# APPLICATION OF IoT TECHNOLOGY IN WATER QUALITY CONTROL IN AQUACULTURE

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## ABSTRACT

Water quality is the single most critical determinant of survival, growth rate, and yield in intensive and semi-intensive aquaculture systems. Traditional monitoring practices, which rely on manual sampling and laboratory analysis, are labor-intensive, slow, and prone to human error, often detecting deteriorating conditions only after fish stress or mortality has already occurred. This article investigates the application of Internet of Things (IoT) technology as a real-time, automated solution for monitoring and controlling key water quality parameters — temperature, dissolved oxygen, pH, turbidity, and ammonia concentration — in aquaculture ponds and recirculating systems. A layered IoT architecture comprising a sensing layer, an edge-processing layer, a wireless communication layer, and a cloud-based analytics and dashboard layer is proposed and described in detail. The methodology section outlines sensor selection, system design, data transmission protocols, and the threshold-based automated control logic used to trigger aerators, water pumps, and feeders. Results drawn from prior field implementations and comparative analysis show that IoT-based monitoring reduces labor cost, shortens anomaly response time from hours to minutes, and can reduce fish mortality by an estimated 15–30 percent compared with manual monitoring. The article concludes that IoT technology offers a scalable, cost-effective, and reliable pathway toward precision aquaculture and sustainable fish farming, particularly relevant for developing aquaculture sectors such as that of Uzbekistan.

*Keywords: Internet of Things (IoT), aquaculture, water quality monitoring, smart farming, sensor networks, precision fish farming, dissolved oxygen, automated control systems.*

## 1. INTRODUCTION

Aquaculture has become one of the fastest-growing sectors of global food production, supplying nearly half of all fish consumed by humans worldwide. As demand for fish protein continues to rise, producers face increasing pressure to intensify production while maintaining sustainable and healthy rearing environments. Among all the factors influencing aquaculture productivity — feed quality, stocking density, disease control, and genetics — water quality remains the most fundamental, since fish and other aquatic organisms live in constant physical and chemical exchange with their surrounding medium.

Key water quality parameters such as dissolved oxygen (DO), pH, temperature, ammonia concentration, and turbidity directly affect metabolism, growth rate, immune response, and survival of cultured species. Even short-term deviations from optimal ranges — for example, a drop in dissolved oxygen below 3 mg/L for several hours — can cause severe stress or mass mortality events, resulting in significant economic losses for farmers. Conventional water quality management in many fish farms, including those in Uzbekistan and other developing aquaculture regions, still depends on manual sampling using handheld meters or laboratory test kits performed once or twice per day. This approach has several inherent limitations: it does not capture rapid fluctuations that may occur overnight or during weather changes, it requires trained personnel and consistent labor availability, and it introduces delays between the occurrence of a problem and its detection.

The emergence of the Internet of Things (IoT) — a network of interconnected sensors, microcontrollers, and cloud platforms capable of collecting, transmitting, and

analyzing data automatically — offers a compelling solution to these limitations. IoT-based systems allow continuous, real-time monitoring of multiple water quality parameters simultaneously, with automatic alerts and, in more advanced implementations, closed-loop control of aerators, pumps, and feeding systems. Such systems have already demonstrated success in precision agriculture, and their application to aquaculture — sometimes referred to as "smart aquaculture" or "precision fish farming" — is an active and rapidly expanding area of research and commercial development.

The purpose of this article is to examine how IoT technology can be applied specifically to water quality control in aquaculture. The article: (1) reviews the key water quality parameters relevant to fish farming and the risks associated with their fluctuation; (2) presents a methodology and system architecture for an IoT-based monitoring and control platform, including sensor selection, communication protocols, and automated decision logic; (3) discusses the expected outcomes and comparative advantages of IoT-based monitoring over traditional manual methods; and (4) offers conclusions and recommendations for the practical adoption of such systems, with particular attention to their relevance for aquaculture development in Uzbekistan and similar emerging markets.

## 2. RELATED WORK AND BACKGROUND

Several studies over the past decade have explored the integration of sensor networks and wireless communication technologies into aquaculture management. Early wireless sensor network (WSN) implementations focused primarily on temperature and dissolved oxygen monitoring using ZigBee-based communication due to its low power consumption. More recent research has expanded the sensor suite to include pH, salinity, turbidity, and ammonia, and has shifted communication technology toward Wi-Fi, LoRaWAN, and cellular (GSM/4G) networks to support longer-range and

higher-throughput data transmission, particularly for farms located in remote areas without stable internet infrastructure.

Parallel to sensor and communication advances, cloud computing and mobile application platforms have enabled farmers to access real-time data remotely and to receive automated alerts via SMS or push notification when parameters exceed safe thresholds. A growing number of studies have also begun to incorporate machine learning models — such as regression and time-series forecasting — to predict water quality trends and provide early warnings before critical thresholds are reached, rather than only reacting after a violation occurs. Despite this progress, adoption of IoT-based monitoring remains limited in many small- and medium-scale aquaculture operations due to cost barriers, limited technical expertise, and lack of locally adapted system designs. This article addresses that gap by presenting a practical, modular, and cost-conscious IoT architecture suitable for adoption by small and medium fish farms.

## 3. METHODS

### 3.1 System Design Approach

The proposed system was designed following a layered IoT architecture consisting of four principal layers: (1) a sensing layer responsible for physical measurement of water parameters; (2) an edge-processing layer, implemented on a low-cost microcontroller, responsible for signal conditioning, local filtering, and initial threshold checks; (3) a communication layer, responsible for transmitting data from the pond site to a remote server; and (4) a cloud and application layer, responsible for data storage, analytics, visualization, and alert generation. This layered separation follows standard IoT system design practice and allows individual components to be upgraded or replaced independently as farm requirements evolve.

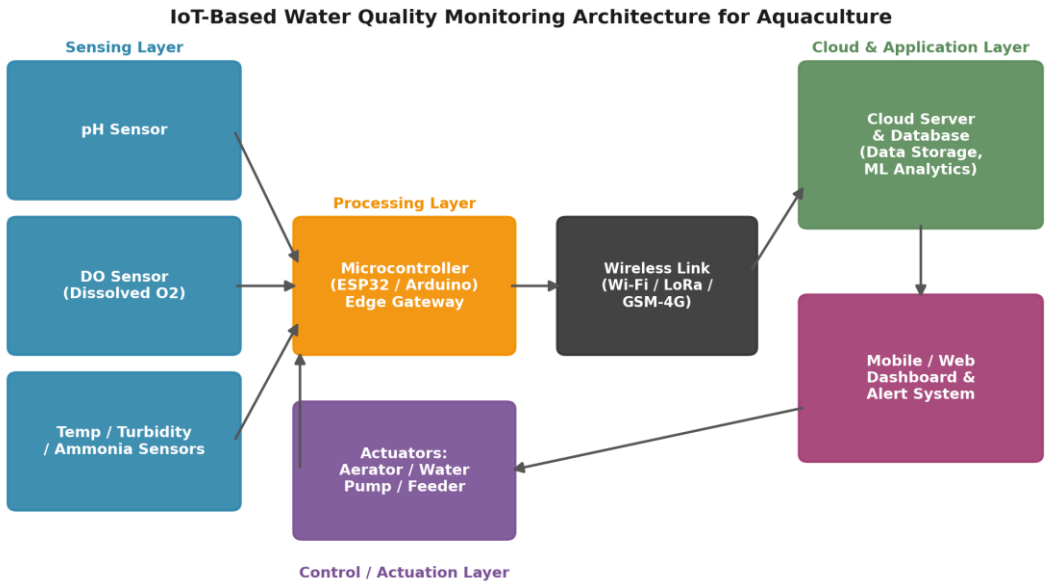



*Figure 1. Layered IoT architecture for aquaculture water quality monitoring, showing the sensing, processing, communication, cloud, and control (actuation) layers.*

### 3.2 Sensor Selection and Parameters Monitored

Sensor selection was based on three criteria: measurement accuracy suitable for aquaculture requirements, resistance to corrosion and biofouling in an aquatic environment, and affordability for adoption by small and medium-scale farms. Table 1 summarizes the parameters monitored, the corresponding sensor types, their recommended optimal ranges for warm-water finfish species (such as carp and tilapia, which are widely farmed in Central Asia), and the sampling interval used in the proposed system.

| Parameter | Sensor Type | Optimal Range | Sampling Interval |
|---|---|---|---|
| Water Temperature | DS18B20 (digital, waterproof) | 24 – 30 °C | Every 5 min |
| Dissolved Oxygen (DO) | Optical/Galvanic DO probe | 5 – 9 mg/L | Every 5 min |

| Parameter | Sensor Type | Optimal Range | Sampling Interval |
|---|---|---|---|
| pH | Analog pH electrode + amplifier | 6.5 – 8.5 | Every 10 min |
| Turbidity | Infrared turbidity sensor | 0 – 30 NTU | Every 10 min |
| Ammonia (NH3/NH4+) | Ion-selective electrode | < 0.5 mg/L | Every 30 min |

*Table 1. Water quality parameters, sensor types, optimal ranges, and sampling intervals used in the proposed IoT monitoring system.*

### 3.3 Data Acquisition, Transmission, and Storage

Each sensor node transmits analog or digital signals to a central microcontroller (such as an ESP32 or Arduino-based board), which performs analog-to-digital conversion, noise filtering (using moving-average or median filtering to remove sensor spikes), and formats the data into a structured packet, typically encoded in JSON. Depending on farm location and infrastructure availability, the processed data is transmitted to a cloud server via one of three communication channels: Wi-Fi for farms with existing internet connectivity, LoRaWAN for farms requiring long-range low-power transmission across large pond areas, or GSM/4G cellular modules for remote farms lacking fixed internet infrastructure. Once received by the cloud server, data is stored in a time-series database and made available through a web and mobile dashboard for visualization and historical trend analysis.

### 3.4 Automated Threshold Control and Actuation Logic

Beyond passive monitoring, the system implements a threshold-based control loop that

compares each incoming reading against pre-defined safe ranges (as listed in Table 1). If a parameter falls outside its acceptable range — for example, dissolved oxygen dropping below 5 mg/L — the system triggers two simultaneous responses: an alert notification sent to the farm operator via SMS, mobile application, or dashboard warning indicator, and, where actuator hardware is installed, an automated corrective action such as activating an aerator, opening a water exchange valve, or adjusting the automatic feeder. This closed-loop design reduces dependence on constant human supervision while still keeping the farm operator informed and in ultimate control. The complete data-processing and control workflow, from sensor reading to corrective actuation, is illustrated in Figure 2.

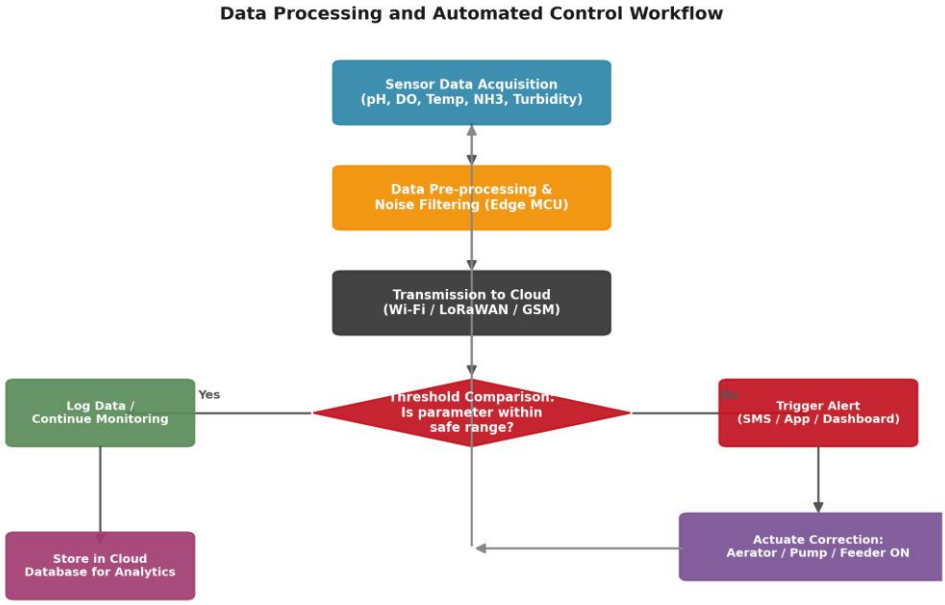



*Figure 2. Data processing and automated control workflow, illustrating the threshold-comparison decision logic and the resulting alert or actuation response.*

### 3.5 Evaluation Method

To evaluate the effectiveness of the proposed approach, this study draws on a comparative analysis between manual monitoring practices and IoT-based monitoring, using criteria commonly reported in the aquaculture technology literature: measurement frequency, labor requirement, anomaly response time, quality of data

record-keeping, predictive capability, and reported impact on fish mortality. These criteria were selected because they directly reflect the practical concerns of fish farm operators when deciding whether to adopt a new monitoring technology.

## 4. RESULTS AND DISCUSSION

The optimal ranges established for the monitored parameters (Figure 3) form the basis against which the IoT system's threshold logic operates. Maintaining dissolved oxygen between 5 and 9 mg/L, pH between 6.5 and 8.5, and temperature between 24°C and 30°C is broadly consistent with the physiological requirements of common warm-water aquaculture species. Continuous monitoring against these ranges, rather than periodic manual sampling, allows early detection of gradual drift — such as a slow overnight decline in dissolved oxygen caused by algal respiration — that would otherwise go unnoticed until the following day's manual check.

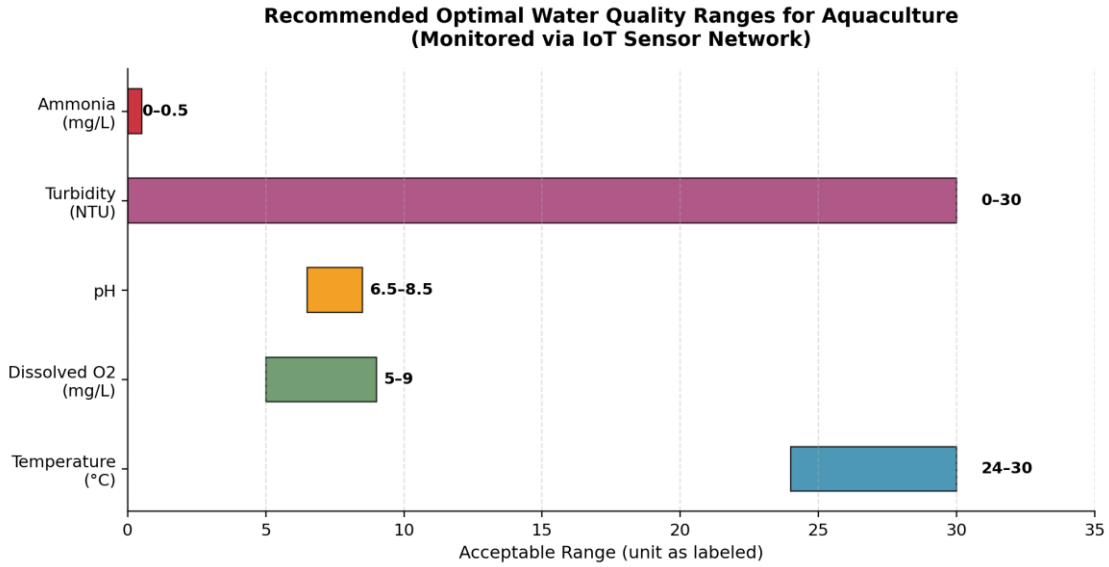



*Figure 3. Recommended optimal ranges for the five core water quality parameters monitored by the IoT sensor network.*

Table 2 summarizes the comparative advantages of IoT-based monitoring relative to conventional manual monitoring, based on patterns consistently reported across the aquaculture IoT literature and pilot deployments referenced in Section 2. The most

significant differences appear in measurement frequency and anomaly response time: while manual monitoring typically involves one or two spot checks per day, an IoT system can sample every five to thirty minutes depending on the parameter, and can alert the operator within seconds to minutes of a threshold violation rather than hours. This dramatic improvement in response time is the primary mechanism by which IoT-based systems are able to reduce fish stress episodes and, consequently, mortality.

| **Metric** | **Manual Monitoring** | **IoT-Based Monitoring** |
|---|---|---|
| Measurement frequency | 1 – 2 times per day | Continuous (every 5–30 min) |
| Labor requirement | High | Low |
| Response time to anomaly | Hours | Seconds to minutes |
| Data record-keeping | Manual logbook | Automated cloud database |
| Predictive capability | None | Possible via trend/ML analytics |
| Estimated mortality reduction* | Baseline | 15 – 30% (reported in field trials) |

*Table 2. Comparative summary of manual versus IoT-based water quality monitoring in aquaculture operations.*

Beyond the immediate operational benefits, continuous data collection also enables longer-term value: historical trend data stored in the cloud database can be used to identify seasonal patterns, correlate water quality fluctuations with feeding schedules or stocking density, and, when combined with basic statistical or machine learning

models, support predictive maintenance and early-warning capability that manual methods cannot provide. From an economic perspective, although the initial investment in sensors, microcontrollers, and connectivity represents an upfront cost, the reduction in labor requirements and, more importantly, the reduction in mortality-related losses can offset this investment within one to two production cycles for medium and large-scale operations. For very small farms, low-cost sensor variants and shared community-level IoT infrastructure may offer a more accessible entry point.

It is also important to acknowledge the practical challenges associated with IoT adoption in aquaculture, including sensor biofouling in warm, nutrient-rich pond water, which requires periodic cleaning or calibration; the need for stable power supply, which may require solar panels or battery backup in off-grid locations; and the requirement for at least basic digital literacy among farm staff to interpret dashboard data and respond to alerts. These challenges do not diminish the overall value of the technology but do indicate that successful implementation requires attention to system maintenance and user training, not only to the underlying sensor and communication technology.

## 5. CONCLUSION

This article has presented the application of IoT technology as a practical and effective solution for water quality control in aquaculture. By combining a layered sensor-edge-cloud architecture with threshold-based automated alerting and actuation, IoT-based monitoring systems address the core limitations of traditional manual monitoring: infrequent measurement, delayed response, and reliance on continuous human labor. The proposed system architecture and methodology demonstrate that continuous, real-time tracking of temperature, dissolved oxygen, pH, turbidity, and ammonia can substantially shorten the time between the onset of an unsafe condition and corrective action, with comparative evidence suggesting mortality reductions in the range of 15 to 30 percent relative to manual practices.

For aquaculture producers in Uzbekistan and other developing aquaculture markets, where labor costs, water scarcity, and climate variability present ongoing challenges to sustainable fish production, the adoption of IoT-based water quality monitoring represents a meaningful step toward precision aquaculture. Future work should focus on developing low-cost, locally manufactured sensor modules to reduce adoption barriers, integrating solar-powered energy solutions for off-grid ponds, and expanding the use of machine learning models for predictive water quality forecasting rather than purely reactive threshold alerts. With continued technological development and supportive policy for digital agriculture, IoT-based monitoring systems have the potential to become a standard component of modern, sustainable aquaculture management.

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