IEEE Control Systems Society (CSS) Outreach Fund Report on

Summer Training Experience for K-12 Teachers in Control Engineering

Yan Wan, Miguel F. Acevedo, Shengli Fu

Electrical Engineering, University of North Texas

Ruthanne Thompson, David Hoeinghaus

Biology, University of North Texas

Contents

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

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

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.

Name	School
Jose Guerrero	R.L. Turner High School, CFB ISD
Chelsea Meyer	The Colony High School, LISD
Georgette Jordan	Emmett J. Conrad High School, Dallas ISD
Gregory Kulle	The Colony High School, Lewisville ISD
Fern Edwards Ferguson	Heritage High School, Frisco ISD
Jesse Bell	Skyline High School, Dallas ISD
Deliah Johnson-Seastrunk	Navo Middle School, Denton ISD
Michael McEver	Hebron High School, Lewisville ISD
Dave Parsons	Flower Mound High School, LISD
Karl KGscheidle	R.L. Turner High School, CFB ISD
Elizabeth Freeman	Frisco High School, Frisco ISD
Dawn Chegwidden	Lewisville High School, Lewisville ISD
Raechelle Jones	Kennemer Middle School, Duncanville ISD
Lori Wolf	Navo Middle School, Denton ISD
Debra Hardy	Krum High School, Krum ISD

Sharon Woods	Marcus High School, Lewisville ISD
Zac Bunn	R.L. Turner High School, CFB ISD

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:

Project Material	Publicly Accessible Links
Project blog developed during the 6-week period, documenting the progress each day	http://untret2013.blogspot.com/
Project report (35 pages)	http://www.teo.unt.edu/ret/pdf2013/Aquaponics-report.pdf
Project poster	http://www.teo.unt.edu/ret/pdf2013/Aquaponics-poster.pdf
Project power point presentation (48 slides)	http://www.teo.unt.edu/ret/pdf2013/Aquaponics-presentation.pdf
Demo of the control for dissolved oxygen level	https://www.youtube.com/watch?v=ODVzNSf-Km4
Demo of the control for water level	https://www.youtube.com/watch?v=AKInu9I2P3Y

Demo of the control for food dispenser	https://www.youtube.com/watch?v=ElC4d9C1gHY
Demo of the control for PH level	https://www.youtube.com/watch?v=L-AN6qAb5Ws

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.

Budget Category	Details	Budget
Student Support	One graduate student to support the aquatic ecosystem control teacher project (salary + fringe for 2.5 months)	$4458
Materials and Supplies	For the aquatic ecosystem control teacher project: sensors, materials, motor, circuit elements	$87
Administrative Overhead	At a rate of 10%	$458
Total		$5000

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?
    - Motiving 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)

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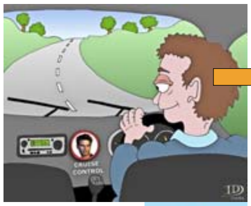
Motivating Example 1

- ❑ *Control systems are in our daily lives…*
  - Air Conditioner

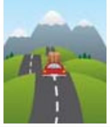
- ❑ *Regulate room temperature*
  - Need sensor to monitor the temperature
  - Need controller to actuate the heating/cooling system to maintain temperature at a pre-set value
  - Sensing and control are typically integrated

Motivating Example 2

- ❑ *Control system are in our daily lives…*
  - Cruise Control



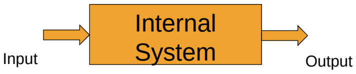
- ❑ *Manuel control*
  - Sensor: eyes
  - Controller: brain that decides when and how much to press the pedals
- ❑ *Cruise control*
  - Sensor: speedometer
  - Controller to actuate the engine to bring the speed to a specified value



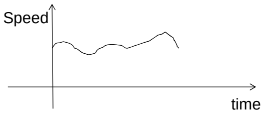
Disturbances:
Hills

Two Basic Terms

- ❑ *What is "system"?*
  - Anything that has interconnected components, that interact to perform an overall function
  - Examples: Machine, human body, environment, economy,…



- ❑ *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.

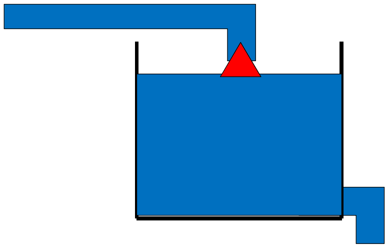
Broad Applications of Control

- ❑ *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	*Control of physical devises*	*Modern applications*
Controller design is based upon intuition. When water level is low, a mechanic component can open the valve to bring in more water	**Mathematical control theory was developed to systematically design controllers**	**Systems and control concepts are extremely helpful for decision-making tasks in modern interdisciplinary applications**

Liquid Level Control

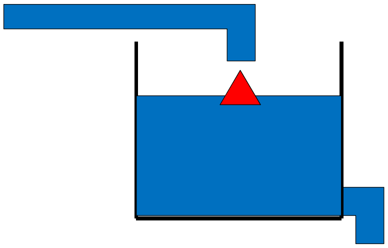
- ❑ *The float serves as both the sensor and the control actuator*



- ❑ *Control theory starts from intuition.*

Liquid Level Control

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



Water level low.

Sensor?

Controller?

- ❑ *Control theory starts from intuition.*

Liquid Level Control

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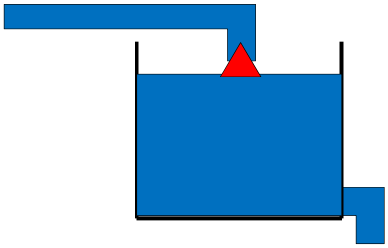


Water level high.

Sensor?

Controller?

- ❑ *Control theory starts from intuition.*

Control of More Complicated Physical Devices

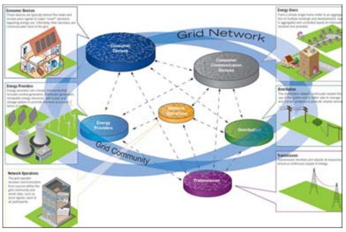
- ❑ *Industrial Automation*

- ❑ *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
  - …



Best produce and distribute energy

New Applications

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Best produce and distribute computing and information storage resources

New Applications

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  - Systems biology
  - …

Best use routers and reduce congestion in a network

New Applications

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Best use airspace and human controller resources

New Applications

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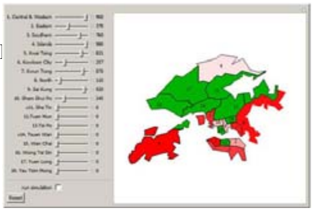

Best use medical resources to stop virus spread

New Applications

- *Control theory is an optimal decision-making theory for modern system applications*
  - Smart grid
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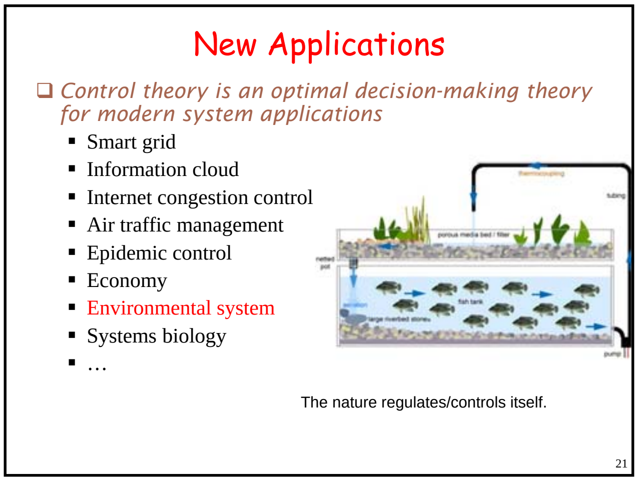
  - Epidemic control
  - Economy
  - Environmental system
  - Systems biology
  - …

Optimize the profit



New Applications

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  - Economy
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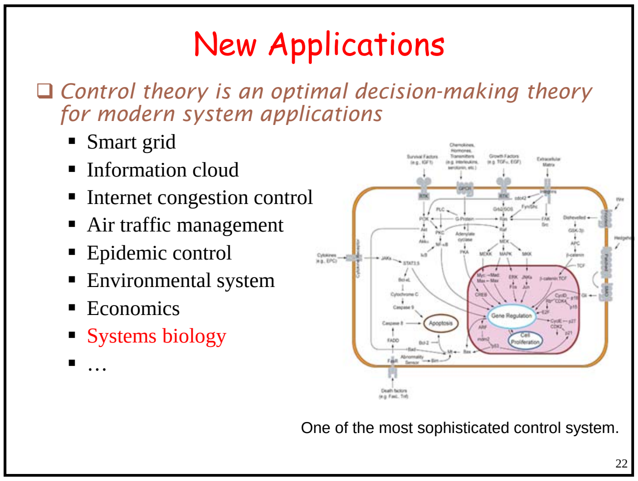
  - …

The nature regulates/controls itself.



New Applications

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  - Smart grid
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  - …

One of the most sophisticated control system.

What Is This Seminar About?

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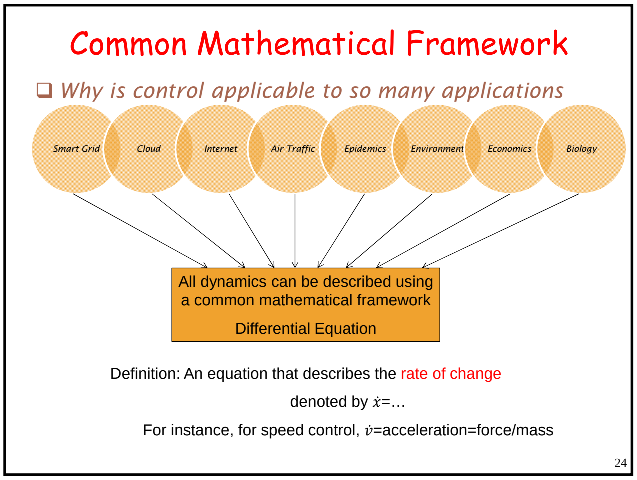


Common Mathematical Framework

- ❑ *Why is control applicable to so many applications*

Smart Grid

Cloud

Internet

Air Traffic

Epidemics

Environment

Economics

Biology

All dynamics can be described using a common mathematical framework

Differential Equation

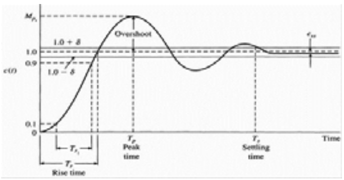
Definition: An equation that describes the rate of change

denoted by $\dot{x}$=…

For instance, for speed control, $\dot{v}$=acceleration=force/mass

Dynamical System’s Performance

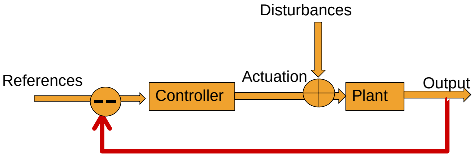
- ❑ *How to measure performance*
  - No need to know the dynamics at every time point.



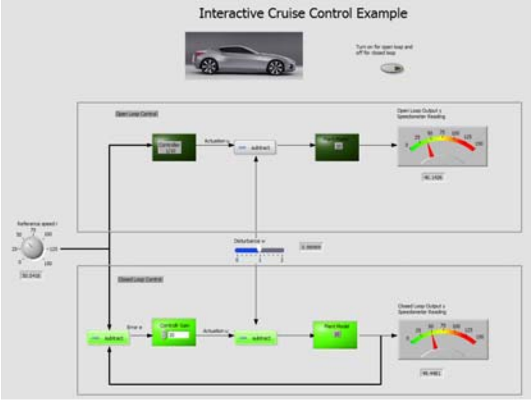
  - Key measures (use cruise control as an example)
    - Stability
    - Steady-state error
    - Rise time
    - Setting time
    - Overshoot

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

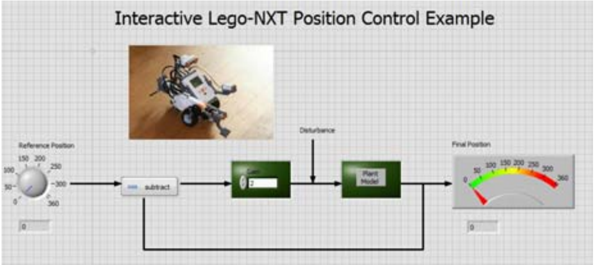


Interactive Cruise Control Example



Interactive Cruise Control Example

Interactive LXT Angle Control Example



Interactive Lego-NXT Position Control Example

Thank you!

Questions?

Introduction to Control
4-hour Seminar
Part 2

Dr. Yan Wan
Electrical Engineering
University of North Texas
yan.wan@unt.edu
www.ee.unt.edu/public/wan
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

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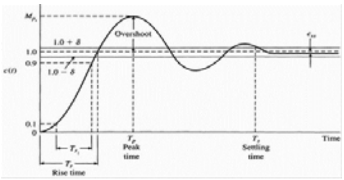

  - Key measures (use cruise control as an example)
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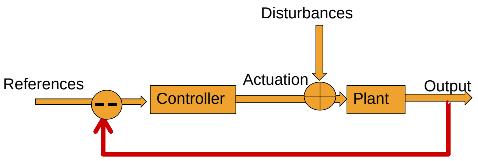

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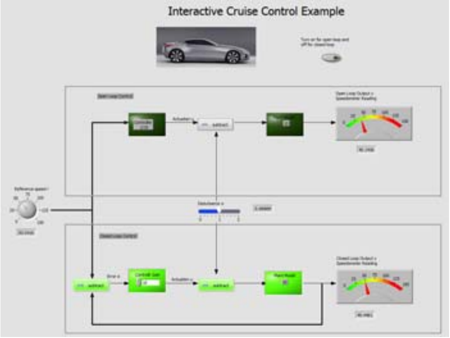
- ❑ *Discussion about lesson plans*

Resolve the Mystery: Why closed-loop works



- ❑ *Let us revisit the example and do the math!*

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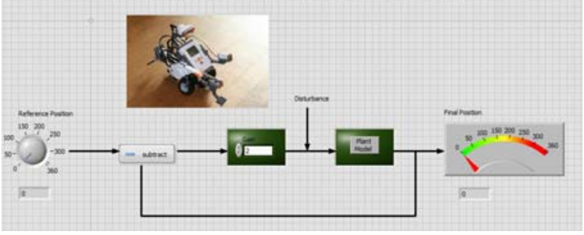
LEGO NXT Angle Control



- ❑ *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?*
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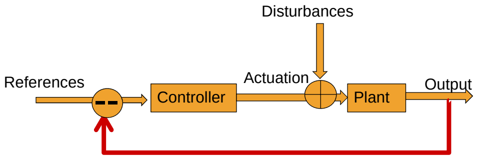
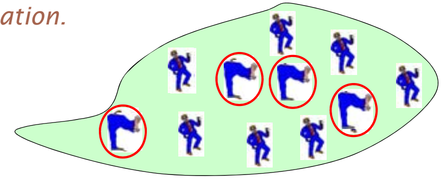


Understand the Plant Model

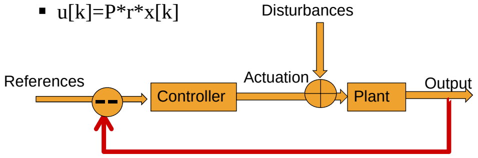
- ❑ *What is input, output, and model dynamics?*
- ❑ *Basic Reproductive Ratio, Ro*
- ❑ *Ro=Infectious Period * Contact Rate=p*r*
- ❑ *If Ro>1, the disease can spread throughout the population.*



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

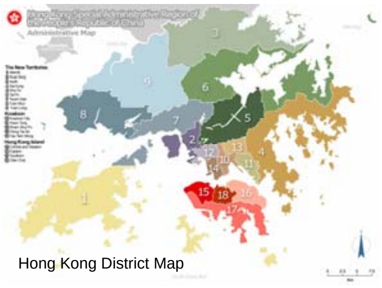
Understand the Control Model and Goal

- ❑ *Reduce contact rate r by R through the closure of schools, restriction of gatherings, etc.*
  - u[k]=p*R*x[k]
- ❑ *Reduce infectious period p by P through quarantine*
  - u[k]=P*r*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.

Extend from Single Region to Multiple Regions



Hong Kong District Map

- ❑ *Virus spreads through contact between individuals.*
- ❑ *Population structure plays an important role in virus spread.*
- ❑ *Control should also account for network structure.*

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:*

$$A=\overline{\beta}\overline{T}diag(t_i r_i \overline{N}_i)\times\left(diag(\overline{f}_{ii})+diag(c_i)\begin{bmatrix}0 & \overline{f}_{21} & \cdots & \overline{f}_{n1}\\ \overline{f}_{12} & 0 & \cdots & \overline{f}_{n2}\\ \vdots & \vdots & \vdots & \vdots\\ \overline{f}_{1n} & \overline{f}_{2n} & \cdots & 0\end{bmatrix}\right)\left[diag\left(\overline{N}_i\right)\right]^{-1}$$

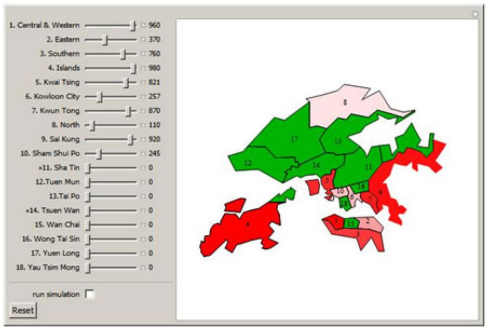
- ❑ *Problem: Design diagonal D or K to minimize the dominant eigenvalue of (D+KG) subject to*

$$tr(K)=\sum K_i \geq \Gamma \quad and \quad 0\leq K_i \leq 1\, for \quad all \quad i \quad or$$

$$tr(D)=\sum D_i \geq \Gamma \quad and \quad 0\leq D_i \leq 1\, for \quad all \quad i$$

Interactive Demo at Wolfram

http://demonstrations.wolfram.com/DynamicalNetworkDesignForControllingVirusSpread/



1. Central & Western	960
2. Eastern	370
3. Southern	760
4. Islands	980
5. Kwai Tsing	821
6. Kowloon City	257
7. Kwun Tong	870
8. North	110
9. Sai Kung	920
10. Sham Shui Po	245
•11. Sha Tin	0
12.Tuen Mun	0
13.Tai Po	0
•14. Tsuen Wan	0
15. Wan Chai	0
16. Wong Tai Sin	0
17. Yuen Long	0
18. Yau Tsim Mong	0

run simulation ☐

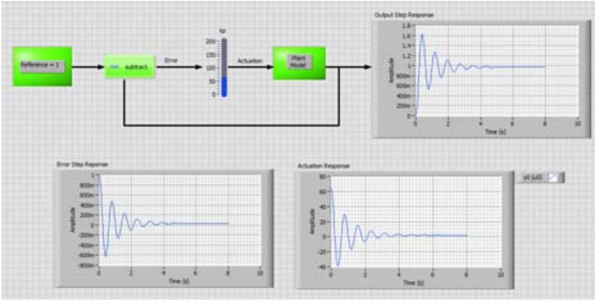
Outline

- ❑ *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*

How to Design Controllers

- ❑ *Goal is to design the controller to achieve desired performance*
  - Stability
  - Steady-state error
  - Rise time, Setting 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.*

Interactive Section on Finding the Best Controller



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*
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- *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

Outline

- *Review*
- *More about control----Controller Design*
  - Why closed-loop works?
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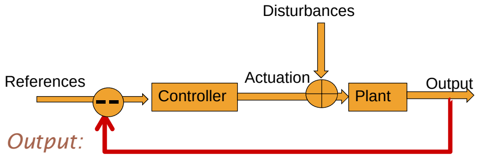
- *How to implement controllers*
- *Discussion about lesson plans*

Summer Project 1: Water Quality Control

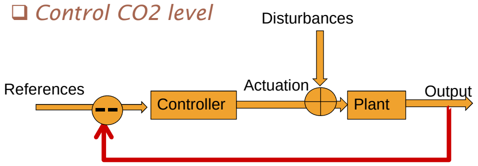
- *Control PH, Devolved Oxygen, Temperature, etc.*



- *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

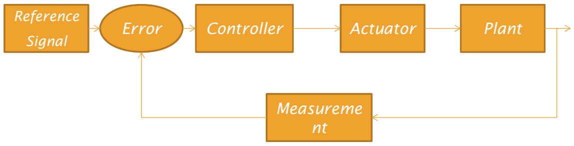
Summer Project 3: Robot Control

- *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/rxhbiszzwou91zj/20130425_201712.mp4?n=64983007
  - https://www.dropbox.com/s/5ivsshpshvmcigz/20130425_194305.mp4?n=64983007

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

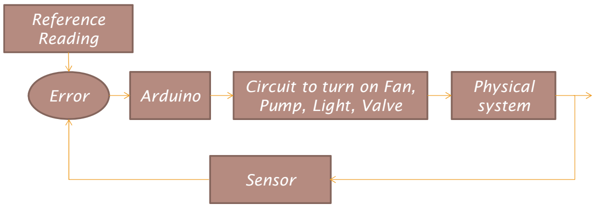
Plant

Measurement

Figure: Block Diagram

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



Reference Reading

Error

Arduino

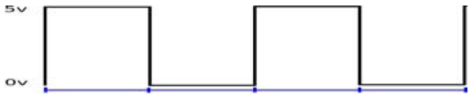
Circuit to turn on Fan, Pump, Light, Valve

Physical system

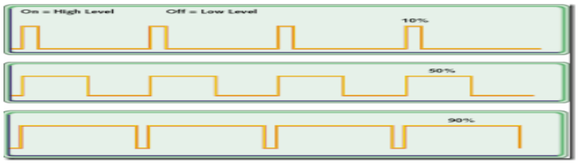
Sensor

Different types of control signals

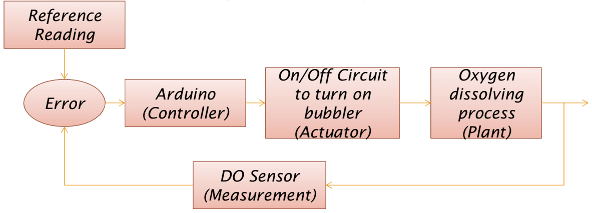
- ❑ *There are various types of controls*
  - On/off control (actuation Signal is either high or low)



  - Proportional Controller (actuation signal is PWM signals, which is variable)



Aquaponic Ecosystem



Reference Reading

Error

Arduino (Controller)

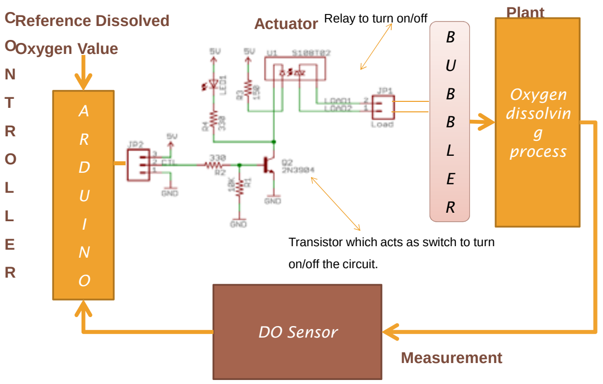
On/Off Circuit to turn on bubbler (Actuator)

Oxygen dissolving process (Plant)

DO Sensor (Measurement)

- ❑ *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

Actuator Circuit



CONTROLLER

Reference Dissolved Oxygen Value

Actuator Relay to turn on/off

Plant

ARDUINO

BUBBLER

Oxygen dissolving process

Transistor which acts as switch to turn on/off the circuit.

DO Sensor

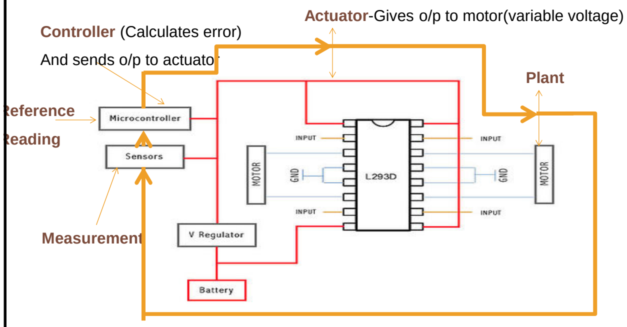
Measurement

Arduino Snap Shot

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

```
// Turn on/off Bubbble
if(DOvalue<=7)
{
  digitalWrite(A2,HIGH);
}
else
{
  digitalWrite(A2,LOW);
}
}
```

Indoor Air Quality



Controller (Calculates error)

And sends o/p to actuator

Actuator-Gives o/p to motor(variable voltage)

Plant

Reference

Reading

Measurement

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 on 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

University of North Texas

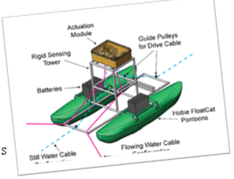
Department of Electrical Engineering

RET (Research Experiences for Teachers) Site on Sensor Networks, Electrical Engineering Department, and Institute of Applied Sciences, UNT, Denton, Texas. This material is based upon work supported by the National Science Foundation (NSF) under Grant No. 1132585 and the IEEE Control Systems Society (CSS) Outreach Fund. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF or the IEEE.

Introduction

Aquaponics is a special form of recirculating aquaculture systems - namely a polyculture consisting of fish tanks (aquaculture) and plants that are cultivated in a soil free environment (hydroponics). The primary goal of aquaponics is to reuse the nutrients released by fish to grow crop plants. By exploiting this natural phenomenon one can easily design and build an aquaponics system that is capable of sustaining plant growth and producing crops and food that is essentially chemical free and healthier. Our design is not unique but instead mimics different parts of various systems. One of the draw backs one encounters in aquaponic systems is the difficulty in maintaining optimal levels of production and the time it takes to monitor and manually reset parameters to the required amounts. A primary goal for this project therefore is to integrate various sensors that would remotely monitor and respond to changes in water parameters; namely pH, temperature and dissolved oxygen. A self monitoring system would enhance a system that has already been tried and proven and would take away a lot of the 'grunt work'. Our hopes with developing our own aquaponic control system is to control pH levels, dissolved oxygen and water levels in the fish tank.

Control Systems/ Wireless Sensors



There are a wide array of uses for control systems in industrial and commercial platform. Autonomous control systems are designed to perform well under significant uncertainties in the system and environment for extended periods of time, and they must be able to compensate for significant system failures without external intervention (Antsaklis, P. 1991).
Control systems aimed at monitoring the conditions of a stream are of importance as water resource availability increases. As the demand increases so too does the need for smart aquatic technology. Aquatic Networked InfoMechanical System (NIMS- AQ) centers around critical water resource monitoring objectives such as temperature, flow and contaminant levels. Experimental results for autonomous depth profiling using a submersible sonar system were also of research interests (Stealey, M. 2008). Similarly, Robotic Networked InfoMechanical System (NIMS-RD) is technology for measuring hydraulic and water quality conditions in rivers, lakes and estuaries and is capable of authoritatively mapping flow, velocity fields, contaminant loadings and mass balances, and groundwater accretions. NIMS-RD supports aquatic sensors, including acoustic Doppler velocity, pressure/depth, temperature, turbidity, salinity, fluorescence, pH, salinity, nitrate, and other water quality parameters (Harmon, T. 2007).

The aquaponic systems controls included a pH & food dispenser; bubbler for DO levels & a reservoir container to refill fish tank—these two controls worked off of an on/off power switch.

Our sensor cluster utilized an Arduino and Xbee shield to transmit and receive data. High quality sensors provided through Atlas-Scientific reassures accurate data collection.

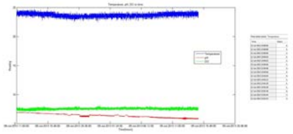
Abstract

This research uses a wireless sensor network (WSN) node to monitor and remotely control various water parameters in an aquaponic system. The aquaponic system served as a model for an aquatic ecosystem found in nature. Research indicates that dissolved oxygen (DO), pH and water levels are the most important parameters to monitor and control for successful growth in both fish and plants. Temperature and ammonia levels were also monitored but a control system was not developed because of the difficulty in re-establishing these two conditions using a control system. An aquaponic system is not entirely a closed system as fish need to be fed almost daily so an automatic dispenser was created. The aquaponics control system used an Arduino as the microprocessor and an XBee shield--radio transmitter and receiver respectively. Dissolved oxygen, pH, and temperature were collected in a database initially for 24 and then later at 48 hrs. When this data was compared to the more developed and commercially used sensor probe ware, PASCO, less than a 3% error was calculated. Data was also collected for dissolved oxygen, pH, and tank refill control systems and results show reliability and sustainability in each control.

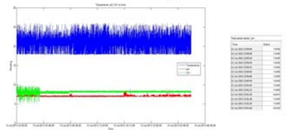
Results

Sensor Cluster collecting 35hr. & 48hr. of data from fish tank. Readings for pH, DO, and temperature were compiled onto a database every 8 seconds.

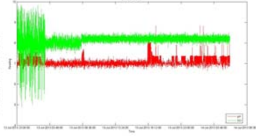
35 hr. collection



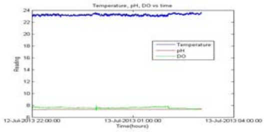
48 hr. collection without algorithm



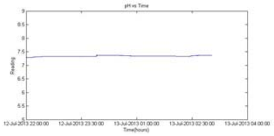
pH & DO without algorithm



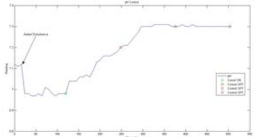
6 hr. collection with algorithm



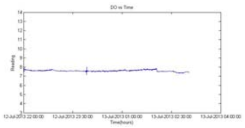
pH with algorithm



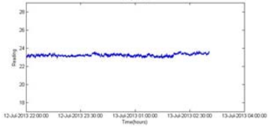
pH Control



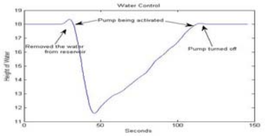
DO with algorithm



Temperature with algorithm



Water level Control



Discussion

Our initial data collection gave satisfactory readings for the first 5 minutes of testing. DO, pH and temperature probes of cluster gave less than a 3% error when compared to the PASCO probe ware. The problem arose when left for more than 5 minutes and also having the DO and pH probes in the tank at the same time. When each of these probes are taking live readings at the same time there is a voltage interference that then translates to a digital error reading. The errors were significant, more than a point off. This error required to isolate DO from pH using a 6N137 single-channel and utilizing a dual-channel HCPL2630. This change isolated ground for each of the probes. Monitoring the tank's conditions for 48 hrs. and activating controls gave us the graph and data table shown above. After adding a disturbance for pH there is no immediate control input, instead there is a 2 min delay but we do continue to gather data in our database. The actuator only dispenses after the average results are collected. This average are 10 data points or collections at 8 seconds apart. So a total of 80 sec. passes before there is some action from actuator. This allows the added control (fluid, etc.) to diffuse through water before taking the appropriate next steps. The disturbance in this experimental trial was added at 20 sec. (pH right above 7), levels dropped to just under 7 (fluctuating a little), and after 2 minutes a volume of pH corrector was added; the system continued to collect data, averaging the points. One factor different to this graph compared to all others is that the algorithm allows for a much smoother sloped line. The graph also shows where control is turned off and levels rise back to normal. Similar to pH we used an isolated volume of water to test tank refill. We began our data collection with water depth of 19 cm, pump turned on for a total time of nearly two minutes.

References

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- edu/pub/TwoPagers/NIMS-AQ_2pager_March07sm.pdf

Classroom Application

Level 1 tank was raised 2.5' off the ground and set on a sturdy table. We used a 30 gallon storage tank to house 6 goldfish and 6 gambusia; a bulkhead inserted through one side of tank served as the tanks overflow drain; a second bulkhead 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 tanks 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 aquariums 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 alternately floods the system and is allowed to ebb away .

Level 3 was reserved as our drainer/sump and included a small pump with a 4' uphill power. Both level 1 & 2 drained down to 3rd level. We grew 3 water lilies in a hydroponic condition..

Classroom Aquaponic

The costs of building a classroom aquaponics depends on the scale and purpose you intend it to serve. There are numerous designs available online, some which utilize household supplies and others that are more extensive and of greater scale.
In each case, students should have researched extensively to cross out any designs that do not fit with the constraints of the classroom or which require a budget beyond their means. Our summer trainings project expectations were to build a cost efficient aquaponic system and maintain it making sure plants and fish receive their daily nutrients. We purchased all of our supplies from Lowe's

Lesson Plan - The Design & Monitoring of an Aquaponics Systems

Subject Areas:

Biology & Chemistry & Acquatics

Associated units:

Variables affecting plant growth in an inert media

Solubility of gases in liquids

Lesson Title: Automatic control of an Aquaponic Ecosystem

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.[1] 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.

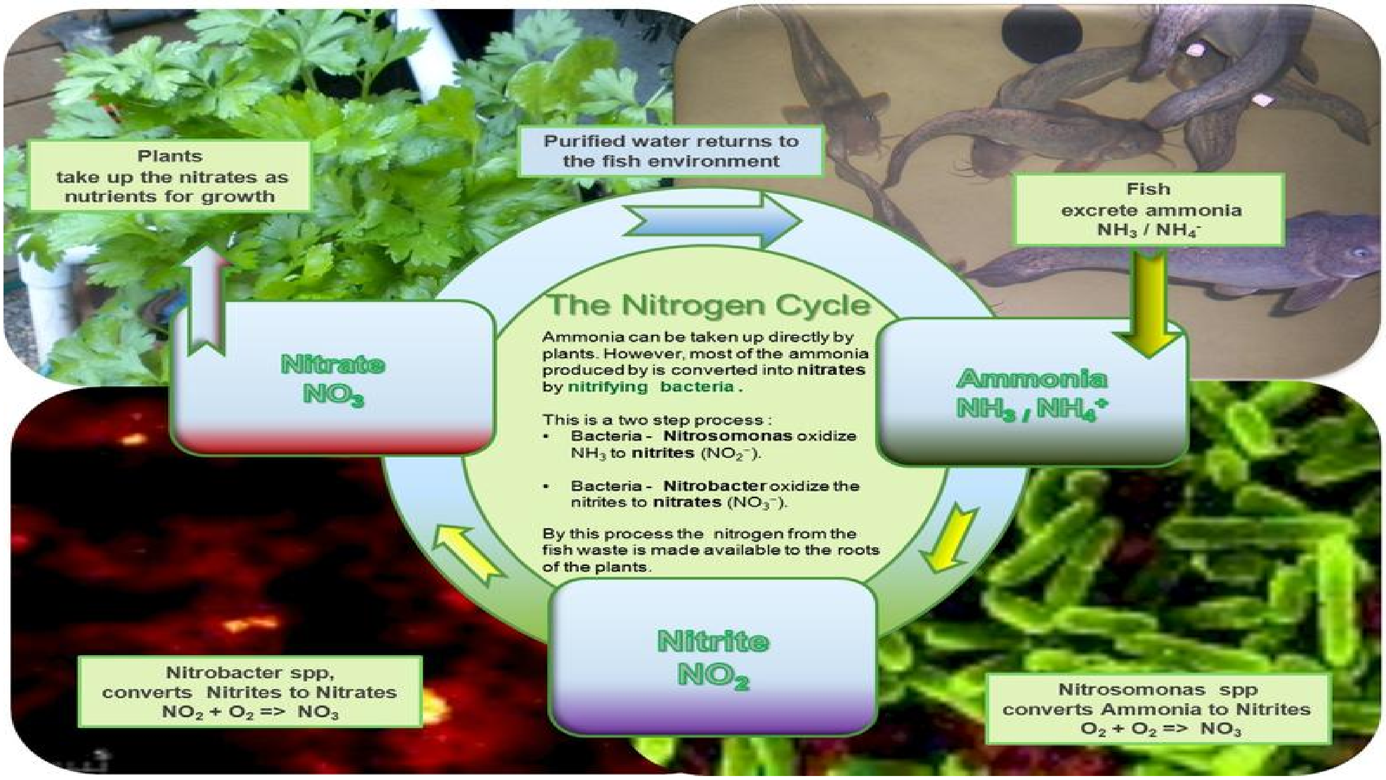
Students will watch three video clips. The first one explains the importance of vertical farming as an option for sustainable living. The other two clips show designs of class-room aquaponics.

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.

Lesson Background & Concepts for Teachers

Figure 1:



Ammonia can be taken up directly by plants. However, most of the ammonia produced by is converted into **nitrates** by **nitrifying bacteria**.

This is a two step process:

- Bacteria - **Nitrosomonas** oxidize NH_3 to **nitrites** (NO_2^-).
- Bacteria - **Nitrobacter** oxidize the nitrites to **nitrates** (NO_3^-).

By this process the nitrogen from the fish waste is made available to the roots of the plants.

Figure 1

Image file: The Nitrogen cycle in an Aquaponics System

ADA Description: Nitrogen cycle in figure1 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

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

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

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
2. http://www.un.org/waterforlifedecade/quality.shtml
3. Classroom Aquaponics: Exploring Nitrogen Cycling in a Closed System: Teacher’s Guide Sean Mullen, Cornell University http://csip.cornell.edu/Curriculum_Resources/CEIRP/Aquaponics.pdf

Contributors

Jose Guerrero

Fern Edwards-Ferguson

Vardhman Sheth

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