Aquaponic Growbed Water Level Control Using Fog Architecture

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Abstract— Integrated Multi-Trophic Aquaculture (IMTA) is an advance method of aquaculture which combines species with different nutritional needs to live together. The combination between aquatic live and crops is called aquaponics. Aquatic waste that normally removed by biofilters in normal aquaculture practice will be absorbed by crops in this practice. Aquaponics have few common components and growbed provide the best filtration function. In growbed a siphon act as mechanical structure to control water fill and flush process. Water to the growbed comes from fish tank with multiple flow speeds based on the pump specification and height. Too low speed and too fast flow rate can result in siphon malfunctionality. Pumps with variable speed do exist but it is costly. Majority of the aquaponic practitioner use single speed pump and try to match the pump speed with siphon operational requirement. In order to remove the matching requirement some control need to be introduced. Preliminarily this research will show the concept of fill-and-flush for multiple pumping speeds. The final aim of this paper is to show how water level management can be done to remove the speed dependency. The siphon tried to be controlled remotely since wireless data transmission quite practical in vast operational area. Fog architecture will be used in order to transmit sensor data and control command. This paper able to show the water able to be retented in the growbed within suggested duration by stopping the flow in once predefined level.

Keywords— Internet of Thing, IoT, Cloud, Automation, Remote, Monitoring, Control, Aquaponics, IMTA, MQTT

1. Introduction

Internet of Thing (IoT) is the inter-networking of physical devices, vehicles, buildings, and other items embedded with electronics, software, sensors, actuators, and network connectivity which enable these objects to collect and exchange data [1]. This technology evolves with the emerging internet capabilities. The introduction of this technology connects anything to the internet, enabling data and...
insights that never available before. According to Cisco Visual Networking Index [2], by 2020 46% of internet access will be represented by Machine-to-Machine (M2M) connection.

IoT works based on currently trending cloud computing. It is a type of internet-based computing that provides shared computer processing resources and data to computers and other devices on demand [3]. There are many companies provide cloud service with the names like Amazon, Microsoft Azure, IBM Watson, Google Cloud, Oracle, Salesforce, Bosch, Cisco, GE Predix and Thingspeak – just to name some of them. The introduction of this cloud consequently enables the generation of unprecedented numbers and variety of data. However, by the time the data available on the cloud for analysis, the opportunity to act on it might be gone. It seems like the cloud is suitable only for reference source.

Fog architecture has been introduced in order to avoid vast underused data to be uploaded to the cloud. This architecture seems to be more suitable to be implemented in data acquisition and control system like manufacturing, modern agriculture and aquaculture sector. The implementation also can remove the need for tedious wiring requirement especially in vast control area or remote location.

Modern aquaculture like IMTA or specifically aquaponics is currently getting more interest and adding automation will upscale the operation efficiency. In aquaponics, the implementation of growbed method seems to replace the need for expensive biofilter and drum filter. According to [4] this method provides high aeration and can support all types of plant. However the flood-and-drain mechanism in plant tanks requires careful calculation of water volume. Normal and affordable single speed pump specification affected by this requirement. This paper will show how to control flood-and-drain operation of a growbed by water level control method without the need to depend on water flow speed.

2. Background research

Aquaculture area nowadays in majority mostly is practiced in traditional way. Mechanical structure and human related operation widely used. The operational efficiency always in doubt when there is no automation involved. To eliminate this error-prone process, this paper will focus in automatic test which involve more on the electronic data acquisition and analysis. Three related elements of study had been carried out prior to the implementation of fog computing in aquaponics. Those three elements are fog computing, aquaponics and aquaponic growbed.

A. Fog Computing

Fog computing was introduced after the introduction of cloud computing. Edge computing or Fog computing is a new way of data sharing intended for IT and operational technology professionals. This is a new model which performs instant gathering and action on IoT data. Fog computing offers reduction of network traffic by providing a platform to filter and analyse the data generated by the devices which close to the edge and for local data views [5]. As the result, it will automatically reduce the traffic being sent to the cloud.

Fog computing suitable for IoT tasks and queries too where most of the smart devices need to capture events within hundred meters distance and no need to access global data from cloud. Low latency requirement also provided by fog computing which critical parameter can be reflected with high speed real time response. Furthermore, it can reduce the scalability issue since fog computing aims the incoming data to get closer to the data source itself and reduces the burden of that processing on the cloud and without concern of the increasing number of endpoints. Fog in actual is not a separate architecture; it merely extends the existing cloud architecture to the edge of the network—as close to the source of the data as possible—to enable real-time data processing and analytics [6]. Figure 1 shows how fog computing extends cloud capabilities to the edge of the network.
B. Aquaponics

The word aquaponic comes from aquaculture and hydroponic. It is the integration of recirculating aquaculture system (RAS) and hydroponics in one closed production system [7]. The concept of by-product recycles happen here – this is why this system is categorized as Integrated Multi-Trophic Aquaculture (IMTA). The fish or aquatic animal produces waste and the crop system treat it as nutrient and absorb it. The clean water then return back to the tank. This is actually how aquaponic RAS works. In order to success in operating aquaponic, the RAS should be at the best performance. Inefficiency in RAS will result in catastrophic loss especially to the aquatic life.

Nutrient Recovery Efficiency (NRE) is affected by many factors. By using this concept of IMTA, the variable can be limited and easily managed and hence can produce greater result. The source of nutrient purely comes from fish ponds or tanks, and this variable can be said to be constant. The one need to be altered in order to maximise NRE is the crop side. If the crop area is made easily accessible and easily adjusted, then this process could be easier.

In aquaponic there are two major things need to be taken care of – water flow and water quality. There are different water flow requirement for different type of aquaponic setup. Aquaponic most common components can be Growbed (mediabed), Nutrient Film Technique (NFT) or Deep Water Culture (DWC) [4].

C. Aquaponic Growbed

Common mediabed system component are cultivation tank, cultivation gravel (clay aggregate or pebbles) and siphon. There are three common area which are dry zone, root zone and sludge zone. Dry zone is normally 1 to 2 inches depth at the top area. Water definitely will not reach this area. The sludge area is the lowest area and considered all-time-wet area. The root area is the middle area which normally between 8 to 10 inches depth. Light Expanded Clay Aggregate (LECA) normally used as the grow media since it is near neutral pH and light in weight [8]. The granule feature of LECA or pebbles enables the air to exist between them.

The siphon functions to control the water level in the mediabed tank. It allows the water to fill the tank up to certain maximum level and then flush them out immediately. This gives the root of the crop to have contact with air. Hence, the result of this mechanical operation will permit the crop exposed to water and air alternately. Figure 2 shows the component of the growbed.
The flush operation improves the oxygen content in the filtered water. As stated by [9] the bell siphon should start, drain, and stop every 15 – 20 minutes for optimal filtration and plant growth.

3. Test setup

A set of testing has been carried out using Affnan bell-strainer siphon design [10]. The siphon function and basic structure act like a covered standpipe with a trapped outlet as described by [11]. The difference between Affnan siphon and the structure illustrated by Garret is at the end of the outlet pipe. Affnan’s design just uses an elbow pipe and a straight pipe. However, the latter create a crest height at the end of the pipe.

The siphon construction for this test and actual implementation will follow the one created by Affnan. This design was used since the construction needed less effort and save time since the parts that were used were available on the shelf. The guard area was constructed using 80mm unplasticized polyvinyl chloride (uPVC), covered by the end cap at the top and vent cowl at the bottom. Three siphon standpipe sizes were prepared to be used in this test setup - 15mm, 20mm and 25mm PVC type. The vent cowl was drilled to house the suitable PVC tank connector. The base of the barrel was also drilled in order to install the siphon. At the bottom part PVC P/T connector fitting connected to the tank connector in order to tightly attach the siphon to the tank.

The test used normal tap water from the main domestic outlet, feed to the liquid flow speed sensor and enter the half-cut barrel filled with LECA. Water inlet speed was controlled using a mechanical ball valve. The initial setup set as in Figure 3. Flow speed sensor equipped both in the inlet and outlet section. The inlet water flow speed aimed to be varied from 100 up to 800 liter per hour (L/H).
In order to implement fog to this system, a Raspberry Pi had been used as the broker, a personal computer (PC) as the client that subscribe the data and publish the control command. NodeMCU board used as the client that located at the growbed tank which subscribe to the PC command and publish the data.

The initial test involved the functionality of the siphon with the variation of inlet water speed. The inlet flow speed data together with the outlet flow speed data sent from the NodeMCU to the network. The data transmission will be monitored or supervised by the Raspberry Pi. The result tabled and plotted in the graph form to see how the siphon performs.

The setup later upgraded by equipping ultrasonic level sensor to the growbed. The ultrasonic sensor will report the current water level in the growbed. The PC will subscribe to this water level data together with inlet flow speed and outlet flow speed data.

4. Initial result

As previously stated, the ideal operation of a siphon at specified constant inlet flow speed is when the time between two flushes of water happens within 15 to 20 minutes. This timing range provides enough time for the bacteria in the growbed to extract nitrate and nitrite from ammonia. Bacteria involved in this process hence make this system the way a biofilter works.

Figure 4 shows the result of siphon operation at the inlet flow speed of 100 liter/hour for 15mm standard pipe size. As can be seen in the graph two flush and drain process has successfully happened. The flow in rate constantly exists along the process. The flow out rate was initially at zero rate and then spikes to the highest rate to flush out all the water in the barrel. The rate then goes to zero once the water level reaches to the lowest flushable level. The duration between two successive flushes for this inlet rate was around 18 minutes.
A problematic siphon happens when the cycle is too short or it cannot continuously fills and flushes alternately. Figure 5 shows a problematic siphon operation in term of timing. The test was done at the flow speed of 200 L/H. For this speed of water inlet, the duration between two successive flush was around 12 minutes.

The following Figure 6 shows the flow pattern for 300 L/H water inlet for 15mm siphon standpipe size. This pattern exhibit a bit different shape compared to the previous flow pattern.

The same pattern also happen when the flow of 400 L/H feed to the growbed as shown in Figure 7. The flow out starts with the spike and then follows the inlet flow rate.
Both represent the flow pattern of malfunctioning siphon in term of flushing capability. Initially the siphon able to demonstrate the flushing operation but fail to repeat and this shown by the almost equal flow speed between the flow in and flow out. This means that the incoming flow will directly goes out at almost at the same rate.

Based on these flowspeed tests, it can be said that for 15mm standpipe siphon size placed at barrel-type growbed only 100 L/H inlet speed fit to the required operational condition. The siphon able to work well in term of flushing capability at 200 L/H inlet flowspeed but cannot obey 15 – 20 minutes fill-and-flush requirement. Meanwhile for 300 and 400 L/H inlet flowspeed obviously shows that the siphon cannot flush as desired. They can flush once only and then when the flow out rate equal to flow in rate they seems to be constant.

From these test results a fill-up table can be constructed. The table consists of the duration from the moment the flow-out rate become zero until the next flush out happened. Since the 100 L/H and 200 L/H inlet flowspeed show multiple fill-up duration, both of them will be recorded in Table 1 together with the average value.

| Flow In Speed (L/H) | Estimated Time | Fill 1 | Fill 2 | Average |
|---------------------|----------------|--------|--------|---------|
| 100                 | 12m 28s        | 15m 56s| 14m 12s|
| 200                 | 7m 58s         | 7m 38s | 7m 48s |
| 300                 | 4m 50s         | NA     | 4m 50s |
| 400                 | 3m 39s         | NA     | 3m 39s |

Before continuing to solve the problem by putting control elements, one more test has been done. This test involves water level checking. An ultrasonic sensor was placed in the siphon guard pipe and the water level kept published to the client. Figure 8 shows the water level graph when tested with 100 L/H flow speed for 15mm siphon standpipe.
Figure 8: Level pattern at 100L/H inlet flow speed

The height data represent the real water level in the growbed. The values calculated by subtracting the sensor position with the read value. The difference will give the actual water level in the siphon.

From this graph the lowest level the water can go is around 4 cm. This can be said as the sludge area height. From the graph also we can see that the maximum height achievable was around 19.5cm. This was the highest level can be reached before the flush process happen.

5. Implementation of control

Siphoning mechanism is not only good to the crop by providing the nutrient but also beneficial to fish since it helps to oxygenate the flow out water. What can be done is to improve the design by removing the flow speed dependency, controlling the flushing duration while maintaining the good aspect of siphon.

From both Figure 4 and 5, the duration between the start of flush until the end of it can be estimated constantly at 3 minutes for this 15mm siphon pipe size. Meanwhile from Figure 8 the maximum water level before flush out is around 19.5cm.

In order to make the siphon able to function well regardless of the flow in speed, adjustment needs to be done to the flow in part. The suggested adjustment was by stopping the flow in before the water level reach to flush level. Figure 9 shows the water level pattern introduced for 100 L/H flow speed.

Figure 9: Flow pattern at 100 L/H with water level detection

The following Figure 10 shows the level pattern for 200 L/H inlet speed. The flow in cut-off time come around the 6th minute and it needs 9 minutes to wait before further fill up can be added to force flushing condition.
The following Figure 11 shows the level pattern for 300 L/H inlet speed. The cut-off time comes around the 3rd minute and it needs 12 minutes to wait before further fill up can be added to force flushing condition.

In this water level control adjustment experiment the level before the flow in cut off was set to 18 cm. The wait time then introduced until the 15th minute of the cycle. The flow in then re-introduced for around 3 minutes to force the flow out. The water level experiment for 400 L/H flow in was also exhibit the same pattern. The set level reached at faster rate and the wait time needed to be longer.

6. Conclusion
Growbed replaces the need for costly biofilter in recirculating aquaculture system. By performing as a trickling filter this growbed together with beneficial bacteria helps to remove nitrate and nitrite from the fish water. Hence the catastrophic ammonia level can be reduced.

Preliminary test shows that mechanical setup can lead to unsatisfactory operation when operated with various flow-in rates. The unsatisfaction happens once the fill-and-flush operation fails to be in sequence or in term of timing.

From the mechanical operational analysis also the flow pattern can be examined and solutions can be planned for this problem. The solution plays around with the flow-in control.

The first solution can be done by controlling the flow-in based on the accumulated volume. The flow-in can be stopped before the total accumulated volume reach to 24.6 L as calculated before. This way will need to have flow sensor at the inlet channel.

The second solution can be done by controlling the flow-in based on the flow timing. Each flowrate should have pre-calculated duration of valve on and off. By doing this way also there will be a need to have flow sensor.
The third solution which is based on the water level seems to be the best since it involve simpler method and cheaper component.

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