



## Intelligent control system in aquaponics

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### Abstract

Food security, population growth, soil degradation, water shortage, and climate change all call for effective and sustainable food production. Aquaponics is a highly effective method of farming that combines hydroponics and aquaculture. The method of the current automatic control system (i.e. control by timers and probes) alone cannot, nevertheless, meet the needs of this system due to the system's ongoing development and the rise of growing objectives. The automatic control system, which is in use today, is unstable because unforeseen faults frequently occur, and it is particularly challenging to implement remote monitoring and control. Based on these flaws, the premise and basis for ensuring the steady functioning of the aquaponic system is the monitoring and control of the environment and equipment through intelligent technology. Currently, the Internet of Things (IoT), wireless sensors, and other technologies can be used to create intelligent aquaponic systems with automatic monitoring and control. The real-time monitoring and control of the greenhouse environment, water quality parameters, and nutrient cycling in aquaponic systems are all possible with the application of intelligent technology (IoT plus intelligent algorithm). The precise optimization and regulation of water resources, nutrient cycling, and the cultivation and breeding environment in the aquaponics system will be realized on the basis of monitoring of animal and plant statuses and environmental information, and the high quality and efficient production, resource saving, and water and nutrient recycling can be accomplished.

**Keywords:** aquaponics, internet of things (IoT), intelligent technology

### Introduction

Aquaponics is a new technology in modern agricultural production that combines aquaculture with hydroponics. Thus, vegetable planting no longer requires fertilization, and fish cultures do not need water changes as frequently. This change allows fish, cultivated crops and microorganisms to form mutually beneficial symbiosis and harmonious coexistence of ecological balance relationships. It is a viable technique for producing healthy, sustainable food (Azad *et al.*, 2016). Due to their resource savings, high efficiency, and low consumption, aquaponic systems have drawn increasing attention in the face of soil pollution, drought, and climate change and have evolved into the trend and direction of modern agricultural development (Mchunu *et al.*, 2018). The idea behind an aquaponic system is that microorganisms can utilize waste and unfinished bait released by farmed fish to break down ammonia-nitrogen in water into nitrite. The nitrifying bacteria break it down into nitrates so that the grown crops can absorb it as nutrients and use them for growth. As a result, the aquaculture water environment has been significantly enhanced. Through the use of a circulation system, the ammonia-nitrogen-containing water can be reused as fresh aquaculture water after being purified, conserving water resources and lowering the water exchange efficiency to less than 2% per day.

Aquaponics systems are continually evolving because of the increasing demand for food and the depletion of natural resources like water due to rising energy costs and a growing global population (Thorarinsdottir, 2015). However, with the continuous development of this system, the approach of current automatic control system (i.e.

control by timers and probes) alone cannot meet the needs of this system. Current automatic control system is not stable as some unexpected errors always occur. Based on these shortcomings the monitoring and control of environment and equipment through intelligent technology is the premise and foundation to ensure the stable operation in aquaponic system. The greenhouse environment, water quality parameters, and nutrient cycling in aquaponic systems may all be monitored and controlled in real time using intelligent technology (Internet of Things (IoT) plus intelligent algorithm). By continuously monitoring data and making the required adjustments, an ideal environment is maintained. Real-time data visualization and analysis are offered by IoT analytical platforms. It not only increases planting and breeding efficiency but also makes nutrient control with pinpoint accuracy and healthy growth of fish and vegetables possible. It also promotes a healthy cycle of water resources and increases the effectiveness with which water resources are used. Here, we have discussed intelligent methods for managing the nutrient cycling in an aquaponics system, monitoring and controlling water quality parameters, and greenhouse environment.

### 1. The overall system architecture of IoT in aquaponics

The aquaponics system, data acquisition, control equipment, Wi-Fi wireless data transmission module, cloud data processing server, social communication platform, and mobile application are the primary components of the environment monitoring system. Fig. 1. depicts the IOT architecture in aquaponics.

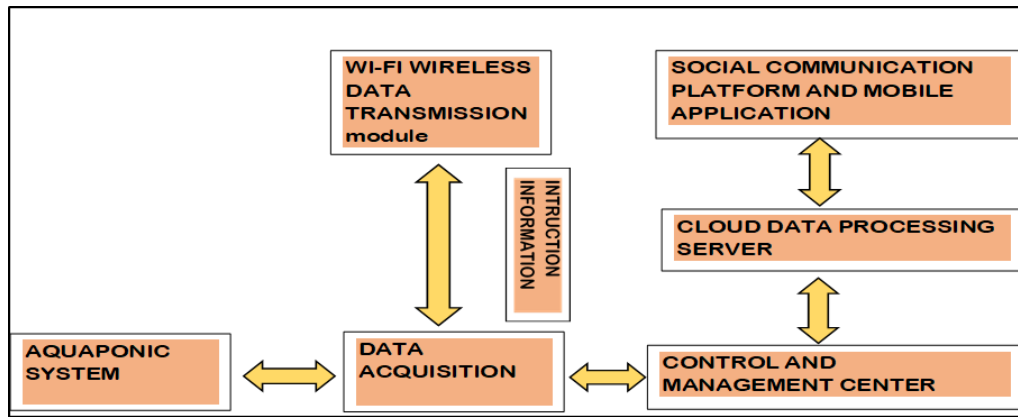


Fig 1: The overall system architecture of IoT in aquaponics

1.1. Major components of Internet of Things (IoT)

- **Physical Layer:** The physical layer of the system is made up of the sensors and control devices. Sensors are used to collect data and control devices works through control relay.
- **Gateway Layer:** The gateway layer is made up of a microcontroller like NodeMCU that connects to the physical layer's devices, gathers data, and sends control signals to the relay. The collected sensor data is then periodically published to the cloud via MQTT (Message queuing telemetry transport). Client certificates, which offer authentication and encryption, safeguard the connection to the cloud.
- **Middleware Layer:** The MQTT broker, which offers publish and subscribe semantics, is part of the middleware layer. This cloud-based broker connects the users with the physical layer. The complete physical infrastructure needed to run the broker is included in this layer.
- **Application Layer:** the application layer provides the user interface. It gives the user access to monitoring and analytics by subscribing to MQTT topics and retrieving sensor and alarm data from the MQTT broker.

2. Monitoring and control of environment

The prerequisite and foundation for guaranteeing the stable functioning of aquaponic ecosystems is the monitoring and control of the greenhouse environment. In the greenhouse, it is necessary to analyse the environmental variables, such as temperature, humidity, carbon dioxide, and light, in real-time. Therefore, the exhaust fan, evaporative cooler, warm lamp, greenhouse lighting, and other system components can be intelligently controlled to monitor these parameters. Currently, the Internet of Things, wireless sensors, and other technologies can be used to create an intelligent aquaponics system with automatic monitoring and control. However, due to the large fluctuation in control parameters in the greenhouse environment, it is necessary to combine the corresponding intelligent algorithm to solve the control of related parameters in a complex greenhouse environment. Nagayo and Jamisola (2017) developed an intelligent and energy-efficient aquaponic greenhouse system by designing wireless monitoring systems for aquaponic greenhouses based on cloud technology. They also automatically monitored and controlled the environmental conditions for Nile tilapia, spinach, and greenhouses. Nagayo *et al.* (2017) used NI Lab View software, a microcontroller connected to

sensors, and a GSM shield to successfully monitor and regulate greenhouse environmental conditions and important water quality parameters in aquaponics. According to Qu *et al.* (2011), Ferreira *et al.* (2002), and Wang *et al.* (1999), there are three categories of traditional greenhouse climate control methods: proportional-integral-derivative (PID) control methods, fuzzy control out of which Proportional integral derivative (PID) control is a control system that has long been used in industry because it is easy and simple to use.

3. Monitoring and control of water quality

The growth of fish and vegetables in the aquaponic system is significantly impacted by the quality of the water. It serves as a conduit between fish and vegetables, giving fish a growing environment while simultaneously delivering essential nutrients to plants. Water quality can change quickly as a result of fish feeding density, growth rate, food intake rate and quantity, and related environmental disturbances (Bodenmiller, 2017). In order to create a healthy environment for the growth of fish and vegetables, it is therefore required to monitor and regulate the major factors impacting water quality (Somerville, 2014; Thorarinsdottir, 2015). Temperature, pH, salinity, phosphate, nitrate, ammonia, and DO are the seven primary factors that affect the water quality of aquaponic systems. Each factors has unique requirements depending on the environment in which fish and vegetables are grown. There are growing numbers of instances of real-time monitoring and control of water quality in aquaponic systems owing to the Internet of Things technology as a result of the ongoing development of information technology. Table 1. depicts the work done on use of IoT for monitoring and control of water quality.

Table 1: Work done on use of IoT for monitoring and control of water quality

Authors	Prediction model used
De Silva (2016)	Fuzzy adaptive controller
Manju <i>et al.</i> (2017)	Wireless sensor devices
Valiente <i>et al.</i> (2018)	Automated aquaponics system (using Nile Tilapia and Romaine Lettuce)
Da Silva <i>et al.</i> (2018)	New toxicity early warning sensor Toxicity prediction model
Ren <i>et al.</i> (2018)	DO prediction model based on a fuzzy neural network

#### 4. Monitoring and control of nutrient solution

Recirculating aquaculture wastewater serves as a source of nutrients for hydroponic vegetables in aquaponic system. Basic nutrients for vegetables, such as N, P, K, Ca, Mg, and S, can be obtained from aquaculture wastewater (Suhl *et al.*, 2016). Monitoring and controlling the nutrient solution refers to regulating the pH (5.5-6.5), electric conductivity, Dissolved oxygen, and temperature in addition to accurately controlling the basic nutrient components of the nutrient solution (the six essential nutrients: N, P, S, K, Ca, and Mg) in order to increase crop yield and quality (Tellez *et al.*, 2012). The monitoring of crop growth and the monitoring of nutrient solution content are the two basic components of the monitoring of nutrient components. The conditions for the rational delivery of a nutrient solution depend on determining whether crops require nutrients and which nutrients are missing; thus, we can detect crop growth by introducing ontology sensors. Different aspects of a plant's nutritional requirements can be seen, for instance, how much chlorophyll is present in the leaves is closely related to the nitrogen availability (Penuelas *et al.*, 1998). Plants absorb more purple light when nitrogen is deficient and more green light when phosphorus is deficient. Therefore, we can assess the current nutrient deficiency in plants by detecting physiological status of plants. New non-destructive sensor technologies can assist us in identifying nutrient requirements and adjusting the elements of the nutrient solution required by plants (Raun *et al.*, 1998). To ensure precise fertilisation, Lee *et al.* (2000) developed an in-field hyperspectral sensor system that could assess the nitrogen status of maize plants. In order to ensure that plants grow to their full potential. Morimoto and Hashimoto (1991) developed a system for neural network-based intelligent control of nutrient solution concentration. Massa *et al.* (2008) developed an empirical model of sodium absorption concentration in hydroponic rose production, and it not only had the ability to forecast sodium concentration in nutrient solution but also to effectively output electrical conductivity and manage nutrient solution.

#### 5. Benefits of using IoT in aquaponics

- Conversion of environmental parameters into a readable output through digitization.
- Maintaining the system's conditions stable by using IoT devices and sensors to regulate factors including temperature, humidity, pH, light intensity, ammonia, water temperature, and dissolved oxygen.
- Constant data monitoring and trigger notifications that enable farmers to make necessary modifications from a distance.
- Automating repetitious operations, for example employing intelligent algorithms to regulate switches to control the water flow when specific threshold is reached.
- Data visualization and analytics platforms analyse sensor feedback and provide recommendations for increased yield and sustainability.
- Predictive analysis of data sets that can use machine learning modules to generate insights into future events and suggest particular measures to be taken to prevent event occurrence (component replacement, maintenance activities run, etc.)

#### 6. Challenges of using IoT in aquaponics

- The benefits of deploying cloud-based IoT for flexible aquaponics have been shown but there exists some challenges which should not be neglected and need to be addressed.
- The first obstacle to be addressed is connectivity which needs to be overcome.
- The absence of IoT standards reduces interoperability and results in the usage of a variety of automation devices from several brands, or even from one single brand, with various protocols that are incompatible at the data layer.
- Cost of deploying IoT solutions (initial costs, relatively high cost of IoT enabled sensors, purchase of mobile data for real-time monitoring and storage to the cloud or remote centers for analysis) is another crucial factor that shouldn't be overlooked. It is frequently viewed as overwhelming since it adds costs to a system that is already in place and functioning. As a result, factors including ease of use, training, adoption etc. should be considered while choosing an IoT platform.
- The absence of sufficient knowledge is the other problem. The majority of aquaponic owners and operators lack IT training. Despite having all the information, they are unable to use it. A major issue is that many locations lack the specialized labour necessary to fully use IoT technology.
- The requirement for dependable energy and mobile internet for aquaponics is another crucial element.
- The well-known security challenges are last but certainly not least. IoT devices automatically connect with one another. The adoption of IoT could result in brand-new security difficulties and vulnerabilities in the absence of a safe and adequately protected network.

#### Conclusion

With the rapid development of information technology, the Internet of Things, big data and other technologies have mature applications in the aquaponics system. Wireless sensors, for example, are intelligent gadgets that have been added to the system, simplifying and improving system control. A focus of current monitoring and control research, the intelligent algorithm is also where future progress will continue to go. It can execute the necessary controls after effectively predicting all the parameters monitored in aquaponic systems. In comparison to conventional manual operations, it saves time and energy, lowers costs, boosts system performance, and increases the automation, intelligence, and efficiency of the aquaponics system.

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