Using Wireless Sensor Network Controls to monitor an indoor Aquaponic System

Jose Guerrero & Fern Edwards
In collaboration with Dr. Yan Wan & Vardhman Sheth
Skyscraper farming

A futuristic concept converts skyscrapers into crop farms that could help reduce global warming, improve the urban environment, and help feed the world’s growing population. How it would work:

SOLAR PANEL
Energy is supplied by a rotating solar panel that follows the sun; drives interior cooling/heating system.

GLASS PANELS
Clear coating of titanium oxide collects pollutants and makes rain slide down the glass where it is collected and used for watering.

ARCHITECTURE
Circular design allows maximum light into center.

ECONOMY
The plan combines farming with office and residential stories.

IRRIGATION
Filtered, sterilized wastewater from sewage system can be used for irrigation.

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SOURCE: Vertical Farm Project

1. Applying the most conservative estimates to current demographic trends, the human population will increase by about 3 billion people during the interim.

2. An estimated 10⁹ hectares (1 hectare = 10,000 sq. meters) of new land (about 20% more land than is represented by the country of Brazil) will be needed to grow enough food to feed them, if traditional farming practices continue as they are practiced today. At present, throughout the world, over 80% of the land that is suitable for raising crops is in use (sources: FAO and NASA).

3. Historically, some 15% of that has been laid waste by poor management practices. What can be done to avoid this impending disaster?
Vertical Farming

http://www.youtube.com/watch?feature=player_embedded&v=1cIRcxZ5Ss&noredirect=1

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Aquaponics - An Option for Sustainable Living

- Aquaponics combines hydroponics (soil-less farming) with aquaculture (rearing of fish) in a continuous nutrient cycling system.
- The fish produce waste (ammonia) that is fixed by denitrifying bacteria which help convert ammonia into nitrates that the plant can use.
- The plants filter the water and that water is then recycled into the aquarium.
How does aquaponics work?

The Nitrogen Cycle

Fish & Food

Ammonia

Plants

Nitrate

Nitrite

Nitrosoomonas Bacteria

Nitrobacter Bacteria

$O_2$

The Nitrogen Cycle

$O_2$
<table>
<thead>
<tr>
<th><strong>Advantages</strong></th>
<th><strong>Disadvantages</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reuse and recycling of water</td>
<td>1. Single points of failure</td>
</tr>
<tr>
<td>2. Organic fertilization (healthier food/pesticide free food)</td>
<td>2. Depending on systems it can get expensive</td>
</tr>
<tr>
<td>3. Reduction of environmental footprint on crop production</td>
<td>3. Conflicting research</td>
</tr>
<tr>
<td></td>
<td>4. Excludes plants whose edible portion are roots (carrots, potatoes)</td>
</tr>
</tbody>
</table>
Why use sensors?

A successful aquaponic system requires constant monitoring of:
1. pH, temperature, dissolved oxygen levels
2. water height levels
3. Feed fish

Integrating an autonomous control system would allow for continuous autonomous monitoring and control of a dynamic system.
Hypothesis

1. We anticipate the arduino sensor cluster to give us 5-10% error to that of the more developed and commercially used PASCO sensor.

2. The control system will work as programmed and will require no human interference and minimal maintenance.
System Designs

1.
<table>
<thead>
<tr>
<th>Why didn't we use Dr. Wan's Design?</th>
</tr>
</thead>
<tbody>
<tr>
<td>There was no real reason why we did not go with Dr. Wan's system setup instead we designed ours while choosing tank containers at Lowe's and an added recommendation from Dr. Acevedo:)</td>
</tr>
</tbody>
</table>
System Design

2.
Setup

1. 1st tier- 30 gallon plastic container housing 10-15 fish. Fixed sensor cluster in a waterproof otterbox. pH buffer solution dispenser plus food dispensers hovered right above water; multiple sensing probes; control valves.

2. 2nd tier- 20 gallon grow bed for tomatoes and cucumbers. Clay pebbles are clean, pH stable, and allow for excellent aeration and drainage. This gives us control over how our plants grow and what goes into their growth.
Continue setup

3. Ground level - water reservoir with an added pump

our complete setup

---------->
Us at work:)
Our Aquaponic System
Ebb and Flow

Why put this slide in here? Because it was the most important part to our entire aquaponic system.
Arduino Microprocessor

- Working off last year's sensor cluster concept
- Using ATLAS Scientific
Implementing Controls
Utilizing Tweeter

1. Arduino send data to computer and with programming it tweets data

2. Real time data

3. Environmental conditions can easily be controlled by collaborators
<table>
<thead>
<tr>
<th>Sensor Cluster</th>
<th>Temperature</th>
<th>pH</th>
<th>Dissolved Oxygen</th>
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<tr>
<td>Sensor Cluster</td>
<td>23.32</td>
<td>7.26</td>
<td>8.5</td>
</tr>
<tr>
<td>Fish Tank</td>
<td>22.7</td>
<td>7.17</td>
<td>8.5</td>
</tr>
<tr>
<td>PASCO Fish Tank</td>
<td>23.1</td>
<td>7.64</td>
<td>7.9</td>
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<table>
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<tr>
<th>% errors</th>
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Next steps

1. How can we measure ammonia levels autonomously?
2. Run the sensor cluster and PASCO for 24 hrs. to retrieve data
3. What biotic parameters should we be testing in the next 3 weeks to show us if our design is effective? Plant and Fish growth only?
4. Can we create an autonomous water dispenser to compensate for evaporation?
5. Dr. Wan would like us to create our stream system from last year and deploy a control
Next steps

- Adding clams to system (as a bioindicator)
  clams help clean up wasted foods and other debris on the bottom of the fish tank, as well as processing some of the fish wastes which helps prevent fish diseases in the tank. Freshwater clams are a natural, living filter organism, which helps keep the water clean as well. Invertebrates add to the waste, which provides more fertilizer for your plants.

- Build an online database
- Introduce a disturbance to tank and monitor
- Video monitoring
- Add references for quotes
- Relate nitrate levels to plant growth
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**Problem**

- How do we develop a control system, while utilizing an arduino and Xbee, to maintain normal environmental conditions in an aquaponic system?
  - Monitoring aquatic variables: pH, temperature, dissolved oxygen

How will we do this?

1. Collect sensor cluster data for 24hr. & 48hrs.
2. Create an online database to collect tank readings
3. Test each control independently from each other, then all together
4. Determine whether controls reestablished normal conditions
Cont. Recap (Initial Data)

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Formulating the Problem

How do we formulate it in a scientific way?
- We needed to know the dynamics of the plant
- We needed to design the controller to achieve desired parameters
- We need to define the goal of the control
Block diagram at the aquarium side
Design of our controller

Aquaponic Ecosystem

- Controller: Arduino calculate the error and sends electrical signal i.e. high/low signal to the actuator
- Actuator: Turn on/off circuit + bubbler
- Plant: Oxygen dissolving process
- Measurement: DO sensor reading feeds back to the Arduino
Actuator Circuit

Circuitry used for both DO & pump. When a high pulse (digital 1/5v) is supplied by arduino, circuit is activated and bubbler/pump turns on. When desired reference level is met arduino sends digital low value and turns off bubbler/pump.
pH Sensor isolation

- Opto-isolator is a component that transfers electrical signals between two isolated circuits by using light.

Whatever disturbance/interference that happens at Arduino will not affect pH sensor, the opto-isolator provides an isolation of ground. It provides communication between the two circuits that have different potentials.
Control circuit for pH

Control Circuit for pH

ARDUINO

Solenoid

Q1

1K or 2.2K

TIP102 for solenoids up to about 4A

Solenoid power U+

Solenoid power GND

GND
DO isolation

Diagram showing a circuit with components labeled Arduino, DC-DC Converter, Opto-isolator, and DO Sensor. Connections include Vcc1, Vcc2, Gnd1, and Gnd2.
Control circuit for DO
Food Dispenser

The dispenser (bottle) is attached to a motor; the dispenser activates every 24hrs. from the start of the system
Food & pH Dispensers

- 4 full rotations once a day dropping 4-5 food pellets for each rotation
- pH control only activated every 8hrs, if needed.
- Volume dispensed is an ~ amount that dispenses in 0.7sec
Initial data (07/09)

Sensor cluster deployed on July 8th at 11am until 3pm the following day. No controls activated.
Algorithm (07/12 - 07/13)

Developed algorithm to remove sensitivity points of sensor
Dissolved Oxgen (DO)
pH
Temperature
pH Control

There is a deliberate delay in response time from control….delay time is 2 mins/120 seconds. Once delay period passes after a disturbance the control turns on and delivers 0.7 seconds worth of correct pH solution. In aquarium controls would only be activated every 8 hrs to avoid drastic changes in pH.  
http://www.youtube.com/watch?v=L-AN6qAb5Ws
A sonar sensor to be placed at the top of the tank points downward so as to measure the distance between the point of placement and the surface water. Taking the difference between known quantities: the distance between the bottom and the measurement read from the sensor, we get the height of the water surface. http://www.youtube.com/watch?v=AK1nu9l2P3Y&feature=youtu.be
http://www.youtube.com/watch?v=ElC4d9C1gHY&feature=youtu.be

Arduino Database & Processing software

Arduino processor receives information from the sensors and that information is transmitted by Xbee to a processing software. This communication is one-way.

The processing software:
1. stores the data in a .txt file
2. tweets data after every 20 minutes
Literature Review

Andreas Graber, Ranka Junge. "Aquaponic Systems: Nutrient recycling from fish wastewater by vegetable production"

This paper describes the possibility to combine wastewater treatment in recirculating aquaculture systems (RAS) with the production of crop plants biomass. A special design of trickling filters was used to provide nitrification of fish wastewater.

Steve Diver Aquaponics: Integration of Hydroponics with Aquaculture

This publication provides an overview of aquaponics with brief profiles of working units around the country.


The conclusion is that building scalable mobile UWSNs is a challenge that must be answered by interdisciplinary efforts of acoustic communications, signal processing, and mobile acoustic network protocol.

An aqueous sensor network is described consisting of an array of sensor nodes that can be randomly distributed throughout a lake or drinking water reservoir. In this work the aqueous sensor network is described, with application to pH measurement using magnetoelastic sensors.


This work provides an in-depth study of applying wireless sensor networks (WSNs) to real-world habitat monitoring. A set of system design requirements were developed that cover the hardware design of the nodes, the sensor network software, protective enclosures, and system architecture to meet the requirements of biologists.