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Real and simulated control laboratories: a case study via the *foot spa*

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ABSTRACT: The case study presented in this article reviews the use of a real plant within control systems engineering education as part of a relatively new three-year degree programme at the Christchurch Polytechnic Institute of Technology (CPIT), Christchurch, New Zealand. An outline of the qualification is provided with an emphasis on the control systems engineering courses. The development and subsequent enhancement of a simple real world plant example to supplement virtual experiments in control system engineering is described. Improvements to the existing plant are outlined and reactions from both students and staff are briefly reported. It is concluded that the use of a physical plant is required in order to supplement the use of a virtual plant in control systems engineering at this level so as to maximise student learning opportunities.

INTRODUCTION

The changing scene of secondary and tertiary education in New Zealand has led to the establishment of many tertiary polytechnic training providers now offering both two-year diploma and three-year degree level qualifications. Four-year professional engineering degrees and postgraduate qualifications remain the province of the university sector.

The School of Engineering at the Christchurch Polytechnic Institute of Technology (CPIT), Christchurch, New Zealand, has, in line with this changing trend, responded by setting up and establishing a technologist-level qualification called the Bachelor of Engineering Technology (Electrotechnology). This programme commenced in 2000 and has its first graduates in 2003. It is actively supported by industry involvement in many areas of the programme with industry speakers and representatives having regular input into the programmes directly and, in some cases, directly into the classes and students [1].

Control systems engineering has, in recent times, matured into a recognised field of learning. Unfortunately, the training equipment on offer by recognised industry training suppliers does not always reflect the requirements of the training provider, is generally too expensive for small providers and can contain obsolete technology. Control systems engineering is taught, although separately and by different tutors, in both the electrical and mechanical diploma programmes, as well as in the degree programme.

The main aim of this project was to set out a specification for a simple first order control system using water, a holding tank and a simple Proportional Integral and Derivative (PID) controller. With these basic elements, third year degree students were asked as part of their design project for the Controls Engineering 2A elective course to design a piece of teaching equipment for use in the networks part of the course later in the same year that would also be simple enough to allow an understanding and appreciation of the dynamics of plant operation and behaviour, PID operation, safety systems for plant operation and Programmable Logic Controller (PLC) control.

The inspiration for the name of the project, *foot spa*, came directly from the students involved after their first laboratory session.

CONTROL SYSTEMS EDUCATION AT CPIT

The Bachelor of Engineering Technology has been created by the Christchurch Polytechnic Institute of Technology in response to a requirement for technologists in the electrotechnology industry. The technology degree is offered as a three-year degree, offering specialisation in the third year with the options of electrical engineering, electronics engineering, control systems, computer engineering, engineering management, or communications engineering, with students taking any two of these subjects.

The second year of the degree programme is classified as endeavouring to introduce students to the basic principles of engineering in the following areas: engineering science, electrical engineering, electronics engineering, engineering mathematics, computer engineering, communications engineering, engineering management and control systems engineering. It should be noted that control systems engineering has not previously been delivered to this level within the CPIT prior to the introduction of the BEngTech programme.

In the Year 2 degree course on control systems, the following topics are first taught: sensors and sensor technology, PLCs,

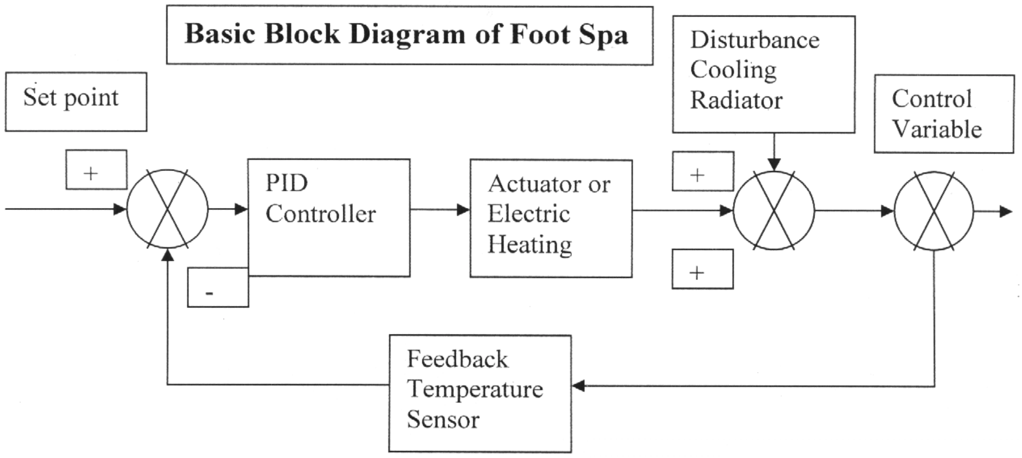

Figure 1: Block diagram of the foot spa.

valves and actuators. This is followed by the basics of PID control, which is reinforced by using a computer-based simulation training package and synchronous servomotor experiments. Students undertake a study of the process reaction method and the ultimate cycle method of PID tuning, which is applied to both the computer-based and synchronous servo laboratory equipment [2-4].

The National Instruments *virtual laboratory* PID trainer met some of the objectives of the laboratory programme, presenting students with quick graphical feedback on the changes in plant behaviour. However, there were some problems encountered with the trainer in that it left students under a false impression as to how a first order control system with some slight time delay (the plant in this case) operates when controlled by a PID controller, as well as wider considerations, such as plant interactions, safety interlocks and alarms.

In the first year that the control system course was taught, a clear requirement was shown for a practical piece of teaching equipment that could easily and safely simulate a practical plant situation [5][6].

Where there is a requirement for the practical aspect of a course, some computer simulation and modelling may be used [7]. However, as has been shown to be the case with the foot spa, there is, as yet, no substitute for operating a piece of physical plant in the manner in which a student would find it when they graduate from a tertiary training facility.

Having determined the requirement for more practical training equipment, a task was set for the final year (Year 3) degree control students as part of the practical assignment for the assessment in this course. Firstly, the revised specification was given and then the final design decided with students having to implement and prove their design.

The foot spa has been aimed at providing reinforcement of the objectives of the control systems engineering course by way of a practical laboratory experiment and reinforcement of the theory taught in the class.

The foot spa was then incorporated into the revised Year 2 control systems laboratory programme with a measure of success. After some fine-tuning of the PID control block, the laboratory experiment was repeated for a second laboratory class with much greater success.

Following the projects successful conclusion, some refinements were made to the operation of the foot spa, with additional safety interlocks being added to better represent industry considerations.

THE FOOT SPA

The system is typical of a first order lag control system, which can be represented by the diagram shown in Figure 1.

The foot spa is essentially a PID temperature controller connected to an operating plant and a PLC. The PID controller control output, or actuating signal, is connected to the electric heaters via relays and a final safety thermostat. The PID controller actuates the electric heaters based on the operators set point and entered values of Proportional Band (P) (or Gain), Integral (I) and Derivative (D).

The PLC provides an overall safety management function depending on the conditions, demands and various safety parameters, and will not allow the foot spa to operate outside these parameters without alerting a student via the safety alarm system. The component parts of the foot spa are shown in Figures 2, 3 and 4.

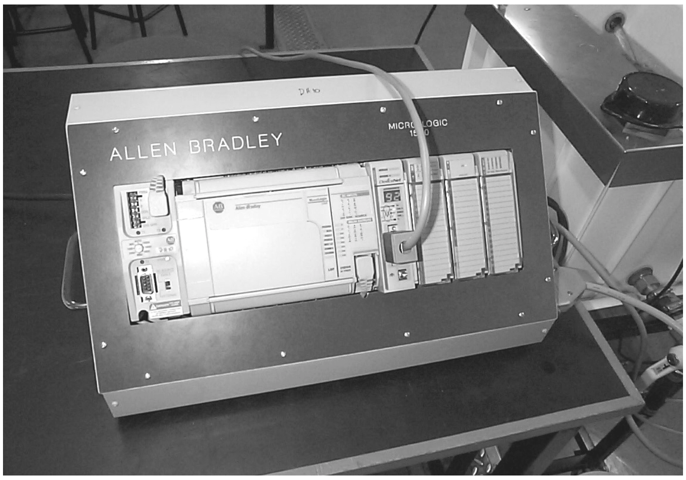

Figure 2: An Allen Bradley PLC module.

A circulating pump, as shown Figure 4, takes water from the bottom of the tank via a fan-cooled radiator (which simulates a factory or plant) and pumps the water back into the top of the tank.

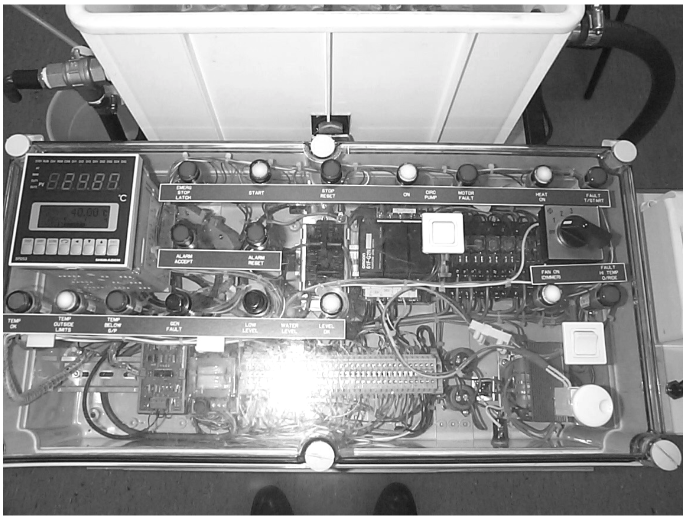

Figure 3: The foot spa front control panel.

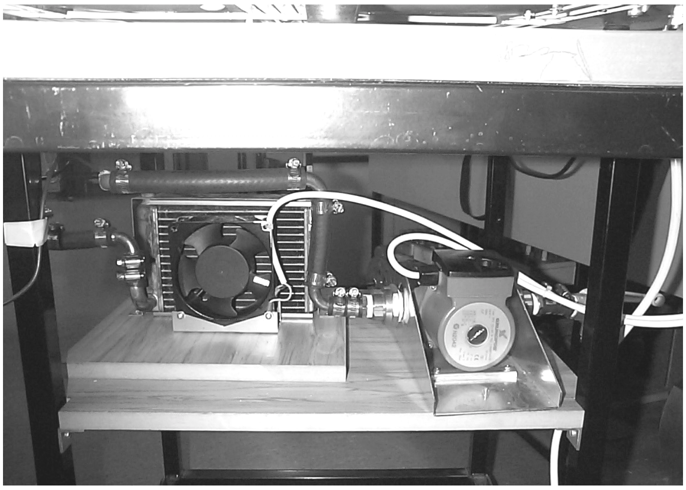

Figure 4: The cooling radiator and circulating pump.

The fan, when selected, is under dimmer control unless a thermostat high temperature alarm occurs. In this fault condition, the fan will operate at a high speed for the duration of the high temperature alarm.

The system has addressed the following safety issues that closely mimic real life industrial environments:

- A low-level interlock isolates heating and the circulation pump.
- A high temperature interlock (from a Shimaden PID controller) isolates heating.
- A high temperature interlock (from the thermostat) isolates heating and, if the fan is running, bypasses the dimmer and then runs the fan at its maximum speed.
- A Residual Current Device (RCD) isolates the tank control panel should any electrical leakage occur.
- The emergency stop halts the operation of the tank completely.

As with many industrial plants, when an alarm occurs, the general alarm light will flash and continue until muted or silenced by the operator depressing the alarm accept push button.

Should an alarm occur, be this low-level or over temperature, then the student will be presented with a general alarm and a descriptive condition that specifies which alarm occurred and what remedial action is required to correct the action. Once the operator has cleared this fault condition, the alarm reset is depressed; this resets the plant back to normal operation.

If the operator does not correct the defect in plant operation but still presses the alarm accept and then the alarm reset, the control system is designed so that if the fault condition still exists, then the alarm will still trigger. In a normal plant operation, there would also be a siren, pocket pager or modem attached to alert appropriate staff. However, it was decided at an early stage in this project that there was no requirement for any additional noise-generating device in the laboratories.

Should the operator decide to press these two buttons in the reverse order, the general alarm light will mute when the alarm accept push button is depressed, being the last action taken.

STUDENT OPERATION

In operation, the student will try to ascertain the dynamic response of the tank as well as the response time for the test rig. Once this has been obtained, the student will then enter a set point into the PID controller and then, using PID controller settings, try to tune the test rig plant to the PID controller. If the student has entered the optimal settings into the PID controller, the overshoot of the temperature is restricted to 1.5^{o}C or less, with a time frame of 8-10 minutes. The student can use a variety of tuning methods to achieve the desired result. With this shortened timeframe, the student's interest is maintained.

From this experiment, students gain an appreciation of how a plant behaves, alarms handling and typical control issues that confront control engineers. Students also appreciates that computer simulation of PID behaviour can bear no resemblance to the actual behaviour of a PID controller in a plant environment. Figure 5 shows the completed foot spa.

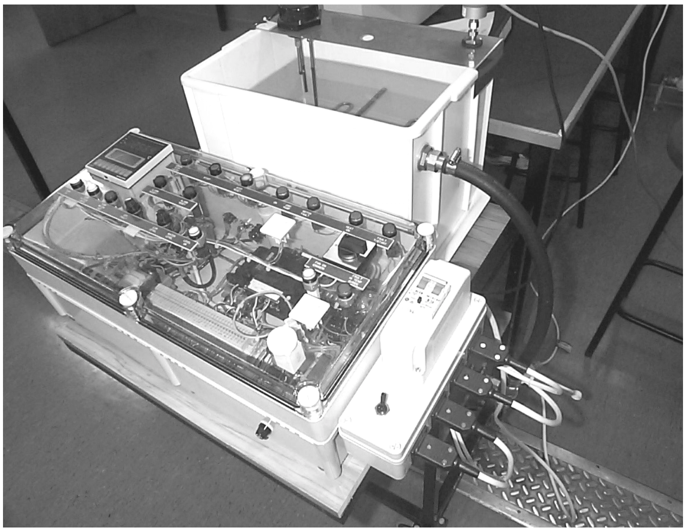

Figure 5: The foot spa completed.

IMPROVEMENTS

The foot spa control systems experiment has been through two successful iterations with students. However, as with many laboratory experiments, some potential areas that can improve the overall system have been identified as described in further below.

In order to further improve the control system response time, the addition of second load radiator and fan is anticipated. This will also require a slight modification to the pipe work and valving, as well as requiring the addition to the PLC program of a flows switch such that if both valves are isolated, the circulation pump does not burn out by running *dead-ended*.

A significant and industry demanded improvement is in the area of remote control and access so as to allow students to gain some familiarisation with *SCADA* and telemetry principles. This will allow the PLC to control the system, either via remote access or via the Ethernet/DeviceNet systems being established within the Department.

One further area for improvement will be to develop a *LabVIEW* program that utilises a recently acquired DAQ (Data Acquisition Card) to also control and display the operation of the tank test ring [2]. This is being proposed as a student final year project for 2003.

The final improvement would be to allow for full remote control of the foot spa and may, at some point, also be implemented, complete with the National Instruments software and a simple Charge Coupled Device (CCD) camera [2][8]. This would allow for a completely flexible control and teaching system using either the PLC or the PC.

By incorporating these potential improvements and ensuring a number of independent safety features, this would allow the test rig to be used across a wide variety of networks, such as DeviceNet, wired or wireless modems, and/or data highway such as Ethernet.

The flexibility of the foot spa temperature test rig has allowed it to be integrated across a number of other associated teaching programmes in complete safety. Laboratory programs have been written by other tutors in the department to make full use of the test rigs networking and monitoring capabilities for other courses taught within the Faculty and within the School of Engineering.

STAKEHOLDER REACTION AND COMMENTS

Student reaction, both anecdotal and in formal student evaluations, has been favourable, with many students realising that the plant, although located in a laboratory environment, is actually a real live plant with real process demands and real outcomes required and real liquids used.

Many students have also commented that they prefer this type of practical laboratory experiment to virtual simulated experiments on the computer. The most typical comment is that this is because in this small plant, they actually get to control the plant and, if a mistake is made, the control system interacts with the student and shuts down the plant until the fault conditions are remedied, as would occur in a normal plant.

Staff preference from two years of operating the test rig is still to teach the basics and introduction by using *LabVIEW* simulated PID trainers followed by the so-called foot spa control test rig. Many students have in fact remarked, following the first use of this approach in 2002, that this process is preferred. Although more in depth analysis is required, initial indications are that student results are improved by the adoption of a dual approach, that is virtual and real laboratories, to control systems experiments.

CONCLUSIONS

The foot spa demonstrates a simple first order system to students and allows them to develop skills in PID tuning, not on a computer simulation package, but a piece of test equipment, safely and efficiently. Initial comments from students have been very positive with students appreciating the opportunity to operate a physical plant rather than a computer simulation package. Students also appreciated the other learning opportunities that are presented by the test rig, namely in PLC programming, PLC networking and monitoring, safety control systems and, finally, PID control.

Student feedback indicates that a combined approach, that is some virtual laboratories to gain first principles followed by actual process plant experiments to gain appreciation of the realities, is the preferred method for maximising their learning in control systems courses.

REFERENCES

1. Wilson, P. and Li, Y., Learning objects: the new panacea for ‘e’? *Proc. 6th UICEE Annual Conf. on Engng. Educ.*, Cairns, Australia, 153-157 (2003).
2. National Instruments, *LabVIEW* 6.1 Manuals. National Instruments (2001).
3. Feedback Process Controls Simulator (PC327) Manual PCS327-1 (1974).
4. Feedback Modular Servos System MS150 MKII Manual 160/1 Rev 1081 (1983).
5. Ewald, H. and Page, G.F., Client-server and gateway-systems for remote control in engineering education. *Proc. 6th UICEE Annual Conf. on Engng. Educ.*, Cairns, Australia, 167-170 (2003).
6. Roth, H., Rösch, O., Kuhle, J. and Prusak, A., Virtual laboratories for control engineering education. *Proc. 6th UICEE Annual Conf. on Engng. Educ.*, Cairns Australia, 158-162 (2003).
7. Lawrence, P.J., The multiple roles of Discrete Event Simulation in the workplace. *Proc. 6th UICEE Annual Conf. on Engng. Educ.*, Cairns, Australia, 149-152 (2003).
8. Bereznai, G., Chankow, N. and Chanyotha, S., Distributed education for nuclear engineers. *Proc. 4th UICEE Annual Conf. on Engng. Educ.*, Bangkok, Thailand, 89-92 (2001).