Session 1566

Teaching Controls With PLCs

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Abstract:

In industrial practice it is much more common to control a process using logical control for discrete on/off states. As a result most industrial equipment designs use Programmable Logic Controllers (PLCs). These controllers support multiple control schemes such as Boolean logical control, sequential logic control, structured programming, linear controls, graphical interfaces, fuzzy logic, etc.

A majority of engineering students are taught control of continuous systems using linear control theory. These courses often include topics such as step response and design of lead/lag controllers. In terms of the pedagogy, linear controls are less desirable for the mechanical engineering students because they are very difficult to implement in actual designs. The linear approach makes more sense for electrical engineering students who are familiar with the mathematical tools, and can implement the control system easily with common electronic components.

This paper will describe a course, EGR 450 - Manufacturing Control Systems. The course includes lectures, laboratories and a project. This course uses rigorous design techniques and theoretical methods to teach industrial control to junior and senior engineering students. Topics include the design of basic combinatorial logic, sequential and state based logic, sensors and interfacing, communications and networking, analog I/O and PID control. This course has been very well received by students and local manufacturers.

1.0 Introduction

For the last few decades, engineering students have primarily learned control using linear con-trol theory. These techniques are rich mathematically, but far removed from common practice. This approach is not beneficial for the majority of our students who will graduate with a Bachelors degree and enter industry. This is not to say that they will not encounter linear controls, but they will encounter logical control systems. Industries are desperate for engineers capable of dealing with real controls systems for day-to-day equipment. This has been recognized by the SME (Society of Manufacturing Engineers) Education Foundation Report[7] that lists significant industry needs, including knowledge of physical control of machinery including CNC (Computer Numerical Control), PLCs, sensors, etc.

For the benefit of our students, and in light of newer developments such as ABET 2000, we should be considering how we can make our controls courses more responsive to our 'customers' needs. Control courses that came into existence before many recent developments need to be re-examined to help us fulfill our mission as engineering educators. We can do this by teaching theory and methods that are applicable to the industrial problems our graduates are likely to encounter.

Common engineering control problems can be broken into the categories listed below. Most control systems contain more than one of these models.

- Continuous Linear - these systems can be described with linear differential equations and exact equations can be used to design controllers.
- Continuous Non-linear - these systems can be described with differential equations that are non-linear and the controllers can be designed with some effort. In some systems differential equations are not available forcing reliance on other methods, such as heuristic rules.
- Non-continuous - these systems have discrete states and are characterized with on/off transitions of inputs and outputs. Logical decisions are required to control the system.

Consider the example of an elevator - the elevator itself requires continuous controls for the height of the elevator, but logical controls for selecting floors and opening/closing doors. All of these systems are implemented primarily with electrical components and software. The elevator also has discrete mechanical systems to brake the elevator cable if the speed/acceleration becomes too high. This by itself makes a good case for linear controls. But, to manufacture the elevator thousands of processes will be required. The production equipment will be controlled by a PLC or a dedicated logical controller. For every engineer engaged in the design of the linear controller there will be many more involved in the design of logical controllers for the manufacturing equipment.

One of the main problems for teaching linear controls is the lack of good design implementations. In electrical and computer based systems, linear controllers are relatively easy to develop. But in mechanical systems these become much more difficult to implement. For example, consider that simple aerodynamic drag leads to non-linearities. Examples of components and implementations for different disciplines are shown in Table 1.

Consider the components shown in Table 1. Components in the electrical column are thoroughly taught in any electrical engineering curriculum. This means that a linear controls course for electrical engineering students is well positioned to build upon other electrical engineering courses. When an electrical engineering student is done a linear controls course they are ready to build controls systems. The same cannot be said for mechanical systems where the mechanical components are often taught, but are rarely used in mechanical and manufacturing control courses. Their use is also rapidly diminishing for use in controlling actual systems.

Linear and Logical control courses can be compared, as shown in table 2 below.

Table 1 - Control System Components Suitable for Various Engineering Disciplines

	DISCIPLINE		
	Mechanical	Electrical	Computer
Continuous Linear	Springs, dampers	resistors, capacitors, linear amplifiers	z-transforms and analog I/O
Continuous Non-linear	cams, linkages, aerodynamic drag	diodes, transistors	analog I/O with fuzzy logic, MRAC
Discontinuous	latches, escapements, ratchets, air-logic	Boolean logic and gates, flip-flops	analog or discrete I/O with program

Table 2 - A Comparison of Linear and Logical Controls Courses

Differences	Linear Controls	Logical Controls
Pedagogy		
Uses theoretical techniques	High	Medium
Lab hardware availability	Medium	High
Cost per lab station per term	$2000 and up	$500 and up
Outcomes		
Desired by graduate schools	High	Low
Desired by manufacturers	Low	High
Desired by product designers	Medium	High
Desired by students	Medium	High
Prerequisites		
Mathematics	High	Low
Electrical	Medium	Medium
Mechanical	Medium	Low
Computers	Medium	Medium

As given, Table 2 shows that the main pedagogical advantages of a linear controls course is that it exercises mathematical theory and analysis, and helps prepare students for graduate schools. But, because of the prerequisites it must be placed later in the curriculum. The cost for a linear controls course is often higher because of the required instrumentation.

There have been a variety of factors that have hindered the adoption of PLCs. Many faculty who have not designed industrial controls lately are unaware of what PLCs can do. They are also unaware of capabilities that have been added in the last two decades. The original use of PLCs in the 1970s were as relay replacers. Modern PLCs are quite sophisticated, and can give access to complex computational functions. This perception is changing quickly as PLCs are finding their way into research publications[4].

The Padnos School of Engineering at Grand Valley State University has a clear mission to support the local community. One of the clear messages from local companies was a need for PLC experience. This need was satisfied with the introduction of a PLC oriented controls course, EGR 450 - Manufacturing Control Systems, in 1997. To date the course has been offered four times and is now well tuned to prepare students to use PLCs as controllers in an engineering capacity.

2.0 Continuous Controls Courses

Almost all continuous controls courses begin with basic linear controls. This form of controls course is well established at most engineering schools. Topics found in traditional controls courses include;

- basic system modeling
- laplace transforms and their use in problem solving
- first/second order systems
- bode plots, initial/final value theorems
- responses to step, ramp and other functions
- standard controller forms (PID, lead-lag, etc.)
- root locus plots to evaluate stability
- advanced topics include nichols charts, etc.

Laboratories for these courses typically focus on system modeling, as opposed to system control. These courses rarely support projects that involve practical implementation. It is unusual to find other subsequent courses, except in electrical engineering, that go on to investigate topics such as non-linear control.

3.0 PLC Capabilities

PLCs are controllers that can be purchased off the shelf at many local industrial supply companies, or ordered from catalogs. The range of controllers is wide, and starts with low cost systems starting at $200 and going up to many thousands.

Most modern controllers have core sets of functions and capabilities. The size and cost of a controller is dependant upon their interface options. Some of the basic interface types are listed in general order of importance below.

- basic AC/DC inputs and outputs at voltages from 10VDC up to 220VAC
- connection to data devices (RS-232, RS-422, ethernet, etc.)
- high speed counters/timers
- analog I/O
- direct control of motors (servo motors, stepper motors)
- direct reading of sensors (such as thermocouples)
- direct human interfaces (HMIs, etc.)

The major benefit of a PLC is the ability to program. The following programming capabilities are provided by most PLCs.

- Basic programming functions
    - basic logical comparison
    - timers and counters
    - latches

- Advanced programming functions
    - math (floating point and integers)
    - ability to work in a variety of number systems (decimal, binary, octal, hexadecmial, BCD)
    - FIFO/LIFO stacks, shift registers, sequencers
    - program control (subroutines, branching, looping)
    - conditional statements
    - string manipulation

- Advanced computational features
    - interrupt driven processes (a program only runs when an event occurs)
    - fault driven processes (eg. a program only run when there is a divide by 0)
    - processor status (such as overflow, last scan time, etc.)

PLCs also provide many alternative programming styles, these are listed below. These allow the programming method to build upon a wide variety of prior programming experiences.

- Instruction List (IL) - looks like assembly language
- Ladder Diagram (LD) - looks like traditional electrical ladder diagrams
- Structured Text (ST) - looks like traditional programming languages (eg. BASIC)
- Sequential Function Charts (SFC) - a diagramming method that allows concurrent processes
- Function Block (FB) - this allows dataflow programming methods (similar to Labview)

With the right hardware and software more advanced topics can be supported with PLCs. This can make it possible to use the PLC for linear controls, non linear controls, networking, etc. For example a PID controller can be developed using an encoder input card on the PLC and an analog output to a motor amplifier. The PID calculation is built into most PLCs.

- PID control
- Networking
- Fuzzy logic

A reasonable controls course is able to cover all of the basics and half of the advanced topics listed.

4.0 A Logical Controls Course

Logical controls courses are taught at various institutions. They are most commonly taught at an introductory level to community college students in technology programs. In engineering programs it is uncommon to find a course that focusses only on PLCs, they are often a topic within automated/integrated manufacturing systems courses. High quality texts that can support introductory PLC courses are available[2,5,6,8,9] and these can support higher level courses with supplementary material. Other high quality texts are available that discuss integrated manufacturing systems with chapters on PLCs[1,3]. You can find an example of a complete logical controls system course at http://claymore.engineer.gvsu.edu/eod/egr450.html.

At Grand Valley State University we designed a logical controls course entitled EGR450 - Manufacturing Control Systems. This course was meant to provide skills that would make the students knowledgeable and capable with industrial control systems. The desired outcome is that student be capable of conducting a good engineering design of a logical control system. At present many of our graduates are doing this work at local companies. EGR450 is required for students in Manufacturing Engineering (typically 5-10 students). It is an elective for mechanical and electrical students (about 40 total), and it is typically taken by 35 of the 40.

In the design of such a course care is needed to present the material at an engineering level. The general core topics are listed below by week for a 14 week semester. This course can go on to discuss other topics if time permits. Throughout the course topics such as ethics and documentation are continually stressed.

Week	Topic
1	PLC Introduction
	PLC Logic and Connection
	Sensors and Actuators
4	Combinatorial Logic with Boolean Algebra
6	Sequential Logic with State Diagrams and Petri Nets
8	Advanced Data Functions
10	Analog I/O and PID control
12	Data Communications
	Design Issues

Laboratories are an important part of this course. The general sequence is outlined below.

1. Introduction to micro PLCs - tutorial
2. Basic ladder logic design and PLC interfacing - combinatorial stamping press control
3. Intermediate ladder logic design and PLC interfacing - encoder controlled motor
4. Advanced ladder logic design and PLC interfacing - sequential traffic lights
5. Introduction to PLC-5s - tutorial
6. Analog I/O and PID Control of a DC motor
7. PLC Networking and Serial Communications - with DH+ and RS-232C
8. Control of a multistation keytag maker
9. Control of a multistation keytag maker (cont'd)
10. Introduction to embedded controllers
11. Programming embedded controllers

The course concludes with a major project that includes some form of controller, most commonly a PLC. The results of these projects, and the course notes can be seen at http://claymore.engineer.gvsu.edu/eod/egr450.html

5.0 Conclusion

EGR 450 replaced a previous linear controls course, EGR 455 - Automatic Controls, that was never highly regarded. The success of EGR 450 was overwhelming, and it continues to be the most popular senior elective for all disciplines. EGR 450 also serves as an excellent prerequisite for EGR 474 - Integrated Manufacturing System which discusses the design and implementation of fully integrated manufacturing facilities.

Indicators of the success of this course are clear. Of the 12 senior capstone projects conducted during the 1998-9 year, only three did not use a PLC for some form of control. Many prospective employers visit Grand Valley specifically to hire students with PLC design skills.

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