



## Implementation and Evaluation of an Internet of Things Controlled Microbubble Generator System for Catfish Pond Water Quality Management

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### Abstract

*The increasing demand for catfish as a source of animal protein in Indonesia has not been matched by adequate management of pond water quality. In many small-scale fish ponds, water quality monitoring is conducted conventionally, so important parameters such as dissolved oxygen and pH cannot be maintained exactly, causing them to be out of the optimal range and reducing productivity. This study aims to produce, implement, and evaluate the performance of the Microbubble Generator (MBG) system integrated with Internet of Things (IoT) technology for managing water quality in catfish ponds. The implementation location is a catfish pond, Bringin Village, Wajak District, Malang, East Java, Indonesia. The method includes the installation of a system consisting of MBG unit (pump, aerator, dissolution tank, and distribution pipe) controlled by an IoT module with dissolved oxygen and pH sensors. Water quality data is monitored in real-time via smartphone, and the MBG can be operated automatically and manually based on the set thresholds for dissolved oxygen and pH. The results showed that the application of MBG with IoT was able to increase dissolved oxygen levels from 1.71 to 4.97 (an increase of 190%) mg/L and maintain water pH in a relatively stable range (around 8.0–8.4), where this condition is optimal for catfish growth. Furthermore, the automated control system enabled more efficient aeration operation and reduced reliance on manual monitoring. This study demonstrates that the integration of microbubble technology and IoT has the potential to be an affordable solution to improve the sustainability of community-scale catfish farming.*

**Keywords:** catfish aquaculture; dissolved oxygen; Internet of Things (IoT); microbubble aeration; water quality monitoring; SDG12

## 1. Introduction

Sustainable farming strategies are vital for increasing aquaculture production in the wake of increased global demand for seafood products [1]. Catfishes are among the most surprising fish groups in the world. Catfish are characterized by their cylindrical body with flattened ventral and prominent barbell(s), mostly scale-less compared to other teleost fishes [2]. The catfish industry is the largest producer of food fish in the U.S., reaching ~170 thousand tons in 2023 and generating \$443 million in sales [3].

The aquaculture sector plays a crucial role in meeting the animal protein needs of the Indonesian population. Increasing awareness of fish consumption has led to a year-on-year increase in demand for farmed fish, including catfish [4]. Catfish is a popular freshwater commodity due to its relatively simple cultivation technology, its ability to operate on limited land, and its minimal infrastructure investment. However, many small-scale catfish farms are still managed conventionally without adequate water quality management technology. High stocking density, low dissolved oxygen (DO) availability, and pH fluctuations can reduce the carrying capacity of the pond environment and inhibit fish growth. Water quality parameters such as temperature, turbidity, DO, carbon dioxide, pH, nitrate, phosphate, and ammonia [5] need to be continuously monitored and controlled to ensure optimal cultivation performance. Microbubble technology has been widely studied as a more efficient aeration solution than conventional aerators. Microbubbles have very small bubble sizes so that the surface area in contact with the water is larger, which increases the efficiency of oxygen transfer [6].

On the other hand, the development of Internet of Things (IoT) technology enables real-time water quality measurement and control [7] through the use of sensors, microcontrollers, and smartphone interfaces, so that decision-making can be done faster and more accurately. These sensors transmit data wirelessly to a centralized monitoring platform, where the data can be analyzed in real-time to detect deviations from established quality standards. Wireless communication protocols such as Wi-Fi and cellular networks are commonly used to facilitate data transmission [8].

Many studies have focused either on IoT-based monitoring systems without integrating advanced aeration mechanisms and control capabilities. As a result, most existing systems are limited in their ability to simultaneously optimize oxygen transfer efficiency and provide adaptive water quality management based on real-time data [6-8]. Furthermore, many IoT-based aquaculture applications emphasize data acquisition rather than active control strategies that respond dynamically to water quality fluctuations.

The traditional catfish cultivation unit is still managed conventionally with high stocking densities and without an adequate aeration system. This condition often results in water quality falling below optimal standards, and low-quality water reduces productivity. Therefore, the implementation of technology-based aeration and water quality monitoring systems is necessary to improve cultivation performance. Aerator functions are to raise the DO concentration in water, circulate the water, and facilitate proper mixing of pond water [9]. Microbubble aeration is used in aquaculture to improve the DO level and water recycling through dissolved air flotation [10].

In this context, the novelty of this study lies in the integration of an MBG with an IoT-based monitoring and control system into a single, adaptive platform. In contrast to earlier methods, this system not only improves oxygen transfer via microbubble technology but also permits responsive control and real-time monitoring of important water quality parameters, especially pH and DO. Specifically created for small-scale aquaculture applications, this integrated approach provides a more effective, affordable, and scalable way to enhance pond water quality management at the farm level. Additionally, by encouraging the effective use of water resources, cutting waste from inadequate water quality management, and reducing energy consumption through optimized aeration processes, this study helps to achieve Sustainable Development Goal 12. By facilitating the proper use of inputs and lessening the environmental effects of traditional farming systems, the integration of MBG and IoT promotes more sustainable aquaculture practices. So, this study aims to design and implement an MBG system integrated with IoT for water quality management of catfish ponds, and evaluate the system's performance on DO and pH parameters and its implications for more efficient water quality management at the farmer level.

## 2. Materials and Methods

### 2.1. Implementation Location

The system was implemented in a catfish farming pond belonging to the ROI Lele Fish Farming Group (Pokdakan ROI Lele) located in Bringin Village, Wajak District, Malang Regency, East Java Province, Indonesia. The pond measures 3 x 4 m with a high stocking density and was previously unfit for aeration.

### 2.2. Design of MBG System

Design of the MBG system consisted of main components such as a water pump (capacity of 300 L/h), a microbubble aerator, a dissolution tank, and distribution pipes. These components were assembled to produce the MBG system unit, as shown in Fig. 1. The total electrical power required to operate this system is approximately 1500 watts. A schematic of the MBG system

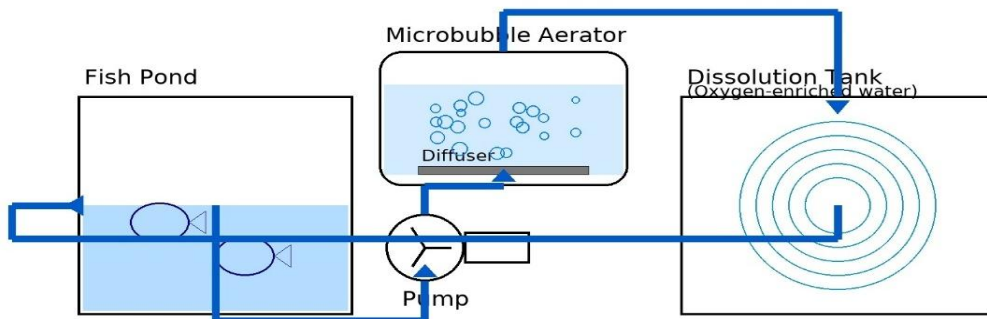


Fig. 1. Scheme of the MBG system

### 2.3. IoT-Based Control and Monitoring Module

The IoT integration into MBG system was conducted using a control module equipped with DO (DFRobot Analog DO Sensor, China) and pH sensors (PH Sensor Kit PH-4502C, China). The sensors are placed in the catfish ponds for monitoring water quality continuously. The sensor sends data through an IoT module to a server and displays water quality information via a smartphone interface, allowing farmers to monitor remotely (Fig. 2).

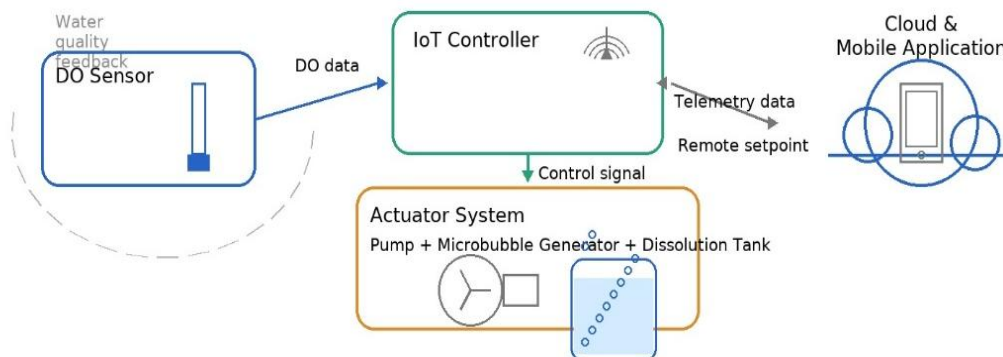


Fig. 2. Scheme of the IoT-based controller module

The system was designed to operate in two modes, which are in automatic mode, where the MBG will turn on when DO levels fall below a predetermined threshold, and automatically

turn off when it reaches the upper limit; and manual mode, where farmers can turn the system on or off via a smartphone app as needed.

## 2.4. System Implementation Stages

Implementation of MBG system was carried out through several stages to ensure the design's suitability to field conditions and the effectiveness of the water quality monitoring function in catfish farming ponds. The initial stage began with a survey of existing pond conditions and discussions with farmer partners to identify needs, operational constraints, and key issues related to water quality for determining the technical specifications and system implementation strategy. After that, the installation of the MBG system with an IoT module in the catfish ponds. The sensor is put at representative points for the aeration/oxygen production process (with threshold DO of min 2 mg/L, max. 5 mg/L and water quality parameter measurement. Water quality data was monitored via the system interface, and routine maintenance was performed to maintain stable equipment performance.

## 2.5. Water Quality Measurement

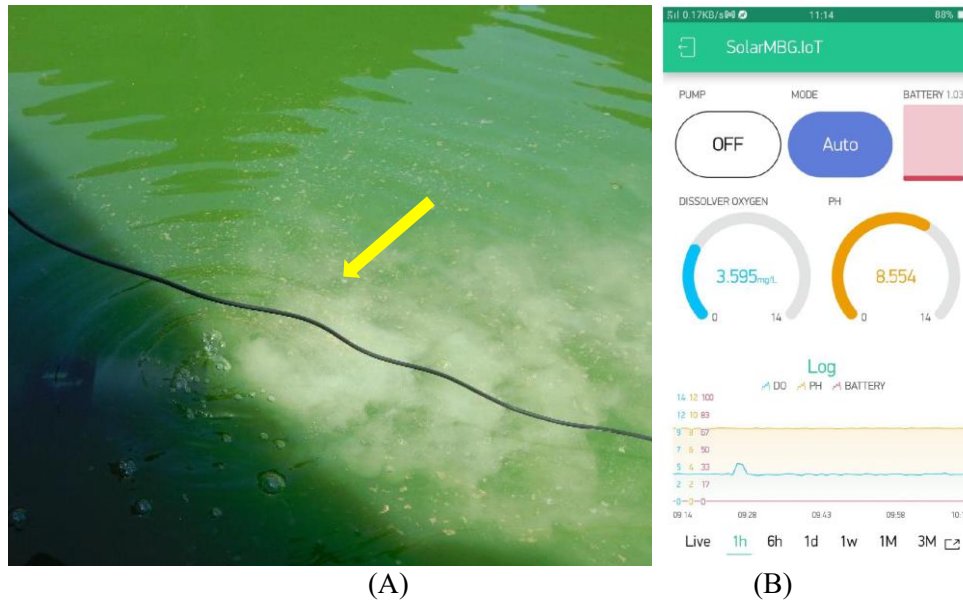
MGB performance was evaluated through real-time water quality monitoring throughout the observation period with observed parameters of DO and pH. These parameter data were recorded at specific measurement intervals for approximately 2 hours of system operation and then displayed graphically for analysis.

# 3. Results and Discussion

## 3.1. Implementation of the IoT-controlled MBG System

Microbubbles are strictly defined in fluid dynamics as bubbles with a diameter of only 100  $\mu\text{m}$  or less. When studying physiological activity, bubbles with a 10–40  $\mu\text{m}$  diameter are classified as microbubbles [11]. Prior to the system's implementation, catfish ponds at the traditional fish farming group were operated at high stocking densities without additional aeration. This resulted in high DO consumption, while the oxygen supply from natural air diffusion was insufficient. This reduced air quality and potentially hampered catfish growth. The installed MBG system generates micro-sized air bubbles (Fig. 3A) that increase the air-water contact surface area, resulting in higher oxygen transfer efficiency. Microbubble generator based on the cavitation principle includes the compression of the air stream to dissolve air into liquid, which is subsequently released through a specially designed nozzle system, to nucleate small bubbles as potentially nanobubbles [12]. These bubbles subsequently grow into much larger bubbles through the rapid dissolution of the supersaturated liquid.

IoT-based control allows the system to be operated as needed based on real-time air quality data [13]. In this implementation, the control module also functions as energy management, turning the MBG on and off depending on the DO levels in the pond (Fig. 3B) using software on a smartphone. Partnering farmers were trained to understand the system's operating principles, operation, and basic maintenance procedures. The training was participatory, ensuring active end-user involvement and the ability to operate the system independently upon completion. Training on the implementation of the MBG and the IoT was conducted through technical training using socialization and presentation methods related to assembly and operation of the system.



**Fig. 3.** MBG white micro bubble (A) and IOT monitoring for fish pond (B)

### 3.2. Water Quality Analysis

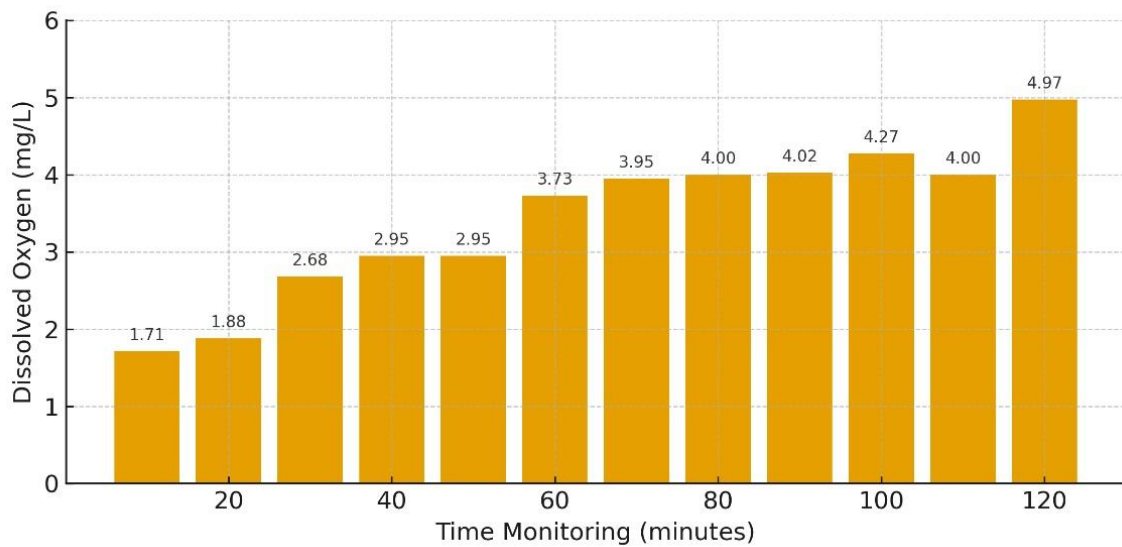
Monitoring results indicate that the MBG with IoT control was able to increase DO levels in the catfish pond compared to the initial conditions without aeration, as shown in Fig. 4. The DO value for 2 hours of operation, with 10-minute measurement intervals, shows an increasing trend and stabilization of DO. DO is maintained at level 2-5 mg/L or increased to about max. 190% from the initial condition.

Bubble size directly influences the effectiveness of oxygen transfer from the gas phase to the liquid phase [14]. Smaller bubbles create a larger gas-water contact surface area for the same volume of air, increasing the interfacial area where oxygen diffusion occurs and increasing the rate of oxygen transfer to the water. Smaller bubbles have a slower ascent velocity, resulting in a longer residence time in the water column and prolonging the contact duration between oxygen and water [15]. This combination of increased surface area and contact time improves aeration efficiency, which is practically reflected in a faster and more stable increase in DO concentration. It should be noted that oxygen solubility under saturated conditions is primarily determined by physical-chemical factors such as temperature, pressure, and salinity [16,17], while bubble size primarily influences the rate and efficiency of oxygen transfer under these conditions.

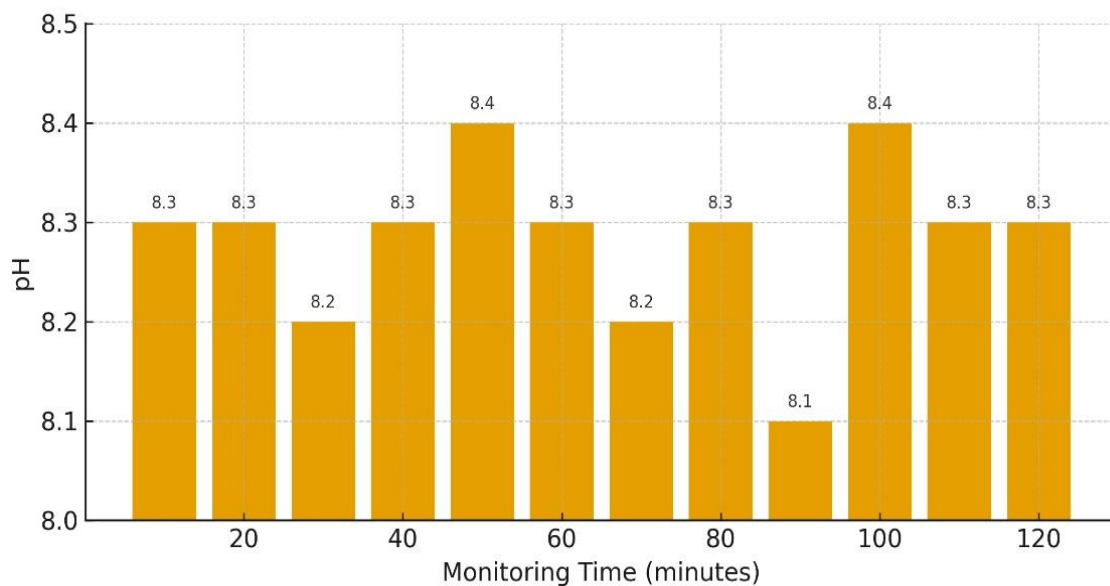
The pH in pond water remained stable at pH 8.0–8.4 (Fig. 5), which is generally acceptable for intensive catfish farming [18]. The MBG can maintain the DO value of the water. Stability of DO and pH can maintain the fish health and prevent stress [19]. This aligns with previous reports emphasizing the importance of managing water quality parameters such as DO, pH, and nutrient concentrations in freshwater fish farming systems. DO can avoid the accumulation of CO<sub>2</sub> or reduce the CO<sub>2</sub> in the fish pond [20], which causes H<sub>2</sub>CO<sub>3</sub>, so it can avoid the reduction of pH. Lower DO value causes an accumulation of organic matter that makes water more acidic. When the DO level is higher, the bacteria decompose organic content in water, as presented by previous reported results that MBG promoted a high load of microorganisms that influenced shrimp growth and survival rates [21], promote the growth of biofloc and *L. vannamei* [22]. DO maintains the aquatic respiratory system; when respiration is good, water quality is better.

pH reflects the acid-base conditions of water, which directly impact the physiology and performance of cultivated fish [23]. pH values outside the tolerance range can trigger stress,

reduce appetite, disrupt gill function and ionic balance [24], and ultimately reduce growth and increase disease susceptibility [25]. Furthermore, pH determines the chemical form and toxicity of nitrogen compounds, particularly ammonia. Higher pH tends to increase the fraction of free ammonia ( $\text{NH}_3$ ) [26], which is more toxic than ammonium ions ( $\text{NH}_4^+$ ) [27]. pH also influences the activity of nitrogen-processing microbes (nitrification), which generally operate optimally under neutral to slightly alkaline conditions. pH can fluctuate daily due to  $\text{CO}_2$  dynamics related to photosynthesis and respiration. pH instability can inhibit these biological processes and increase the risk of ammonia/nitrite accumulation [28]. Real-time pH monitoring is necessary to ensure that water conditions continue to support the health of cultivated organisms and control the risk of toxicity. These data serve as a basis for operational decision-making, such as aeration settings, feed management, and water alkalinity/buffer adjustments.



**Fig. 4.** Monitoring of DO Levels in catfish ponds at the fish pond for 2 hours (DO data recording time interval is every 10 minutes)



**Fig. 5.** Monitoring the pH levels of catfish ponds for 2 hours (pH data recording time interval every 10 minutes)

### 3.3. Implications for Aquaculture Management

The implementation of MBG technology equipped with IoT makes it easier for farmers to monitor pond conditions in real time from anywhere. Through a smartphone app, farmers can reduce routine workloads and make faster and more accurate decisions when pond water quality deteriorates. This allows farmers to control operations under special conditions, such as at night, during high stocking densities, or in extreme weather. Through automatic control, aeration can be easily activated when needed (for example, when DO drops below a threshold), thereby increasing energy efficiency and reducing operational costs.

The primary need for aquaculture management is to maintain healthy water quality to increase fish productivity. This water quality requires consistent attention in aquaculture operations [29]. Several other physical parameters that affect pond water quality include temperature, water depth, turbidity, and total suspended solids [30]. Chemical parameters that require continuous monitoring are DO, carbon dioxide, pH, and nutrient/toxic compounds such as nitrate, phosphate, and ammonia [31]. By measuring DO and pH in real time, farmers gain immediate information about the pond status and its potential impact on catfish performance. When abnormal trends are detected, such as a rapid decrease in DO, unstable pH, or repeated daily fluctuations, timely interventions (e.g., activating the MBG, adjusting feeding intensity, increasing water exchange, or improving mixing) can be implemented more quickly and effectively.

The availability of data sets during fish growth significantly supports informed decision-making. Recorded data sets can be used to identify recurring patterns, evaluate the effectiveness of interventions, and establish evidence-based pond-specific standard operating procedures. This approach can reduce stress events, lower mortality risks, and stabilize production performance by maintaining pond water within optimal ranges. Implementation of the MBG–IoT system contributes to increased capacity at the farmer level, strengthens responsiveness, and encourages more efficient resource use (energy and labor).

## 4. Conclusions

The implementation of a microbubble generator (MBG) system integrated with Internet of Things (IoT) technology in catfish ponds has been successfully applied. The MBG system significantly increases the dissolved oxygen (DO) concentration of up to 190%, while maintaining pH levels within the range of 8.0–8.4. This condition is considered optimal for catfish growth. The IoT monitors the pH and DO continuously and in real-time with optional automated and manual control of MBG operation via a smartphone-based interface. The IoT system reduced the dependence on routine on-site manual inspections and enhanced operational efficiency through more precise and responsive aeration, particularly under dynamic pond conditions. Besides, the deployment of the MBG system also contributed to capacity building among farmers by enhancing their technical competencies in technology-assisted water quality management. Future research should focus on long-term system deployment to comprehensively evaluate its impact on key production performance indicators, including growth rate, survival rate, and feed conversion ratio. In addition, further investigation is required to assess energy consumption and economic feasibility under varying stocking densities and seasonal conditions.

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## Author Declaration

**Data availability statement:** Data will be made available on request.

**CRedit authorship contribution:** AA: Conceptualization, Writing – Original Draft, Writing – Review & Editing. MS: Data Curation, Formal Analysis, Resources. BDS: Data Curation, Formal Analysis, Resources. JSB: Conceptualization, Writing – Original Draft, Writing – Review & Editing, Validation. JPS: Formal Analysis, Supervision, Writing – Review & Editing. FN: Data Curation, Formal Analysis, Visualization; ASR: Data Curation, Formal Analysis, Visualization.

**Declaration of Competing Interest:** The authors declare that they have no known competing financial interests.

**Artificial Intelligence Statement:** This article is the original work of the author without using AI tools for writing sentences.

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