Design and Development of an Aquaponic System with a Self-Cleaning Drainage Pipe and Real Time pH Monitoring System

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ABSTRACT This paper introduces a prototype of a sustainable aquaponic system with a self-cleaning drainage pipe design to control the water level and thus solves the problem of waste accumulation in the fish tank. An Internet of Things (IoT) based monitor system was designed to monitor in real-time the pH value of the water in the aquaponic system. This system is designed for local communities particularly small urban households or for educational demonstration purposes. The result shows that the prototype significantly reduces the waste accumulation, and therefore maintains the water pH levels between 6.5 to 8.0 which is ideal for fish growth. With the help of the self-cleaning mechanism and real-time pH monitoring capabilities, the plant growth was up to 18% better compared to 6% without using the system, and fish growth was 27% better compared to 10.2% to the one not using the system. The implementation of an IoT monitoring system and self-cleaning pipe installation had proven the success of the small scale aquaponic system as shown by the healthy growth rate of the fish and vegetables.

KEYWORDS: Aquaponic system, Small scale, Self-cleaning drainage system, IoT monitor system, pH.
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INTRODUCTION

An aquaponic system is a system that involves the symbiotic integration of aquaculture and hydroponics. Aquaponics recirculate water between the fish tank and the plant grow bed thus minimizes the need for a large volume of water for small scale farming. The land footprint of aquaponics systems is relatively smaller compared to traditional farming; thus, this opens the possibilities for the urban household to have a more self-sustaining food source. In addition, the system also minimizes or even eliminates the use of herbicides and pesticides (Jones, 2002).

The major issue for an aquaponic system is the inconsistency of water quality in the fish tank that could affect the fish health. Water circulation with a constant flow rate is essential to avoid biological growth such as fungi, bacteria and algae (Masser *et al*., 1999) in the system. Other than that, fish waste accumulation in the fish tank could lead to the changes in the water pH and further affecting the fish health and growth rate. Thus, the design of the system to ensure good water circulation is essential.

Dissolved oxygen, pH value, temperature, and ammonia level of the water are the important parameters to observe the water quality of a fish tank (Shete *et al*., 2013). Overall, the tolerance pH for a healthy aquaponic system is in the pH range of 7-9 (Wyk *et al*., 1999). The tolerance range of pH for plants is 5.5 to 7.5. If the pH goes beyond the acceptable range, plants experience nutrients deficiencies (Somerville *et al*., 2014). While for fish, the water pH tolerance is between 5.5 to 10 (Stone & Thomforde, 2003). It is hard to monitor the system manually without any proper guidance, especially for those hobbyists with their busy daily life. Thus, a monitor system with the Internet of Things (IoT) technology is required to assist them to maintain the quality of the aquaponic system.

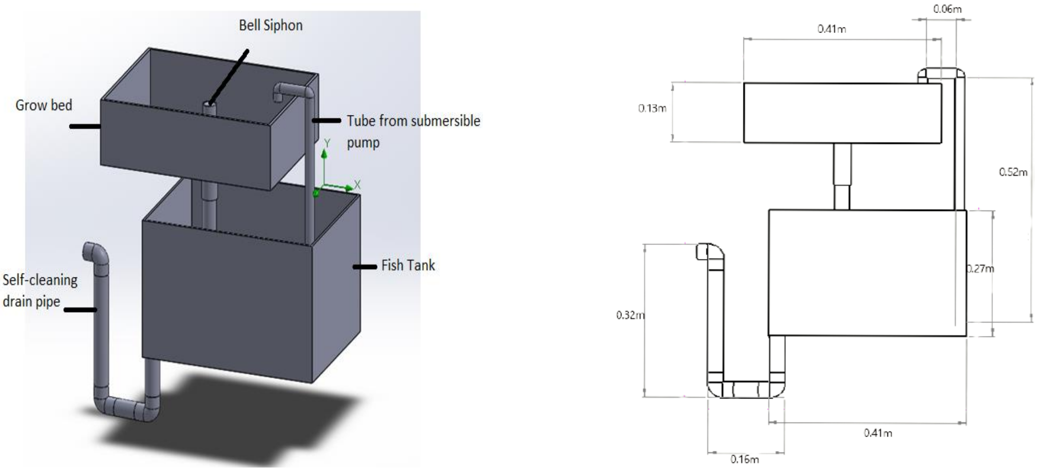
This promotes more energy-saving and a sustainable aquaponics system that will produce substantial crops for the urban setting.

In this work, a small scale of 3 ft^2 aquaponic system with a monitor system to observe the pH value of the water in the system is designed. A self-cleaning drainage pipe is also designed for the system to ensure the water quality of the fish tank. Brazilian spinach and tilapia fish are selected for system testing. The pH of the water tank, water condition, size of the fish and plant growth rate is observed for 14 days duration.

AQUAPONIC SYSTEM DESIGN CONSIDERATIONS

Water Recirculation System

To ensure the water recirculation in the system is smooth, the ratio of the plant grow bed size and volume of the fish tank is fixed to 1:2. The ratio of the grow bed and fish tank is to ensure water is sufficient for the plant and fish growth (Lennard, 2012). The system comprises a plant grow bed and a rectangular fish tank. Leica beads are selected as the medium in the plant grow bed with a customized bell siphon to level the water in the plant grow bed and drained back it to the fish tank. The submersible pump is used to operate the water flow throughout the system thus reducing the energy used for electricity. The fish tank water level is controlled by the self-cleaning drainage pipe to be 19 cm high constantly, besides removing fish waste from the tank. The diameter of the self-cleaning drainage pipe is 25.4 mm. The system design layout is designed and simulated using SOLIDWORK 2018. The layout and dimension of the system are as shown in Figure 1 (a) and Figure 1(b), respectively. The actual view of the aquaponic system is shown in Figure 2.



(a) (b)

Figure 1. Drawing of (a) 3D virtual system; (b) 2D drawing of the aquaponic system design.

Sensor Positioning

Sensors used in this aquaponics are the DS18B20 waterproof temperature probe and the E-201-C pH sensor and are placed near the corners of the fish tank since the fish waste accumulates at the corners of the fish tank.

Programming of the Monitoring System

In Figure 2, the block diagram for the monitoring system shows the communication of the sensors to the Blynk application by using the Arduino Wemos D1R1 board which has an ESP8266 module that allows it to connect to the internet connectivity (Chaudhary *et al.*,2018). The pH sensor measures the acidity of the water and the Arduino board reads and process the data. For monitoring purposes, the real-time data processed by the microcontroller are displayed on Android mobile apps, Blynk application.

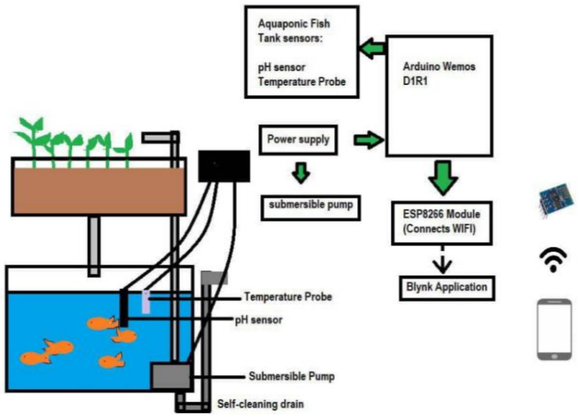


Figure 2. Block diagram for aquaponics system with the control and the monitor system.

Control and Parameters Monitoring

A system without a self-cleaning drainage pipe design is set as the control to compare with the aquaponic with the additional design of self-cleaning drainage pipe. The pH of the fish tank, length of the fish and also the plant is measured.

RESULT AND DISCUSSION

Monitoring System

The use of the Arduino Wemos D1 R1 in this project increases the simplicity of hardware connection and Arduino programming. Since it is based on the ESP8266 module which provides connectivity to Wi-Fi the water condition can be monitored via the mobile phone by using the Blynk application. The sensors were programmed to get the value for every one second.

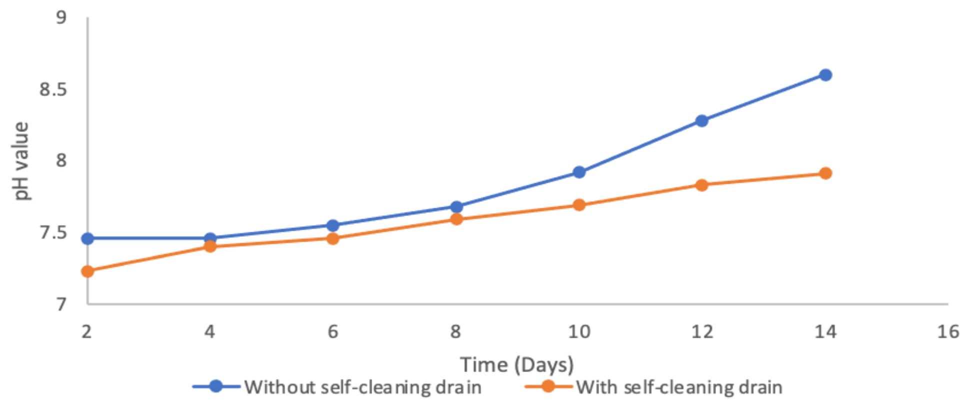


Figure 3. pH comparison with and without self-cleaning drainage for 14 days.

Figure 3 shows the pH value taken from both sets of experiments. The pH value throughout the 14 days for the experiment set without self-cleaning drainage shows an increasing pH value and sudden pH increase rapidly from the 10th day. This is due to the significant accumulation of fish wastes in the tank. This leads to the build-up of a high concentration of ammonia and thus causing the pH to increase rapidly. In contrast, slow rise in pH in the experiment set that have the self-cleaning drainage. The slow rise in pH value is a result of a smaller amount of fish wastes left in the tank due to regular flushing of the waste. The pH value of the water in the tank for the experiment set that has a drainage pipe was within the acceptable range of a good growth environment for fish and plants.

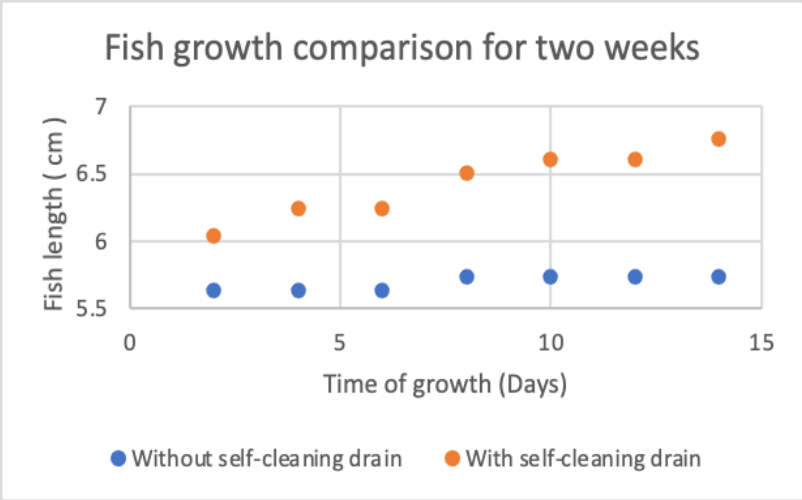
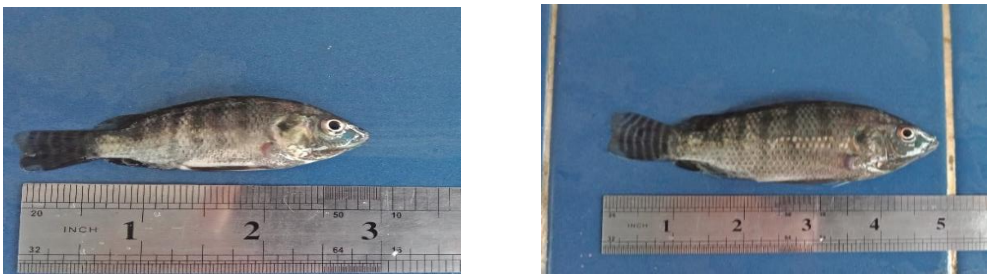


Figure 4. Comparison of fish growth for two weeks with the implementation of self-cleaning drain.

Figure 4 shows the comparison for fish growth based on the length of fish with and without the self-cleaning drainage pipe. The selection fish are from two different batches with length differences within 10%. The growth rate for the weeks without the self-cleaning drainage shows a slow trend with the value of 5.74 cm average as the highest value for the fish length. The aquaponics with self-cleaning drainage shows that the growth rate for the fish was increasing rapidly within the initial two weeks with the highest value of 6.76 cm. Figures 5 and 6 show the comparison of the fish and plant growth with the self-cleaning drainage pipe installed in the system.



(a) (b)

Figure 5. Fish length (a) in the beginning of the week (b) fish length after 14 days with installation of self-cleaning drainage pipe in the aquaponic system.

(a) (b)

Figure 6. Plants growth (a) at the beginning of the week (b) after 14 days with self-cleaning drainage pipe installed.

Figure 7 shows the percentage of plants and fish growth in the self-cleaning drainage pipe throughout the 14 days. The growth percentage was calculated by taking the ratio between the currently measured length to the previously measured length. The growth of the plant increased gradually to 18% from an initial height of 4.86 cm throughout the 14 days. The fishes grow well with a 27% increase throughout 14 days.

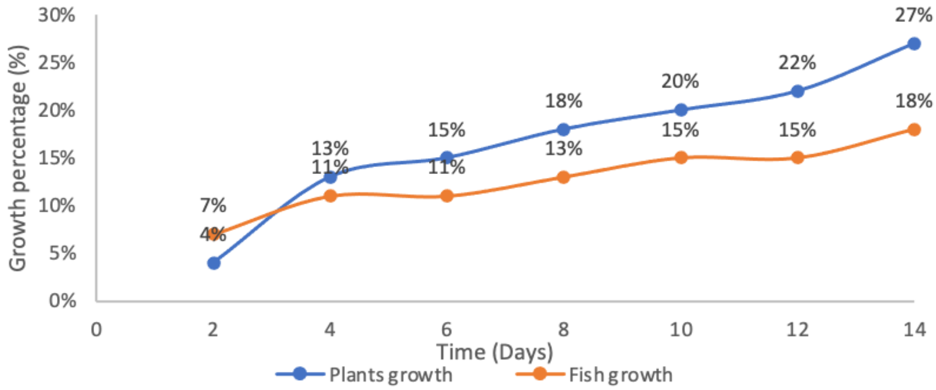


Figure 7. Plants and fish growth in percentage with self-cleaning drainage pipe & real time pH monitoring for initial 14 days.

Figure 8(a) and (b) shows tanks without a self-draining system and with the self-draining system, respectively. Referring to Figure 8 (a), the water of the fish tank was observed to be murky due to the accumulation of fish waste. This greatly affects the health condition and slow down the plant and fish growth rate. The growth of the Brazilian Spinach and the tilapia fish slowed down when the pH of the water has reached above 7.5. Fish eventually only reached up to a 6% increase in growth and the plant reached up to 10.2% growth on the 14th day of observation.

(a) (b)

Figure 8. Water in fish tank (a) without self-cleaning drainage for two weeks (b) with self-cleaning drainage for two weeks.

In Figure 8 (b), the water quality has greatly improved with the installation of a self-cleaning drainage pipe system as the fish waste accumulation is reduced. In addition, the monitoring system could alert the user to change the water fish tank when the pH is above 7.5. As referred in Figure 4, the water pH has been controlled within pH 8 and thus the growth percentage of the plant and fish reached to a maximum of 18% and 27% respectively. It is recommended to improve the monitoring system to self-regulate the water condition to ensure an optimum environment.

CONCLUSION

The aquaponic system with the installed self-cleaning drainage pipe effectively controls the environment of the aquaponic system. The testing of the system using Brazilian spinach and tilapia fish validated the simulation of the smooth water circulation flow in the system and pH value monitored for 14 days. The self-cleaning drainage piping design helps to maintain the aquaponic system in a healthy environment which a pH value below 8. The monitoring system helps to alert the user. Hence, the plant has grown up from 6% to 18% and from 10.2% to 27% for the fish with the self–cleaning drainage pipe during the 14 days observation. This makes the system accessible to the users even without an agriculture farming background to have a self-sustainable food supply in the urban cities especially during the pandemic of covid-19.

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