achieve values close to the pictures shown in FORMAZIN Turbidity Standard [45].

3) Calibration of the Temperature Sensor: The temperature sensor values are compared with a calibrated portable digital thermometer to adjust the system's output values. The calibration procedure uses a known liquid temperature to calibrate the temperature sensor. First, use both the system sensor and the calibrated portable thermometer to measure the temperature of crushed ice at 0°C. Second; use both sensors to measure the temperature of boiling water at 100°C. This should cover the full range of water temperature measurements from 0°C to 100°C. As a result, that will calibrate the sensor-measured values compared to a standard and a known calibration test liquid. Then the sensor values could be adjusted through the controller if there is any deviation similar to the pH calibration in Figure 2.

4) ***Calibration of the Ultrasonic Level Sensor:*** The sensor output value is compared with a calibrated steel ruler that is used to manually measure the distance from the sensor to the water surface. The ultrasonic sensor sends waves and receives them back. The distance between the tank bottom and the sensor is known. The sensor measures how far the water surface in the tank is from the sensor. The subtraction of the two values gives the tank's water level. If the ruler measured for example 5 cm and the sensor showed the value of 5 -matching the ruler value- then there is no need for calibration. For calibration, the value of the sensor-measured water level should match exactly the value measured by the calibrated steel ruler. The sensor value could be adjusted in the controller if there is any deviation between the sensor reading and the ruler reading.

Journal of Industrial Engineering & Management Research
Vol. 5 No. 4
http://www.jiemar.org
e-ISSN : 2722-8878

B. System Verification

The second step is to make sure that the implemented system sensors operate correctly and respond to changes in measurement, which is verification.

1) *Verification of the pH Measurements:* For the verification of the system, the pH for three liquids (vinegar, Nestle water, and Flo alkaline bottled water) was measured. The three liquids had known pH values measured by pH calibration paper to be 2.5, 7, and 8 respectively. The three liquids' pH values were read by the system 50 times each. Data was collected as a sample for statistical analysis. The result of the average vinegar pH samples was 2.5 with a standard deviation of 0.01 and variance of 0. The average pH of Nestle bottled water was 7.00 with a standard deviation of 0.02, and variance of 0. The average pH of Flo alkaline water was 8.00 with a standard deviation of 0.02, and variance of 0. Figure 3(a) shows the responses in pH value changes and the repeatability measurements for the system pH sensor values. The charts show very consistent, repeatable, and accurate pH sensor measurements and responses.

2) Verification of the Turbidity Measurements: Figure 3(b) shows the turbidity sensor verification. To carry on the verification step of the turbidity measurements and to judge the repeatability of the sensor measurements, the actual working conditions are to be simulated. Some white flour was added to the water to increase the turbidity, and then 50 turbidity readings were collected from the system as a sample for statistical analysis. The average measurement was 66.29 NTU, the standard deviation was 6.53 NTU, and the variance was 42.63 NTU. The turbidity values increase with the addition of the flour, which eventually tends to precipitate with time, resulting in a decrease in the turbidity level. The water agitation due to the filter suction increases the turbidity level. Eventually, a decreasing trend of turbidity is achieved due to the action of the filtration system as shown in Figure 4. The measurements show that the turbidity sensor is following the change in turbidity nicely with time. Then, the turbidity sensor can detect the change in water clearness caused by the impurities [46].

3) *Verification of the Temperature Sensor:* The verification of the temperature sensor was carried out by putting water of 30°C in the system, which is above the allowed preset temperature for the system of 23°C. As a result of the system sensor measuring such a high temperature, the fan cooler was immediately turned on to reduce the temperature of the water to the preset acceptable value. The temperature control principle is simple and depends on the heat exchange between the air and the water surface in the tank. The lower temperature air is forced by the fan through the surface of the water, causing water evaporation and resulting in the cooling of the aquaculture water tank [47]. The validation of the temperature sensor is shown in Figure 3(c).

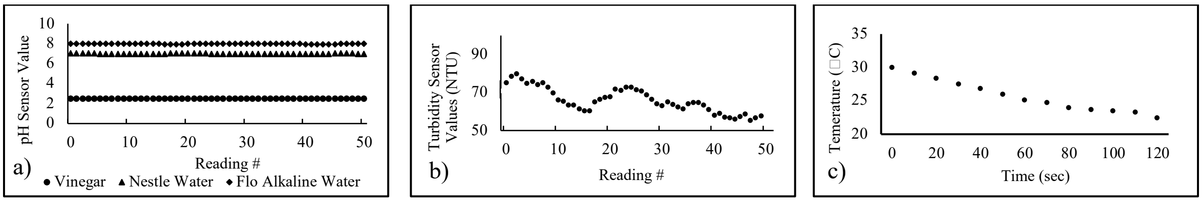


Figure 3. Verification of a) *pH* sensor b) Turbidity sensor c) Temperature sensor

4) *Verification of the Ultrasonic Level Sensor:* The verification of the ultrasonic level sensor was carried out by varying the water level in the system (by setting different level values in the control program) and measuring the system response. Three water level values were set in the system as follows; 10, 30, and 20 cm as the sensor has a resolution of 1 cm. Based on the settings; the system was able to activate the water pump to inject more water into the tank or to remove excess water from the tank.

C. System Validation

The third step is to ensure that the system satisfies its stated functional intent and that the model and the operational logic are working correctly, which is validation [48]. To do this, the validation process of the system needs to be carried out. The validation process ensures that the system fits its intended use and functions as it

Journal of Industrial Engineering & Management Research
Vol. 5 No. 4
http://www.jiemar.org
e-ISSN : 2722-8878

should. Validation is concerned with proving that the right model for the business was built as the proposed model. The validation experiment is focused on testing the system in real conditions concerning the detection and control methods to achieve the research objectives [49].

The validation experiment was carried out on a farm in a nearby village. The farm originally implemented the intensive land tanks system without any monitoring or control measures. It used a traditional feeding schedule and manually operated water pumps.

The tanks were arranged next to each other and surrounded by land to allow the farmer to move between them. The farm tanks' water quality was undefined and the turbidity looked very high as the water color was very dark and the fish was not visible. For the validation experiment, a tank that has a group of small-size Tilapia fish in the early life stage around the length of 5 centimeters, was equipped with the system hardware and software components, and the system was run in fully automatic mode.

The sensors' and actuators' values were collected through the controller. The data was collected in a text file. The system ran smoothly and was able to control the water *pH*, turbidity, temperature, and level in actual service conditions. More validation results are explained in the results and discussion section.

IV. RESULTS AND DISCUSSION

The experiment on the Tilapia fish was monitored for a month to ensure the ability of the system to manage the fish's living environment, and to have detailed and more focused observations of the system. Due to the huge system redundancy of the collected data, the following charts show only a week's amount of data. The system was fully autonomous in monitoring and controlling the water quality parameters to stay within the control limits. The feed was 3 times per day, at specific times 00:00, 08:00, and 16:00.

A. Temperature Measurements

The system controller collects 5.25 readings per minute, which is a total of 7560 readings per 24 hours. The trace of the measured temperature values for a typical winter day is shown in Figure 4 a). The chart shows the capability of the system to control the tank temperature within a very narrow margin of 1°C. The up arrow ① shows the temperature increase due to the actuation of the heater once the temperature goes to the lower limit of 23°C and the down arrow ② shows the temperature decrease with time. The average temperature value was around 23.5°C, even though the temperature range is between 23°C and 30°C. It is clear that the system can keep the temperature stable near the lower control limit (LCL), which avoids the excess usage of the system heater and the heating energy, even though the experiment was carried out during the cold winter season. The ambient temperature affects the temperature of the water in the aquaculture tank, as a result in the summer season the temperature will tend to rise, which will eliminate the usage of the heater and instead engage the fan cooler to reduce the water temperature.

B. Turbidity Measurements

As shown in Figure 4 b), it has been observed that the feeding activity of the fish, at the beginning of each period (the up arrow ①) increases the turbidity to the upper limit. Then the activation of the filtration system causes the turbidity to decrease (the down arrow ②) to reach near the lower limit. This pattern has to do with the fish's stirring movements and the amount of feed added to the water. The Figure shows the system's ability to keep the turbidity stable and very close to being under the UCL. This avoids the excess usage of filtration unit cartridges. As a result, resources are used conservatively, which is reflected in the cost of filter replacement. The average measured daily turbidity value was around 37 NTU on average during the study period.

C. pH Measurements

The pH measurement is shown in Figure 4 c). It is observed that there is an effect for the fish feeding schedule on the pH. At the beginning of each feeding period, pH tops near the upper limit (up arrow ①) due to the introduction of fish food that is alkaline in nature. This is followed by a constant decrease (down arrow ②) at the end of the period reaching the lower limit due to the system adding a pH adjuster, which in this case is an acidic base.
Calculating the average of the 7560-pH readings per day, for a week shows that the system can keep the pH stable near the average value of the control limits of 7.5. This way the system avoids the excess usage of chemicals. As a result, resource consumption can be optimized as the system also accounts for the addition of feed and fish waste in changing the pH of the water.

Journal of Industrial Engineering & Management Research
Vol. 5 No. 4
http://www.jiemar.org
e-ISSN : 2722-8878

D. Water Level Measurements

Figure 4 d) shows the water level daily adjustments. The system pumps the water to bring the level to the UCL (arrows ① and ④) through the pump of the secondary water tank which compensates for the amount of water lost due to evaporation and fish activities. As the sensor has a resolution of 1 cm, it feels when the level drops to the 4 cm level (arrow ②). Once the controller feels the water level dropped to 4 cm, it activates the pump to bring the water level back to the 5 cm level (arrow ③). Calculating the average of the 7560 water level readings per day, for a week, shows the system's ability to keep the water level stable around the average of the control limits (4-6) to avoid the use of excess water.

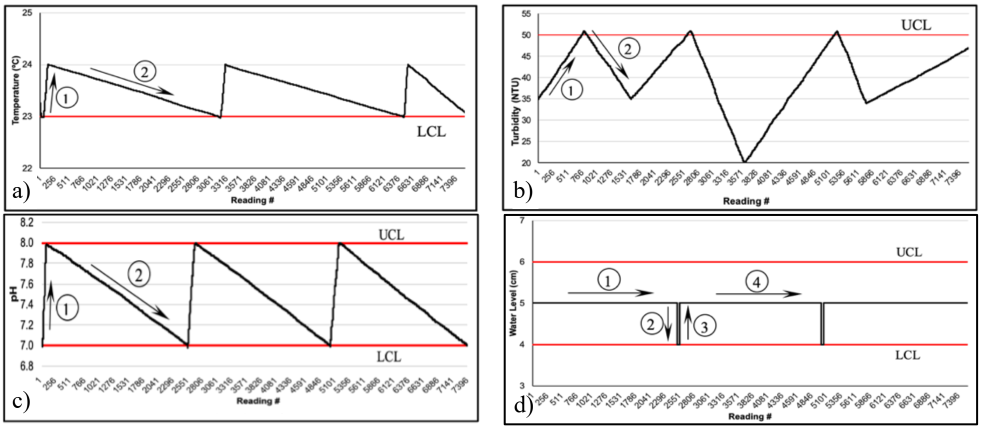


Figure 4. Daily control charts a) Tank Temperature b) Turbidity c) pH d) Water Level

E. Actuators Utilization

The system utilized its components efficiently through the minimal usage approach, as no system component reached a utilization of more than 8% at any time. As a result, the operational cost is reduced to the minimum and is reflected in the rise of the operating profit of the farmer. It is also shown that the ability to monitor and control the water quality parameters of the aquaculture tank in real time provided a stable and improved environment for the fish. This can improve the growth rates, and resource usage optimization, and avoid sudden changes in the tank environment that may lead to fish loss.

F. Assessment of Fish Quality

The level of food consumer acceptability is known as food quality. The term "quality" typically describes the fish's visual appeal, freshness, or level of spoiling. It might also include safety considerations such as being devoid of dangerous substances, parasites, or bacteria.

There are several ways to evaluate the quality of fish, including chemical and biochemical techniques, physical techniques, using senses, and microbiological techniques. The European Union scheme for the assessment of fish quality published by the United Nations Food and Agriculture Organization (FAO) [50] was applied in this research. The results showed that the produced fish satisfies the EU criterion for exporting fish into the EU markets.

G. Reduction of Water Consumption

The majority of the water lost in the system comes from evaporation. Evaporation of water from a water surface - like the aquaculture open tank - depends on water temperature, air temperature, air humidity, and air velocity above the water surface [51] according to formula (1).

$$g_s = \theta A(x_s - x)/3600 \quad (1)$$

Where,

g_s = amount of evaporated water per second (kg/s)

θ = (25 + 19 v) = evaporation coefficient (kg/m^{2}h)

v = velocity of air above the water surface (m/s)

A = water surface area (m^2)

x_s = maximum humidity ratio of saturated air at the same temperature as the water surface (kg/kg) (kg H_2O in kg dry air)

Journal of Industrial Engineering & Management Research
Vol. 5 No. 4
http://www.jiemar.org
e-ISSN : 2722-8878
JIEMAR

x = humidity ratio air (kg/kg) (kg H_2O in kg dry air)
Assuming *v = 0.5 m/s* based on the average air velocity in the experiment area.
θ = *(25 + 19x0.5)* = 34.5 kg/m^{2}h
The area of the fish tank that is 1m by 1m is:
A = (1 m)x(1 m) = 1 m^2
The evaporation from the surface can be calculated as:
g_s = (34.50 kg/m^{2}h) (1 m^2) ((0.0147 kg/kg) - (0.0098 kg/kg)) / 3600 = 4.66x10^{-5} kg/s = 482.8 kg/4-month cycle.
Where, x_s= 0.014659 kg/kg, and
x = 0.0098 kg/kg

The weight of the water in the one cubic meter tank is 1000 kg. This means that the unconsumed water remaining in the tank is 517.2 kg. Assuming 10% of the tank water will be used for fish feed, that is 100 kg. Then the remaining water in the tank would be about 417 kg. Compared to traditional farms such as raceway or pond aquaculture systems [51] -where water gets disposed of at the end of each cycle- the system achieved about 42%.

H. System Layout and Developed Web Interface

A Web Interface called "*iFish*" was developed. The interface shows the farm layout and the IoT components connected to the different farm items to form the smart aquaculture system. The proposed application has an ergonomically designed web interface that allows ease of use for different levels of users, which is one of the challenges the industry faces. The system allows the farmer to monitor and control the entire farm through the cloud to avoid unexpected situations and provide full control of aquaculture quality characteristics.

The Application

1. The user should log in to the farm web interface with his username and password and choose if he is the farm manager or one of the farmers. This allows for more controls and history tracking details.
2. On the application's farm overview page, there is an icon for each farm tank, which shows the status of the tank. A green tick icon beside the tank means that the water parameters are stable and within the defined levels. In contrast, a yellow caution mark means that the system parameters started to be out of control and the system is interacting to retrieve them to the acceptable limits. Finally, a red caution mark shows that the tank is in critical status and there is a major problem. A green connector icon means that the tank is connected to the cloud network. If there is a connection problem, the connector turns red.
3. The user can move into a deeper level of monitoring a specific tank by clicking on the tank icon. A new page is shown that includes the icons of different sensors in the tanks and the status of each sensor if it is acceptable or out of control. The page also displays a small chart next to each sensor that shows the historical values of each sensor.
4. If further details are required, the user can click on the sensor icon to move into a maximized sensor readings chart to better understand the status of the parameter in the fish tank.
5. The farm manager can control the farm components, as the manager can override the automatic predefined system rules. This allows the farm manager for example to have the control to prepare the farm for maintenance and change the farm's parameters to achieve exceeded farm goals.
6. Another important ability of the application is that the interface allows the farm manager to analyze the data gathered from the different components. This gives a better understanding of farm performance parameters for close monitoring of the different harvested fish and the ability to adjust and adapt the different actuators to achieve those goals.

V. ECONOMIC MODEL AND FINANCIAL INDICATORS

A technical economic model has been created by incorporating financial metrics and providing a step-by-step breakdown. To enable the understanding of the proposed methodology a more comprehensive analysis is included.

A. Farm Cost Analysis

The following is the farm cost analysis for the traditional RAS and the IoT farms. The total cost (T) is calculated as:

T = CapEx + OpEx (2)

Capital Expenditures (CapEx)

Capital expenditure or capital expense is
the money an organization spends to buy, maintain, or improve its fixed assets, such as buildings, equipment, or land.

Operating Expenses (OpEx)

An operating expense is an ongoing cost for running a product, business, or system.
OpEx is composed of fixed costs, which are expenses that remain the same regardless of the level of production, and variable costs, which change based on the production output.

OpEx=Fixed Cost(F)+Variable Cost(V) (3)

1) Capital Expenditures (CapEx)

Traditional RAS Farm infrastructure setup: The RAS utilizes tanks (number of tanks, K_n, tank cost K_c), water pumps (number of pumps, P_n, pump cost P_c, water lines cost, W_{lc}), air chiller (number of chillers, C_n, chiller cost, C_c), filters (number of filters, F_n, filter cost, F_c), UV units (number of UV units, U_n, unit cost, U_c), air compressors (number of air compressors, A_n, compressor cost, A_c), electricity generators (number of generators, G_n, generator cost, G_c), portable water quality kits (number of kits, K_{in}, kit cost, K_{ic}), and Farm Civil Work (C_{wc}).

Total Traditional RAS CapEx ($CapEx_{TRAS}$):

$$\boldsymbol{CapEx_{TRAS}} = K_nK_c + P_nP_c + W_{lc} + C_nC_c + F_nF_c + U_nU_c + A_nA_c + G_nG_c + K_{in}K_{ic} + C_{wc} \quad (4)$$

For TRAS farm, $K_n=20$, $K_c=100$, $P_n=2$, $P_c=165$, $W_{lc}=230$, $C_n=1$, $C_c=500$, $F_n=2$, $F_c=675$, $U_n=1$, $U_c=350$, $A_n=2$, $A_c=210$, $G_n=1$, $G_c=800$, $K_{in}=1$, $K_{ic}=135$, and $C_{wc}=\$3{,}500$.

$$\boldsymbol{CapEx_{TRAS}} = 20\text{x}100 + 2\text{x}165 + 230 + 1\text{x}500 + 2\text{x}675 + 1\text{x}350 + 2\text{x}210 + 1\text{x}800 + 1\text{x}135 + 3500 = \$9{,}615/year$$

IoT Farm: The IoT farm incurs the same setup cost as the traditional farm minus the lab kit plus an additional cost of \$265 per tank for the sensors (S_c), controller (C_{oc}), communication modules (C_{mc}), and automatic feeding units (A_{fc}).

$$\boldsymbol{CapEx_{IoT}} = CapEx_{TRAS} - K_nK_c + K_n\,(S_c + C_{oc} + C_{mc} + A_{fc}) \quad (5)$$

For IoT farm, $S_c=100$, $C_{oc}=40$, $C_{mc}=50$, and $A_{fc}=75$

$$\boldsymbol{CapEx_{IoT}} = 9{,}615 - 135 + 20x(100 + 40 + 50 + 75) = \$14{,}780/\text{year}$$

2) Operating Expenses (OpEx)

Fixed Cost (F): This cost is calculated for a 4-month production cycle and then converted to annual costs for a total of 3 production cycles per year. The fixed monthly costs are;

Labor Cost (L_c), Land Rental Cost (D_c) and Cloud Subscription (C_{sc}).

Therefore, the fixed cost per year, F, is calculated by:

$\boldsymbol{F = M\, N_m\, N_y}$ (6)

Where, M is the monthly fixed cost, N_m is the number of months per production cycle, and N_y is the number of cycles per year.

$M = L_c + D_c + C_{sc}$ (7)

$M_{TRAS} = 415 + 80 + 0 = \$495$

Where, for TRAS; $L_c=415$, $R_c=80$ and $C_{sc}=0$ (no cloud subscription)

$F = (L_c + D_c + C_{sc})\, N_m\, N_y$ (8)

$F_{TRAS} = 495 \text{ x } 4 \text{ x } 3 = \$5{,}940/year$

Where, $N_m = 4$ and $N_y = 3$

Similarly, the IoT RAS farm fixed cost is calculated as follows:

$M_{IoT} = 210 + 80 + 60 = \$350$

Where, for IoT farm; $L_c=210$, $R_c=80$ and $C_{sc}=60$

$F_{IoT} = 350 \text{ x } 4 \text{ x } 3 = \$4{,}200/year$

The labor cost for the IoT farm is lower than the traditional RAS farm as it uses lower number of operators.

Journal of Industrial Engineering & Management Research
Vol. 5 No. 4
http://www.jiemar.org
e-ISSN : 2722-8878

Variable Costs (V): The variable costs for both farms per production cycle are: *Fry Cost (Y_c), Feed Cost (F_{ec})* and *Electricity Cost (E_c). Therefore, the variable cost per year is:*

$V = (Y_c + F_{ec} + E_c)\ N_y$ (9)
$V_{TRAS} = (45 + 750 + 700)\ x\ 3 = \$4,485/year$
Similarly,
$V_{IoT} = (45 + 750 + 440)\ x\ 3 = \$3,705/year$
Other cost elements need to be added to the operating cost, which are the Maintenance and Medication Costs (***M_{ic}***). These costs are taken as 6% of the operating cost. Therefore, from equation (2) the total operating cost for the traditional farm is;

OpEx = [Fixed Cost (F)+ Variable Cost (V)] (1+M_{ic}) (10)

$OpEx_{TRAS} = (5,940 + 4,485)\ x\ 1.06= \$11,050/year$
$OpEx_{IoT} = (4,200 + 3,705)\ x\ 1.06= \$8,379/year$

From equation (1), the total farm cost for both farms is:

$T_{TRAS} = 9,615 + 11,050 = \$20,665/year$
$T_{IoT} = 14,780 + 8,379 = \$23,159/year$
From equations 2 to 10, the general equation for the aquaculture total cost model can be written as:

$$T = K_nK_c + P_nP_c + W_{lc} + C_nC_c + F_nF_c + U_nU_c + A_nA_c + G_nG_c + K_{in}K_{ic} + C_{wc} + K_n\left(S_c + C_{oc} + C_{mc} + A_{fc}\right) + (1 + M_{ic})[(L_c + D_c + C_{sc})(N_mN_y) + N_y(Y_c + F_{ec} + E_c)] \quad (11)$$

Which can be reduced to

$$T = P_nP_c + W_{lc} + C_nC_c + F_nF_c + U_nU_c + A_nA_c + G_nG_c + K_{in}K_{ic} + C_{wc} + K_n\left(K_c + S_c + C_{oc} + C_{mc} + A_{fc}\right) + (1 + M_{ic})[(L_c + D_c + C_{sc})(N_mN_y) + N_y(Y_c + F_{ec} + E_c)] \quad (12)$$

B. Financial Indicators

The base price for the Tilapia fish produced in RAS and IoT farms changes based on demand seasonality and sales deals. For this analysis, the traditional fish farm selling price was taken as $2 per kg (sold to the local market). The targeted selling price for the IoT farm high-quality fish is $3.5 per kg (sold for the export and premium markets), with the opportunity to increase the total production output from the farm due to the improved aquaculture environment [52].
A 20-tank farm will produce 4000 kg of fish per cycle as every tank produces 200kg/cycle. Three cycles per year give 12,000 kg/year.

1) ***Profit:*** Gross profit (GP) = Revenue (R)– OpEx (13)

Traditional farm
GP_{TRAS} = 12,000 kg x \$2 – 11,050 = \$12,950/year

IoT farm
GP_{TRAS} = 12,000 kg x \$3.5 – 23,157 = \$18,843/year
That is about a 45% increase in gross profit above the traditional farm.

2) ***Benefit-to-Cost Ratio (BCR):*** BCR is an evaluation technique for projects to judge the effect of a project in terms of the benefits of investment related to the investment cost, which is a decision-making tool in the field of aquaculture [53].

$$BCR = \frac{NPV\ of\ benefit\ expected\ from\ the\ project}{PV\ of\ the\ cosrt\ of\ the\ project} \quad (14)$$
$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} \quad (15)$$
Where *PV* is the Present Value and *NPV* is the Net Present Value, Rt is the net cash inflows-outflows during a single period t, i is the return rate and t is the number of periods, taken as 10 years.

Rt_{TRAS} = 12,950, Rt_{IOT} = 18,843, i = 10%, t = 10, PV_{TRAS} = 20665, PV_{IoT} = 23159

$$NPV_{TRAS} = \sum_{t=1}^{10} \frac{12950}{(1+0.1)^t} = 79572$$

$$NPV_{IoT} = \sum_{t=1}^{10} \frac{18843}{(1+0.1)^t} = 115782$$

The benefit-to-cost ratio for the traditional fish farm is calculated as follows:

$$BCR_{TRAS} = \frac{79572}{20665} = 3.85$$

$$BCR_{IoT} = \frac{79572}{20665} = 5.0$$

This means that the benefits-to-cost ratio of the IoT farm is higher by 29.87% than the traditional farm.

3) Payback Period (PBP)

PBP is defined as the number of years required to recover the original cash investment.

$$PBP = \frac{Cost\ of\ Investment}{Average\ Annual\ Cash\ Flow} \quad (16)$$

$$PBP_{TRAS} = \frac{20665}{12950} = 1.6\ years$$

$$PBP_{IoT} = \frac{23159}{18843} = 1.2\ years$$

This means that it takes 1.6 years for the traditional RAS to recover its investment, while it takes only 1.2 years for the IoT farm.

VI. CONCLUSION

Mankind has a responsibility to produce quality food and reduce the consumption of water and energy. The amounts of fish types that come from seas, rivers, and lakes have dropped significantly due to environmental changes, the limitations of wild catch, and the contamination of water resources. Aquaculture is a valuable source of fish. Aquaculture fish farming can provide a suitable environment where the fish can be farmed, thus contributing to food security. The fact that farmed fish production and quality are affected by environmental changes; leads to an important conclusion that monitoring the water quality parameters is vital to improving growth rates, and avoiding the loss of the farmed fish and the loss of water. This work introduces the development and application of a real-time management system, to monitor and control the values of four water characteristics, namely; temperature, pH, turbidity, and water level. Real-time monitoring of the aquaculture environment and the autonomous intervention to control those changes are core to providing a smart solution to common aquaculture problems. The main goal of this work is to introduce the IoT as an application in the aquaculture environment which gives advantages of finding solutions for the aquaculture industry limitations.

The development of an effective smart water quality management system for the recirculating aquaculture system (RAS) aims to improve the aquaculture environment, leading to more output, improving food quality, utilizing limited water resources, and eliminating human errors in production operations. This should lead to the reduction of the operational cost and increase the profit of the fish farms. In addition, the suggested system gives a robust control of the water quality characteristics to avoid any diseases that may affect the farmed fish and hence the farm productivity and fish quality. The system's components usage is optimized to not be used unless needed to reduce the utilization of the system components and the energy. The system also saved 42% of the water.

In conclusion, the work provides a foundation for advancing the aquaculture industry through IoT-driven solutions, offering a glimpse into the potential for autonomous and efficient fish farming practices. The findings encourage further research and development to address evolving challenges in aquaculture and promote sustainability in food production.

REFERENCES

[1] Ahmad A., Abdullah S.R.S., Abu Hasan H., Othman A.R., and Ismail N.I., Plant-based versus metal-based coagulants in aquaculture wastewater treatment: Effect of mass ratio and settling time, J. of Water Process Engineering, 2021; 43, 102269. DOI 10.1016/j.jwpe.2021.102269.

[2] Jincai Su, and Yanyan Wei, Novel tri-bore PVDF hollow fiber membranes for the control of dissolved oxygen in aquaculture water, J. of Water Process Engineering, 2019; 30, 100572. https://doi.org/10.1016/j.jwpe.2018.02.007

[3] Estim, A, Saufie, S, and Mustafa, S, Water quality remediation using aquaponics sub-systems as biological and mechanical filters in aquaculture, J. of Water Process Engineering, 2019; 30, 100566. DOI 10.1016/j.jwpe.2018.02.001.

Journal of Industrial Engineering & Management Research
Vol. 5 No. 4
e-ISSN : 2722-8878
http://www.jiemar.org

[4] Setyo B. K., Muhammad F. I., Siti R. S. A., Ahmad R. O., Hassimi A. H., Coagulation–flocculation of aquaculture effluent using biobased flocculant: From artificial to real wastewater optimization by response surface methodology. J. of Water Process Engineering, 2023; 53, 103869. https://doi.org/10.1016/j.jwpe.2023.103869.
[5] Andrea C., Alessandro V., Edoardo C., Roberto S., and Andrea S., Advantages of IoT-Based Geotechnical Monitoring Systems Integrating Automatic Procedures for Data Acquisition and Elaboration, Sensors, 2021; 21(6): 2249; https://doi.org/10.3390/s21062249.
[6] Verdegem M., Bosma R. and Verreth J. Reducing, Water Use for Animal Production through Aquaculture. International Journal of Water Resources Development, 2006, 22(1): 101-113, https://doi.org/10.1080/07900620500405544.
[7] Rojko, A., Industry 4.0 Concept: Background and Overview. International Journal of Interactive Mobile Technologies (IJIM), 2014; 11(5): 77–90.
[8] AlMetwally, S.A., Hassan, M.K. and Mourad, M.H., Real Time Internet of Things (IoT) Based Water Quality Management System. Procedia CIRP, 2020; 91: 478-485.
[9] Lu, Y., Industry 4.0: A survey on technologies, applications and open research issues. J. Ind. Inf. Integr., 2017; 6: 1–10. DOI:10.1016/j.jii.2017.04.005.
[10] Crnjac, M., Veža, I. and Banduka, N., From concept to introduction of industry 4.0. Int. J. Ind. Eng. Manag., 2017; 8(1): 21–30.
[11] Manavalan, E. and Jayakrishna, K., A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements. Comput. Ind. Eng., 2019; 127: 925–953. DOI:10.1016/j.cie.2018.11.030.
[12] Anirudh, D.B., Srivatsava, K.S. and Doss, P., Smart Water Conservation and Management System Using IoT. International Journal of electronics & communication technology, IJECT, 2018; 9 (2): 9–12.
[13] Pujar, P. M., Kenchannavar, H. H. and Kulkarni, U. P., Water quality assessment and monitoring for river malaprabha using the internet of things (IoT) system. Int. J. Recent Technol. Eng., 2019; 8(2): 3839–3844. DOI: 10.35940/ijrte.B2466.078219.
[14] Wang, X. and Yang, W., Water quality monitoring and evaluation using remote-sensing techniques in China: A systematic review. Ecosyst. Heal. Sustain., 2019; 5(1): 47–56. DOI:10.1080/20964129.2019.1571443.
[15] Joseph, J., Manju, K., Sajith, R., Nair, S., Viay, V. and Krishnan, S., Water Management System Using IoT. International Research Journal of Engineering and Technology, 2018; 5(4): 1887-1890.
[16] Sudhakar, J. M., An IoT Based Smart Water Monitoring System at Home. International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES), 2017; 3(11): 60–67.
[17] Khadri, M. N. S and Kalshetty, J. N., Smart Water Quality Monitoring System Using IoT Environment. Int. J. Innov. Eng. Technol., 2018; 10(4): 74–78. DOI: 10.21172/ijiet.104.12.
[18] Adly, I. and Badawy, N.M., Evaluation of Real-Time Water Quality Monitoring System in Nile Tilapia- Lettuce Aquaponic Based on Wireless Sensor Network. 6th. Global Fisheries and Aquaculture Research Conference, Hurgada- Egypt, 2013.
[19] Chowdury, M. S. U., IoT based real-time river water quality monitoring system. Procedia Comput. Sci., 2019; 155: 161–168. DOI: 10.1016/j.procs.2019.08.025.
[20] Shaalan, M., El-Mahdy, M., Saleh, M. and El-Matbouli, M., Aquaculture in Egypt: Insights on the Current Trends and Future Perspectives for Sustainable Development. Rev. Fish. Sci. Aquac., 2018; 26(1): 99–110. DOI: 10.1080/23308249.
[21] Norman-López, A. and Bjorndal, T., Is Tilapia the same product worldwide or are markets segmented?. Aquac. Econ. Manag., 2009; 13(2): 138–154. DOI: 10.1080/13657300902885360.
[22] Sadek, S., An overview on desert aquaculture in Egypt. Aquac. desert Arid lands Dev. constraints Oppor. FAO Tech. Work. 6–9 July 2011, Hermosillo, Mex., FAO Fisheries and Aquaculture Proceedings No. 20: 141–158.
[23] FAO, Towards Blue Transformation, A Vision For Transforming Aquatic Food Systems. https://www.fao.org/state-of-fisheries-aquaculture. Visited Nov. 1, 2022.
[24] FAO, The state of world fisheries and aquaculture, disponível em http://www.fao.org/docrep/013/i1820e/i1820e.pdf, 2010; 218.
[25] Bostock, J., Aquaculture: Global status and trends. Philos. Trans. R. Soc. B Biol. Sci., 2010; 365(1554): 2897–2912. DOI:10.1098/rstb.2010.0170.
[26] Bahnasawy, N. F., Mohamed H., El-Ghobashy, Ahmed, E. and Abdel-Hakim, A., Culture of the Nile tilapia. Egypt. J. Aquat. Biol. Fish., 2009; 13(2): 1–14.
[27] Prabu, E., Rajagopalsamy, C. B. T., Ahilan, B., Jeevagan, I. J. M. A. and Renuhadevi, M., Tilapia – An Excellent Candidate Species for World Aquaculture: A Review. Annu. Res. Rev. Biol., March 2019: 1–14. DOI: 10.9734/arrb/2019/v31i330052.
[28] Agyakwah, K., Asmah, R., Mensah, T. D., Ragasa, C., Amewu, S., Tran, N., Oyih, M. and Ziddah, P., Farmers Manual on Small-Scale Tilapia Pond Farming in Ghana, International Food Policy Research Institute, 2020.
[29] Samy-Kamal, M., Status of fisheries in Egypt: reflections on past trends and management challenges. Rev. Fish Biol. Fish., 2015; 25(4): 631–649. DOI: 10.1007/s11160-015-9404-z.
[30] Rohit, M. H., Barua, S., Akter, I., Karim, S. M. M., Akter, S. and Lutfe Elahi, M. M., IoT Based Submersible ROV for Pisciculture.

Journal of Industrial Engineering & Management Research
Vol. 5 No. 4
http://www.jiemar.org
e-ISSN : 2722-8878

28th IEEE Int. Conf. Robot Hum. Interact. Commun. RO-MAN November, 2019. DOI: 10.1109/RO-MAN46459.2019.8956441.

[31] Tigadi, A.S., Khilare, T., Kesarkar, N., Kittur, Z. and Kambale, T., Aquarium Automation Using IoT. International J. of Engineering Science Invention (IJESI), 2019; 8(6): 36–40.

[32] Jain, A., Malhotra, A., Rohilla, A. and Kaushik, P., Water Quality Monitoring and Management System for Residents. Int. J. Eng. Adv. Technol., 2019; 9(2): 567–570. DOI: 10.35940/ijeat.b3521.129219.

[33] Kawarkhe, M. B. and Agrawal, S., Smart Water Monitoring System Using IoT at Home. IOSR J. of Compu. Eng., 2019; 21(1): 14–19. DOI: 10.9790/0661-2101021419.

[34] Perumal, T., Sulaiman, M. N., and Leong, C. Y., Internet of Things (IoT) enabled water monitoring system. IEEE 4th Glob. Conf. Consum. Electron. GCCE April 2015: 86–87. DOI:10.1109/GCCE.2015.7398710.

[35] Dickson, M., Nasr-Allah, A., Kenawy, D. and Kruijssen, F., Increasing fish farm profitability through aquaculture best management practice training in Egypt. Aquaculture, 2016; 465: 172–178. DOI: 10.1016/j.aquaculture.2016.09.015.

[36] Patel, S., Gaikwad, A., Gupta, D. and Dhargonar, S., Smart Fish Tank Using IoT. Int. J. Adv. Sci. Res. Eng. Trends, 2020; 4(11):1–4.

[37] Ardjosoediro, I. and Ramnarine, I. W., The influence of turbidity on growth, feed conversion and survivorship of the Jamaica red tilapia strain. Aquaculture, 2002; 212(1–4):, 159–165. DOI:10.1016/S0044-8486(01)00881-X.

[38] Buratti, C., Conti, A., Dardari, D. and Verdone, R., An overview on wireless sensor networks technology and evolution. Sensors, 2009; 9(9): 6869–6896. DOI: 10.3390/s90906869.

[39] Farhan, M.H., Abdul Malik, M.R and Khan, M.R., Water Quality Monitoring System Based on Microcontroller and LoRa. Malaysian Journal of Science and Advanced Technology MJSAT, 2021; 1(2): 32-35.

[40] ALICAT, validating, verifying, and calibrating flows, https://www.alicat.com/ knowledge-base/verification-validation-calibration/#:~:text=Verification%20ensures%20a%20process%20or,instrument%20meets%20a%20known%20standard. Visited on 12/8/2023.

[41] Jiao, D., and Luo, X., Water Quality Monitoring System Based on LoRa. DEStech Trans. Comput. Sci. Eng., 2018; 10: 1107-1116. DOI: 10.12783/dtcse/iece2018/26605.

[42] B. Sigdel, Water Quality Measuring Station, pH, Turbidity and temperature measurement thesis, Helsinki Metropolia University of Applied Science, 2017; 1-37.

[43] Jin, H., Open-Source Low-Cost Wireless Potentiometric Instrument for pH Determination Experiments, J. Chem. Educ., 2018; 95(2): 326–330.

[44] Water on the web, Understanding water quality parameters, Turbidity, https://waterontheweb.org/under/waterquality/ turbidity. html, visited on 12/26/2023.

[45] Zhang, C., Wu, J. and Liu, J., Water quality monitoring system based on Internet of Things, Proc., 2020 3rd Int. Conf. Electron Device Mech. Eng. ICEDME, 2020; 2(4): 727–730.

[46] Gillett, D., and Marchiori, A., A low-cost continuous turbidity monitor, Sensors (Switzerland), 2019; 19(14): 1–18.

[47] Babaremu, K., Omodara, M., Fayomi, O., Okokpujie, I. and Oluwafemi, J., Design and optimization of an active evaporative cooling system, Int. J. Mech. Eng. Technol., 2018; 9(10): 1051–1061.

[48] Amer, H., Galal, N., and El-Kilany, K., A simulation study of sustainable agri-food supply chain, Proceedings of the International Conference on Industrial Engineering and Operations Management, Jul 2018; 2264–2275.

[49] Sargent, R., Verification and validation of simulation models, Proc. Winter Simul. Conf., January 2011; 166–183.

[50] https://www.fao.org/3/V7180E/V7180e09.htm#:~:text=There%20are%20three%20quality%20levels,EU%20countries%20for%20sensory%20assessment. Accessed on January 20, 2024.

[51] Martins, C., Eding, E., Verdegem, M., Heinsbroek, L., Schneider, O., Blancheton, J., d'Orbcastel, E., and Verreth, J., New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability, Aquacultural Engineering, 2010; 43(3), 83-93, doi:10.1016/j.aquaeng.2010.09.002.

[52] Ngoc, P., Meuwissen, M., Cong Tru, L., Bosma, R., Verreth, J., and Lansink, A., Economic feasibility of recirculating aquaculture systems in pangasius farming, Aquac. Econ. Manag., 2016; 20(2): 185–200.

[53] Frierson, M., Vassalos, M. and Beecher, L., Evaluating the Economic Profitability of Establishing an Aquaculture Research Facility. The case of Clemson University's Aquaculture Center, 2017, Southern Agricultural Economics Association Meetings, Mobile, AL.