# AC 2011-2862: TEACH AND ASSESS AN INSTRUMENTATION AND CONTROL CLASS FOR ELECTRONICS TECHNOLOGY STUDENTS

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## Abstract

McNeese State University is located in the Gulf of Mexico corridor between Houston and New Orleans. The majority of electronics graduates from the Department of Engineering Technology will find their careers in local process plants together with our process technology and instrumentation graduates. The department investigation found out that a lot of electronics students are assigned jobs of instrumentation while being electricians at the same time.  Traditionally, electronics students take electronic classes such as circuit analysis, solid-state devices, amplifiers, computer networking etc. There is a gap between their knowledge to the real-world application in these process plants. To meet the industrial needs, the department designed our curriculum this way:  for electronics students, the focus will be the above-mentioned electronics classes, and add instrumentation classes INST 333 as a mandatory class and INST 304 as an elective one.

This paper presents the courseware and the assessment for the course INST 333: Instrumentation Overview. This course teaches electronics students with the knowledge of control system and instrumentation through the following work:  1) Realizing that the current technology trend is that technicians work more with systems, sub-systems, software, modules, PC boards and so forth, and work less with components and circuits,  so in teaching we seek the connection between the functions of the sub-system instead of putting too much emphasis on the internal structure of components, which they've had some learning in each specific course. 2) Stress how different basic electronic circuits are put together to make instrumentation, and 3) Teach what performance each electronic component needs to make in order to build a successful control system.  At last the assessment method and the result of six years' teaching is given.
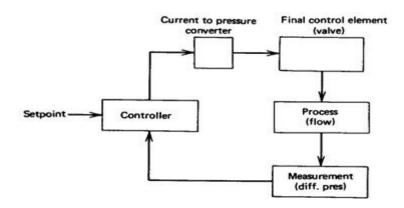
## Introduction

The same as any other electronics engineering technology programs, the EET in McNeese State University requires students to take appropriate amount of electronics classes, which is 71 hours out of 128 total required hours. Of these classes the majorities are basic topics such as circuit analysis, electronic devices that introduces semiconductors, amplifiers, digital electronics, networking, and some basic microcontroller and programming classes. Advanced topics include microcontrollers, advanced electronic measurement techniques, PLDs, etc.  These classes provide students knowledge on the concepts, principles, techniques of individual electronic devices, i.e. at the component/single function level, but not the application and system level. McNeese State University is located in the Gulf of Mexico corridor between Houston and New Orleans. This special location, with abundant oil and natural gas resources, makes Lake Charles a center of multinational petrochemical and refinery industries, manufacturing, and an established aviation refurbishing facility. We have process plants such as PPG , ConocoPhillips, Citgo Petroleum Corporations, Shaw Group manufacturing facility, Dupont, Cheveron and many other smaller plants sprawling around on the land and offshore.

The majority of electronics graduates from the Department of Engineering Technology will find their careers in local process plants together with our process technology and instrumentation graduates. The department has been doing investigation for years and found out that a lot of electronics students are assigned jobs of instrumentation while being electricians at the same time. All the electronics principles that are learnt in college will find their final applications in local industry in the format of industrial electronics, instrumentation, or any other process devices that serve as part of a process control system. As already mentioned, traditionally electronics students take electronic classes at an individual component level which focuses on electronic devices themselves, rather than focus on application or system level. This causes a gap between their knowledge to the real-world application in these process plants. To meet the industrial needs, the department designed our curriculum this way: for electronics students, the focus will be the above-mentioned electronics classes, and add instrumentation classes INST 333 and INST 304 as an elective one. Later on as more dialogues between our program and industry went on, INST 333 became a mandatory class for non-instrumentation major students.

The catalog description for INST 333 is: Instrumentation Overview. Process control instrument system used as methods of measurement and control in industry. It is a 4-hour course with 3-hour lecture and 2.5- hour lab per week. The textbook is "Process Control Instrumentation Technology" by Curtis Johnson. The textbook covers everything that constitutes a process control system, from measurement to signal conditioning, to controller, final control elements and processes. The information amount is huge and it is good for a 2-semester teaching if everything is included.

**Course Structure Development**

Figure 1 is the familiar process control system block diagram[1]. While the figure uses flow as an example, this block diagram applies to all other process variable such as temperature, pressure, level and etc. Not like that engineers perform mathematical analysis for blocks, our graduates will work with real devices that locate at a certain node in the control loop. Therefore, the goal of this course is designed to make electronics students understand how electronics are applied in process control instrumentation in order to better meet the local industry expectation. It consists of the learning of each component of a typical process control system, their interfaces, and combinations.

Figure 1 A typical Process Control System

The difficulties in teaching the course are:

1) Each block consists of complicated sub-functions, how to select topics that should be covered in one semester so that the students gain the knowledge of that certain block while will not be buried by the huge amount of details and still realize the overall image of the system?

2) The course was taught by different teachers since it was first added to the curriculum. We always had strong association with industries but in earlier years the format was not so specific and detailed. The course was designed according to convention, how most other people do it and according to instructor's personal expertise. For example, a teacher who had been working on measurements of different process variables chose to teach all sensors including different types of thermal, displacement, position, motion, pressure, flow and optical sensors. A different substitute teacher chose to teach all topics about motors. They still introduced some basic concepts about process control system, however, the author and the department think the course can benefit students more if the courseware is redesigned at a different level. There is a need to change the existing courseware and establish a comparatively fixed pattern. Laboratory needs to be changed to match up the course contents and teaching philosophy.

To resolve the above difficulties, we examined the diagram of a typical control system as in Figure 1. Every block in the system consists of multiple sub-functions depending on how detailed you want to draw it. For example, Figure 2 shows the complicated combination of a "measurement" block. The other blocks have the same situation.

Primary sensor + analog signal conditioning (bridge, voltage divider, filter, amplifier, variable converters, etc.)+digital signal conditioning (sample-and-hold circuit, ADC, multiplexer etc.)

Figure 2 Functions of a block in control loop

Expected problems in analyzing or troubleshooting a system include range, accuracy, linearity, timing, power, loading effect, so on and so forth. A typical unexpected problem is: when everything seems correct by calculation, the system does not work when devices are put together. How to take in account all of these aspects in the course?

After examing every block in the diagram, we decided that we re-design the courseware from 2 aspects: 1) bring in more applications to each component. 2) seek the connections between the functions and change the course level from the previous component-level to system-level. More

blocks and signal paths, less schematics. The course will teach a few representative components for each block and will focus on their input/output, their interface and application. For example, there are three chapters in the textbook that talk about thermal sensors, mechanical sensors and optical sensors. In each chapter there are more smaller categories. We decide only teach thermal sensors that include RTD, thermistor and thermocouple because temperature is the most commonly used process variable. Other process variable measurement is taught in INST 101 and INST 102. Instead of just teaching the principles of each thermal sensor, we stress where input signals are coming from, what kind of output signals will the same input quantity converted to, after that where are the output signal going? How can we make our computer access the physical quantity change? The more specific objectives and described them as "Body of Knowledge" that is posted in the college website as shown in Figure 3. The "Body of Knowledge" is written according to the state and ABET TAC requirements.

**The Laboratory**

There could be many different lab designs to implement the same body of knowledge as shown. The lab design should also complement with our course objective and topics, i.e., more applications and system level. If you ask a student what a bridge is and how it works, he may be able to draw a schematic and calculate the offset voltage given the formula. If you ask students how we should use it in a process control system most of the time they have no clue about it. The same thing happened to other components such as op amps, sensors, motors, and etc. As we already stressed, knowing the structure of a small circuit, how to calculate the output given the input and the formula, is far not sufficient for the applications in the real world control loop.

First we checked the labs that come with the textbook. These experiments are good in a general sense to reinforce the concepts and the calculation for individual device. However, for the reason that is already been stated, we need to change. The searching from the internet gave the similar results as well. For example, searching bridge circuit lab, you will get most experiments that change the arm resistance and measure the offset voltage, then students will see how the offset voltage varies over the input resistance as a dependent variable[3,4]. Only very few add physical quantity measurements such as adding a thermister. However, they did not point out the use of this circuit in a signal conditioning function and a process control loop. Also the author posted message in technology listserve to ask for the inputs about how other colleagues using the same textbook do. Dr. Julio Garcia's in San Jose State University uses a project similar to Capstone as in Figure 4.

It would be the best way to train students if they can design and complete a small but including-everything project after finishing the class. The difficulty here is that they still have to follow through the course and pass the tests in one semester, by attending the lectures, and finishing homework which tests basic concepts and calculation. The time is not enough for them to

# Body of Knowledge

- Explain the principle of a process control system; draw a block diagram of a process control loop and identify each element.
- Define parameters in a process control system and give practical examples.
- Describe three criteria to evaluate the performance of a process control loop.
- Recognize the common P&ID symbols and read the diagrams. Draw the block diagrams from a P&I diagram and describe the system work strategy.
- Observe and record a process response, and draw a typical first-order time response curve, calculate the output value at different times.
- Explain different devices and functions of analog/digital signal conditioning circuits, perform calculation in a linear relationship of data representation.
- Design a Wheatstone bridge to convert a process variable change to voltage change under different application.
- Design low-pass and high-pass filter circuits to eliminate unwanted noises based on application requirements.
- Draw schematics of four common op amp circuits and provide the transfer functions. Develop I/O equation for process variable conversion to a proper format of electrical quantity and design op amp circuits that can implement this.
- Design an analog signal conditioning system to convert an input range of voltages to some desired output range of voltage.
- Design an analog signal conditioning system so that some input range of resistance variation is converted into a desired output range of voltage variation.
- Develop Boolean equations for a multivariable system and implement it using logic circuits.
- Design an application of comparator for different process variable alarm system.
- Calculate the input/output, reference voltage, resolution of a DAC/ADC.
- Design interface between a sensor and ADC, and between a controller and DAC.
- Describe the principle of different temperature sensors (RTD, thermistor, thermocouple and others). Calculate a sensor's output using formula or tables.
- Design the application of an RTD/thermistor/ thermocouple to specific problems in temperature measurement.
- Define different parts of final control element and their functions.
- Explain the basic principles of the pneumatic nozzle/flapper system/valve and calculate input/output for signal conversion.
- Power electronics and calculation.
- Determine the control valve size.
- Calculate how much a certain controller output changes the process variables.
- Define process load, process lag, self-regulation and other process concepts.
- Describe two-position, floating control mode, P, I, D, PI, PD and PID control mode.
- Calculate the controller output of different control modes and find proper control modes for different applications.

Figure 3 Body of Knowledge for INST 333

> Design the electronic system that meets the following criteria:
> 1.      The input varies from -1.2V to +3.8V
> 2.      Convert the input signal to an output varying from 0 to +10V
> 3.      When the output signal is only 0V, a sound alarm will be activated
> … …
> 8. When the output signal reaches 10V, a triangle-wave signal will be generated.
> 14. Study your design, test it thoroughly.

Figure 4 A sample course project

complete a full project. Dr. Julio Garcia's project does not include everything in a control loop yet. If everything is put in, it will take more time.

For each experiment that teaches the small electronic circuit, the author expanded it to include more possible inputs or outputs. For bridge circuit, include a RTD or other sensors that output resistance variety. The students will first select a convenient null resistance value in order to measure a certain temperature range. Then use RTD output equation $R(T)=R(T_0)[1+\alpha_0\Delta T]$ and the voltage offset from the bridge to figure out say body temperature or any other temperature they like to measure. Then ask them to design the interface to the next stage circuit. This way students can appreciate the real application of the bridge circuit.

Another example is temperature sensor. Instead of just measuring the output signals from a temperature sensor such as a resistance or a voltage, we connect the output to a transmitter (for example, Rosemount 3244 temperature transmitter), and study the relationship between the temperature change and the usable output signal from transmitter. Then connect transmitter output to some other devices for better understanding of the signal path and system.

The last lab is to use Honeywell TDC 3000 system to control water temperature in a flask. Figure 5 shows the input/output cabinet of the system before any connection. The industrial people came to help setup the whole system and the teacher did a lot of system configuration for the lab in order that students can focus on the system function part. Students do wiring and some parameter adjustment. The process, controller and wiring part are not shown. Room temperature water is being pumped into the flask as the manipulated variable and ice water is being pumped in as disturbance variable. A thermocouple is first used as the primary sensor. Students are asked to replace the sensor with other type and connect the sensor to proper input module and slot of the Honeywell system. Also they need to calibrate the system to accept the signal accordingly. The process, controller (workstation) and the cabinet are located far from each other and students witnessed a miniature field operation and control. It is an old system donated by the company (even though it is still used in Citgo, Exxon and some other plants) but using it students

experienced almost every aspect in a fluid temperature control. If we have more time, we can change the process to flow rate or level.



Figure 5 Honeywell TDC 3000 system LCN cabinets

## Pedagogy

As electronics graduates, students need to know how a specific circuit works, what is a Wheatstone Bridge, a noise filter, an op-amp and many other circuits of certain functions. As instrumentation technicians in process plants, they also need to understand that the majority of the electronics in this area works to serve the whole control system, and need to stand at a higher position to look down on the big picture of a control system. When one subsystem in a process control system needs troubleshooting, nowadays the technician usually don't need to go down to component level such as to find if a resistance in a bridge is off from its nominal value or a wire between a capacitor and a resistor is broken. Instead, what they need to do is, which function block malfunctions, determine which board/card to fix/replace, or if any software parameter is set wrong. Under this scenario they should know what signals come into a board, do they really come with a proper value and what kind of tool we can use to detect them? Know what the output of this board is and where it is going to? Does the signal really reach the next function block with proper value and polarity?

The author's thoughts about changing courseware to more system level coincidently agrees with a group of electronics people who are advocating revitalizing electronic programs by changing

the program from traditional component level to system level[5]. They are from NetWorks which is an NSF-funded ATE Resource Center (Grant #0702753) supporting faculty in semiconductor, automated manufacturing, and electronics education. They state that technicians work less with components and circuits and more with ICs, modules, PC boards, sub-assemblies and complete pieces of equipment. Technicians spend their time on testing, measuring, installing, troubleshooting, servicing, repairing, calibrating, and operating at the systems level. They suggested some steps to change the program:

- Examined current technician needs in industry and validated their duties and tasks.

- Determined that most courses still focused on discrete components and circuits and less on ICs and larger systems elements.

- Determined that techs work with systems and sub-systems and less with circuits.

- Create a revised curriculum that uses the same course framework but adds a systems approach more in keeping with the real world.

- Adopt a stronger relationship with industry in your area. Seek their input and guidance. Survey job needs.

Even they did not discuss process control system, the author thinks that process control systems is the field where the change to system level for electronics program should carry out most necessarily because of the nature of the process control and how electronics are used there. In one word, less to the component level, more system troubleshooting, measurement, test and etc.

**Assessment**

The way to design the courseware connects and integrates topics that are taught in previous electronic and instrumentation courses, therefore the course deepens students' understandings and enhances their ability to tackle practical problems. They know what to look for at each part of a control loop and become more efficient to troubleshoot. It is very hard to evaluate the above statements. We did two things as a course-level assessment.

The first is a pre-course and end-of-course investigation. There are five different levels of understanding. If they understand an item thoroughly, they choose "Strongly agree". If they don't understand at all, they choose "Strongly disagree" Some example questions are like:

- I know the principles/functions/calculations of bridge, filter, and OP-Amp circuit.

- I know the application of the above components and how they interact with other components in a process control system.

- I know the function and components of different types of analog/digital signal conditioning techniques.

For pre-course survey, the result is that most of the students know the basic concepts, the principles, but not the applications or interface, they don't know that all of those small circuits are part of signal conditioning and where they are located in a process loop, they don't know how to select bridge parameters in a signal conditioning sub-system. For the end-of-course survey, 85% and above of the answers shifted from "Strongly disagree" or "Disagree" to "Agree" or "Strongly agree".

Another way to assess and improve is that the survey listed the experiment titles that have been done in the whole semester and asked students to select what are the two experiments that they think are the most helpful for them to expand or deepen their knowledge mastery, enhance their analyzing or troubleshooting skill. Also ask them to select two labs that they think need to improve and give some suggestions to change. All of the students selected Honeywell system as the most helpful. It is within the expectation because that is a real world control system and they did go through every node in a control loop. The other two most selected helpful experiments are bridge and control system response to setpoint change. The reason is that to study the system response to setpoint change motivates them to think how electronics are used in a control system.

Also the department keeps investigating local industry about our graduates' quality. We change our investigation questions according to our curriculum and courseware change and get the feedback to see if the change will really help industry.

**Conclusion**

Always talk to industry about what they anticipate in order to adjust our curriculum updated and needed because no engineering technology program can survive by just teaching on campus. But we cannot always listen to them since most of technicians or technologists have been working on a specific area of one section of industry for years and may not be able to recognize the importance of possessing higher and global level knowledge. We believe that the course design helps students career efficacy and local industry significantly by providing students systematic view and helping them think further and wider than small circuit areas.

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