A Data Acquisition System Used in Didactic Experiences on Control System for Engineering Courses

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Abstract: This paper presents the use of data acquisition systems in the development of laboratory experiments for teaching control of continuous processes. The approach shows the association between the concepts learned in theory, simulation and practical results obtained using a computerized system applied in a temperature control system and in mathematical modeling and control of motors. The didactic experiments are versatile, easy to implement, facilitate the learning of the student and are compatible with industrial applications.

Keywords: Data acquisition, teaching, engineering, laboratory, control system

1. Introduction

A major challenge in engineering education is to link the theoretical concepts demonstrated in classroom with the experimental results obtained in the laboratory. Particularly in the area of continuous processes, many results can be obtained easily by using tools of simulation but, typically, due to several operational factors and practical aspects, not always the same results can be verified experimentally. Furthermore, the didactic experiments should, where possible, prevent the assembly of complex electronic circuits, because in general, this is not the specific objective of the practical experiment and use considerable time making it long and boring. It should be noted that the most important is to train the student to acquire a systemic view to the development of applications and solution of problems in the area of process control.

Currently, the growing trend of digital electronics and the production of new technologies and computational tools, new experiments have been developed in laboratories allowing reproduce with relative ease, various aspects studied at theory [1]. Within this context, this article presents the application of
computational tools and modern equipment in the development of experience for control of continuous processes at engineering courses. For evaluate the effectiveness of the approach in engineering education are presented practical results obtained for a didactic temperature control system and a speed control system. Similar systems are typically found in industry and are studied in academic researches [1], [2].

2. Data Acquisition System

A computerized control system usually consists of a digital computer, a data acquisition board, electronic interface circuit and a software package that allows to obtain, to analyze and to display the data obtained in the acquisition. For the communication between the computer and external devices are available in the market several solutions. At this case, for to develop laboratory experiences has been used the educational kit ELVIS™ (Educational Laboratory Virtual Instrumentation Suite). This kit, illustrated at Figure 1, is constituted of a data acquisition board (DAQ) programmable by software based on LabVIEW™, multifunctional device and a workstation with protoboard where the student can develop the applications [3]. In addition, to handling the input and output, analog and digital, the kit allows to develop a series of virtual instruments including oscilloscope, signal generator, voltage variable source, among others. The data acquisition board available is the model NI PCI-6251 that has eight channels of differential analog inputs (or 16 single-end) with A/D converter of 16 bits and sampling rate of 1.25 MS/s to 1 MS/s with configurable range ± 10 V, ± 5 V, ± 2 V, ± 1 V, 0.5 V, ± 0.2 V or ± 0.1 V. It has two channels of analog output with D/A converter of 16 bits and sampling rate of 2.86 MS/s to 2 MS/s with configurable ranges ±10 V or ±5 V.

Figure 1 Implementation of data acquisition with kit ELVIS™
3. Temperature Control System

The temperature control system is shown at Figure 2. It is a heating system that allows control the temperature of a didactic oven built in wood and heated by voltage control in a lamp. A thermocouple (Pt100) is used as a temperature sensor and provides a level of voltage proportional to the temperature in the oven. The conversion of the sensor signal and the electric power control at lamp are made by devices distributed in an electric panel (Figure 3).

Figure 2 Temperature control system

Figure 3 Electric panel used to control of power / temperature
At the top of the control panel there are two transmitters of signals (model CTA-3). These transmitters are responsible for converting the signal from the thermocouple in a level of tension appropriated for the control and the conversion of signal of control in a voltage level appropriated for the solid-state relay (AFC-01). At the bottom left is the solid-state relay used for control of the electric power of lamp (the phase angle) based on the tension generated by the transmitter ATC-3. The control can be implemented externally using the signal of sensor (after conversion in CTA-3) and generating a voltage control. The system presents industrial PID controller (model CTM-44) available. Using the CTM-44 or developing the control externally through other tools (such as data acquisition cards, electronic circuits, etc.), the control of temperature should be implemented as the block diagram of Figure 4, where PV is the process value, SP is the set point, E is the error obtained and CO is the controller output.

The modeling of thermal systems can be made analyzing the capacitance and thermal resistance, resulting in the equation that represents the behavior of the system [4]:

$$C \frac{d\theta}{dt} = h + \frac{1}{R} (\theta_i - \theta_0)$$

where $R$ is the thermal resistance ($\text{s}^\circ\text{C}/\text{kcal}$), $C$ is the thermal capacitance ($\text{kcal}/\text{C}$), $h$ is the variation of the heat produced by the heating system relative to the point of operation ($\text{kcal/s}$), $\theta_i$ is the variation of air temperature at input in relation to the point of operation ($\text{C}$) and $\theta_0$ is the variation of air temperature at output in relation to the point of operation ($\text{C}$). After some mathematical manipulations and simplifications (for example assuming that has no variation of temperature at input), using Laplace transform considering $\theta_0 = 0$ when $t = 0$ s, and adapting this solution to the temperature control system of Figure 2, we get:

$$PV(s) = \frac{K}{T s + 1} CO(s)$$
where $K_S$ is the gain constant gain in open loop and $T_S$ is the time constant of the system. The resulting transfer function is estimated by the students in laboratory applying theoretical concepts [4], [5]. To validate the transfer function is obtained the response in loop open and using as reference a set point with 100% of the reference voltage. The typical simulation and practical results obtained at output are illustrated at Figure 5. Note that there is a similarity at the results.

![Figure 5 Open loop response in the temperature control system (a) Simulation (b) Practical result with data acquisition](image)

Using the estimated transfer function, the students apply methodologies for process control for determining different types of controllers such as proportional, integral and differential (PID) controllers, fuzzy controllers, lead-lag compensators, etc [1], [2], [4], [6], [7], [8], [9]. The typical waveforms obtained by simulation and by data acquisition using proportional and integral (PI) controller are shown at Figure 6. It is observed that: there is a great similarity in the responses; were used a setpoint of 0.12 (12% of the reference voltage), low value to prevent saturation in the control signal; the response do not presents error and is faster than the original system; the signal of control presents a snapshot peak but after about 300 s it stabilizes.

### 4. Modeling and Speed Control of DC Motors

Consider a speed control system of a direct current (DC) motor illustrated at Figure 6. The system consists, besides the motor, a power electronic drive including pulse width modulation (PWM) converter, an electric DC generator that acts as variable charge for the motor, a tacho-generator which acts as a speed sensor and a sensor of current based on effect Hall [1]. The DC motor used, has rated speed of 1800 rpm, rated voltage of 200 VDC, rated current of 11.5 A and
power of 2kW. The motor is driven by configuration with winding-field powered independently and has its speed controlled by the voltage of armature provided by the controller in LabVIEW® software.

![Figure 6 Closed loop response with PI controller in the temperature control system](image)

(a) Simulation (b) Practical result with data acquisition

![Figure 7 Speed control system](image)

When starting the DC motor the current produced increases considerably and may reduce its life and cause damage to electronic components of the system drive. Therefore, a sensor based on effect Hall is introduced at internal loop of the control system in order to limit the electric current as illustrated at Figure 8. The sensor used allows measurement of AC or DC currents from 0 to 57 A, has response time of 3 µs and offers a sensitivity of 49.6 mV/A.
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Figure 8 Block diagram of speed control system

At Figure 8, $K_w$ is the constant of speed, $K_t$ is the constant of torque, $K_{PWM}$ is the relationship of proportionality of the pulse width modulation (PWM) converter, $K_{TACO}$ is the relationship of proportionality between the speed of motor and voltage measured at tacho-generator, $K_{ia}$ is the relationship of proportionality between the current of motor armature and voltage measured produced by sensor, $J$ is the moment of inertia of motor, mechanical load, coupling, etc., $b$ is the viscous friction between the motor and load, $L_a$ is the reactance of the armature, $R_a$ is the resistance of the armature and $T_L$ is the torque load.

For estimate the parameters of the model proposed, made up of data acquisition of voltage in tacho-generator and electrical current in armature using at input a rated voltage (setpoint = 10 V). The results obtained are illustrated at Figure 9. Data were filtered to minimize the noise in the signal of sensors. Applying several methods of parameters estimation [1], [5], [10], the students can obtain the mathematical model of speed motor control system. To check the validity of the model a simulation is done, comparing the waveforms obtained with the practical results (Figure 10).

Figure 9 Data acquisition of motor - voltage in tacho-generator and current in armature
Having estimated the mathematical model, two PID controllers is tuned by students, respectively for the loop of limitation of the electrical current and for the loop of speed control. Based on the project, practical tests is performed with data acquisition and by simulation using setpoint = 8 V. The typical results are shown at Figure 11 that presents the measurement of electrical current and voltage in tacho-generator. It can be observed, the rapid response of the motor speed when the load is randomly introduced, abruptly, during the running of the motor after 20 seconds, and the withdrawal of the load, also abruptly, after 35 seconds. It also notes that comparing simulation and practice that there is a great similarity in the responses and the PID control is efficient because eliminates the steady state error control, limits the electrical current when the motor is starting and presents rapid response.

Figure 10 Open loop response in the speed control system (a) Voltage in tacho-generator (b) Electrical current in armature

Figure 11 Closed loop response with PID controller in the speed control system (a) Simulation (b) Practical result with data acquisition
5. Final comments

This work presented examples of applications and efficient tools to the didactic teaching of control of continuous processes in engineering courses. The experiments also can be used to teach concepts related to power electronics, protection of power systems, instrumentation, among others. The proposal uses data acquisition system and software recognized in academia [3] as well tools and equipment similar to those typically found in industry. The results show the applicability of the solution with equivalence between simulation and practical results, and its relations with the theoretical concepts presented in the course of engineering.

The use of computational tools in the design of control systems allows the students to develop the non-parametric modeling of systems and implement a variety of techniques of digital control with relative ease, precision and efficiency. In addition, the computational approach allows assess aspects that are not typically explored in theory such as the analysis and the compensation of the effect of saturation in sensors and actuators, the presence of noise in the signals measured, non-linear components presents in the system, etc.

Finally, it is important to note that due to the teaching resources available in the equipments and ease of use of the software, there is not practically spend of time on assembly of electronic circuits and programming the algorithm. The results in terms of learning are clear and students show up much more interested. They have easy to assimilate concepts that are typically very difficult to understand in the classroom, and are manifested often surprised when observe that there is actually the equivalence between the expected results and those obtained in experiments in the laboratory.

References
