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Implementing a Distributed Process Control System in a Unit Operations Laboratory

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Implementing a Distributed Process Control System in a Student Unit Operations Laboratory

Abstract

As part of the renovation and relocation project for the Unit Operations Laboratory at the University of Illinois, a commercial distributed process control system (DCS) was incorporated into the facility. The purpose of the system is both to provide process control functions for the unit operation experiments and to introduce students to the equipment and instrumentation that comprise a modern control system. While the benefits of having a DCS system have long been recognized, the maintenance and cost of an advanced control system have been a significant deterrent to its effective inclusion in many student laboratories. This paper discusses the evaluation procedure that we used to identify the type of control system that would be best for a student laboratory, the management, operational, and maintenance activities necessary in order to use the system effectively, and the educational objectives we hope to achieve.

Secondly, this paper will present our approach for utilizing the capabilities of a DCS in a quantitative and time-effective manner. In particular, this paper will present our approach for providing students experience working with a modern control system and with process control experiments.

Introduction

Incorporating a distributed control system (DCS) into a student unit operations laboratory is often a key objective of chemical engineering departments. Nonetheless, this is a decision that requires careful thought, as there are several issues that need to be considered. Prominent among these are the cost of a commercial DCS system and the benefits that such a system may provide to students. To fully realize the benefits of a DCS, one must be familiar with the educational objectives of the courses in which the system will be implemented.

In the first part of this paper, we will discuss our reasons for choosing a commercial Distributed Control System for our Unit Operations Lab and the necessary operational and maintenance activities required to fully utilize the capabilities of such a system in a student laboratory. We will then follow-up this discussion with our approach to achieving the educational objectives of a DCS in both the Laboratory and Process Control courses.

At the University of Illinois Urbana-Champaign, the driver for considering a DCS was a recent renovation and relocation of the Chemical Engineering Unit Operations Laboratory. A part of this effort involved evaluating the types of experiments and experiences that would be most beneficial to students. Of primary concern in our evaluation was the long-standing feedback from both students and employers that the curriculum should include more practical, hands-on experiences for students. It has long been debated how to weigh the benefits of providing students with the required theoretical foundations of science and chemical engineering against a better introduction to the practical and experimental factors of engineering, within the constraints of the allowable credit hours for a four-year program. The objective of a university should be, and must be, to provide the theoretical, mathematical, and modeling foundations of the profession. However, the need to provide students with the more practical and empirical aspects of the profession cannot be overlooked.

In this debate of theory versus practice, both the unit operations laboratory and the senior-year design course play a central role. A principal objective of these courses is to transition students from a structured, textbook analysis of the unit operations in chemical engineering to an analysis of open-ended problems that better reflect what might be encountered in industry. As such, the emphasis of the classes changes from one of theory, derivations, and examples to independent study and investigation, the application of engineering analysis, and the communication of results. Instead of small, well-defined homework problems that attempt to illustrate specific examples of theory or a solution method, there are engineering problems that are broader and open-ended. What these two senior-level courses try to do is to teach a new engineer how to approach a problem and how to develop a pathway to a solution. The development of a solution requires that one applies the engineering skills and analysis methods that have been learned in prior classes. Nevertheless, these must be teaching courses in that, just as in a standard course, the application of chemical engineering models must be reviewed and reinforced. Furthermore, in a laboratory course, students must be encouraged to explore the proper and safe use and operation of equipment.

One of our first efforts in improving the unit operations laboratory was reaffirming the role of the laboratory in the curriculum. We felt that there was substantial benefit in retaining the traditional unit operations experiments as they directly reinforce many of the theoretical concepts and models that comprise the chemical engineering profession. As such, the laboratory retains experiments in flash separation, fluid flow, distillation, absorption, heat exchange, drying, chemical kinetics, and bioengineering. However, there was also a desire to broaden the scope of the lab to better incorporate a few of the newer aspects of the profession. This includes experiments focused on topics such as rheology, surface science, and solid-state physics as well as experiments in process control and circuit analysis.

Once the educational objectives were established, we then undertook a careful evaluation of the process control system that we would want to use in a student laboratory. In other words, which approach to process control best aligns with the educational objectives of the program? This is not a simple question, and the choice between various options is never entirely clear; the answer will be institutional specific.

A number of papers in the literature describe the use of a commercial process control system in a student laboratory, but do not clearly address the reasons for choosing such a system [1] – [3]. Many different approaches to demonstrating or incorporating process control in a laboratory are possible. Using a distributed control system (DCS) is just one option from many.

In our analysis, we considered the following questions to determine which control system best aligns with our educational goals and needs. First, what type of control system might be most meaningful to students and provide an introduction to industrial practices? Second, what is the total cost of the system? Certain systems may have higher up-front costs but can save money in the long run because they require less on-going maintenance and are less likely to become obsolete. Another aspect of a system's cost is the personnel required to maintain and update it.

There must be adequate instructor interest and time to prevent the system from becoming poorly used.

There are three main ways of implementing control systems. The first is to purchase the control system that is often packaged with a unit operations experiment sold by manufacturers. The second is to develop control systems in-house using microcontrollers. The final way is to purchase a commercially available control system like those used in industrial applications.

Although there are many types of control systems and software programs available – most of which are powerful and have interesting features – every software and hardware system requires both time and effort to master. One must learn the features and structure of the software, the wiring and instrumentation, and the underlying theoretical framework of the control system. As a result, given the limited lab time available to a student, it is important that learning how to use the system and mastering its capabilities be done efficiently. While many companies offer control systems packaged with standalone, pre-designed experiments, these systems often vary wildly in their wiring and software function. In addition, the control hardware and wiring are often hidden away and poorly documented. This makes it difficult for students (and instructors) to understand and properly use these standalone systems or to make any changes to the system. Having a common, well-developed hardware and software system across all experiments, as is available with a commercial control system, will simplify both instructional effort and student learning. Furthermore, using a commercial system will give students hands-on experience with an industrially relevant system.

It is also important to balance the initial cost of a control system with the maintenance and upkeep of the system. While a commercial control system is initially much more expensive than a system developed in-house, the maintenance of an in-house system is more difficult. Turnover in laboratory personnel as well as decreasing instructor interest can quickly turn a system into one that is only minimally used or that becomes a 'black box'. This issue is compounded by the fact that in-house systems often have multiple control features or designs that were developed over time and that may function in slightly different ways or become obsolete. In this regard, a commercially supported system has the advantage because of good documentation and vendor support, as well as design features that are common across a range of manufacturers. Furthermore, commercial manufacturers tend to maximize the lifetime of their hardware.

One illustration of the balance between upfront and upkeep costs is our earlier experience with a small Arduino system that we had developed during the Covid pandemic. Although this system is ideal for experimentation and low-cost applications, we found it to be too cumbersome for a large lab that often has almost 80 students per semester and that is operated on a tight schedule. The work required to develop the individual control systems, provide adequate documentation and explanations to students, and maintain the system – as well as to expand its capabilities – was beyond the available resources. While effective and low cost, it had the drawback of being a system better suited as an individual experiment rather than as a process control system for a large student laboratory. Our experience with this system led us to prefer a commercial control system. We believe that such a system allows instructors to focus more of their efforts on teaching rather than on development and maintenance work. We also believe that the long-term upkeep costs of an in-house system can be higher than the upfront cost of a commercial system.

In summary, we feel that a central control system that has common features and functionality is the best option for a student lab. A commercial system has common and well-documented functionality, design, and operating features, has support and continuity for when in-house resources may be lacking, and is unlikely to become obsolete. Furthermore, the common approach to control problems and a single software system will allow students to more quickly become comfortable operating the system and more easily gain an understanding of its architecture. This common approach also allows the experimental concepts to be introduced into a process control class more efficiently. Finally, a commercial DCS provides true hands-on experience with systems students are likely to encounter in industry and provides the industrial relevance that employers often seek.

The Control System

Our preferred approach was facilitated by our industrial partner, Yokogawa Corporation, who donated the system hardware and software. We had detailed discussions with Yokogawa to determine the best setup for our needs. While some features that are included by default, such as extensive data routing and system interconnectivity for multiple operating domains, sophisticated alarm setups, multiple permission levels, and batch process controls, are not needed for a typical student laboratory, they do have significance from an instructional perspective and as an introduction to features common in industrial applications. Our system is not set up for automation or complex control functions but rather for learning. We operate the system in a straightforward, simple manner; the operation of the laboratory is not dependent on the control system running. Nonetheless, it is certainly possible to utilize these advanced features in other applications.

The principal components of the Yokogawa Distributed Control System consist of a central server; the control processor ('controller'); input and output (I/O) cards that provide analog to digital conversion; and a series of terminal boards that handle 4-20 mA analog inputs and outputs, direct thermocouple inputs, and direct (3-wire) RTD inputs. Currently, we are not configured for digital input or output signals, but this feature can be added to the system. A diagram of the principal components is shown in Figure 1. All the hardware and wiring are clearly visible, allowing students to trace connections and to see the various components of the system that are described above.

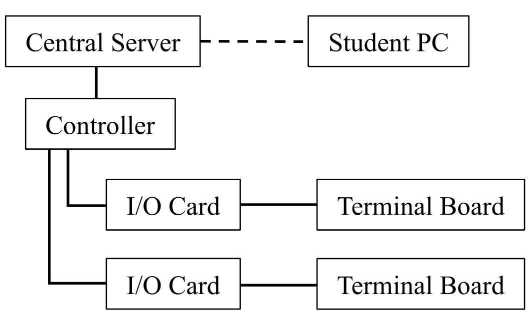

Figure 1. A schematic of the Distributed Control System (DCS) installed in the Unit Operations Laboratory. Solid lines denote wired connections; dashed lines denote wireless connections.

The server has all the features and software of a standard industrial process control system. The system software allows the development of a process model that can be used in place of a physical operation or an experiment. This ability to replace a physical system with a model is a central feature of most modern commercial systems. We provide an example of our use of this functionality later in this paper.

The software also contains a graphics program that allows the development of pictograms of the unit operation for each individual experiment. The pictograms display the stream flows and control functions – both automatic and manual – of the unit operation using a consistent design layout. A typical pictogram for an experiment is shown in Figure 2. Such pictograms are a common feature of almost all commercial systems and have become fairly standardized. As a result, experience with any one control system will provide useful learnings that are relevant to most industrial DCS systems.

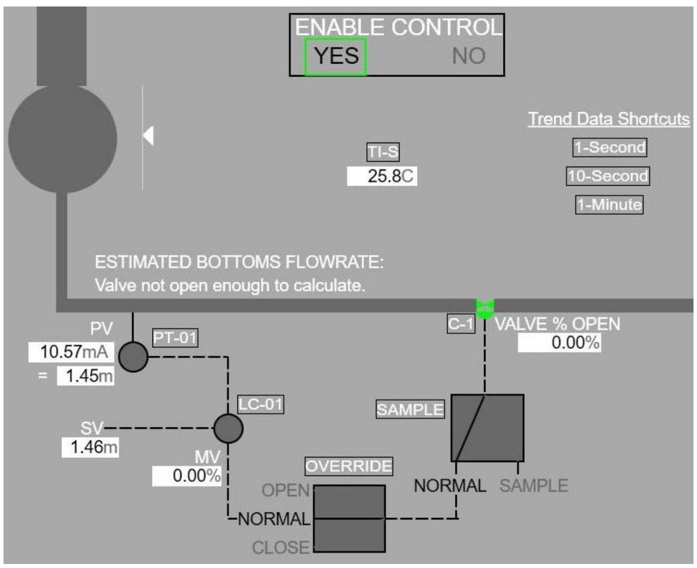

Figure 2. A sample schematic that a student sees when operating an experiment. This schematic describes the level control of the fluid in a distillation column. Students can see the current values of key variables, and some labels also serve as buttons that allow students to manipulate the equipment directly from this screen.

To keep costs down, our control system is not designed to perform any critical safety or interlock operations. This means that, for example, we have only one server instead of two. In other words, unlike in an industrial application, our system is designed as a test system, whose operation is not critical to the functioning of the laboratory itself. If the control system is down, the functionality of the equipment may be limited, but experiments can still be performed. In many cases, a significant part of the experiment is still operated manually. The goal is to provide data acquisition and some control features for each of the experiments in the lab, not to provide automation. The system is intended to be a teaching tool.

Our Yokogawa control system has a server that allows students to have remote access to the laboratory experiments and to their experimental data. Several experiments run for longer than the laboratory period, and the ability for students to follow an experiment and to remotely control functions is an important feature of the system. In years past, the laboratory was open to students at off-hours, but this is no longer the case.

The system allows up to eight remote operator stations to be connected to the server. Each operating station can run any experiment that is part of the system. This allows multiple student teams to interact with the DCS either in the laboratory or remotely. Modifying the system's control logic, however, can only be done by a single team or individual. Various permission protocols can be incorporated into the system to prevent improper access.

Enabling the system to have remote access capabilities through the University's network required a careful balancing of the security protocols in both the University's and the manufacturer's software systems. To access the DCS server, a Windows Client Access License (CAL) is required – one for each user. Originally, the DCS server was connected directly to the University's network domain, which allowed the use of CALs purchased by the University. However, this method did not work, as the University network domain policies conflicted with the internal licensing and security permissions of the Yokogawa software. After extensive troubleshooting and discussions with Yokogawa technicians and University IT specialists, we determined that the best solution was to connect the DCS server to the University's network, but not its domain. This meant that the CALs needed to be installed directly on the DCS server rather than on the University system. This arrangement did not cause any issues with remote access, aside from the work that was needed to develop a solution to the operational conflicts that resulted from the original setup.

The Unit Operations Laboratory

While the emphasis of the first part of this paper was on describing our decision-making process, in this part, we wish to describe in greater detail how the control system is implemented and how we plan to maximize the benefits of a DCS in the Unit Operations Laboratory. While every university's experiments are different, we hope this information will give the reader ideas for the breadth of what is possible with a control system.

As we described previously, our Unit Operations Laboratory contains a number of traditional experiments, most of which are tied to the DCS. In some cases, only minimal control and data acquisition functions are utilized, whereas in other experiments, more extensive use is made of the control system. In general, most control functions are limited to simple, independent control loops. Nonetheless, examples of the most common instrumentation and control functions in chemical engineering are represented. The various experiments in the laboratory and the control functions included with them are described below.

Distillation – This is the principal controlled experiment in the lab. The Oldershaw-style distillation column has nine stages and a diameter of 100 mm. The column is steam heated; the steam supply to the reboilers is controlled manually by regulating the steam pressure. However, the liquid level in the reboiler is controlled automatically, and the column pressure is also maintained automatically by controlling the flow rate of cooling water to the condenser. In addition, the reflux ratio can be adjusted by setting the on-off signal to a solenoid that moves the reflux paddle from fully closed to fully opened. The feed to the column is supplied by a metering pump that uses a 4-20 mA signal from the DCS to control the flow rate. Distillate, bottoms, feed, and tray temperatures are measured by thermocouples that are connected to the DCS.

Absorption – This is an experiment that uses a packed column to remove CO_2 from an air stream using a dilute solution of methyl-ethyl amine (MEA) in water. To minimize cost, rotameters are used to mix the air and CO_2 that is fed to the column. The MEA solution, however, is provided by a metering pump that uses a 4-20 mA signal from the DCS. CO_2 concentrations in the feed and exit streams are measured using an IR analyzer, and the signal from the analyzer is sent to the DCS. A set of manual switching valves is used to determine whether the inlet or outlet stream is sampled.

Tray Dryer – This experiment is a pre-engineered module that has a dedicated control system. We still use the built-in heater and fan control functions, but all other process measurements – temperature, humidity, velocity, and weight – are sent directly to the control system. Since several of the instruments provide only a serial RS-232 output, we use an RS-232 to 4-20 mA converter to supply an analog signal to the DCS.

Reaction Engineering – Reaction engineering is a pillar of the chemical engineering profession. We developed both continuous (CSTR and PFR) and batch reactors to study the hydroxide-catalyzed saponification of ethyl acetate. The control system is used to control the pumps for the continuous reactors and to collect process data (pH, conductivity, and temperature).

Bioreactor – The control features of this experiment were developed in-house to avoid the need for purchasing several commercial bioreactor modules. The principal control functions are a process heater to supply tempered water to the reactor, a mixer, and a feed pump to allow fed-batch operation. Various process variables are also automatically recorded by the DCS.

Typically, pre-engineered unit operations experiments are expensive, and often the cost is largely due to the control system that is included with the experiment. Eliminating the need for such a control system can significantly reduce the cost of an experiment. Of course, integrating an experiment with a distributed control system does require experience and knowledge. However, this skill can usually be quickly mastered. The cost difference between an in-house designed system and a purchased unit operations experiment can be over $50 K.

Control Experiments – Two process control experiments were added to the laboratory. The experiments were chosen for their simple design yet complex dynamic features. One experiment is an interacting level control system that has a second-order response. This experiment can be operated either as a single column or as an interacting two-column system. The second experiment is a simple heating and mixing problem that involves control of both the flow rate and the temperature. The experiment features a transportation lag and the control functions operate independently but can be set up in a cascade mode.

The control experiments are designed to allow students both to run the physical experiment as well as to follow the output of a dynamic model. The ability to substitute an analytical function block for the physical operation allows students to directly and easily compare model results to experimental data. This approach eliminates the need for other software modeling programs, and unlike a simulation model, the output is shown in real time, rather than being output as a graph of the process variable vs. time. Furthermore, by utilizing a common software system for both the dynamic model and the control functions of the physical equipment, we believe that learning effectiveness can be improved and that students can better understand the relationship between modeled and physical processes.

As an example, we will consider the interacting level control system, which consists of two columns in series as shown in Figure 3.

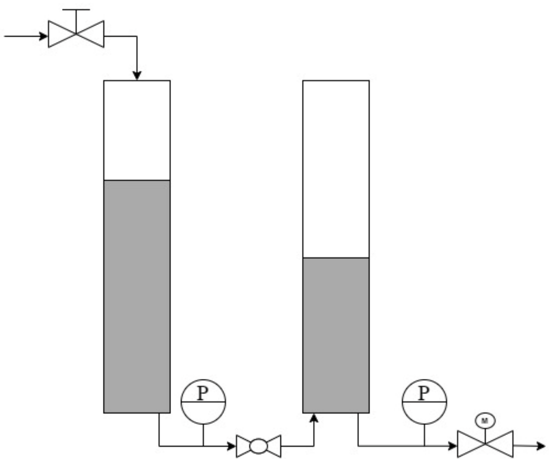

Figure 3. A flow diagram for the two-column system being analyzed. The valve at the inlet to the left-hand column is manually adjustable to act as a disturbance variable. The ball valve between the two columns is fixed but acts as a flow resistance, so the height in the two columns is different. The gate valve on the outlet from the right-hand column is controlled by the DCS software using the height data provided by the pressure transducer on the right-hand column.

The block diagram representative of this experiment is shown in Figure 4.

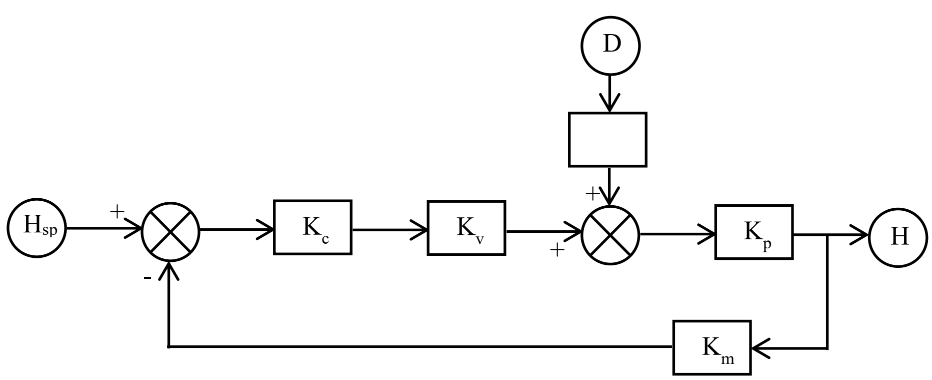

Figure 4. Block diagram for the two-column level control experiment. Definitions: H_{sp}: Height setpoint; K_c: PID controller; K_v: Controller output rescaling to engineering units; D: Disturbance; K_p: Process dynamics; K_m: Measurement delay; H: Height output.

This block diagram is used as the basis to understand the features of the control system – the required inputs to and outputs from the experiment – and to help with the setup of the function blocks in the control system software.

While the setup of the blocks in the software is similar for both the physical equipment and the dynamic model, there are a few key differences that are worth highlighting. We will use the following, slightly simplified block diagrams to explain.

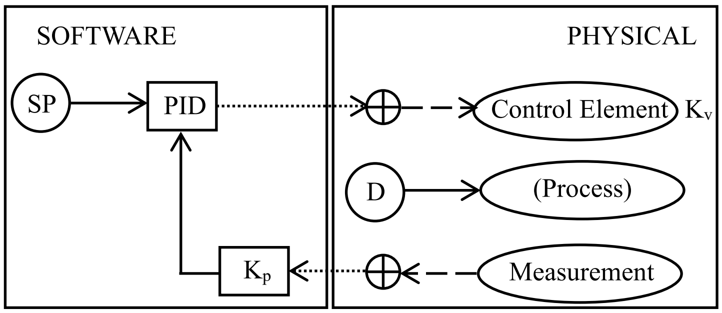

Figure 5. Example block diagram for a physical experiment. Definitions: SP: Setpoint; PID: Controller; K_v, K_p: Process variable conversion; D: Disturbance. Circles represent user-adjustable inputs; boxes represent one or more blocks in the software; ovals represent physical equipment; the "plus" signs represent terminal connections on the DCS hardware. Solid lines denote values in engineering units; dotted lines denote values that are 0-100%; dashed lines denote control signals.

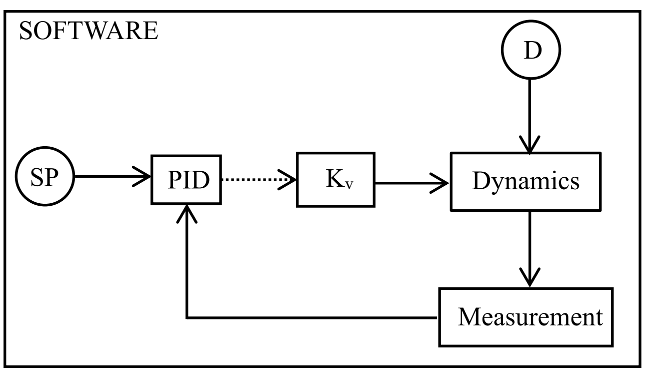

Figure 6. Example block diagram for a modeled system. Definitions: SP: Setpoint; PID: Controller; K_v: Process variable conversion; D: Disturbance. Circles represent user-adjustable inputs; boxes represent one or more blocks in the software. Solid lines denote values in engineering units; dotted lines denote values that are 0-100%.

One objective of the control system is to correct a disturbance, which in this case is a change in the inlet flow rate. The liquid height in the second (right-hand) column is maintained at a setpoint after the disturbance by applying the PID control algorithm to the measured height of water in the column. For the experimental setup, the input to and output from the control system are shown in Figure 5. The 4-20 mA signal from the pressure transducer that measures the water height in the column must be converted to a process variable (PV) in appropriate engineering units based on the calibration of the pressure transducer. Since the control system operates as a discrete digital system, measurements are obtained in real time every second. Measurement frequency is adjustable, but for many chemical engineering applications, a control frequency of 1 Hz is adequate. This PV is then sent to the control system PID block that compares the input signal to the setpoint and converts the error signal to an output signal.

The PID block is a digital controller and uses the velocity form of the PID algorithm. The digital controller, like the analog version, has three adjustable parameters, K_c, τ_I, and τ_D, for proportional, integral, and derivative control, respectively. The digital, velocity form of the PID algorithm is [4]:

$$\Delta y = y_k - y_{k-1} = K_c\left[(\varepsilon_k - \varepsilon_{k-1}) + \frac{\Delta t}{\tau_I}\varepsilon_k + \frac{\tau_D}{\Delta t}(\varepsilon_k - 2\varepsilon_{k-1} + \varepsilon_{k-2})\right]$$

where Δy is the difference in the output signal between the current, ε_k, and previous, ε_{k-1}, error measurements obtained at a discrete time interval of Δt:

$$y_k = y_{k-1} + \Delta y$$

The PID block outputs the Δy signal and increments the 4-20 mA signal in the output card to its new value. Once the controller initiates reading the input signal, the new output signal is immediately generated.

The 'conversion' of the PID output signal to engineering units happens at the valve, where the 4-20 mA signal sets the position of the valve, and thus the flow rate of the water. Because the conversion occurs at the valve, the K_v term appears on the physical side of Figure 5 rather than the software side. The outlet flow rate can also be calculated in the software using the manipulated value from the PID.

In short, for an experimental setup, the function of the software is to convert the input signal to an engineering value, perform the control function, and convert the PID increment back to a 4-20 mA output signal.

It is also possible to use the DCS software to model the control experiment by replacing the physical equipment with a dynamic function block as shown in Figure 6. This 'Dynamics' block is the primary difference between model and physical setups. For the level control experiment, the dynamics are a set of coupled differential equations derived by completing a mass balance around each column. The 'Dynamics' function block calculates the height of liquid in each column at the same 1 second time steps as the physical experiment using the output of the PID block and the inlet flow rate (the disturbance variable). The function block can be programmed with either a real-time analytical solution or, for more complicated dynamics, a set of governing differential equations that can be solved numerically at each time step. In our application, we used a Runge-Kutta routine to solve the dynamics equations numerically in the function block. Although the single column dynamics can be readily solved analytically, this is not the case for the interacting columns. We feel that the numerical approach is more general and provides students with an alternative approach to process dynamics.

For the ‘model’ case, the height of liquid calculated by the ‘Dynamics’ function block, rather than the experimentally measured height, is passed to the PID controller, which compares the value to the user-specified setpoint height. Since the controller output is an incremental change given as a percentage, it must be rescaled in the software to a flow rate (in engineering units) using another calculation block (K_v). This flow rate value is then the input to the ‘Dynamics’ function block, rather than being sent to the experiment itself.

The final key difference between the model and physical columns is how the disturbance is implemented. In the case of the model, the disturbance is input directly into the ‘Dynamics’ block; in the case of the physical setup, the disturbance is set by changing the input flow rate to the columns using a valve.

To summarize, the DCS software can provide a useful model for the system, provided a set of differential equations (linear or non-linear) can be developed to describe the system dynamics. The engineer then creates a calculation routine that combines the controller output with the disturbance and the process dynamics at each time step to calculate a new value of the process variable (height). At the next time step, this new PV value is used as the input to the PID control block.

While the above description was tailored to our level control experiment, the general concepts can be applied to a variety of experiments. If a set of differential equations can be generated to describe the dynamics of the system, then that system can be modeled directly in the control system, without requiring any inputs from a different software program. Modeling the system in this way provides a useful way for students to connect theory to actual systems. It enables investigations of how a physical system operates compared to a model. It should be emphasized, however, that this approach is not a replacement for a traditional analysis of a control loop using Laplace transforms. This approach does not provide the analytical insights obtained from a transfer function analysis.

It is also important to consider how the students will interact with the model and the physical system in the DCS software. The software components of both the model and the system are coded in the DCS using function block diagrams. Generally, each of the blocks in Figures 5 and 6 can be mapped to a block in the software. It is possible to see the diagrams of these function blocks from the student’s view, but because they can become quite complicated, there are several tools in the software that allow lab staff to create schematics of the process in a way that mirrors the physical connections of the equipment, like in Figure 2. These schematics are similar in structure to what students may see in industrial applications of control systems. The benefit of using a single DCS throughout the lab is that these schematics can be created using a consistent design language, which makes it easier for the student to quickly pick up what the graphic is showing them once they understand the basics. Laboratory staff can also determine which data will be automatically collected. Essentially any numerical value in the software can be collected. Students can see the data plotted in the DCS software, and they can also easily export the data to a spreadsheet for later use. This automated data collection is a better reflection of industrial practice and provides students experience analyzing large datasets.

Summary

Cost – We feel that this is probably the principal deterrent for employing a commercial distributed control system in a student lab. This may be less of an issue at large state universities that have significant industrial and alumni support. Nonetheless, there are many willing industrial partners – having their system in a student lab gives the company visibility among students – and used equipment is perfectly adequate for this application. In addition, costs can be reduced by automating only parts of an experiment and by utilizing simple, analog control loops and basic instrumentation. Of greater utility is having the license to use the software program. This is a key feature for providing a consistent application that can be quickly comprehended by students. In addition, a commercial control system's hardware is easier to maintain and understand and has reduced documentation requirements compared to most in-house systems. This is a significant advantage where lab support and staffing are limited, where turn-over of instructors is an issue, and where systems may become obsolete. The last thing anyone wants is for the control system to become a white elephant because documentation or an understanding of the system has been lost or the system has become obsolete.

Implementation – In our case, the leadership for the acquisition of the control system was provided by an instructor who had many years of industrial process and product development experience, although only a limited control system background. The day-to-day implementation of the system and much of the documentation, however, was done entirely by the lab manager, who took full responsibility for the system and was able to work through the many issues and problems that arose when connecting wires and programming the software. Of critical importance in any process control system is appropriate documentation and record keeping, as well as maintenance of the system and associated instrumentation. This is an extensive workload and the resources needed to keep a control system functioning properly must be carefully considered and adequately addressed.

Benefits – Allowing students to work with a commercial control system provides a direct connection to actual industrial operations. Students can bypass the inefficiencies of learning to operate a school-based system and instead can become directly familiar with the operational characteristics of commercial equipment. Although learning the operation of any control system is a significant challenge, it is hoped that teaching effectiveness can be enhanced by introducing students directly to actual commercial equipment and by using a single software system for modeling, instrumentation, and control.

Conclusions

We have attempted to highlight the principal factors that we used in our decision-making process for choosing a process control system for our renovated laboratory. The cost, the management and maintenance of the system, and the educational benefits were all considered. We propose that a careful assessment of these factors is an important first step when considering the implementation of a control system in a student laboratory.

We feel that the benefits of a centralized control system to student education in Chemical Engineering are significant. In particular, we emphasize that such systems simplify instructional aspects, allow both modeling and experimentation to be done with the same software and protocols, and provide students with needed practical experience handling not only process control but also control loops and instrumentation. Finally, we believe that, if properly implemented, using a commercial DCS is reasonably cost efficient.

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