

**AC 2010-1508: INSTRUMENTATION BASED MOBILE LABORATORIES FOR AN
ELECTROMECHANICAL ENGINEERING TECHNOLOGY DISTANCE
EDUCATION PROGRAM**

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Instrumentation Based Mobile Laboratories for an Electromechanical Engineering Technology Distance Education Program

Introduction

The TAC/ABET accredited B.S. Electromechanical Engineering Technology program described in this paper includes a distance education component that connects with ten community colleges within a 300 mile radius of the host institution. This paper begins with a brief overview of distance education lab structures. Then a series of labs for a computerized instrumentation course are presented that focus on having the students become involved in the design of common components. Examples include an encoder, tachometer, accelerometer, motor torque and fluid discharge coefficient measurements. These labs are mobile in the sense that the entire course is in a utility box that can easily be transported from campus to campus. Also the labs use inexpensive components that can be easily replaced.

The outcomes, procedure, and equipment associated with each lab are presented, along with subsequent photographs and descriptions of the results.

Finally assessment results of the labs are displayed.

Distance Education Engineering Labs

Distance education labs have been used frequently for the last ten to fifteen years. Feisel ¹ notes that distance education has dramatically affected laboratory instruction, allowing for remote data access and instruction. Experiments can now be conducted at a distance of hundreds of miles from the equipment. These labs help guide future engineers as they learn how to collect experimental data that guides in the design of products.

Etkina notes, that the engineering lab is also "...an experiment that typically involves solving a practical problem or determining an unknown quantity by performing experiments. Students need to solve these experimental problems using at least two different methods and then compare the results. Often they need to perform additional experiments or make informed estimates to determine some physical quantities."² Distance labs are focused on having students develop a solid understand of how basic instrumentation and control software and equipment (encoders, tachometers, image processing, actuators, and servomotors) operate.

Models of Lab Delivery for Distance Programs

One of the most challenging aspects of this program is the student laboratory experience. Data acquisition, signal processing, sensors, PLCs, hydraulics and pneumatics, and motor control are important subjects in an electromechanical program. In order for students to fully understand their operation, they need to work on this equipment. Equipping engineering and engineering technology laboratories at distance sites has been on-going for years at universities. These laboratories usually fall into some combination of the following models:

- A. *Distance Students Travel to the Host Universities.* Here students travel to the main campus to do a compressed form of the labs. There is little time to do more than follow a set of instructions. This severely limits access. Students living 100

miles or more from a campus find it difficult to travel to the university on weekends or during the summer. These labs are typically done on a Saturday or in the summer.

- B. *Grant Supported Trainers at Each Site.* These trainers are typically large and not only costly to purchase, but also expensive to maintain.
- C. *Computer Simulation or Programming Based Labs.* This type of lab is common in Electrical or Computer Engineering Technology programs. There is no experience with equipment (other than computers).
- D. *Small Component Electrical Labs.* These usually centered around wiring chips on a breadboard. These are typically used in Electrical Engineering Technology (EET) programs, and incorporate the use of meters, oscilloscopes, and signal generators.
- E. *Web Controlled Equipment Trainers Stationed Located at Host Site.* These trainers are viewed over interactive video or video streaming and are connected to an http stack. The equipment typically includes HVAC trainers, conveyors, wind tunnels, and fluid trainers.
- F. *Laboratories in Vans Driven to Distance Sites.* This equipment is driven to the distance sites. Some community colleges use vans to teach labs at distance sites. The problem with this method is that it allows access to equipment for a limited time, making it difficult to accomplish more than competency based tasks. The California Distance Learning Project states that these types of mobile labs are becoming less popular as distributed learning increases.³
- G. *Smaller Portable Trainers* located at each site. These trainers are mobile in the sense that they are brought back to the main campus periodically for maintenance and repair. Their light weight, low cost, and compact design makes transportation relatively simple. They are larger than the breadboard labs described above, and may include sensors, hydraulic trainers, PLC trainers, and servo trainers. One advantage of this method is that the trainers can be returned to main campus, so the laboratory equipment doesn't take up space at the distance site if the course is not currently taught. Sometimes students build part of the trainer as a component of the lab exercise.

At first it might seem that Model B *Grant Supported Trainers at Each Site* would be the best choice, and indeed many schools have applied for large grants to buy trainers to be located at each site. However this inhibits growth to new sites, and can be very expensive to maintain. In addition the equipment must take up space at the local community college.

Many distance ABET accredited engineering technology programs use Model A *Distance Students Travel to the Host Universities* described above, where students travel to campus to do the labs. That can be a great inconvenience to students living over 100 miles from the host

institution. This paper focuses on Model G *Smaller Portable Trainers*, in part because students can complete their B.S. degree without traveling to the host campus.

One reason for the success of these Model G based labs is that students inspect the lab parts the first week of class. They then sign an agreement that they will replace any damaged parts (cost of part replacement is purposely kept below \$30). Knowing that they will have to replace broken parts has helped students take care when handling the equipment. Courses that include these laboratories are related to instrumentation, control, and industrial automation.

Computerized Instrumentation Course

There are ten labs in the computerized instrumentation course. The following is a description of four of them, namely encoder/tachometer design, accelerometer, fluid discharge coefficient trainer, and motor torque measurement. Not included here are additional labs that incorporate a load cell, LVDT, voice recognition (using a power spectrum), bar code reading, and image processing (using histograms to recognize parts on a conveyor)

Relative Encoder/Tachometer Lab

ABET Outcomes:

- an ability to apply creativity in the design of systems, components, or processes appropriate to program educational objectives.
- an ability to conduct, analyze and interpret experiments, and apply experimental results to improve processes.

Equipment:

- Tamiya 70110 4-Speed Crank-Axle Gearbox Kit
- encoder stand
- resistors
- photocell
- 4.5V supply
- 6V supply
- DAQ 6008 card
- encoder paper
- Scotch sticky back pads
- breadboard
- 1 inch paper punch
- 2 inch paper punch
- 2 large washers
- black marker
- scissors
- wire clips

Procedure:

This lab is divided into two parts. The first part requires students to put together the encoder so that there is a change in voltage across the photocell when it passes through a light source. The second part requires students to interface the encoder to Labview, decoding the photocell reading either through a digital design or Labview VI.

NOTE...The student is responsible for all parts provided with the lab. If a part breaks or is lost, the student must replace it. The motor cost is about \$10 and can be obtained from <http://www.pololu.com/catalog/product/68>

Encoder/Tach Lab Part 1.

Cut out a 4 inch disk from the encoder paper provided by the lab attendant.

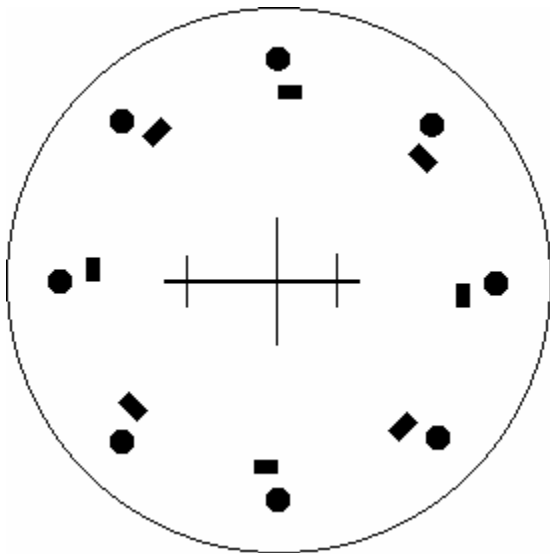


Figure 1: Paper Encoder Wheel Cutout

Next use the 1 inch paper punch to punch holes in the eight black outer circles of the disk, as shown below.

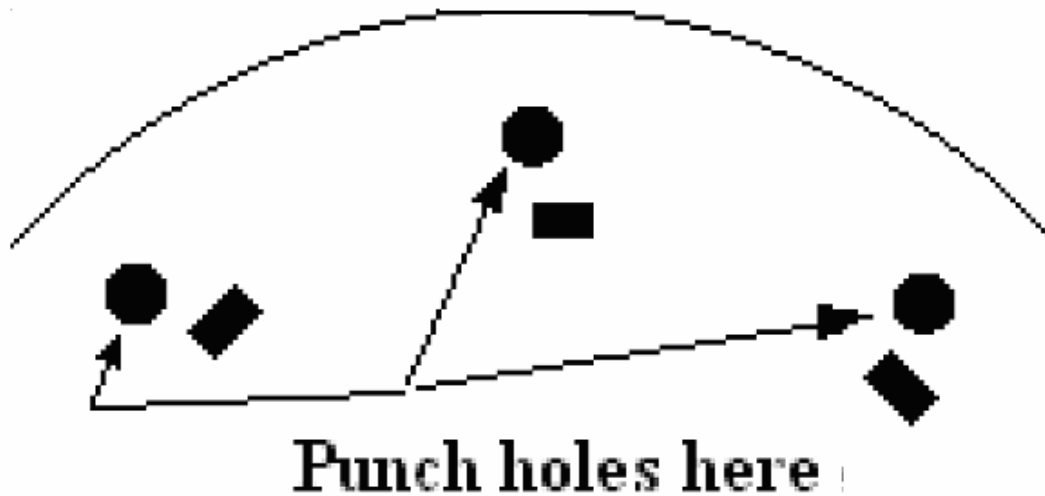


Figure 2: Enlarged View of Encoder Paper Cutout Showing Edge Holes

Next use the 2 inch hole punch to punch start shaped holes at the locations shown below. Do not punch a hole in the center of the disk.

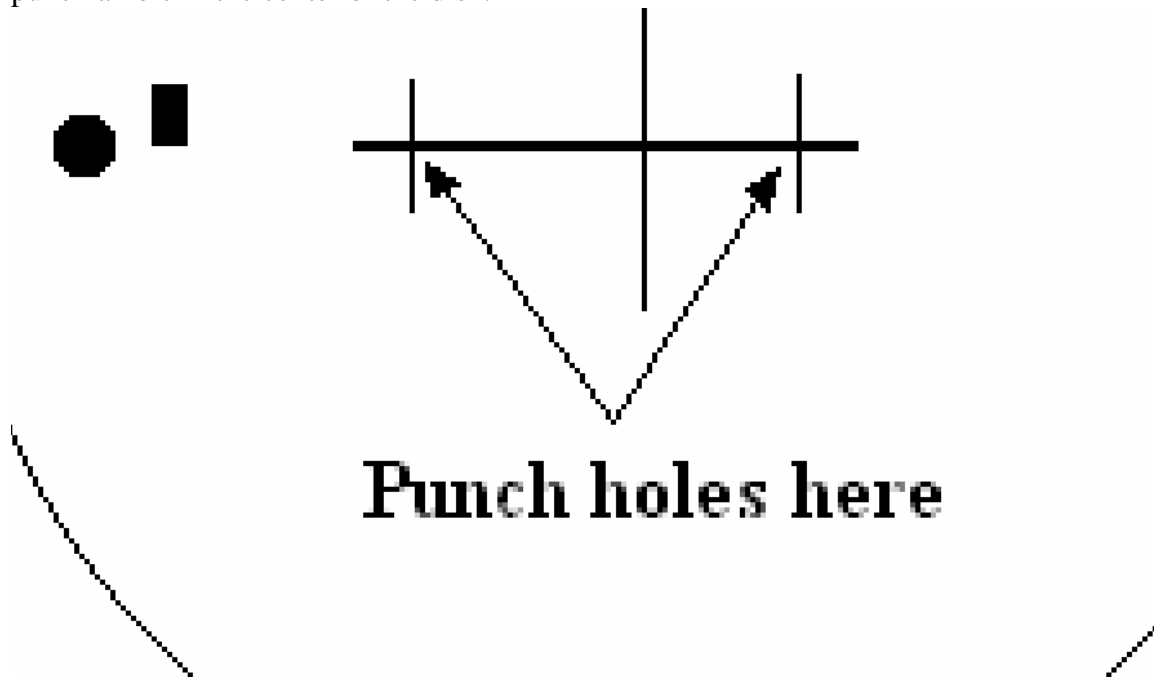


Figure 3: Enlarged View of Encoder Paper Cutout Showing Center Holes

The star shaped holes are used to mount the encoder to the motor. Now use the black marker to color the disk black. Also color two of the large washers black. Next use the screws and nuts that are in the box that came with the motor plus two large washers to mount the encoder disk onto a crank. A sample mounted encoder disk can be viewed in the second half of the video called ENT 401Encoder located at www.users.muohio.edu/hergerd/ent401

Now mount the photocell on the stand using the sticky back paper. The instructor will go over how to position it.

Mount the motor on the motor stand with sticky back paper so that a hole on the encoder wheel will pass directly in front of the photocell when it moves.

Use the wire clips to connect each end of the photocell to the banana plugs. Wire the 4.5 volt supply to the motor and compare its operation to the video.

Place an ohmmeter across the banana plugs and measure the resistance when the photocell receives light and when it is dark.

Dark resistance _____

Light resistance _____

Now select a combination of resistance to closely match the dark resistance. Use the breadboard to wire this resistance as a pull up resistor with the 6 volt source as shown below:

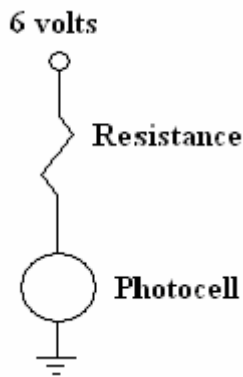


Figure 4: Photocell Pull Up Resistor

Using a voltmeter, measure the voltage across the photocell while the motor is running. The higher voltage should be between 2-3 volts. The low voltage should be less than one volt.

Dark voltage _____

Light voltage _____

If the is not the case, adjust the pull up resistance.

Encoder/Tach Lab Part 2

Design an interface to read the photocell voltage into Labview using an RS-232 meter or a DAQ 6008 card. One way to do this would be with a digital interface that takes a changing voltage and produces a count state. Since there are eight holes on the wheel, the count would change from 000 to 111. This count state would then be fed to the DAQ card. Of course some wave shaping will need to occur. This could be done with a comparator or Schmidt trigger.

Another way to interface the photocell voltage would be to read the voltage directly into Labview. This will present a significant challenge because a VI that senses an edge trigger and have Labview do the counting will have to be written.

Whichever method is chosen, make the screen look like the Labview angle increment disk on the video.

Next use Labview to compute the length of time between edges. In other words, how long does it take from when the photocell first receives light from one hole to when it first receives light on the next hole. If this time is multiplied by eight, we have the number of seconds to complete one revolution. Using this information, display the RPM of the motor. This can be done by first calculating the revolutions per second of the wheel, multiplying by the gear ratio (5402 to 1), then converting to RPM.

Encoder/Tach Lab Part 3

Use the wheel and another photocell to create quadrature encoding. This type of encoder senses direction as well as position. A second photocell aligned with the rectangle produces a second bit. The name quadrature encoder comes from the fact that there are four count states. From the diagram below, counterclockwise has a count of 00 10 11 01, and clockwise has a count of 01 11 10 00.

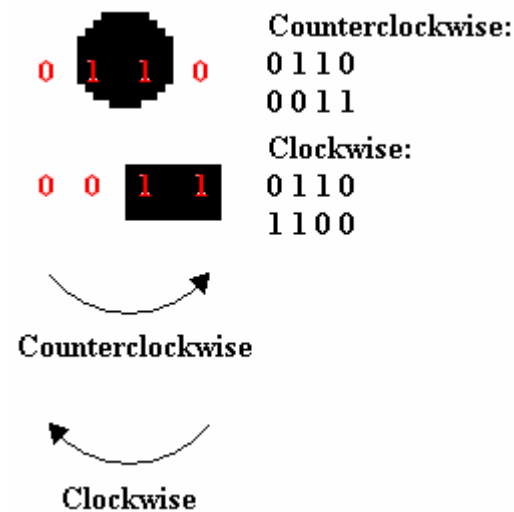


Figure 5: Quadrature Encoding

Labview can detect which direction the wheel is turning from observing the count state. This should not be attempted until Parts 1 and 2 are completed. The equipment from Parts 1 and 2 must be used. The encoder stand can be modified as long as it is returned to its original condition at the end of the course.

Results:

Shown below is a working version of the encoder/tachometer project:



Figure 6: Encoder/Tachometer Lab Project

Note in Figure 6, two photocells are used on the encoder, one on the upper right and one at the bottom of the wheel. The photocells are offset and the Labview program detects which photocell receives light first to determine direction. The stand for the motor, wheel, light, and photocell was designed by the professor and manufactured by a local polymer company. Students typically spend about three weeks designing this project. The Labview Front Panel and Block Diagram for the encoder/tach lab is shown in Figure 7.

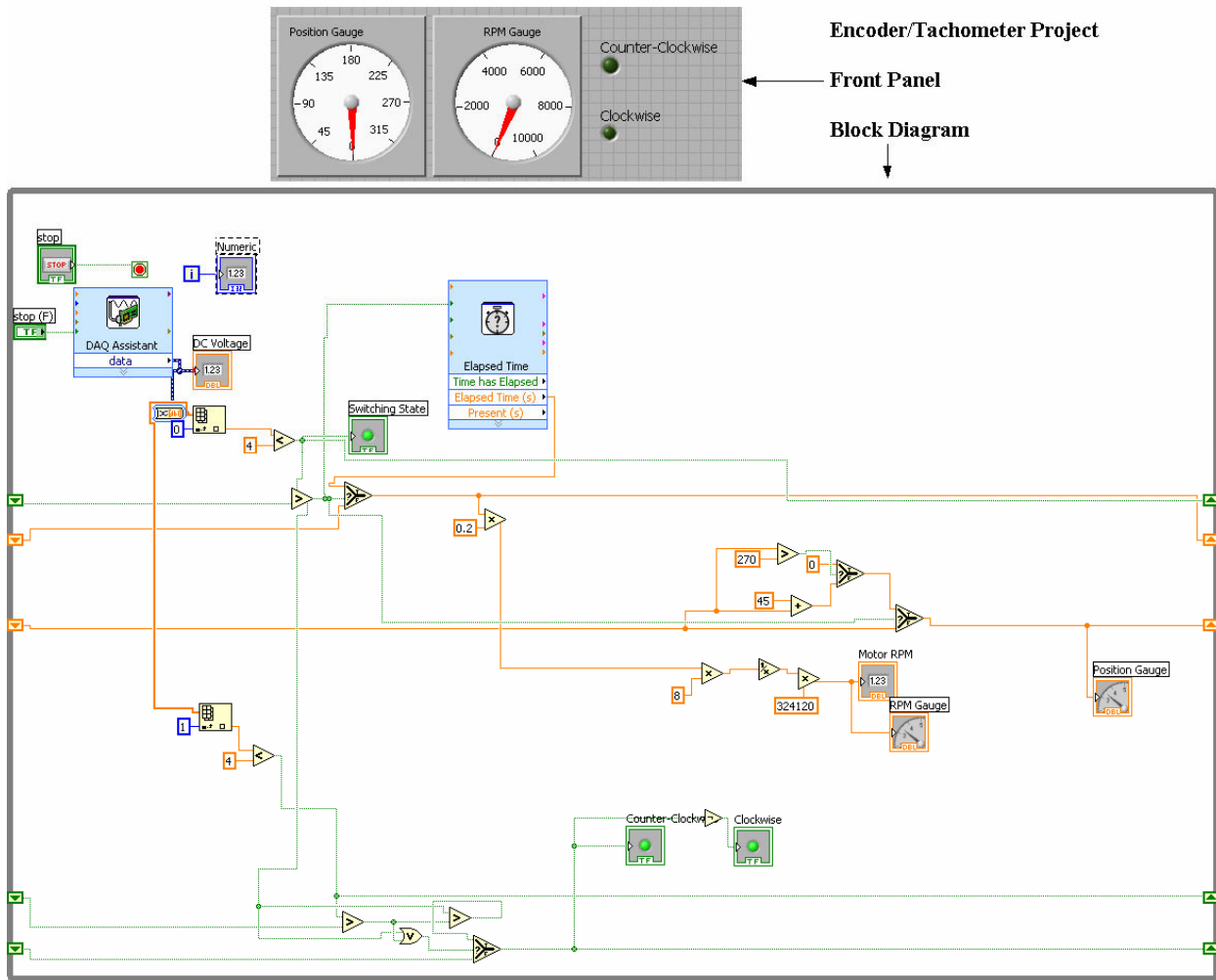


Figure 7: Sample Labview Front Panel and Block Diagram for Encoder/Tachometer Project

Accelerometer Lab

ABET Outcomes:

- an ability to apply creativity in the design of systems, components, or processes appropriate to program educational objectives
- an ability to conduct, analyze and interpret experiments, and apply experimental results to improve processes.
- an ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering, and technology

Procedure:

Accelerometer Lab: Part 1

Locate the DE-ACCM3D accelerometer chip and the red box with a breadboard in it. Turn the chip over and determine where the V, GND, X, Y, and Z axis are located. Wire V and GND to the 9 volt battery. Use two banana plugs to help wire the battery. Wire the Y axis to a multimeter with the other lead attached to GND. Again use banana plugs to help with this. The DE-ACCM3D should be positioned as shown in Figure 8.

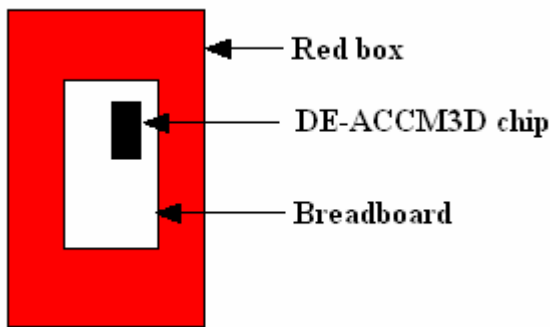


Figure 8: DE-ACCM3D Chip Alignment

Set the multimeter to DC Volts. In the position shown above, the meter should read about 1.99V. The default bias is 1.66V. With a sensitivity of 333 mv/g, the g force should be $(1.99-1.66)/.333 = 1g$.

Turn the box on its side. The meter should now read 1.66V giving a g force of 0g. This is to be expected since the Y axis will not experience g force in the horizontal direction.

Turn the box upside down. The g force should now be $-1g$.

Accelerometer Lab: Part 2

Use the accelerometer to create your own experiment. Some suggestions are:

- Study the effects of damping by running the a quarter horsepower motor with the accelerometer on the table. Now place rubber padding under the motor to see how much the vibration is decreased. When observing vibration, the multimeter should be on AC.
- Create a tilt meter, by having an LED bar display light up when the red box is tilted to the right or left.
- Do some research on acceptable vibration on an engine and compare your finding with readings from an actual engine.
- Study the effects of g force going around curves in a car (keep to the speed limit of course!)

There are many more experiments listed on the company's website (www.dimensionengineering.com) as well as other sites on the web.

The lab grade in this part will depend partly on the quality of research and partly on the design (added electronics, Labview VI, etc).

Results:

The *accelerometer* project has students design their own lab that uses a DE-ACCM3D chip to measure some form of acceleration. The chip is shown in its case in Figure 9. Past projects have included Figure 9a, an LED tiltmeter, measuring the g force in an elevator or automobile engine (and researching what the forces should be), and Figure 9b, a toy “light sabre” (where the sword changes sounds depending on how quickly and in what direction it is moved), and measuring the g force when a toy Boe-Bot car hits a wall.

Figure 9a: Labview Front Panel / Block Diagram and DE-ACCM3D Chip and Case for Tilt Meter



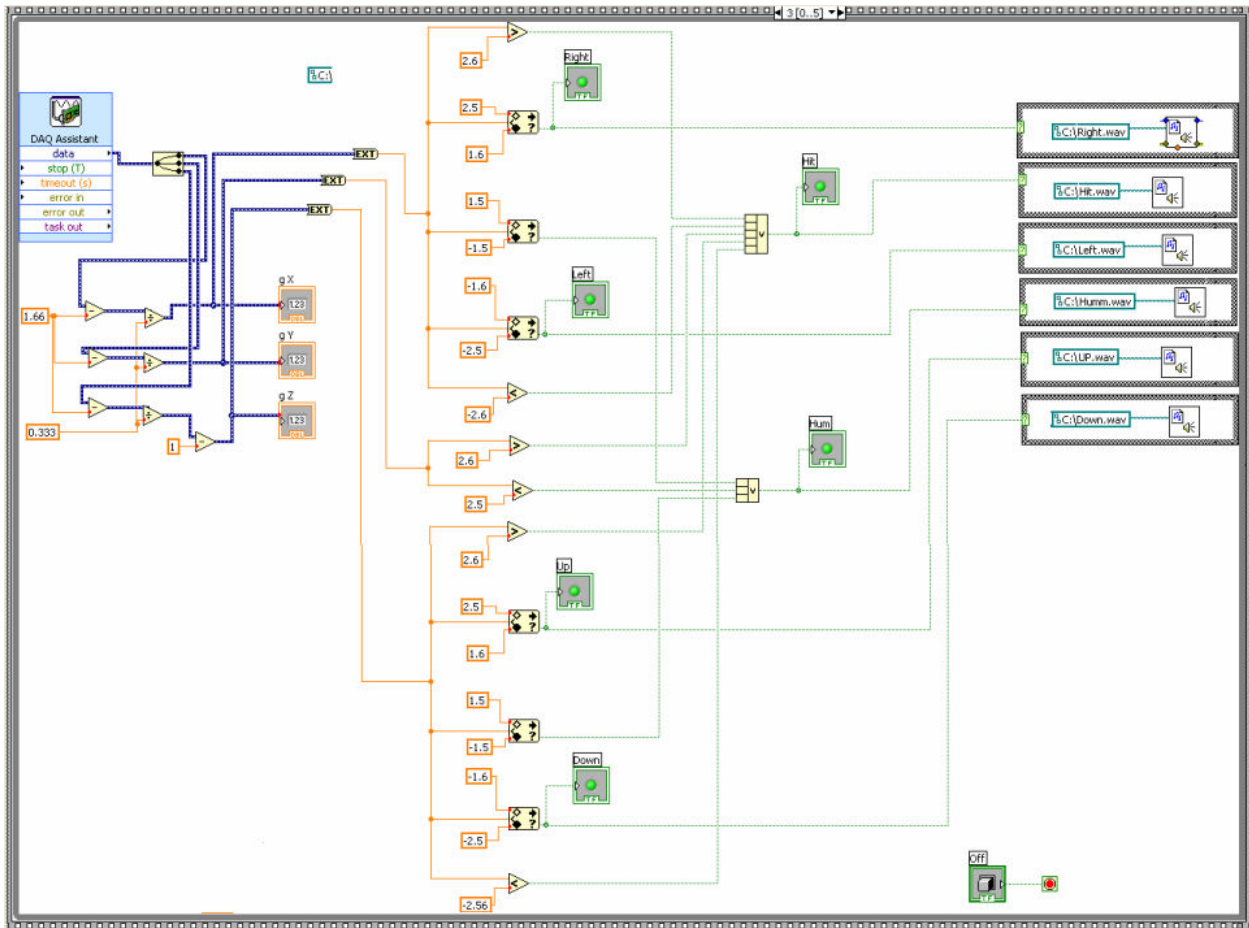


Figure 9b: Labview Front Panel and Block Diagram for Light Sabre Using DE-ACCM3D Chip Attached to Toy Light Sabre

Fluid Discharge Coefficient Lab

ABET Outcomes:

- an ability to conduct, analyze and interpret experiments, and apply experimental results to improve processes
- an ability to identify, analyze, and solve technical problems

Background:

In this lab Labview is used to determine the discharge coefficient for a tank. The tank is provided as part of the lab equipment for the course. A picture of it is shown in Figure 10.



Figure 10: Labview Block Diagram for Fluid Discharge Lab

The time it takes for a tank to drain with a nozzle at the bottom can be found from Equation 1:

$$C_o = \frac{A\sqrt{\frac{2}{g}}}{A_o t} [\sqrt{H_i} - \sqrt{H_f}]$$

Equation 1

where A = the cross sectional area of the tank

A_o = the cross sectional area of the orifice

C_o = the discharge coefficient (normally about .62 for a nozzle)

H_i = initial height in feet

H_f = final height in feet

The discharge coefficient for water in a tank can be estimated to be about .62. Our tank has a nozzle with a valve to start and stop flow. It also has a box at the center with wires that are connected to the upper and lower water sensors. These sensors will provide 5V when water is present. Also a red light comes on when water is on the sensor, a green light when no water is present.

Wire the red and black banana plus to the 6V power supply (red to positive, black to negative).

Wire the remaining wires to the DAQ 6008 card. The pin numbers for the DAQ card are shown on the wires.

Procedure:

1. After connecting the wires, write a VI to read in the state of the lower sensor. This is tied to Pin 1, Digital Input. Pour a small amount of water in the tank and discharge it to change the state of the sensor. Show a Boolean light in Labview that turns off and on, depending on whether or not water is present. Repeat this process for the upper sensor, which is tied to Pin 0, Digital Input.
2. Measure the diameter of the tank and nozzle. Also measure the height of both sensors from the center of the nozzle. Use the information, along with a Co of .62, to calculate the time to discharge from the upper to lower sensor. Write a VI that times how long it takes to discharge from the upper sensor to the lower.
3. Solve the above equation for Co. Revise the VI to display the actual discharge coefficient in Labview, based on the time to discharge from the upper sensor to lower.

Results:

A Labview Block Diagram for the completed fluid discharge lab is shown in Figure 11. Students performing the lab display a discharge coefficient (Co) that is close to .62.

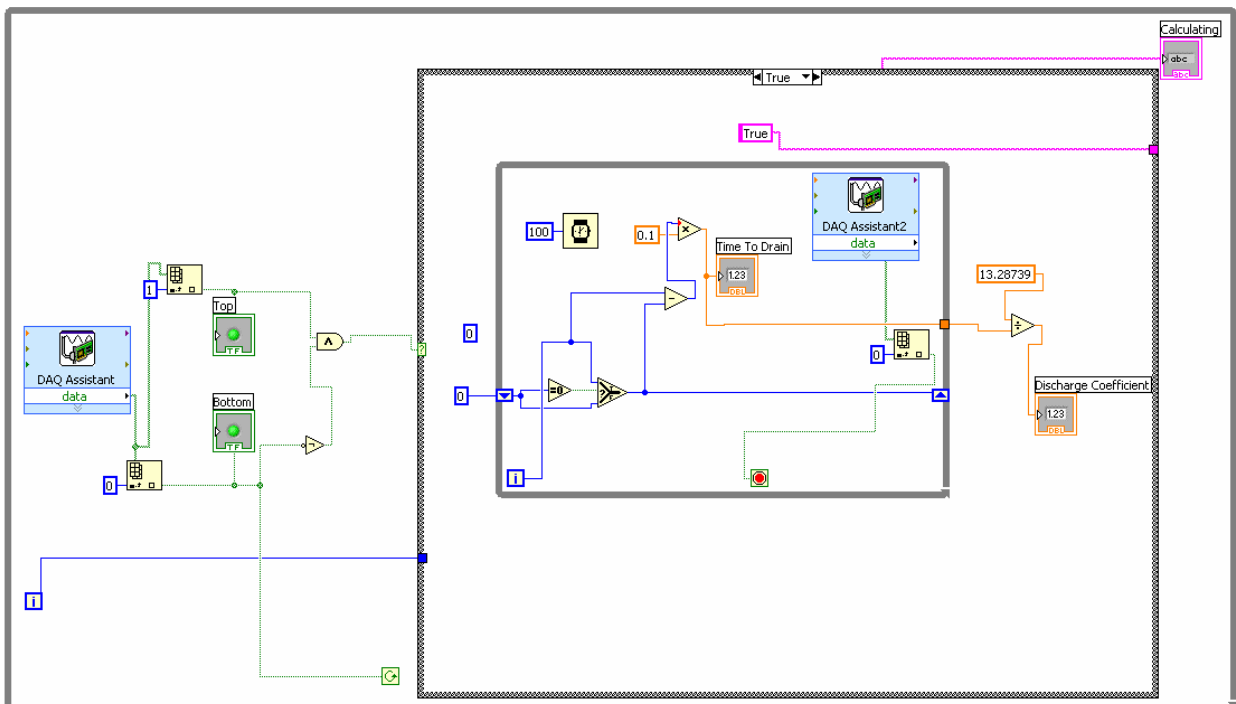


Figure 11: Labview Block Diagram of Fluid Discharge Unit.

Torque Measurement Lab

ABET Outcome: an ability to identify, analyze, and solve technical problems

Equipment:

Motor (with white gear) from the encoder/tach lab.

2 large washers

2 small washers

Wire

Small wood screw

Weights from load cell lab

Ammeter

4.5V power supply

Procedure: A prony brake is often used to measure torque in small motors. A prony brake consists of a pulley and scale. In this lab the prony brake will be constructed with washers and calibrated weights.

1. Locate the DC motor.
2. Measure the radius of the smaller washer in centimeters (there are 2.54 cm in an inch).
3. Arrange the washers on the motor shaft so that the two smaller ones are in between the larger two.
4. Wrap the wire around the inner washers and use the wood screw to attach one end of the wire to the encoder base as shown in the photograph.
5. Attach the empty 50g weight stand to the loose end of the wire.
6. Wire the ammeter in series with the motor and the 4.5V power supply.
7. Turn the power supply on. Record the current and 50 grams. Add more weights and record the current for each addition. The configuration should look like Figure 12.

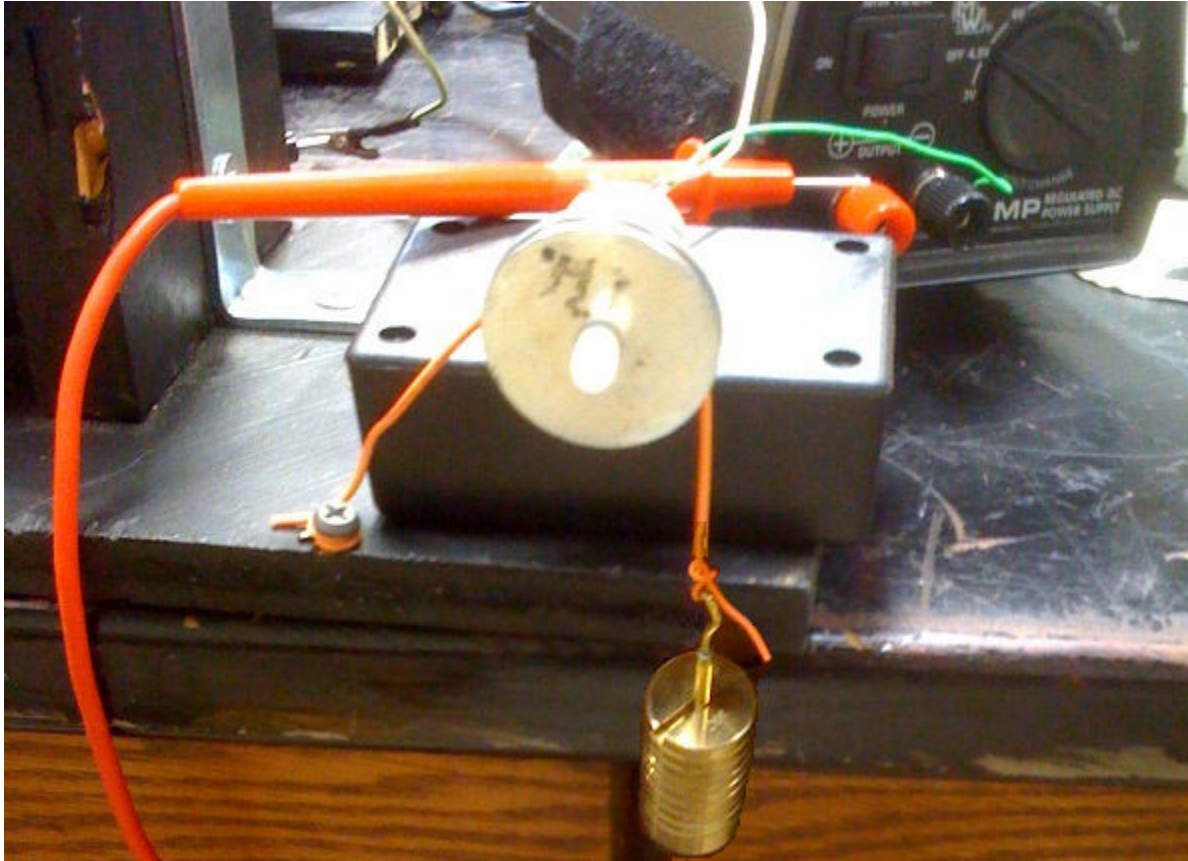


Figure 12: Motor Torque Measurement

8. Use Excel to graph torque on the X axis and current on the Y axis. Multiply the radius of the smaller washer times the weight to get torque in grams-centimeters.

Results:

Rather than using a scale, this lab uses calibrated weights to produce a load on the motor. A sample graph of the current vs. torque for this lab is shown below:

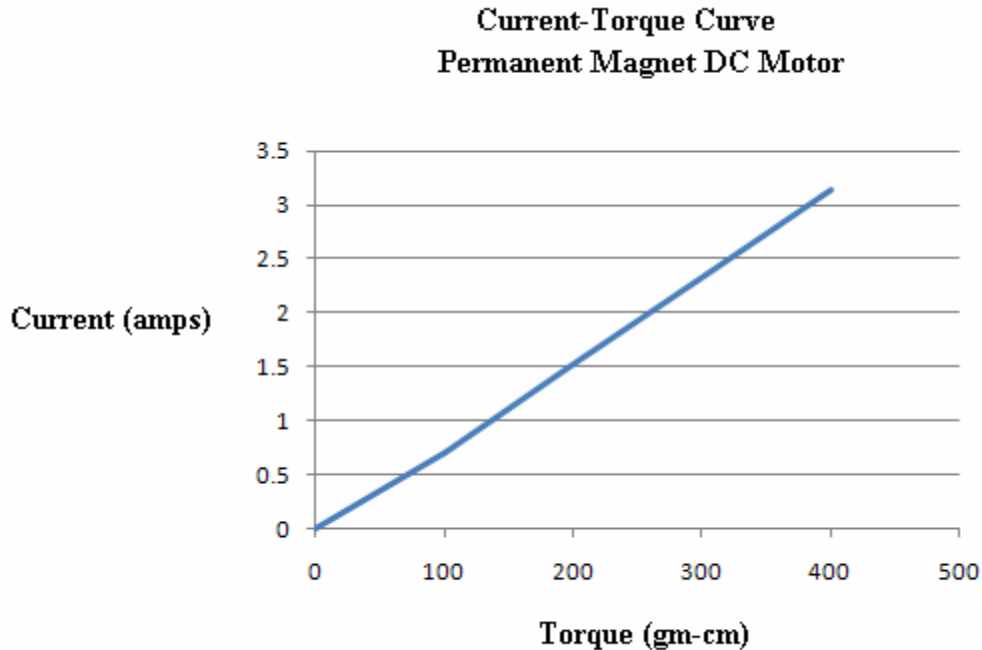


Figure 13: Torque-Current Curve

Results of Reformatted Labs

Students have expressed a strong satisfaction with the mobile labs. In general, engineering technology students want to learn how to design and build equipment. They would much rather build something themselves than only obtain data from existing equipment. The labs described above have also had a great impact on assessment. Figure 14 shows a multi-year assessment of the following TAC/ABET outcomes for the instrumentation and control courses. A summary is below:

- b. an ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering, and technology (Increase from 3.0 in Spring 2006 to 3.5 in Fall 2009).
- c. an ability to conduct, analyze and interpret experiments, and apply experimental results to improve processes (Increase from 3.0 in Spring 2006 to 3.9 in Fall 2009).
- d. an ability to apply creativity in the design of systems, components, or processes appropriate to program educational objectives (Increase from 2.0 in Spring 2006 to 3.9 in Fall 2009).
- f. an ability to identify, analyze, and solve technical problems (Increase from 3.0 in Spring 2006 to 4.0 in Fall 2009).

Note the new lab structure started in Fall 2008. The scores were on a 1 to 4 scale with 4 being excellent. They are an average of individual student performance and instructor evaluation forms. Student evaluations of the course were not included.

Another benefit of the new labs is that students are better able to program and design applications in the Senior Design course. For example, recently a group of electromechanical students programmed an iPhone to interpret a code 39 barcode⁵. This project was done in part for a clean room at a local diabetes drug manufacturer. The students first learned how to program the phone using Objective C. They then used an FFT convolution and gradient directional filter to interpret photos of barcodes. After the barcode was interpreted, the data was sent to a server over a 3G network.

Another Senior Design group is currently designing a computerized LCD display for an electric car that displays critical information such as current draw and battery voltage.

All Senior Design students commented that they could not have done these projects without the solid lab experience they received in the instrumentation, controls, and industrial automation courses.

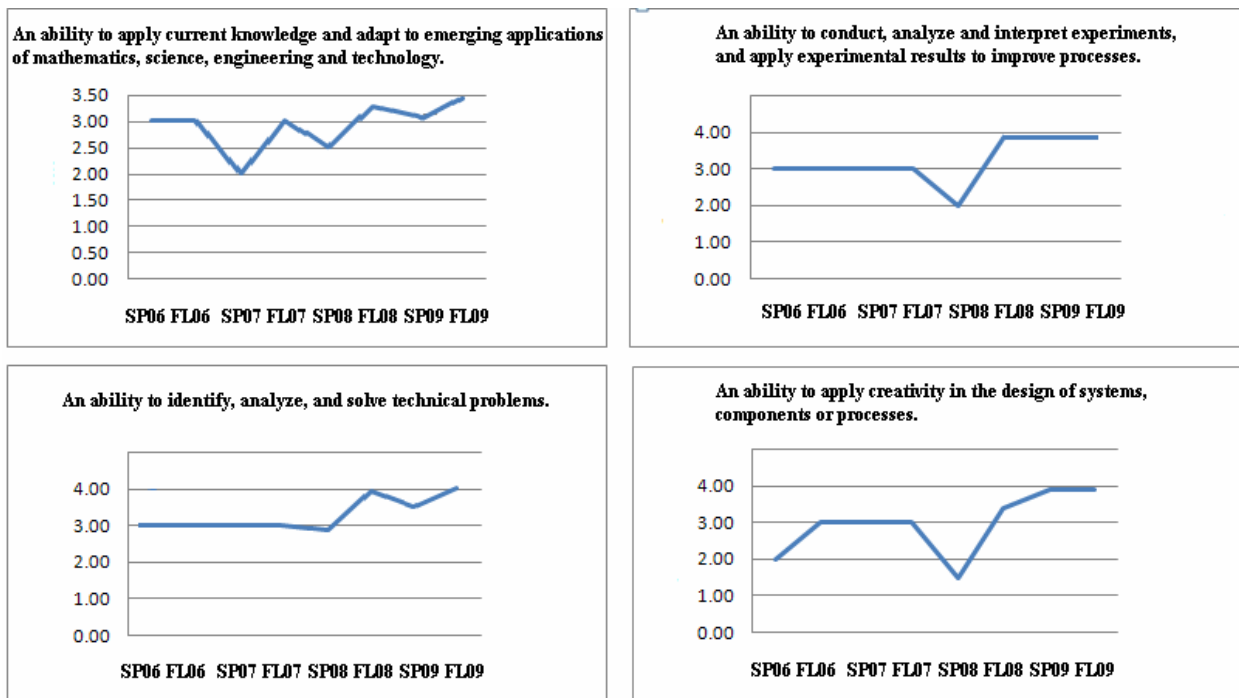


Figure 14: Trend Assessment of Mobile Labs in the Instrumentation Course and Controls Course.

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