Reestructuring of the Teaching of Automation and Control Through the Implementation of Laboratories

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***Abstract**: This work will present the implementation of an Automation and Control Laboratory. Some design aspects related to the development of low cost teaching processes are stressed. Additionally, a teaching kit of Programmable Logic Controllers –PLCs is shown as an important part of this laboratory. These PLCs are largely employed in the Brazilian industrial setting.*

Introduction

The Engineering Schools have a fundamental role in the improvement of techniques used by engineers throughout their professional careers. Despite the quick changes the technological advancement imposes on the methods used in the engineering practices, the techniques used by engineers, even many years after leaving the university, are largely influenced by the training they received during their undergraduate program. This fact shows that changes in the practices used in the engineer's professional career must start in the engineering schools which should be the basis and the driving force for these changes.

The length of the training received by an engineer at the university and the high influence of this training on his/her professional practice makes the engineering programs pioneers in the use of new technologies. The engineering programs which only communicate practices already mastered by the industry have few chances of remaining competitive in the marketplace for very long.

We can see worldwide a concern with the teaching of electrical engineering, with the search of new ways and teaching alternatives. This concern is founded taking into account the growing dropout rates in the electrical engineering programs, together with a decrease in the number of candidates for this programs recorded through statistical analyses in the last few years. Based upon these analyses it was deemed necessary to change the way in which the subjects were being normally taught in the classroom through the preparation of experiments which motivate students and make the presentation of theoretical subjects of reasonable complexity more pleasant.

This alternative is being currently implemented in the teaching of industrial automation and control systems with the use of practical experiments as a way of settling the theoretical concepts taught in the classroom.

This article will describe the implementation process of an automation and control laboratory, including alternative strategies to make resources feasible and to obtain them as, for example, the partnership with private companies. A set of experiments related to the automation and control area, developed with the participation of members of the faculty and students is also shown. These experiments are simple to build, robust and the costs involved are low.

Implementation of the Laboratory

The idea to create an automation and control laboratory started as part of an agreement between the university and a national company which is rather relevant in the area of automation. On a first phase, the agreement establishes that employees and/or trainees from the company study at the university and get semestral discounts. On the other hand, the company offers equipments which are of interest for the university at a subsidized cost. As a result of this initiative the relationship between the company and the university is becoming increasingly closer and company training programs are even held in the facilities of the automation and control laboratory. This way, in addition to getting the equipment used to make and update the laboratory, the university is also able to generate revenues by making available, in idle hours, the resources available in the laboratory so that those companies interested can carry out their training programs.

From the beginning of the implementation phase of the laboratory, on the first semester of 1996, there has been a growing number of students linked to the agreement, which can be seen on Figure 1.

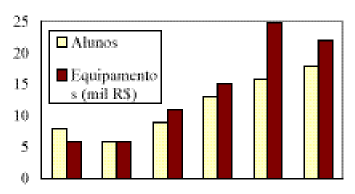


Fig. 1: Number of students and value of equipments.

The graph on Figure 1 shows information related to the number of students linked to the agreement each semester, as well as the amount delivered to the university in the form of equipments. We can see that after the implementation of the laboratory with the effective use of the equipment delivered through the agreement there was a significant increase in the number of students, specially in the relationship amount in equipment/student. We can also see that in the second semester of 1997 there was a decrease in the number of students and, as a consequence, in the amount delivered, which can be explained as the need of permanent equipments by the laboratory tends to decrease each semester. However, we know that as new equipment which include more advanced technologies are launched in the market there is the need to update laboratory equipments. The very nature of the agreement and of the link between company/university takes charge of this renewal.

Laboratory Conception

As a first initiative the programmable logic controller teaching kits [1] and [2] were implemented based upon microcontroller 8051.

These kits were designed in a modular fashion, integrated by a set of optional boards which can be reconfigured according to the experiment to be made. The basic kit is composed of one industrial PLC which contains 16 digital inputs and 8 digital outputs, two 8 bits analog channels which can be reconfigured according to its use, two fast counter inputs, one 8 channels AD converter of 12 bits board, one 4 channel PT100 temperature sensors board, one 8 output relay power board and one interface with LCD display and keyboard as shown on Figure 2. The original conception was made in a way that would take into account the modularity of each kit, allowing new experiments to be easily implemented through the replacement of peripheral modules and the proper programming of the programmable logic controller.

A fundamental aspect for the implementation of these kits in the teaching laboratory is related to the fact that these kits are made up of industrial equipments which ensure the necessary robustness for this use.

Not less important is the fact that future engineers work, still at the university, with equipments which are largely used in industrial settings.

Fig. 2 - Teaching kit of PLCs.

In addition to their use in courses which deal with subjects directly linked to programmable logic controllers, such as the teaching of relay logic and ladder diagrams, these equipment are also used in control system courses together with pilot processes developed by professors and students for the automation and control laboratory.

Laboratory Experiments

The initial set of experiments was chosen for its applicability in processes in general, taking into account systems which may be used for industrial, commercial and building automation. Next, we describe the set of basic experiments which may be made through the use of the kits described in the previous section.

- Correction of the power factor - This aim of this experiment is to get the reduction in the consumption in industrial, commercial and residential installations, decreasing the reactive power of these consumers. The rationalization of consumption brings as a direct benefit the reduction of the operational cost and additionally makes consumers adapt to the constraints imposed by the concessionaires ($\cos \o > 0.92$). Indirectly, the consumption rationalization brings environmental benefits, since the construction of new power generation facilities lead to an environmental impact because they consume natural resources. The distributed application of the capacitor bank to avoid the need of special electrical components with a high nominal value is discussed. Additionally, the ways of switching the capacitor banks and to avoid the wear of the parts involved is also discussed. At last, ways of determining the tensions and currents involved in the systems by using hall effect sensors for the monitoring of tensions and currents in the electrical load [3] are discussed.
- Energy storage - This experiment presents ways to store energy, avoiding unnecessary consumption during the peak periods and, thus, more expensive. Methods to select, switch charges on and off according to the

consumption behavior are discussed. This strategy has found a place in the market mainly in industrial plants and intelligent buildings in which water heating and air conditioning are preferably made outside these periods.

- Automatic Power Consumption Rationalization - This experiment aims at avoiding power wastes, automating workplaces with the use of presence sensors. The use of these sensors allows the automatic control of the lighting of rooms and corridors, of the air conditioning, as well as switching on and off equipments such as PCs and printers based upon predetermined hours for the functioning of the facilities. Additionally, the use of automatic blinds with the possibility of controlling room lighting, determining when artificial lighting has to be switched on is discussed. In order to do that, the use of a variety of sensors used for each of these tasks and their interfacing with the PLCs is discussed.
- Controlling of electrical machines - This experiment deals with the switching on and controlling of servomechanisms of position and velocity using continuous current engines and induction engines. The use of induction engines switched on by vectorial inverters is presented at the simulation level by the use of a simulation environment totally developed in Matlab/Simulink [4] [5]. This environment was designed so as to enable graduate students to apply different control strategies and parameter estimation algorithms.
- Flow rate and temperature control - Thermal processes are found in many different forms in several industrial plants and commercial buildings. A pilot process has been developed in which it is possible to control two variables: the flow rate and temperature of the air in a given point of the process. With this pilot process non-parametric identification techniques [6] [7], order and parameter identification [8] can be applied and, afterwards, controllers can be chosen and designed [9]. This experiment may use several temperature transducers such as PT100 or thermopairs and flow rate sensors.
- Conventional controller adjustments - In this experiment the controller adjustments typically used in the industry and the strategies to tuning their parameters are discussed. Together with the thermal process there is also a commercial program which makes the automatic parameters adjust of PID controllers. This software allows the real time viewing of the reference and control signals and the output variable of the process.

Building Pilot Processes

The need of having pilot processes to use a variety of control techniques studied in the classroom has been shown to be fundamental for the better use and resulting motivation of students. However, we know that teaching processes usually have a high cost which does not allow to acquire, neither in numbers nor in diversity, processes which can meet the necessary demand.

This problem has been satisfactorily overcome through a joint effort between faculty and students, resulting in the initiative of designing and building these processes. Due to the simplicity of the building process, allied to the several control techniques and algorithms which may be used, the design and building of a thermal process was initially chosen, which is shown on Figure 3.

The working principle of this plant consists of forcing an air current by means of a fan into the piping. In passing through the resistance the air flow will be heated and its temperature will be measured by a proper sensor whose signal is used for comparison with a reference value.

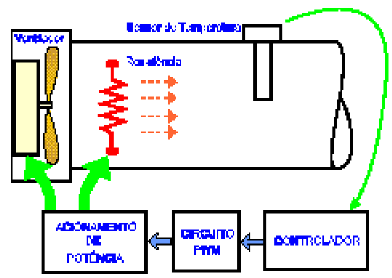


Fig. 3 - Block diagram of the thermal process.

This process is used as a basis for the following experiments:

- Joint or separate temperature and air flow rate control;
- Modeling and identification of physical processes in which continuous or digital controllers may be developed;
- Physical position variation of the sensor element, changing the time constant and the delay in transportation inherent to systems of this kind;

In Figure 4 we can see the thermal process with all electrical circuits involved in the treatment of signals and in the power switching.

We can see on Figure 4 that the process is rather simple, involving only low cost materials. We can also see that along the pipe there are three different positions for the placement of the temperature sensor which allow us to vary the time constants and the delay in transportation of the process [10].

Integration of the Tools

An experiment which can be made by integrating the PLC teaching kit with the thermal process is the temperature control using the routines of controllers of the proportional, integral and derivative type - PID, contained in the programming of the PLC.

Through this simple example students will be able to learn in the laboratory the classical ways [5] [6] for the heuristic adjustment of this kind of controllers.

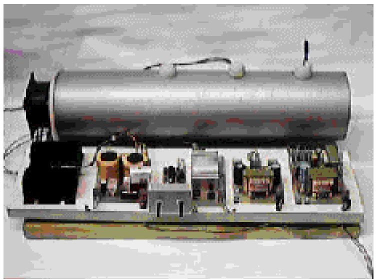


Fig. 4. Prototype of the thermal process.

The Figure 5 shows the PLC kit used together with the thermal process. The thermal sensor used is a PT100 thermoresistor type whose terminals are connected to a signal acquisition and processing board customized for this kind of temperature transducer.

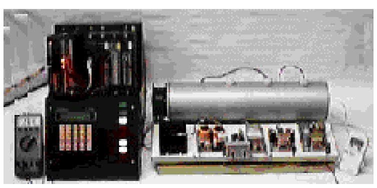


Fig. 5 - Thermal process and the PLC kit.

The tension signal from the PT100 is send to the PLC memory where it will be normalized in a 0 to 10 volts range which corresponds to 0 to 100 degrees centigrade in a temperature scale.

The measured signal is compared with a reference signal, causing the error signal which will be used as an input of the proportional, integral and derivative controller - PID, whose parameters can be manually adjusted by the user, or automatically adjusted through the use of a program called PID TOOL. This program is part of the set of functions available in the PLC.

Experiment Example

A simple application example which can be developed using the PLC kit together with the thermal process is related to the non-parametric modeling of the process through the reaction curve method [6] [7], where the gains of a PID controller are achieved through the minimization of the integral square error - ISE. This error is the difference between the output of the process and the output of the reference model, as shown in Figure 6.

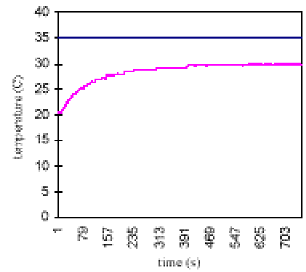


Fig. 7: Reaction curve of the process and reference signal.

The set of data acquired result in the following approximation for the transfer function of the thermal process operating in open loop:

$$G_p(s) = \frac{0.28e^{-11s}}{116s+1} \quad (1)$$

Considering the sampling rate of 20 seconds and zero order hold, the discrete transfer function of the process described in (1) is obtained. The equation (2) is used for the optimization process.

$$G_p(z) = \frac{0.0412z - 0.0412}{1 - 1.842z + 0.842} \quad (2)$$

The Figure 8 shows the behavior of the real output of the thermal process and that of the output variables generated by the approximate transfer functions of the process equated in (1)-(2), considering the same operation conditions, i.e., room temperature of 20°C and reference temperature of 35°C.

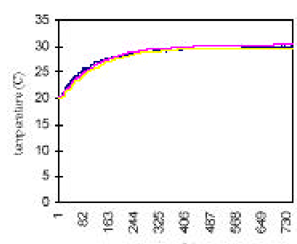


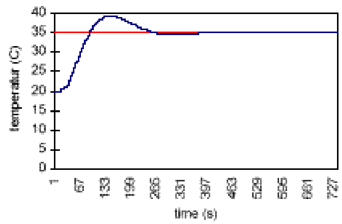
Fig. 8: Real and approximate output of the process

For the reference model a second order transfer function has been chosen, describe by equation (3)

$$G_m(s) = \frac{w_n^{\,2}}{s^2 + 2xw_n s + w_n^{\,2}} \quad (3)$$

considering as a damping coefficient **x**=0.5 and natural frequency $\mathbf{w}_n$=0.025 rad/s.

Figure 9 shows the performance of the controlled system operating in closed loop, considering the gains of the controller determined according to the scheme on Figure 6. The gains calculated by the optimizer were Kp=4.162 and Ki=1.709, and the ISE criterion resulting from the sum of the difference between the output of the reference model and the output of the controlled process is 0.0956.



This example clearly illustrates how a kit made up of industrial equipments may be used together with a real process in the classroom, being the parameters of a given controller determined by optimization algorithms which are not very used in the industrial setting.

Conclusions

This paper has presented an effective proposal for the implementation of a control and automation laboratory at a reduced cost. Still during the implementation phase of this laboratory some programmable logic controller kits were developed, as well as some pilot processes and some individual experiments.

The way in which the teaching kits and the pilot processes were designed allow them to be easily moved around. This feature makes it possible to use these experiments even in other academic units. Due to its broad application the PLC kit can be moved to control a plant which is located far from the laboratory in which the application has been developed. This allows students to design and simulate the application in the laboratory and to take the PLC to the field to validate its application.

The development of other processes, as well as the completion of the PLC modules are already in the implementation phase and will be reported on a timely fashion.

Acknowledgments

We want to thank Mr. Gerson Pozzi and Mr. Paulo Borba, human resources managers of ALTUS Sistemas de Informática S.A. for their effort and care which contributed to the good functioning of the agreement between this company and the Pontifícia Universidade Católica do Rio Grande do Sul.

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