AC 2008-843: A PROJECT-DRIVEN APPROACH TO TEACHING CONTROLS IN A GENERAL ENGINEERING PROGRAM

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A Project-Driven Approach to Teaching Controls in a General Engineering Program

In East Carolina University's General Engineering program, a *Sensors, Measurements, and Controls* course was developed to teach topics on industrial instrumentation and controls. The challenge for the development of this course was offering two traditional courses (feedback control systems and instrumentation) into one effective course to fit within the general engineering curriculum. A project-driven approach was used to teach the two subjects, each taking approximately one half semester. This paper presents how this teaching approach helped us cover control theory and design. A project—design of a controller for a coupled-tank apparatus—was used as the hands-on experience for making connections between the theory discussed in the lectures and the implementation of the control concepts, such as transfer functions, performance, and stability of feedback control systems, in the laboratory. During the five-week project, students were required to: 1) characterize level sensors and variable speed pumps; 2) mathematically model the coupled tanks; 3) design a closed-loop transfer function; 4) design the controller for the system; and 5) implement the controller using LabVIEW. Several ABET outcomes were successfully supported by this course: the substantial design work provides the students great opportunities to apply their problem-solving and decision-making skills; the combination of MATLAB simulation and hands-on system integration allows the students see the power of modern engineering tools; and the derivation of transfer functions and dynamic system modeling fully demonstrate application of math in real engineering problems. In this paper, the project is detailed, student feedback is presented, and assessment results are reported.

I. INTRODUCTION

At East Carolina University, a General Engineering program was initialized to meet the regional economic development needs of eastern North Carolina. A broad and interdisciplinary engineering degree with a systems focus was designed to equip students with skill sets to prepare them for "identifying user needs, developing a complete business case for technology, analyzing problems from a life cycle (concept-to-recycle) perspective, and solving the core problem rather than just superficial parts of it" [1]. The Engineering program at East Carolina University "differs from many other engineering programs" since it:

- "Emphasizes the application of engineering knowledge in solving real-world problems by engaging in hands-on engineering activities beginning in the first semester;
- Blends math and science with engineering courses, software, and labs to offer a curriculum that puts theory into practice and turns dreams into reality;
- Provides an environment in which students work closely with faculty and classmates in a team-based process that promotes learning and achievement" [2] .

The *Sensors, Measurements, and Controls* course discussed in this article demonstrates all the above philosophical uniqueness of our engineering curriculum. This paper presents an example project that was designed to emphasize application of controls theory in designing a coupled-tank level control system, to blend differential equations, Laplace transforms, and MATLAB programming, and to provide an environment that students work together in teams under the direction of faculty members and lab supervisors. The paper starts with a brief introduction of the topics covered in this course, within the context of the general engineering core curriculum, and points out the difficulty of covering all the desired topics within the available time if conventional instructional approaches were used. It then moves to a project-driven instructional approach that can efficiently cover all the required topics. Furthermore, the second of the two course design projects—the design of a control system for the level of a coupled-tank apparatus—is detailed. The modeling, design, and testing activities during a five-week period are described in a great detail to explain how key concepts in the controls area are closely tied to the project. Finally, assessment results, including the students' feedback, and several improvement opportunities for the future are discussed.

II. COURSE BACKGROUND

The Engineering program at East Carolina University consists of four concentrations: Systems Engineering, Engineering Management, Bioprocess Engineering, and Biomedical Engineering. The general structure of the engineering curriculum is shown in Figure 1: An engineering curriculum core including 15 courses (43 hours) is designated to support all four concentrations. The *Sensors, Measurements, and Controls* course (3 credit hours) is one of the core engineering courses. To ensure that the course provides a systems view of instrumentation and controls theory and methods and provides sufficient background for advanced study in these concentrations, the following course objectives were planned:

- describe fundamental measurement and controls concepts,
- describe categories of transducers needed in industrial processes,
- analyze experimental uncertainty with statistical methods,
- identify possible causes of experimental errors,
- apply engineering tools to measure and analyze industrial processes,
- identify key parameters of instrument system design,
- describe basic signal conditioning techniques,
- apply mathematical models to describe physical systems,
- describe characteristics and performance of feedback control systems,
- analyze and determine stability of linear feedback systems,
- design control systems that meet basic control criteria and specifications, and
- document and present control system analyses in a professional manner.

While the objectives and the chosen topics in the course were attractive and fulfill the requirements for the entire engineering curriculum, it is obvious that the coverage of all the planned topics is extremely challenging given the amount of credit hours and more so if conventional instructional approaches are used. To ensure effective coverage of necessary key concepts and analysis and design methods, the course calls for a creative instructional approach. We adopted a project-driven approach for the first offering of this course in Fall 2007. Part of the rationale behind this decision was based on the effectiveness of inductive teaching methods, such as project-based learning, which are found to be at least equal to and in general more effective than traditional deductive methods, such as lecture-based teaching followed by exams [3]. This approach requires the students to perform meaningful learning activities in the laboratory, such as characterizing a physical system, determining the transfer function of the plant, and designing a controller to meet given performance specifications. These sequential activities help the students make close connections between subject theory in the lecture material and the laboratory project. Even though it is impossible to cover depth of the material, such as robust control design, with the semester time restriction, this approach enables general engineering students to develop autonomous learning skills that can be applied toward their professional careers.

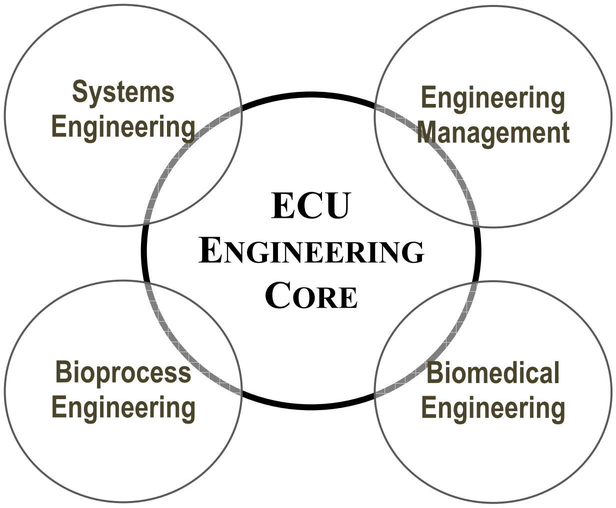
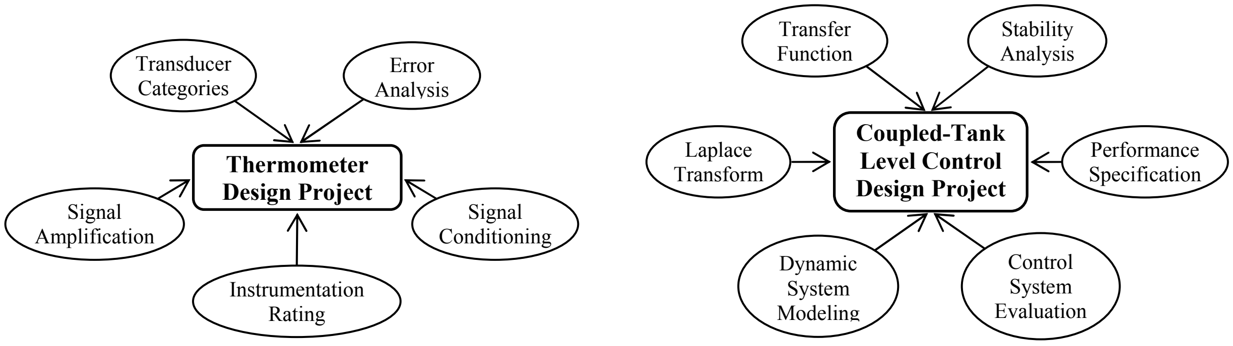


Figure 1. The general structure of the Engineering curriculum at ECU.

III. THE PROJECT-DRIVEN TEACHING APPROACH

To successfully meet the course objectives, two major design projects were developed to cover fundamental concepts in the instrumentation and controls areas. The first project was a thermometer design project that requires the student to design a thermistor-based digital thermometer; the second was a coupled-tank level control system design project. The concepts, analysis methods, and design approaches tied to the two projects are illustrated in Figure 2. This paper, however, addresses only the second project and discusses how control concepts were taught through this project-driven approach. Specifically, we used the second project to teach:

- Laplace transforms
- Transfer functions
- Dynamic system modeling
- Stability analysis
- System performance evaluation
- Feedback control system design



a. Digital thermometer design project **b. Coupled-tank level control system project**

Figure 2. Key instrumentation and controls concepts/methods tied to the two multi-week design projects.

All these concepts were presented in lecture sessions within the context of the coupled-tank control system design. Whenever possible, the lecture topics were tied to the concurrent design project that emphasizes hands-on experience in the lab. At the same time, whenever possible, concepts/methods from lectures were incorporated into project activities to help the students make the connections between theories learned from the classroom and their applications on a real-world system.

A. Project Overview

A coupled-tanks level control system was utilized in this course project for a number of reasons: 1) pharmaceutical and other chemical-related industries flourish in the eastern North Carolina region and tank level control is a common task that plant engineers in these industries often encounter; there is a good possibility that our graduates will work on systems like this; 2) compared to other control objects (e.g., motor speed), tank level has reasonably long time constants that allows the students to observe the dynamic changes without the need for electronic equipment (e.g., oscilloscopes). This direct visual effect should facilitate students' understanding of dynamic systems and their transient responses.

This project consisted of five sequential lab activities in five consecutive weeks: the students were required to:

1) calibrate the level sensors and the pump;
2) model the coupled-tanks process with a transfer function;
3) obtain a closed-loop transfer function that satisfies the system performance requirements;
4) determine the controller's transfer function *Gc(s)* and convert the transfer function into a difference equation that can be implemented as a digital controller on a computer; and
5) integrate the controller with the sensors, the pump, and the coupled-tanks apparatus to test and analyze the entire system's performance.

Each of these five activities is detailed in subsequent sub-sections. To help the students visually understand the big picture of the entire project and all the steps involved, an introductory document with a feedback control block diagram (see Figure 3) was provided. Each of the above activities was mapped to the corresponding block(s) in the diagram.

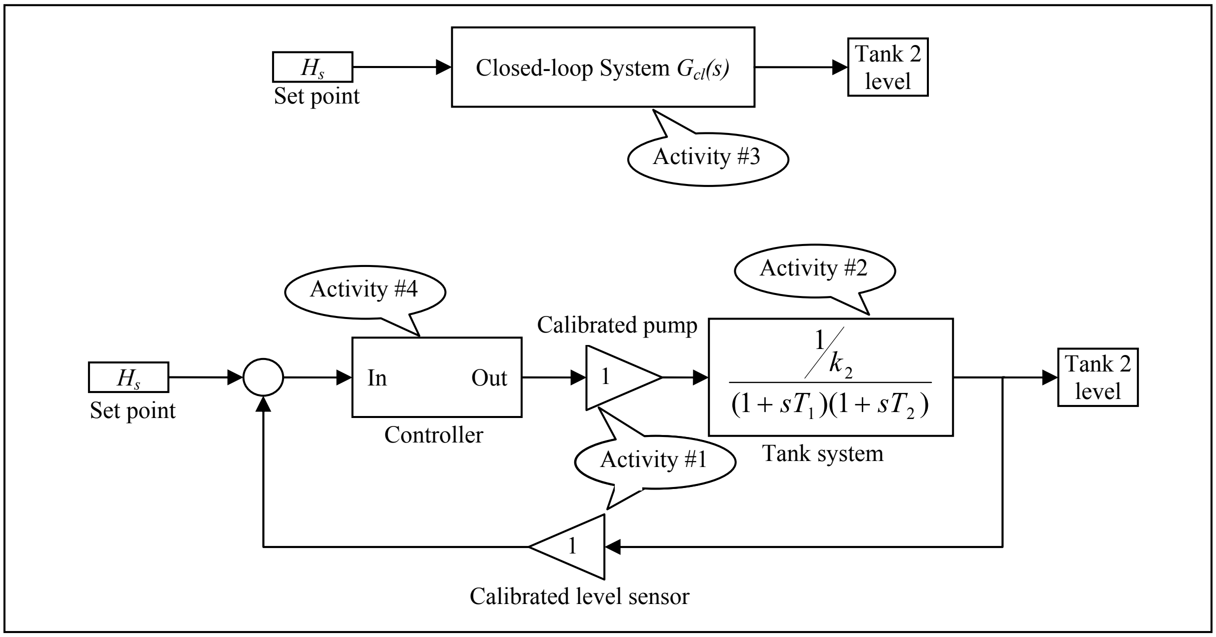


Figure 3. Mapping of laboratory activities to block(s) in the feedback block diagram.

B. Activity #1: Sensor and Pump Characterization

1. *Level Sensor Characterization*

The outputs of the level sensors are voltage signals (0-4V). A LabVIEW program converts these voltage signals back into level signals that the user can read and the feedback controller can use as well. To ensure accurate voltage-level conversion, the students collected data on the voltage-level relationships. The relationship curves were fit to 4th-order polynomials in Excel and the coefficients were used to calibrate the level signal in the LabVIEW program.

2. *Pump Characterization*

The output of the designed controller (refer to Figure 4) needs to be the input flow rate into tank 1. The controller first finds the flow rate required based on the current and previous level information. This flow rate is physically obtained by changing the speed of the pump, which is determined by the pump input voltage. Therefore, the mapping relationship between the pump input voltage and the flow rate needs to be characterized. To characterize the pump, students measured the voltage -flow rate (read from a round-tube flow meter with a cast-acrylic rod) relationship and fitted the curves to 4th-order polynomials in Excel. Since the repeatability of pump performance was difficult to obtain, the students used the average of two voltage-flow rate datasets to characterize of the pump: one from increasing the voltage from 0 V to 5 V incrementally; the other from decreasing from 5 V to 0 V.

C. Activity #2: Coupled-Tanks Modeling [4, 5]:

1. *Theory*

The basic experimental system consists of two hold-up tanks which are coupled by an opening between them. The water input is supplied by a variable speed pump to the first tank. The opening allows this water to flow into the second tank and then out to a reservoir. The goal is to control the water level in one of the tanks by varying the speed of the pump in the opposite tank. In our project, we controlled tank 2 level by varying pump 1. The system is a second order system with transfer function [3],:

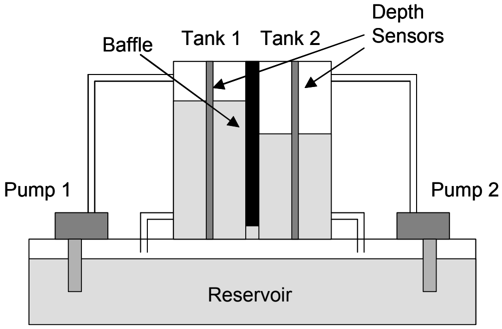


Figure 4. A coupled-tanks system.

$$G_p(s) = \frac{H_2(s)}{q(s)} = \frac{1/k_2}{(1+sT_1)(1+sT_2)} \tag{1}$$

where $H_2(s)$ is tank 2 level, $q(s)$ is the flow rate into tank 1 (or the input flow), and the time constants T_1 and T_2 are related to k_1, k_2, and A by:

$$T_1T_2 = \frac{A^2}{k_1k_2} \quad \text{and} \quad T_1 + T_2 = \frac{A(2k_1+k_2)}{k_1k_2} \tag{2}$$

where A= cross-sectional area of tank 1 and tank 2 = 3.45"x 1.6", and

$$k_1 = \frac{c_1a_1\sqrt{2g}}{\sqrt{H_1-H_2}} \quad \text{and} \quad k_2 = \frac{c_2a_2\sqrt{2g}}{\sqrt{H_2-H_3}} \tag{3}$$

where:

c_1 and c_2 = discharge coefficients for tank 1 and tank 2, respectively;
a_1 and a_2 = cross sectional areas of the opening between tank 1 and tank 2, and that of the drain tap of tank 2, respectively; (It is very difficult to measure the cross sectional area of the baffle gap between the two tanks, a_1. Thus, we used the products c_1a_1 and c_2a_2 as single quantities to model the coupled-tank system.)
H_1 and H_2 = the quiescent or steady state levels in tank 1 and tank 2, respectively, for a given input flow rate and obtained as part of the measurements;
H_3 = height of the drain tap of tank 2 = 0.45";
g = gravitational constant (386.22"/sec^2);

Equation (1) describes the transfer function between small variations in the input flow $q(s)$ and small variations in tank 2 level $H_2(s)$. A closer examination of Equation (3) reveals the reason for having to use a small signal (or linearized) equivalent model—the coupled tanks system is a nonlinear system—since the output flow rate from a tank is proportional to the square root of the level difference.

The expressions for time constants illustrate that only the products of the discharge constants and areas (c_1a_1 and c_2a_2) need to be known or measured to determine the system's transfer function. Therefore, two steps are required to obtain the plant's transfer function as shown in Equation (1): 1) Find the constants c_1a_1 and c_2a_2; and 2) Find the transfer function from c_1a_1 and c_2a_2 using Equations (3) and (2). More information can be found from reference [4] on how to obtain constants c_1a_1 and c_2a_2.

2. *Student Work*

In the lab, the students conducted both the dynamic response and steady-state response experiments [4] and collected tank level changes over time. They then programmed a MATLAB script to complete all the steps required to obtain the transfer function using Equations (3), (2), and (1).

D. Activity #3: Determine the Desired Closed-Loop Transfer Function:

1. *Theory*

The time-domain performance measures of a dynamic control system include: rising time (T_{r1}), percentage overshoot ($P.O.$), settling time (T_s), and steady state error (e_{ss}). When a second-order system is provided with a step input, all the performance measures are fully determined by the damping ratio ζ and natural frequency ω_n, as shown in the following equations [6]:

$$T_s = \frac{4}{\zeta\omega_n} \tag{7}$$

$$P.O. = 100\ e^{-\pi\zeta\ \sqrt{1-\zeta}} \tag{8}$$

$$T_{r1} = \frac{2.16\zeta + 0.6}{\omega_n} \tag{9}$$

A system is designed from the performance requirements by determining ζ and ω_n, which will fully determine a second-order system with a transfer function represented as:

$$G_{cl}(s) = \frac{\omega_n^{\ 2}}{s^2 + 2\zeta\omega_n s + \omega_n^{\ 2}} \tag{10}$$

2. *Student Work*

The students were given a set of performance specifications: (a) percent overshoot <20%; (b) rising time T_{r1} = 30 seconds; and (c) settling time T_s < 200 seconds. They were required to use MATLAB to obtain the desired closed-loop transfer function that met these specifications and conduct a MATLAB step response simulation to analyze the peformance to ensure the designed closed-loop transfer function satisfies all the requirements.

E. Activity #4: Determine the Controller

1. *Theory*

With the obtained plant transfer function $G_p(s)$ and the desired closed-loop transfer function $G_{cl}(s)$, the controller's transfer function $G_c(s)$ can easily be found by:

$$G_c(s) = \frac{G_{cl}(s)}{(1 - G_{cl}(s))G_p(s)} \tag{11}$$

The *s*-domain transfer function needs to be converted into a difference equation before it can be implemented as a digital controller. Generally, the difference equation should take the form:

$$Q = kk_1 e(n) + kk_2 e(n-1) + kk_3 e(n-2) + kk_4 Q(n-1) + kk_5 Q(n-2) \tag{12}$$

where: $e(n)$: level 2 deviation of this sample cycle
$e(n-1)$: level 2 deviation of the last sample cycle
$e(n-2)$: level 2 deviation of the cycle before the last
Q : flow rate to be determined by the controller
$Q(n-1)$: flow rate of the last sample cycle
$Q(n-2)$: flow rate of the cycle before the last
$kk_1, kk_2, kk_3, kk_4,$ and kk_5 : coefficents

Here, quantities kk_n*'s* are used to distinguish between the two constants k_1 and k_2 in the tank model.

2. *Student Work*

The students were required to write a MATLAB script to obtain the controller's transfer function, which is a 4th-order transfer function from MATLAB's numerical manipulations. The students were required to simplify the expression to obtain a 2nd-order transfer function by cancelling like poles and zeros. The simplified transfer function was converted into a difference equation that can be implemented as a digital controller in the LabVIEW program. The MATLAB code converting the transfer function into a difference equation was provided to the students since it requires knowledge of digital control and Z-transform—subjects that were beyond the scope of this course.

F. Activity #5: Integrate the System to Test and Evaluate the System Performance

The integrated control system including the coupled-tank apparatus is shown in Figure 5. The characteristics (polynomial coefficients) of the level sensors and the control pump had been all included in the corresponding modules so the level signals sent to the controller and displayed on the front panel (see Figure 6) reflect the actual levels (in inches) in the tanks. The flow rate quantity generated by the controller was converted into a voltage signal that allows the pump to produce the desired flow. The coefficients of the digital controller are entered into an AUTO CONTROL module (see the block diagram in Figure 7) in a LabVIEW virtual instrument provided by the instructor.

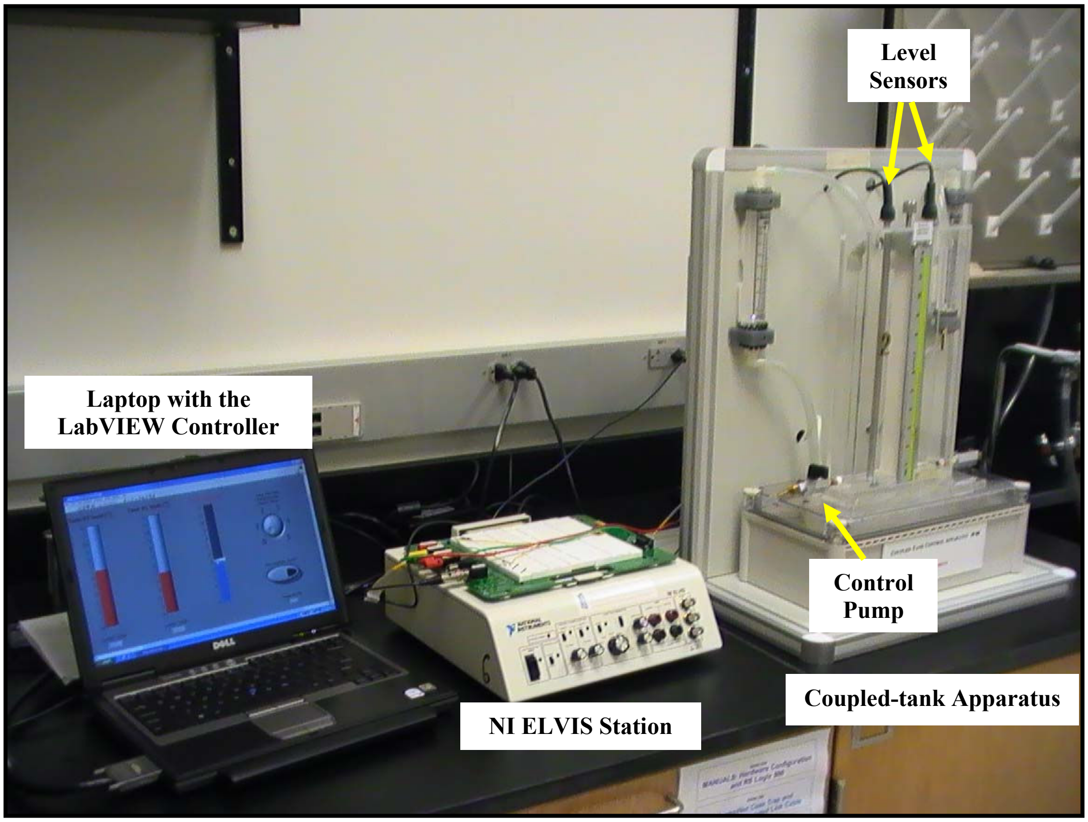


Figure 5. The integration of the experiment setup.

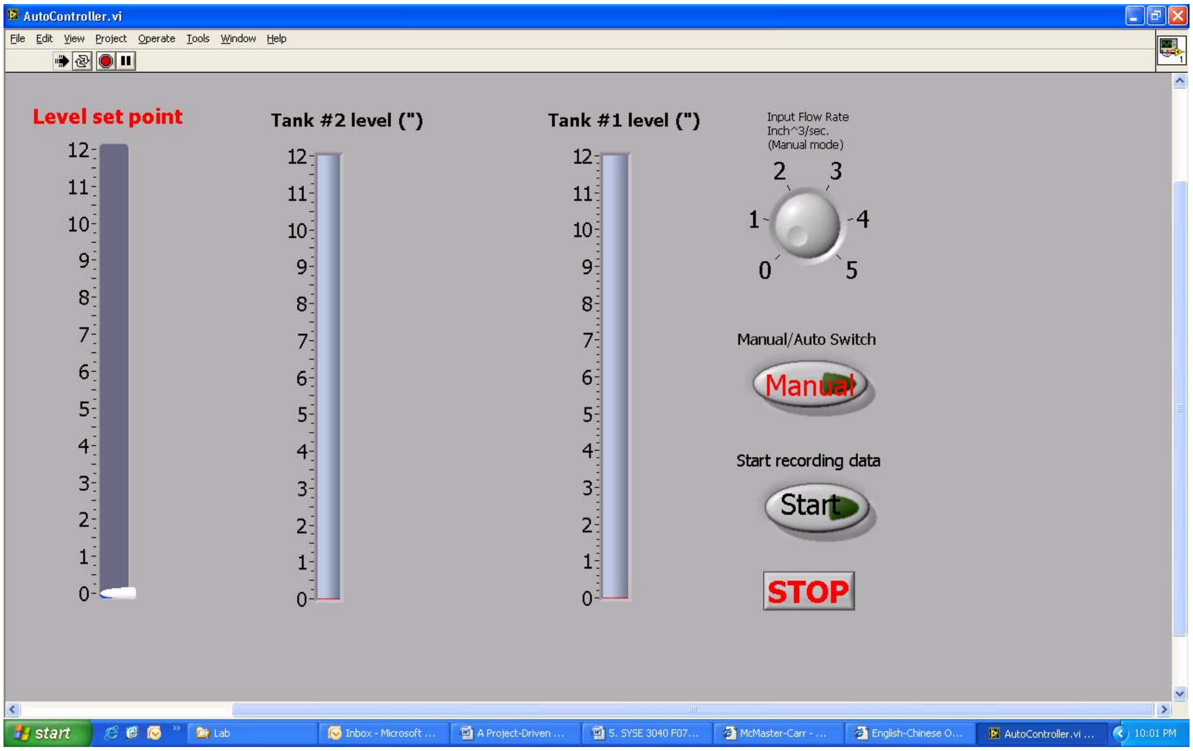
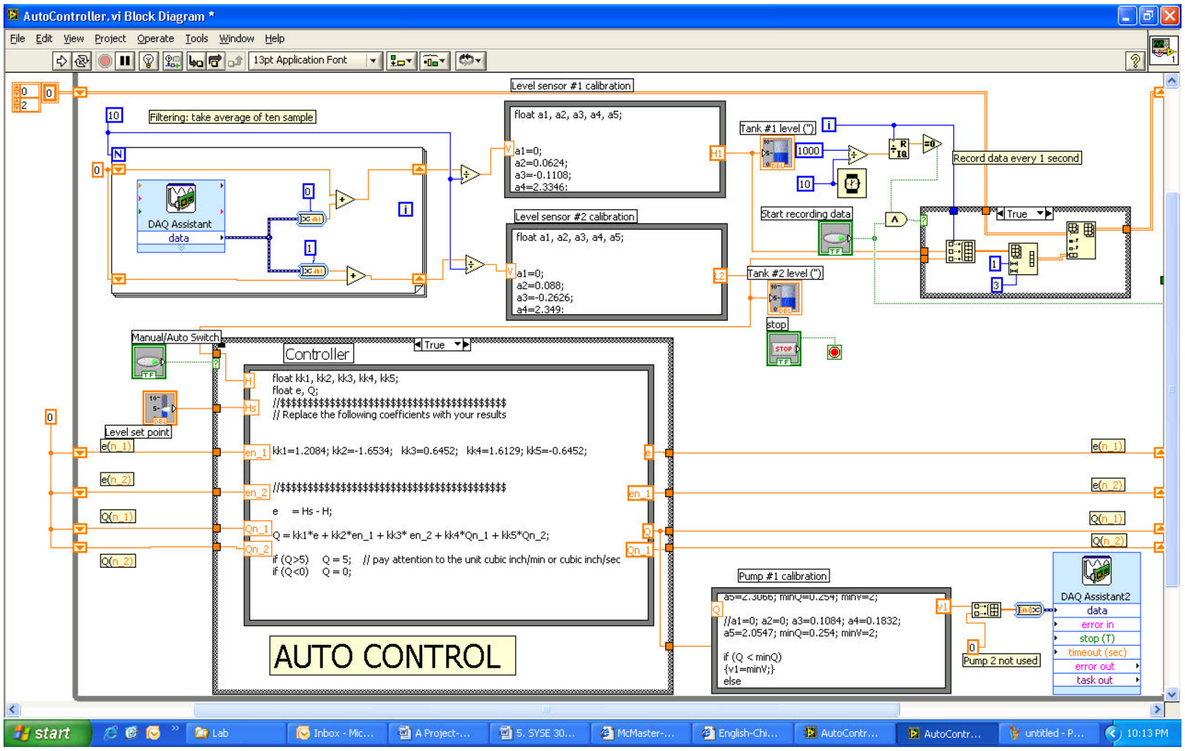


Figure 6. The LabVIEW front panel of the level controller.



Level sensor #1 calibration

```
float a1, a2, a3, a4, a5;


a1=0;
a2=0.0624;
a3=-0.1108;
a4=2.3346;
```

Level sensor #2 calibration

```
float a1, a2, a3, a4, a5;


a1=0;
a2=0.088;
a3=-0.2626;
a4=2.349;
```

Controller

```
float kk1, kk2, kk3, kk4, kk5;
float e, Q;
//$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
// Replace the following coefficients with your results


kk1=1.2084; kk2=-1.6534;   kk3=0.6452;   kk4=1.6129; kk5=-0.6452;


//$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

e    = Hs - H;

Q = kk1*e + kk2*en_1 + kk3* en_2 + kk4*Qn_1 + kk5*Qn_2;

if (Q>5)    Q = 5;    // pay attention to the unit cubic inch/min or cubic inch/sec
if (Q<0)    Q = 0;
```

Pump #1 calibration

```
a5=2.3066; minQ=0.254; minV=2;

//a1=0; a2=0; a3=0.1084; a4=0.1832;
a5=2.0547; minQ=0.254; minV=2;

if (Q < minQ)
{v1=minV;}
else
```

Figure 7. The LabVIEW diagram of the level controller.

G. Assignments

Pre-lab assignment: To encourage students to prepare for each lab, pre-lab assignments were included. These assignments either required the students to read the lab instructions and answer specific questions for the lab or practice problems that were needed to achieve the objectives in the lab session.

Lab activities check off: The students were required to obtain the instructor's initials every time they accomplished a certain task and answer questions posed by the instructor before they received credit.

Project report: The students were required to write team project reports. A submission package guideline was provided to them, which defined general format expectations and the required items for the report. These items include an abstract, summary paragraphs of each activity in their own words, data collected, MATLAB scripts used (with clear and descriptive comments), intermediate results, simulation results, testing results, and a project reflection.

H. Integration of Modern Engineering Tools and Mathematics

As stated earlier, modern engineering tools such as MATLAB, LabVIEW, and Excel have been extensively used in lab activities. Similarly, the project required the students to understand mathematics (Laplace transforms, transfer functions, and difference equations, etc.) so that they can apply the math knowledge into their design process. Figure 8 illustrates how these modern engineering tools and mathematics have been integrated into individual activities of the entire project.

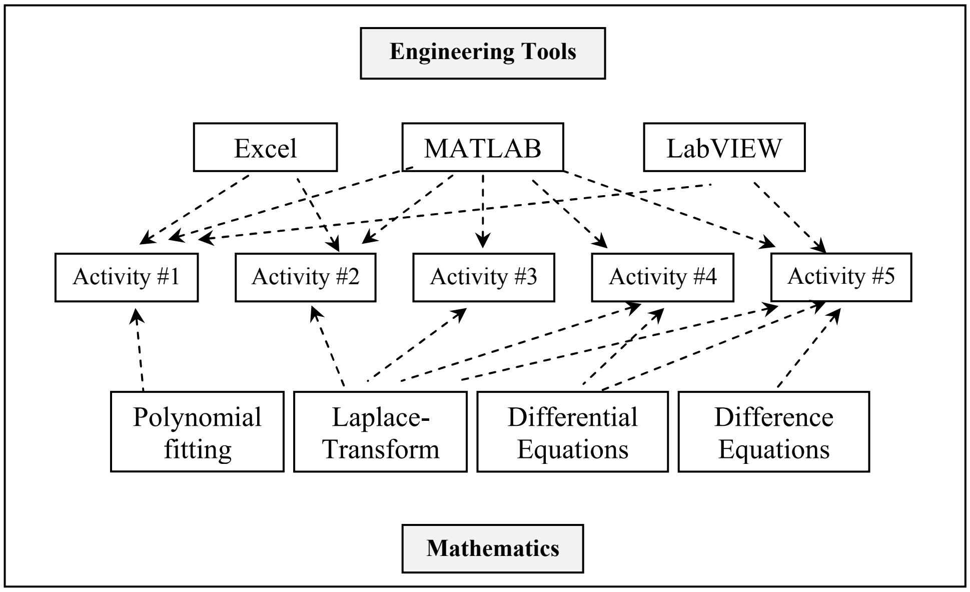


Figure 8. Integration of modern engineering tools and mathematics into the coupled-tanks control system design project.

IV. ASSESSMENT

The project was primarily assessed using two instruments: a student survey and project report.

A. Student Survey

A Likert scale survey (1-Strongly disagree; 2-Disagree; 3-Neutral; 4-Agree; and 5-Strongly agree) was conducted to collect the students' opinions. The objectives surveyed are shown below in Figure 9:

1. *The coupled-tank control system design project helps me see how mathematical knowledge is applied to engineering problems.*
2. *The coupled-tank control system design project improves my ability to design experiments.*
3. *The coupled-tank control system design project improves my ability to conduct experiments.*
4. *The coupled-tank control system design project improves my MATLAB programming skills.*
5. *After the coupled-tank control system design project, I am able to use differential equations to model dynamic processes.*
6. *After the coupled-tank control system design project, I am able to evaluate performance of feedback control systems.*
7. *After the coupled-tank control system design project, I am able to determine stability of feedback control systems.*
8. *After the coupled-tank control system design project, I am able to design feedback controllers to meet performance specifications.*

Figure 9. Survey questions for the design project.

The results shown in Table 1 reflect the 9 responses received from the 25 enrolled students. The survey results demonstrate that, out of the students who responded, most of them expressed they achieved the laboratory objectives.

TABLE 1. STUDENT SURVEY RESULTS.

Questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	% Rated 4 or Higher
1	0	0	1	5	3	88.9
2	0	0	1	4	4	88.9
3	0	0	2	1	6	77.8
4	0	0	0	4	5	100
5	0	0	3	3	3	66.7
6	0	0	1	5	3	88.9
7	0	0	2	2	5	77.8
8	0	0	2	5	2	77.8

B. Assessment of Project Report

As described earlier, the students submitted team project reports, in which they described the steps that they used to design the controller. The reports were used to assess the students' ability to:

a. apply mathematics knowledge to model dynamic systems and control systems;

b. design experiments;
c. conduct experiments;
d. use MATLAB to analyze and design control systems.

Assessment rubrics were developed for each outcome a through d. The project team report was assessed using these rubrics and a rank of 1 through 4 was assigned to each team. Individual assessment was also conducted based on performance of individual students over the project period. Each student was ranked 1 through 4 for each outcome. As an example, Figure 10 on next page shows the rubric and team/individual evaluation tables for assessing outcome d (students' ability to use MATLAB as an engineering analysis and design tool). The assessment results are presented in Table 2.

TABLE 2. PROJECT REPORT ASSESSMENT RESULTS.

Outcome	Percent rated 3 or 4
a)	68%
b)	75%
c)	63%
d)	75%

V. DISCUSSION

The results of this paper are from the first offering of the *Sensors, Measurements, and Controls* course. The control systems component of the course was based on the design and implementation of a controller for a coupled-tank system. This laboratory project was used as the active learning element to enable the students to make logical connections between theory and practical hands-on applications. The effectiveness of our project-driven teaching approach is reflected in two assessment mechanisms: end of project student survey and project assessment of four specific outcomes.

Feedback from the students, based on the end of project survey, indicated that, in general, they appreciated the integration of mathematic models with physical systems and enjoyed the opportunities to have hands-on design experience. All the students agreed that the extensive use of MATLAB exposed them to the great capability of this engineering tool and improved their MATLAB programming skills. Although the students indicated they have a high level of understanding of how mathematical knowledge is applied to engineering problems they scored comparatively low in assessing their own ability to use differential equations to model dynamic systems. This indicates some students did not make a strong connection between differential equations in the time domain and how these equations are represented in the *s*-domain. Delivery of the course material in the classroom can be fine-tuned to emphasize these connections. Overall, these survey results indicate a high level of self-confidence in the students, which may

Assessed Outcome:

Graduates of the Engineering Program will demonstrate an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Project Description:

This is a five-week project that requires students to characterize the sensors, model the coupled-tanks, and design a controller to satisfy specified performance requirements. The project requires extensive use of MALTAB programming. In multiple activities, MATLAB or Excel is used to:

- *characterize the sensors and pumps*
- *obtain the transfer function of the coupled-tank process with data collected from the process' dynamic response and steady-state response*
- *find the transfer function of the desired closed-loop system based on given specifications*
- *simulate the designed systems to evaluate their performance*

Assessment Rubrics:

4 (Superior): the students are proficient in using MATLAB for engineering problem analysis and design. The documentation of the program is clear and well organized. Comments provided are clear and sufficient

3 (Satisfactory): the students are able to use MATLAB for engineering analysis and design with some mistakes. The code is generally well documented. Most of comments are included.

2 (Below Expectation): that the students have problems with using MATLAB to analyze and design engineering systems. The code is not well document. No sufficient comments are provided.

1 (No Progress Shown): the students cannot use MATLAB for engineering analysis or design.

Assessment Results:

Team I

	Student A	*Student B*	*Student C*
Team score based on report	*4*	*4*	*4*
Individual performance during the course of the project	*4*	*2*	*1*
Individual assessment	*4*	*3*	*2*

Team II

	Student D	*Student E*	*Student F*
Team score based on report	*3*	*3*	*3*
Individual performance during the course of the project	*4*	*3*	*1*
Individual assessment	*4*	*3*	*2*

Team III

	Student G	*Student H*	*Student I*
Team score based on report	*3*	*3*	*3*
Individual performance during the course of the project	*2*	*2*	*1*
Individual assessment	*3*	*3*	*1*

Figure 10. Rubric and Assessment Results of the Students' Ability to Use MATLAB.

be interpreted as a positive indication that this project-based approach is an effective way to present challenging material and also promote autonomous learning.

Student reports on the coupled-tank design project were used to assess the students' abilities to apply mathematics, design and conduct experiments, and use MATLAB to analyze and design control systems. The results are presented as the percentage of students scoring satisfactory (a rating of 3) or superior (rating of 4) on a scoring scale of 1 to 4. Based on the assessment results, 75% of the students scored a 3 or 4 in the ability to design experiments and the ability to use MATLAB to analyze and design control systems. However, they scored slightly lower in the ability to apply mathematics and conduct experiments at 68% and 63%, respectively. Our standard for reporting that the students are achieving the outcomes of the project is 75%. Based on this standard, only two of the four outcomes were successfully achieved. This may be interpreted as a positive indicator that our project-driven approach to this course is successful, but that improvements and fine tuning need to be made for future offerings of this course.

In many respects, the coupled-tank laboratory design project was a challenge for the students. The students were challenged in mathematically modeling the system based on experimental data and were further challenged in designing a controller that met given design specifications. A level of frustration was experienced by every group since the final controller design did not work as expected. Nevertheless, this experience was a valuable lesson. The students gained insight and a profound respect for how difficult it is to model a physical system and design a component of the system which relies on the completeness and accuracy of the mathematical model.

However, some improvements in future delivery of the design project are needed. The design of the controller in the current project is based on the precise modeling of the object. This design approach was proven to be difficult for two reasons: (a) the less than ideal components (flowmeters, pumps, level sensors, etc.) used in the system, and (b) the fact that the students lacked sufficient practice on dynamic system modeling. The imprecision of the object model, plus many other factors (e.g., the nonlinearity of the level system, dead-band of the pump, time-delay of the physical systems, and digitization inaccuracies), all played a role and made the final integrated system's performance less ideal than originally expected. In future offerings, use of more robust control laws (e.g., PID) should alleviate the consequence from modeling errors in the apparatus. In addition, intermediate verifications at each phase of sensor characterization and plant models should improve performance of the final control system.

VI. CONCLUSIONS

This paper presented a project-driven approach to teach a compact Instrumentation and Controls course in a general engineering program. Although there is great room for improvement in many aspects, the experience did demonstrate that it is feasible to tie controls concepts with design projects to improve instructional effectiveness. This hands-on, project-driven approach allowed the coverage of the broader range of topics that would otherwise be impossible with a conventional lecture-based approach.

REFERENCES:

[1] East Carolina University. "Homepage of the Department of Engineering," Available: http://www.tecs.ecu.edu/engineering/.

[2] East Carolina University. Available: http://www.tecs.ecu.edu/engineering/mission/mission.html.

[3] M. J. Prince and R. M. Felder, "Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases," *Journal of Engineering Education*, vol. 95:123-138, 2006.

[4] E. Laubwald. "Coupled Tanks Systems 1," Available: www.control-systems-principles.co.uk/whitepapers/coupled-tanks-systems.pdf.

[5] L. Limberis, "Coupled Tanks Modeling: System Characteristics Measurements," in *ENG 354 Control Systems Laboratory Design Project Instructions*.

[6] R. C. Dorf and R. H. Bishop, *Modern Control Systems*, 10 ed: Pearson Prentice Hall, 2005.