IEEE Control Systems Society (CSS) Outreach Fund
Report on
Summer Training Experience for K-12 Teachers in Control Engineering

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1. Project Description

1.1. Motivation

There is an increasing need to develop high-performance decision-making algorithms to manage complex systems, including but not limited to environmental, biological, economic, and infrastructure-type systems. Over the years, increasing number of algorithm developers, researchers in interdisciplinary areas, and practitioners in application-specific domains have realized the important role of control engineering, as providing invaluable concepts and tools to address various decision-making tasks in these broad applications. The PI Wan, as the instructor of the undergraduate/graduate courses on control systems at UNT and a researcher in the field of control, feels the need to educate students in early stage of education with the value and interdisciplinary asset of control engineering. An effective approach is to provide trainings to K-12 educators and help them integrate the basics of control into their teaching plans.

1.2. Objectives

The objective of this CSS outreach project is to provide opportunities and university resources for high-school teachers, students, and communities to 1) understand the value of interdisciplinary control engineering in early stage of education, 2) practice control concepts through hands-on projects and interactive activities, and as a result 3) prepare more students to the control engineering discipline. To achieve these objectives, we proposed to hold a 6-week summer training program for teachers in control engineering, and intertwined follow-up activities to strengthen the outcomes and to foster broader participation.

1.3. Summary of Activities and Impacts

The CSS Outreach Fund produced a series of activities that benefit the controls community, as summarized below.

1) Seminars on basic control engineering concepts to local high school teachers help them learn control engineering basics and introduce such knowledge to their students;

2) Six-week summer training and hands-on project on the aquaponic control system allows high school teachers to obtain first-hand knowledge in control engineering and its broad applications, and integrate this knowledge to their curricula; Web dissemination of the teacher project permits broad public access;

3) High school lesson plans on control and classroom teaching equipment (in particular, a lab prototype of aquaponic control system) benefit high school students to learn control concepts over years;

These activities benefited the controls community by providing broad dissemination of control concepts to pre-college teachers, students, and the community. We note that this outreach benefited populated under-represented districts. For instance, the Dallas ISD (DISD), the largest school district in Dallas MSA and the major target in this outreach, has more than 28% of the population African American, and more than 65% Hispanic. We expect the outreach to guide more students to the field of control engineering (at UNT), as DISD is one of the 20 largest public school districts in the United States, and Dallas MSA accounts for more than 50% of UNT’s student population.
2. Activities and Outcomes

Activities 1 and 2 were carried out during the 6-week summer training program from June 10, 2013 to July 19, 2013. Activities 3 and 4 were carried out in the following-up academic year from June 2013 to May 2014.

2.1. Participates and Time Tables for Activities

<table>
<thead>
<tr>
<th>Index</th>
<th>Activity</th>
<th>Participants</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 1</td>
<td>2-hour seminar on control (Part 1)</td>
<td>17 teachers</td>
<td>June 11, 2013</td>
</tr>
<tr>
<td></td>
<td>2-hour seminar on control (Part 2)</td>
<td>17 teachers</td>
<td>July 1, 2013</td>
</tr>
<tr>
<td>Activity 2</td>
<td>Summer training and project development on Aquaponic Control Systems</td>
<td>2 teachers</td>
<td>6 weeks in the summer training program (9AM-5PM, M-F)</td>
</tr>
<tr>
<td>Activity 3</td>
<td>Teaching plan development</td>
<td>2 teachers</td>
<td>Academic year (June 2013 to May 2014)</td>
</tr>
</tbody>
</table>

A total of seventeen K-12 teachers selected from seven school districts (Carrollton-Farmers Branch ISD, Denton ISD, Frisco ISD, Lewisville ISD, Duncanville ISD, Krum ISD, and the largest under-represented Dallas ISD) participated in this summer training program. The following 17 K-12 teachers participated in the summer training program. Among them, Jose Guerrero and Fern Fern Edwards Ferguson participated in the aquaponic control systems project.

<table>
<thead>
<tr>
<th>Name</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jose Guerrero</td>
<td>R.L. Turner High School, CFB ISD</td>
</tr>
<tr>
<td>Chelsea Meyer</td>
<td>The Colony High School, LISD</td>
</tr>
<tr>
<td>Georgette Jordan</td>
<td>Emmett J. Conrad High School, Dallas ISD</td>
</tr>
<tr>
<td>Gregory Kulle</td>
<td>The Colony High School, Lewisville ISD</td>
</tr>
<tr>
<td>Fern Edwards Ferguson</td>
<td>Heritage High School, Frisco ISD</td>
</tr>
<tr>
<td>Jesse Bell</td>
<td>Skyline High School, Dallas ISD</td>
</tr>
<tr>
<td>Deliah Johnson-Seastrunk</td>
<td>Navo Middle School, Denton ISD</td>
</tr>
<tr>
<td>Michael McEver</td>
<td>Hebron High School, Lewisville ISD</td>
</tr>
<tr>
<td>Dave Parsons</td>
<td>Flower Mound High School, LISD</td>
</tr>
<tr>
<td>Karl KGscheidle</td>
<td>R.L. Turner High School, CFB ISD</td>
</tr>
<tr>
<td>Elizabeth Freeman</td>
<td>Frisco High School, Frisco ISD</td>
</tr>
<tr>
<td>Dawn Chegwidden</td>
<td>Lewisville High School, Lewisville ISD</td>
</tr>
<tr>
<td>Raechelle Jones</td>
<td>Kennemer Middle School, Duncanville ISD</td>
</tr>
<tr>
<td>Lori Wolf</td>
<td>Navo Middle School, Denton ISD</td>
</tr>
<tr>
<td>Debra Hardy</td>
<td>Krum High School, Krum ISD</td>
</tr>
</tbody>
</table>
2.2. **Activity 1: Seminars on Control**

Two seminars on control systems were given to all K-12 teachers who are involved in the summer training program. In the first seminar, we explained the “dynamics” and “closing-the-loop” concepts rudimental to control engineering using easy-to-understand examples. We also leveraged the PIs’ research to discuss the novel use of control in broad modern decision-making applications, such as air traffic management, smart home design, power grid management, and epidemic spread control. In the second seminar, we explained the details of controller design and went through several examples to explain the design procedures. Please refer to the Appendices A and B for the slides of the two control seminars.

2.3. **Activity 2: Summer Training and Project Development on Aquaponic Control Systems**

Aquaponic systems involve intricate biological and chemical processes to breakdown fish waste, generate nutrition for plants, and produce clean water to fish. Maintaining the healthy condition of system water is critical for the functioning of the aquaponic system. Important health indicators of an aquaponic system include: temperature, dissolved oxygen, pH, and those related to the nitrification process, such as ammonia, nitrite, and nitrate. In this project, teachers built a simple automatic control of aquaponic ecosystem. In particular, the system performs the following functions: Maintain constant water level through a water-level triggered circuit to open/close the water inlet, Maintain temperature through a heater system, based upon temperature readings, Control dissolved oxygen level using a dissolved oxygen sensor and an air pump, Control pH-level through pumping out waste water out of the system, A timer-controlled motor to drop fish food, Timer-triggered pump to water the plant. The teachers learned through this project the fundamentals of automatic control, the functioning of an aquaponic system, programming microcontrollers, and the design of simple control circuits. Please refer to the Appendix C for the project poster, and Appendix D for the project powerpoint presentation. The following information can also be accessible from the web:

<table>
<thead>
<tr>
<th>Project Material</th>
<th>Publicly Accessible Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project blog developed during the 6-week period, documenting the progress each day</td>
<td><a href="http://untret2013.blogspot.com/">http://untret2013.blogspot.com/</a></td>
</tr>
<tr>
<td>Project power point presentation (48 slides)</td>
<td><a href="http://www.teo.unt.edu/ret/pdf2013/Aquaponics-presentation.pdf">http://www.teo.unt.edu/ret/pdf2013/Aquaponics-presentation.pdf</a></td>
</tr>
<tr>
<td>Demo of the control for dissolved oxygen level</td>
<td><a href="https://www.youtube.com/watch?v=ODVzNSf-Km4">https://www.youtube.com/watch?v=ODVzNSf-Km4</a></td>
</tr>
<tr>
<td>Demo of the control for water level</td>
<td><a href="https://www.youtube.com/watch?v=AKInu9I2P3Y">https://www.youtube.com/watch?v=AKInu9I2P3Y</a></td>
</tr>
</tbody>
</table>
### 2.4. Activity 3: Teaching Plan Development

Within the summer training program, the two teacher participants created lesson plans that teach the fundamental principles of control, based on the knowledge learned from this training program. The lesson will be implemented in the following academic year. The PIs assisted with editing the plan, and evaluating the student learning outcomes. Please refer to Appendix E for the teaching plan.

### 3. Evaluation

Comparative tests to teacher participants were collected before and after the training program, on several “What” and “Why” types of basic questions on control engineering. Statistical analysis of the pre- and post-test results (an increase from 2.87 to 4.37 on a 5-point scale) suggested the successful gaining of control knowledge. In addition, all teachers after the training were willing to introduce basic control engineering concepts to their classes, compared to only half of them before the training.

### 4. Expenses

The NSF Research Experience for Teachers (RET) project “RET in Sensor Networks” (http://www.teo.unt.edu/ret/index.php) co-funded the project, supporting the 6-week stipend of the K-12 teachers. The CSS Outreach Fund supported the specific activities of the new track on control engineering. The graduate student will start the preparation 1 week ahead of the 6-week summer training period, and complete project dissemination within 1 week after the end of the period.

<table>
<thead>
<tr>
<th>Budget Category</th>
<th>Details</th>
<th>Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student Support</td>
<td>One graduate student to support the aquatic ecosystem control teacher project (salary + fringe for 2.5 months)</td>
<td>$4458</td>
</tr>
<tr>
<td>Materials and Supplies</td>
<td>For the aquatic ecosystem control teacher project: sensors, materials, motor, circuit elements</td>
<td>$87</td>
</tr>
<tr>
<td>Administrative Overhead</td>
<td>At a rate of 10%</td>
<td>$458</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>$5000</td>
</tr>
</tbody>
</table>
5. Appendix
A. Control Seminar 1
B. Control Seminar 2
C. Project Poster
D. Teaching Plan
Introduction to Control
4-hour Seminar
Part 1
Dr. Yan Wan
Electrical Engineering
University of North Texas
yan.wan@unt.edu
www.ee.unt.edu/public/wan
June 11, 2013

Background
- NSF Research Experience for Teachers (RET)
  - in Sensor Networks
  - Control is a critical component in sensor network applications
  - http://www.teo.unt.edu/ret/
- IEEE Control Systems Society (CSS) Outreach Program
  - http://www.ieeecss.org/general/control-systems-society-outreach-fund
- We will have three projects and two seminars related to Control, ...
  - Automatic control of aquaponic ecosystem
  - Wireless sensor networks for stream monitoring
  - Indoor air quality monitoring and control system
- TA
  - Vardhman Sheth VardhmanSheth@my.unt.edu

What Is This Seminar About?
- Understand the interdisciplinary asset and fundamental principles of control including "Dynamics" and "Closed-loop".
  - Why control?
    - Motivating examples
    - Goals
    - History and broad new applications
    - let student know how to use technology to make life better
  - Basic concept of control
    - Common mathematical framework
      - motivate students to learn math
    - Dynamical system’s performance
    - Closed-loop control (via two interactive examples)
Motivating Example 1

- Control systems are in our daily lives...
  - Air Conditioner
  - Regulate room temperature
    - Need sensor to monitor the temperature
    - Need controller to actuate the heating/cooling system to maintain temperature at a preset value
    - Sensing and control are typically integrated

Motivating Example 2

- Control system are in our daily lives...
  - Cruise Control
    - Manuel control
      - Sensor: eyes
      - Controller: brain that decides when and how much to press the pedals
    - Cruise control
      - Sensor: speedometer
      - Controller to actuate the engine to bring the speed to a specified value
    - Disturbances: Hills

Two Basic Terms

- What is “system”?
  - Anything that has interconnected components, that interact to perform an overall function
  - Examples: Machine, human body, environment, economy, etc...
- What is “dynamics”?
  - A quantity of interest changes with time

Goals of Control

- Goals
  - Manage/regulate system dynamics to achieve desired performance
  - Reject disturbances to system dynamics.
  - Control provides a systematic approach
    - to optimally improve system performance.
    - to come up with the best decision-making strategies.
**Broad Applications of Control**

- History and broad applications of control
  - Transformation and development of control theory to address optimal decision-making tasks in modern interdisciplinary applications

- Very simple control mechanics
  - Controller design is based upon intuition. When water level is low, a mechanic component can open the valve to bring in more water

- Control of physical devices
  - Mathematical control theory was developed to systematically design controllers

- Modern applications
  - Systems and control concepts are extremely helpful for decision-making tasks in modern interdisciplinary applications

---

**Liquid Level Control**

- The float serves as both the sensor and the control actuator

- Control theory starts from intuition.

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**Liquid Level Control**

- The float serves as both the sensor and the control actuator

- Control theory starts from intuition.

---

**Liquid Level Control**

- The float serves as both the sensor and the control actuator

- Control theory starts from intuition.
Control of More Complicated Physical Devices

- Industrial Automation
- Flight Control System
- Sophisticated mathematical control theories have been developed.
- Control is not only applicable to these systems.

New Applications

- Control theory is an optimal decision-making theory for modern system applications
  - Smart grid
  - Information cloud
  - Internet traffic control
  - Air traffic management
  - Epidemic control
  - Environmental science
  - Economics
  - Systems biology
  - …

New Applications

- Control theory is an optimal decision-making theory for modern system applications
  - Smart grid
  - Information cloud
  - Internet traffic control
  - Air traffic management
  - Epidemic control
  - Environmental science
  - Economics
  - Systems biology
  - …

Best produce and distribute energy
Control theory is an optimal decision-making theory for modern system applications

- Smart grid
- Information cloud
- Internet congestion control
- Air traffic management
- Epidemic control
- Environmental science
- Economics
- Systems biology
- ...

Best use routers and reduce congestion in a network

Best use airspace and human controller resources

Best use medical resources to stop virus spread

Optimize the profit
New Applications
Control theory is an optimal decision-making theory for modern system applications
- Smart grid
- Information cloud
- Internet congestion control
- Air traffic management
- Epidemic control
- Economy
- Environmental system
- Systems biology
- ...

The nature regulates/controls itself.

New Applications
Control theory is an optimal decision-making theory for modern system applications
- Smart grid
- Information cloud
- Internet congestion control
- Air traffic management
- Epidemic control
- Environmental system
- Economics
- Systems biology
- ...

One of the most sophisticated control system.

What Is This Seminar About?
Understand the interdisciplinary asset and fundamental principles of control including "Dynamics" and "Closed-loop".
- Why control?
  - Motivating examples
  - Goals
  - History and broad new applications
    - Let students know how to use technology to make life better
- Basic concept of control
  - Common mathematical framework
    - Motivate students to learn math
  - Dynamical system's performance
  - Closed-loop control (via two interactive examples)

Common Mathematical Framework
Why is control applicable to so many applications

All dynamics can be described using a common mathematical framework
Differential Equation

Definition: An equation that describes the rate of change
denoted by \( \dot{x} = \ldots \)
For instance, for speed control, \( v = \text{acceleration} \cdot \text{force/mass} \)
Dynamical System's Performance

- **How to measure performance**
  - No need to know the dynamics at every time point.

- Key measures (use cruise control as an example)
  - Stability
  - Steady-state error
  - Rise time
  - Setting time
  - Overshoot

The Concept of Closed-loop Control

- **Open-loop control**
  - No sensor, no closed loop

- **Need of feedback control**
  - Open-loop system is not robust to disturbances

- **What does “Closed-loop” mean?**
  - Use of sensor-measured output to modulate the input to a system
  - Control reacts to the current system’s dynamics

Interactive Cruise Control Example

Interactive LXT Angle Control Example
Thank you!

Questions?
Introduction to Control
4-hour Seminar
Part 2
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July 1, 2013

Outline
- Review
- More about control—Controller Design
  - Why closed-loop works
  - The control view of the world
  - How to design controllers
  - Advanced control
- Let us discuss your summer projects
- How to implement controllers
- Discussion about lesson plans

Review
- Understand the interdisciplinary asset and fundamental principles of control including “Dynamics” and “Closed-loop”.
  - Why control?
    - Motivating examples
    - Goals
    - History and broad new applications
      - Let student know how to use technology to make life better
  - Basic concept of control
    - Common mathematical framework
      - Motivate students to learn math
    - Dynamical system’s performance
    - Closed-loop control (via two interactive examples)

Review: New Applications
- Control theory is an optimal decision-making theory for modern system applications
  - Smart grid
  - Information cloud
  - Internet traffic control
  - Air traffic management
  - Epidemic control
  - Environmental science
  - Economics
  - Systems biology
  - …
Review: Goals of Control

- **Goals**
  - Manage/regulate system dynamics to achieve desired performance
  - Reject disturbances to system dynamics.
- **Control provides a systematic approach**
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  - to come up with the best decision-making strategies.

Review: Dynamical System’s Performance

- **How to measure performance**
  - No need to know the dynamics at every time point.
  - Key measures (use cruise control as an example)
    - Stability
    - Steady-state error
    - Rise time
    - Setting time
    - Overshoot

Outline

- Review
- More about control—Controller Design
  - Why closed-loop works?
  - The control view of the world
  - How to design controllers
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- Let us discuss your summer projects
- How to implement controllers
- Discussion about lesson plans
Resolve the Mystery: Why closed-loop works

- Let us revisit the example and do the math!

Outline

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LEGO NXT Angle Control

- How do we formulate it in a scientific way?
  - We need to know the dynamics of the plant
  - We need to design the controller
  - We need to define the goal of the control

Epidemic Control: Problem Formulation

- Epidemic Spread Control
  - Viruses spread among human population
  - Goal: stop the spread as quickly as possible
- How do we formulate it in a scientific way?
  - We need to know the dynamics of the plant
  - We need to design the controller
  - We need to define the goal of the control
Understand the Plant Model
- What is input, output, and model dynamics?
- Basic Reproductive Ratio, Ro
- Ro = Infectious Period * Contact Rate = p * r
- If Ro > 1, the disease can spread throughout the population.

Model: \( x[k+1] = x[k] \cdot Ro = x[k] \cdot 4 = x[k] \cdot (p \cdot r) - u[k] \)

Understand the Control Model and Goal
- Reduce contact rate \( r \) by \( R \) through the closure of schools, restriction of gatherings, etc.
  - \( u[k] = p \cdot R \cdot x[k] \)
- Reduce infectious period \( p \) by \( P \) through quarantine
  - \( u[k] = P \cdot r \cdot x[k] \)
- Goal of control
  - Find the optimal \( R \) and \( P \) to let the converge rate of \( x[k] \) becoming as close to 0 as possible,
  - under the requirements that \( R \) and \( P \) must be smaller than certain values.

How can we apply limited control resources (e.g., associated with vaccination, isolation, etc.) in a population to limit the spread of virus?

Network Modeling and Problem Formulation: Epidemic Control
- Next generation matrix with control parameters included:
  \[
  A = \mathcal{P} \text{diag}(\tau, \mathcal{N}) \times \text{diag}(\mathcal{T}) + \text{diag}(c) \begin{bmatrix}
  0 & \mathcal{T}_{11} & \cdots & \mathcal{T}_{1n} \\
  \vdots & \ddots & \vdots & \vdots \\
  \mathcal{T}_{n1} & \cdots & \cdots & 0
\end{bmatrix} \text{diag}[\mathcal{N}]
  \]
- Problem: Design diagonal \( D \) or \( K \) to minimize the dominant eigenvalue of \((D+KG)\) subject to
  \[
  tr(\mathcal{K}) = \sum K_i \geq \Gamma \quad \text{and} \quad 0 \leq K_i \leq 1 \quad \text{for all} \quad i
  \]
  \[
  tr(D) = \sum D_i \geq \Gamma \quad \text{and} \quad 0 \leq D_i \leq 1 \quad \text{for all} \quad i
  \]
How to Design Controllers

- Goal is to design the controller to achieve desired performance:
  - Stability
  - Steady-state error
  - Rise time, settling time
  - Overshoot
  - More complicated ones

- The controller could be a number, or something very complicated.
  - P, PI, PID

- As these performance measures typically contradict to each other, we need to find a balance among them.
- There is systematic way to do this, but here let us just try manually.
Let Us Find Out the Answers

Questions:
1. How to decrease steady state error? Should the gain increase or decrease?
2. For the answer you have in step 1, how does the overshoot change?
3. What conclusion you can draw about the relationship between steady-state error and overshoot?
4. What is the change of actuation with the increase of gain?
5. Find a gain that gives a steady-state error less than 0.3, and overshoot less than 0.7.

Outline

Review
More about control—Controller Design
- Why closed-loop works?
- The control view of the world
- How to design controllers
- Advanced control
Let us discuss your summer projects
How to implement controllers
Discussion about lesson plans

Advanced Control

Optimal control
Adaptive control
Fuzzy control
Model predictive control
- Controllers react upon predicted future system states
Summer Project 1: Water Quality Control
- Control PH, Devolved Oxygen, Temperature, etc.

- **Output:**
  - DO concentration

- **Plant:**
  - Oxygen dissolving process in the water tank

- **Controller:**
  - On if DO is less than the reference

- **Actuation Signal:**
  - On and off switch of the bubbler

Summer Project 2: Air Quality Control
- Control CO2 level

- **Output:**
  - CO2 concentration

- **Plant:**
  - Air spread in the container

- **Controller:**
  - Constant value

- **Actuation Signal:**
  - Speed of the fan

Summer Project 3: Robot Control
- **Student project—Precision control**
  - Control the balance of wheels
  - Control the precise distance to travel
  - Control the precise 90-degree angle turn
  - Demo: https://www.dropbox.com/s/1qtiwf6tt4a5z34/20130429_142231.mp4

- **Demo 2: Use Lego to mimic the mobility of UAV**
  - https://www.dropbox.com/s/rxhbiszzwou91ar/20130425_201712.mp4?dl=1
  - https://www.dropbox.com/s/5ivshpsvmeigz/20130425_194305.mp4?dl=1

Outline
- **Review**
- **More about control—Controller Design**
  - Why closed-loop works?
  - The control view of the world
  - How to design controllers?
  - Advanced control

- Let us discuss your summer projects
- How to implement controllers (by Vardhman)
- Discussion about lesson plans
**How the Control System Works**

**Reference Signal** -> **Error** -> **Controller** -> **Actuator** -> **Plant**

*Figure: Block Diagram*

- **Controller:** Arduino (Microcontroller) sends the signal to the actuator.
- **Actuator:** Electric circuit to drive the mechanical component.
- **Plant:** Physical system.
- **Measurement:** Sensor feedbacks the reading.

**Implementation of Each Block**

- **Controller:** Arduino (Microcontroller) sends the signal to the actuator.
- **Actuator:** Electric circuit to drive the mechanical component.
- **Plant:** Physical system.
- **Measurement:** Sensor feedbacks the reading.

**Aquaponic Ecosystem**

- **Controller:** Arduino calculates 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.

**Different types of control signals**

- There are various types of controls:
  - On/off control (actuation Signal is either high or low)
  - Proportional Controller (actuation signal is PWM signals, which is variable)
Actuator Circuit

If the DO sensor reads less than 7 then turns on the bubbler

Indoor Air Quality

Discussion about Teaching Plan

- Incorporating control concepts?
  - Engineering (Lego)?
  - Biology?
  - Math?
- Interactive materials?
- Application examples?
Thank you!

Questions?
Using Wireless Sensor Network to monitor and control an indoor Aquaponic System

UNT Research Experiences for Teachers - Sensor Networks
Summer 2013

By
Jose Guerrero, Carrollton-Farmers Branch ISD, Fern Edwards, Frisco ISD
Mentor: Dr. Yan Wan, Grad Student: Vardhman Sheth, EE Department

Classroom Application

Level 1 tank was raised 25” off the ground and set on a sturdy table. We used a 30 gallon storage tank to house it goldfish and 6 guppies, a ballhead inserted through one side of tank served as the tanks overflow drain; a second ballhead with a control valve allowed for water to fill level 2 which housed plants; a bubbler was added and a hose was clamped which came from level 1 pump. The tank lid was modified for placement of our controls along with the sensor cluster and they were braced using a combination of zip ties, bonding solutions, and Velcro.

Level 2 was raised 13’’ off the ground and positioned on top of a 3 1/2 plywood which sat on two 10 gallon aquarium boxes (boxes were used because of accessibility). In total we grew 3 tomato and 3 cucumber plants while utilizing an ebb and flow system which allows for plant roots to get both water and free O2 at variable times. The Ebb and Flow is a form of hydroponics that is known for its simplicity, reliability of operation and low initial investment cost. Pots are filled with an inert medium which does not function like soil or contribute nutrition to the plants but which anchors the roots and functions as a temporary reserve of water and solvent mineral nutrients. The hydroponic solution alternates the flooding of the system and is allowed to ebb away.

Level 3 was reserved as our drain/sump and included a small pump with a 4’ upthrust power. Both level 1 & 2 drained down to 3rd level. We grew 3 water lilies in a ephedrionic condition...
Lesson Plan - The Design & Monitoring of an Aquaponics Systems

**Subject Areas:**

Biology & Chemistry & Aquatics

**Associated units:**

Variables affecting plant growth in an inert media
Solubility of gases in liquids

**Lesson Title:** Automatic control of an Aquaponic Ecosystem

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**Image 1**

**Image file:** Aquaponic Systems

**ADA Description:** Image shows a three-tiered aquaponics system in which fish are at the top tier, grow bed with plants on middle tier and sump on bottom

**Source/Rights:** UNT RET Aquaponics groups

**Caption:** three-tiered aquaponics sytem design
Grade Level 9th – 12th

Time required multiple class periods

Summary
Students will design and build a basic aquaponic system. Students learn about the various parameters at play in an aquatic system and how to monitor and correct them. Students will also learn about the important role the nitrogen cycle plays in the well-being of an aquatic system. They will acquire knowledge about the importance of control systems in our daily lives.

Engineering Connection
Students will have to identify and define the potential problems (the parameters that govern aquatic systems) involved in an aquatic system. They will design and build a suitable system as well as research various designs of control systems within a tank.

Engineering Category = 1
1. Engineering analysis or partial design
2. Engineering design process

Keywords
Aquaculture, aquaponics, bacteria, Biology, Chemistry, dissolved oxygen, gases, hydroponics, nitrate, nitrite, Nitrobacter, nitrogen cycle, Nitrosomonas, pH, solubility, sustainability

Educational Standards
National and State Texas 2010-2011

● Biology- (C) Knowledge and skills:
Science concepts. The student knows that interdependence and interactions occur within an Environmental system, the student is expected to:
(12-A) interpret relationships, including predation, parasitism, commensalism, mutualism, and competition among organisms; (Readiness Standard)
(12-E) describe the flow of matter through the carbon and nitrogen cycles and explain the consequences of disrupting these cycles; (Supporting Standard)

● Chemistry-(C) Knowledge and skills:
Science concepts: The student will:
(2-E) plan and implement investigative procedures, including asking questions, formulating testable hypotheses, and selecting equipment and technology, including graphing calculators, computers and probes

● Aquatics- (C) Knowledge and skills:
Science concepts. The student will:
(4-C) collect and analyze baseline quantitative data such as pH, salinity, temperature, mineral content, nitrogen compounds, and turbidity from an aquatic environment
ITEEA Educational Standard(s)

Grade level (6-8) F:
New products and systems can be developed to solve problems or to help do things that could not be done without the help of technology

Pre-Requisite Knowledge

Conceptual understanding of pH
Nitrogen cycle, carbon cycle

Learning Objectives

After this activity, students should be able to:

• Develop a list of water quality property associated with an aquatic environment.
• Measure pH, temperature and dissolved gas probes (DO) and interpret data collected
• Discuss the importance of the role that pH, DO and temperature levels play in the effectiveness of an aquatic system
• Explain the nitrogen cycle (ammonia, nitrite, and nitrate) with respect to an aquatic system
• Plot a graph using temperature and DO values and then explain how this relationship affects their aquaponic system.
• Discuss the need for control systems in aquatic systems and in other areas of their lives.

Introduction / Motivation

The world is changing around us and the face of agriculture and food production is changing as well. With a constantly increasing world population, urban sprawl is taking over once fertile farm land. Aquaponics systems can provide a more sustainable future. As shown in Figure 1 below; Aquaponics is a blending of two important ideas, combining fish farming with hydroponics (soilless gardening). In aquaponics an ecosystem, fish are fed, their ammonia is converted by beneficial bacteria into a form more absorbable by plants. Nutrient waste is then pumped through the system, where it feeds the plants. The plants act as a natural filter, cleaning the water—which is then recirculated through the system. Water quality is an important part of any aquatic ecosystem. In testing a water samples for temperature, pH, nutrient levels and dissolved oxygen levels, scientists can monitor the health of these ecosystems.

Students will watch three video clips. The first one explains the importance of vertical farming as an option for sustainable living. The other two clips show designs of class-room aquaponics.

Students will be lead in a class discussion about the basic premise of aquaponics and the various design possibilities.

Engineering design and critical thinking skills are invaluable help prepare students for the real world. Students will be required to brain storm and come up with various designs for integrating control systems within an aquatic system. This lesson focuses heavily on student experimental design and students will therefore have to come up with a suitable control and parameters that they wish to test.
Figure 1

**Image file:** The Nitrogen cycle in an Aquaponics System

**ADA Description:** Nitrogen cycle in figure 1 shows the process by which ammonia is converted to nitrite and then nitrate by microscopic bacteria

**Source/Rights:** [http://aquaponics.hunterinstitute.wikispaces.net/The+Nitrogen+Cycle](http://aquaponics.hunterinstitute.wikispaces.net/The+Nitrogen+Cycle)

**Caption:** Figure 1. The nitrogen cycle showing the exchange of nutrients between plants and fish and the conversion of ammonia to nitrites and then nitrates
Vocabulary / Definitions

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
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<tbody>
<tr>
<td>aquaculture</td>
<td>The raising of aquatic life in tanks</td>
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<tr>
<td>hydroponics</td>
<td>Growing plants in water and in a soil-free environment, plant roots grow in a nutrient rich solution</td>
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<tr>
<td>aquaponics</td>
<td>Integrated system linking hydroponic plant production with recirculating aquaculture</td>
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<tr>
<td>pH</td>
<td>Measure of how acidic or basic a system is</td>
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<tr>
<td>Dissolved oxygen</td>
<td>Measure of the amount of oxygen dissolved in an aqueous media</td>
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<tr>
<td>ammonia</td>
<td>First step of nitrogen cycle generated by fish excretions</td>
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<tr>
<td>nitrite</td>
<td>Intermediate nitrogen compound in biological conversion of ammonia to nitrate in the nitrogen cycle</td>
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<tr>
<td>nitrate</td>
<td>Last stage of the aquarium nitrogen cycle converted from nitrites</td>
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<tr>
<td>bacteria</td>
<td>Nitrifying bacteria living in gravel (media) and in association with plant roots play a critical role in nitrogen cycle</td>
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<tr>
<td><em>Nitrosomonas</em></td>
<td>A bacterium responsible for changing ammonia into nitrites</td>
</tr>
<tr>
<td><em>Nitrobacter</em></td>
<td>A bacterium responsible for changing nitrite into nitrates</td>
</tr>
</tbody>
</table>

Associated Activities

Students investigate the design and building of a small-scale aquaponic system. Students will also investigate and monitor the water quality parameters necessary for a healthy aquaponics system. Students will research control systems and discuss the advantages of wireless control systems with an aquaponic system.

Lesson Closure

1. What are the most crucial parameters that must be monitored in an aquaponics system?
2. Why would wireless sensors be advantageous in an aquaponics system? Explain.
3. Which parameters would be best to monitor and control wirelessly?
4. What are the advantages of wireless sensor networks in aquaponics?
5. What effects do plants have on levels of carbon dioxide in water?
6. What effects do plants have on levels of oxygen in water?
7. Do plants affect pH of water? How so?
8. What effect does temperature have on dissolved oxygen? Explain
**Assessment**

**Pre-Assessment**

After watching short video clips on vertical farming and small scale aquaponics students will have a small group discussion on what are the crucial parameters that must be monitored for rearing of both fish and plants. Students will then report back to the entire class with their findings.

Students will then take a ten question multiple choice pre-assessment.

**Lesson summary Assessment**

1. Describe your aquaponic set up. Explain why this particular set-up could be used to measure water quality.
2. List the water quality tests you used to assess your aquaponics system.
3. Which water quality parameter did the addition of plants have the biggest effect on?
4. How does changing the temperature affect the water quality of the aquaponics system?
5. Why do pH and DO change in aquaponics?
6. What is the ideal pH and DO level for aquaponics system with gold fish and cucumber plants?
7. Which factors you tested do you feel are most important to water quality in an aquaponics system? Explain
8. What are the advantages of aquaponics over traditional farming?
9. Describe which parameters could be monitored and controlled using wireless sensor networks.

**Lesson Extension Activities**

Relating the natural cycles within aquaponics (nitrogen, water, carbon) systems to the unit on evolution and how factors and changes in the environment help drive evolution.

**Additional Multimedia Support**

**References**

1. Matt LeBannister: Aquaponics: Key to a more sustainable future
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