A development of experimental education program: computer control of multi-stage level control system

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Abstract

We developed an experimental education program and the apparatus with computer software for chemical process control. A multi-stage liquid level control system is chosen as a target process because it is one of the simplest chemical processes to understand. The target process is composed of one storage tank, two series liquid level tanks and one more interactive liquid level tank with an on-off solenoid valve at the position between the store tank and the first level tank as the actuator and a DP-cell at the last stage level tank as the liquid level sensor. The software is programmed under the platform of both DOS and Windows'95, 98, NT. It is composed of the real-time graphic view of important variables, data sheets, dynamic process flow diagram, manual setting of set-point, manual operation of actuator, setting of control parameters, auto tuning module, zero-span, data editor, signal filtering, etc. The experimental education course was also developed and it consists of 3 or 4 weeks with 3 or 4 h per week program. During the first week, students learn the control system basics and instrumentation and how to realize and check the signal of important variables. At the second week, students learn how to identify the process with the relevant control models. During the third week, they learn how to tune the PID control for the target process. If instructors want to teach 1 more week they may assign students to the task of designing their own tuning parameters and compare their performance with the conventional tuning methods which were prepared in the developed computer software. We could confirm that the experimental education was very helpful to understand the process control theory for undergraduate school students through the survey and grading. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Process control education is going through a period of rapid transition; one of the ultimate objectives is to increase the educational efficiency. In most of the traditional courses on process control, the education has been mainly conducted by using basic theoretical tutorials. However, it is hardly expected that the undergraduate students who generally have little idea of process control could have in-depth understanding of the main concepts and techniques only through the textbook. It is also recognized that without any experience of real problems, they will not be able to understand how to apply the techniques learned in theoretical courses to engineering problems. For this reason, it is highly required for control education to have an experimental course, which allows the students to apply various control theories and techniques and thus provides them an insight into process dynamics and control. Although the importance of the experiment has been recognized for a long time, there is still a limitation in the wide use of experimental devices for the education purpose. The reason is mainly due to their relatively high investment and maintenance cost.

We have currently been involved in a project to develop the experimental systems for process control courses. A whole system was developed which provides every essential function for process control education with low cost. A multi-stage liquid level process was selected as the target process. The level system has many essential features for this purpose: it allows us to test various options in an efficient manner, for example,
one can easily test both linear and non-linear problems, feed forward and feedback problems, interactive and non-interactive dynamics, from low to higher order dynamics, etc.; it is quite easy for the students to handle; it requires no harmful material. In addition, since the level system is most common in most process control textbooks, the students can directly connect the examples in the textbook by Seborg, Edgar and Mellichamp (1989) and Stephanopoulos (1984) with the experiments. Another important component of the project was the development of low cost software and hardware for general laboratory scale devices. A real time software package was developed as a user interactive form both for the platform of DOS and Windows'95, 98, NT. The high performance A/D and D/A converters with low number of channels were specially designed for our particular system to save the cost.

The experimental course consists of 4 weeks. During the first week the control system basics are covered, for example, what the control loop consists of and how each component in the loop works. Students try to operate the process from manual to auto mode (or vice versa) and to understand several issues associated with a PID controller such as bumpless transfer and anti-reset windup. The impact of process design on controllability is also studied. At the second week the emphasis is on how to identify the process with the control relevant model such as the first order plus time delay (FOPTD) model. Several methods such as open-loop step change, PRBN, and relay feedback are tested to get the dynamic model. During the third week the main issue is how to tune the PID control loop. The approach that we take is 'model-based' with an emphasis on the Internal Model Control (IMC) design procedure by Rivera, Morari and Skogestad (1986). In particular, the DCLR method by Lee, Lee, Park and Brosilow (1998) is mainly used to tune the controller and compare with the other conventional methods such as ZN by Ziegler and Nichols (1942) and ITAE tuning by Lopez, Murrill and Smith (1967) and also the students own. The students are also expected to compare the resulting control performance with that by the auto tuning option which is already available in the software. During the last week the students design and tune the feed forward controller against the disturbances in the feed water and incorporate it into the feedback control system.

We have used the proposed experimental course for three semesters. Although the experience of teaching with this apparatus was short, the student group that attended this course clearly out-performed to understand the process control.

2. The configurations of experimental apparatus: hardware of the level control system and instrumentation

Figs. 1 and 2 show the schematic diagram and photograph of multi-stage level control system, respectively. As shown in Fig. 1, the multi-stage level control system is composed of three serial tanks and one optional interactive tank. The upper one is used as a storage tank. The cores of the process are the lower two serial tanks. We want to control the level of the third tank or the interactive tank with an on-off valve, which is installed at the upper position of the second tank. The differential pressure (DP) cell on the third tank or the interactive tank reads the liquid level and generates 0–10 V electric signal. The signal is converted to 4–20 mA and fed to the A/D part of A/D-D/A converter, SL98, which is specially designed for a small laboratory scale [7]. The A/D converter then generates the digital signal with 16bit resolution to the computer.
The real-time software compares this signal with the level set point and calculates the controller output signal by PID control logic. The software stacks the data for a given time period and gives the control command to the digital output part of signal converter. The digital output signal corresponds to the open time rate of on-off valve. Through the solid state relay this signal is converted to on-off power voltage for the actuator (on-off solenoid valve). We could save much of the instrumentation cost by using the on-off valve (instead of a conventional control valve), as well as, using the specially designed converter so called SL98. The feedback control loop can be built up through the level reading by DP cell, A/D part of SL98, computer, D/O part of SL98, and on-off solenoid valve as actuator.

For the general usage of laboratory scale control systems, we designed Small Lab'98 (SL98). SL98 consists of two channels for A/D, one for D/A, one for D/I, one for D/O. The resolution of the converted A/D and D/A signal is 16bit and the maximum speed of reading and generating signal is 3600 samples per s. The feature of SL98 is shown in Fig. 3.

The frame was made of stainless steel and the level tanks were made of transparent acryl resins. We used a general magnetic centrifugal pump for the continuous liquid transfer from the bottom tank to top storage tank.

3. The software package development for process control education

We developed two kinds of software for the platform of both DOS, and Windows series. DOS version of software is for the users who want to use 386 PC or early version of 486 PC IBM compatible. But Pentium or a better system under the platform of Windows 95, 98, NT will be recommended.

The software includes the graphic module, table form of process data, and process configurations with the dynamic values of interested variables. It also has the functions of selecting the interested time range of process data, and several process identification tools, and tuning methods for PID controllers. It also provides the functions for checking signals from sensor to manipulating devices and an easy zero span tool.

The software was programmed with Visual Basic (Lee, 1998) and C++ (Goodwin, 1992). The external C program by the user can be easily integrated into the software. An example of real-time monitoring and data acquisition view is shown in Fig. 4. The software also includes a filtering function for noise treatment and offers an appropriate treatment of reset wind-up and derivative kick.1

4. The contents of 3 weeks experimental education

As mentioned earlier we developed 3-week or 4-week curriculum for the experimental education. In this paper we suggest the 3-week curriculum. During the first week, we deal with the hardware configurations, instruments and devices for signal treatment. Students experiment on the relationship between the major components of the control system such as the real interested variables, the signal by sensor, the commands from computer to actuator, and the specification and range of signals.

The hardware components such as sensor (DP cell), final actuator (on-off solenoid valve), I/O device (SL98), solid state relay, power supply and pump are examined. In Fig. 5, the monitor view of module for signal check is shown.

The zero-span should be achieved for standardization of signals. Fig. 6 shows the module for zero-span of the

1 http://www.analog.cpm/product/Product_Center.html, Home page of Analog Device Co. Ltd.
system. Procedure of the second week experiment is shown in Fig. 7. Fig. 8 shows a monitor view of system identification experiment. Fig. 9 shows an example of data edition and regeneration for identification.

During the third week, real-time applications of parameters on the PID controller are investigated based on the theoretical and actual tutorials for the tuning of these parameters ($\tau_1$, $\tau_D$, $K_c$). During this period students can also apply their own PID parameters to the control system. The procedure of the experiment for this period is shown in Fig. 10. An example graphical view of the third week experiment is shown in Fig. 11.

Students can input the PID tuning parameters by 'Control Parameter Setting Tool Box', a derivative kick and reset wind-up treatment by 'Control Option Tool Box' and a filtering coefficient by 'Control Filtering Tool Box' manually. The tool boxes for the manual input of these parameters are shown in Fig. 12. Students can compare the results with their own tuning and those of the conventional tuning methods given in the software package.

5. Conclusions

The objects of this experiment are to teach the physical meaning of PID control for chemical process control, to give the experience of operating the real system and to teach the roles of instruments and devices used in the chemical process.
Students could learn the concept of process control and why it should be controlled. They could also easily learn the theoretical aspects of chemical process control. It might help them when they are assigned at the real industrial field of chemical plants. We prepared the after-course survey sheet to evaluate how much the experimental education helped the student to understand the control theory. Through this completed survey sheet we validated that the experimental education was a very successful program. Over 90% of students who attended at the experimental education got more than A grade on the theoretical course of chemical process control.

In conclusion, this educational system can give an efficient way for undergraduate (or graduate) students to understand and test the main of process dynamics and control with low cost. Actually, the student group that passed this experimental course outperformed in understanding process control compared with the group that did not attend the course. This development can also be used for the automation of laboratory scale, and their applications in several laboratories and universities have shown promising results.
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References
