AC 2008-2602: DRAG-AND-DROP GRAPHICAL USER INTERFACE FOR PROCESS CONTROL EDUCATION

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Drag-and-Drop Graphical User Interface for Process Control Education

Abstract

One of the difficulties in process control education consists of providing a theoretical foundation maintaining the practicality. Experimental laboratories represent a powerful option to avoid this gap. An experimental laboratory must include industrial equipment and software systems in order to provide a real experience. However, industrial equipment demands several time-consuming procedures (i.e. training, configuration, etc). A *Drag-and-Drop Graphical User Interface* (*GUI*) is designed to facilitate these procedures and to assist students in achieving deeper understanding on process control. The *GUI* allows students the implementation and evaluation of different process control strategies exploiting industrial equipment. Early results are motivating.

Introduction

Important recommendations regarding needed reform in undergraduate control education consider[4]: "to provide practical experience in control system engineering…". Additionally, " the community and funding agencies must invest in new approaches to education and outreach for dissemination of control concepts and tools to nontraditional audiences". The panel also recommended the integration of software tools such as *Matlab* into these courses[29].

The proposal considers a *Drag-and-Drop Graphical User Interface* (*GUI*) that communicates an industrial PID controller with a personal computer. The communication system is hidden to the students. The *GUI,* follows the *plug-and-play* philosophy, which avoids the training and configuration time that every experimental laboratory demands. This interface allows students to interact with real process systems. Several control strategies can be easily implemented based on *Matlab/Simulink* or compiled on *ANSI C* scripts.

This paper is organized in the following way: First, a state-of-the-art review of similar projects is presented. Second, the design principles of the engineering course at *Tecnológico de Monterrey* are briefly described. Third, the academic proposal is described. Fourth, results of undergraduate senior students are presented. Finally, conclusions and future work end this paper in section Fifth.

State-of-the-art

Although there are many significant projects in this field, the projects described below are mainly related to the continuous control systems domain. The papers were organized in three tables based on the main contribution/innovation: simulation, laboratories and remote laboratories.

Table 1 . Simulation/software research works.

Principal Author	**Yea r**	**Approach/Comments**	**Simulated systems**
Mansour[24]	1989	Commercially available simulation and computer-aided control system design packages are used in teaching together with real-time software and with special programs developed for specific purposes.	Traffic systems, HVAC systems, inverted pendulum systems, etc.
Cooper[11]	1999	*CStation* is a training simulator that provides students with a broad range of meaningful. *CStation* can bridge the gap between textbook and laboratory.	Gravity drained tanks, heat exchangers, pumped tank, jacketed reactor, Furnace heater, Multi-tank processes, distillation column, etc
Irawan[19]	2001	Website with tools related to identification systems, design and control experimentation	Coupled tank system
Hough[18]	2002	Students interact with a website : interactive learning, tutorial, instrumentation notes.	Chemical Engineering examples
Martin[25]	2005	Modelling methodology for interactive simulation based on Ejs, Matlab/Simulink and Dymola Modelica	Industrial boiler Batch Chemical Reactor
Alves[2]	2006	EDUcational SCAda with real or simulated device that incorporates OPC server. The system allows the students to face real practical problems. It could be used for training operators in plant supervision. It also allows the implementation of research functionalities	Process simulators or real systems
Lim[22]	2006	Programming environment using the real-time operating system VxWorks from WindRiver Systems.	An analog dynamic simulator represents the process.
Cox[12]	2006	Study operability and design control strategies based on dynamic models.	Examples with: partial condenser, continuous processes, batch processes, polymer processes.
Xuejun[37]	2007	Methodology to implement real-time digital simulation with no hardware-in-the-loop and a pure software real-time digital simulation	The *LabVIEW* Simulation Interface Toolkit provides a seamless integration with MATLAB/Simulink

Table 2 . Laboratories research works.

Principal Author	Year	Approach/Comments	Systems
Lim[21]	1991	A low cost workstation prototype for control design and real time implementation is built (PC with analog input -output adapters and *Matlab*).	Coupled water-tanks and/or motor sets are monitored.
Etxebarria[14]	98	*RealTime Workshop* exploiting a digital signal processor with an analog-digital and digital-analog converter receives firmware generated in *Simulink*.	Simulation and *Comdyna GP-6* analog computer
Bequette6	2002	A control studio that combines lectures, simulations, and experiments in a single classroom is presented.	A prototype chemical process control experiment mimics the behavior of a typical chemical process
Ang[3]	2002	A control interface was implemented in *HP-VEE* (visual programming environment).	Air bath system, water flow system, tank pH control, water tank level, variable measurement time delay system, dye concentration system, 4-tank water level system , temperature / level in a water tank and multi-tank pH.
Bachnak[5]	2002	A series of data acquisition systems based on *NI* systems and *Matlab*.	Flow processes and air heating systems are studied.
Saco[31]	2002	Combine *dSapce* board that implements a real time interface with *Matlab/Simulink*.	3-interconnected water tank.
Morales-Menendez[26]	2005	Educational workstations exploiting industrial sensors, actuators and control systems.	Tank-level system, heat exchanger, heat dryer, pneumatic cylinders, several industrial sensors, flexible manufacturing cell, etc
Klan[20]	2005	A portable instrument called *CTRL* that is an autonomous mini-sized microcontroller-based interface.	Hydro-pneumatic, rotation speed-control, ball and ellipse, temperature air, and time delay.
Novak[30]	2006	Integration of commercial educational equipment with *Matlab/Simulink* software.	3-tank system, inverted pendulum, magnetic levitation, twin rotor system, servomotors and analog controller.

Table 3 . Remote laboratories research works.

Principal Author	Year	Approach/Comments	Systems
Zhang[38]	2004	*Netlab* is a remote laboratory that interacts with real devices. It can execute *ANSI C* compiled scripts.	DC systems, inverted pendulum, triple tank systems, etc.
Burchett[8]	2005	A system identification experiment using physical plants and digital computer controllers.	Educational Control Products: rectilinear control system.
Valera[34]	2005	Using *WinCon* developed remote laboratories.	Servomotor and shaker table.
Coito[10]	2005	Using *SCMRVI*, students from their workplace, access remote experiments.	Temperature air-flow process, Two-tank level.
Selmer[32]	2005	An user-friendly graphical user interface and the interactive, fast responding process were developed.	Heat exchanger.
Davari[13]	2005	Remote Laboratory exploiting Educational Control Products	Torsional and a rectilinear control system.
Viedma[35]	2005	*iLab* is a system based on the *TCP/IP* protocol.	A card stimulates and captures data from a filter build with op-amps.
Chaabene[9]	2006	A real laboratory control based on a web embedded system and an interactive web application is proposed. A set of software embedded in the local control system overcome the time delay due to internet traffic.	Didactic lift.
Wu[36]	2006	Internet-based control engineering laboratory. Several on-line features are incorporated	Fan and plate, coupled tank, inverted pendulum, DC servo and other control systems.
Hassan[17]	2007	An architecture that allows remote development and validation of embedded control applications: *simPROCes.*	Pilot water tank.
Hercog[16]	2007	A framework for remote experiment implementation.	RC oscillator, speed control of DC motor, cascade control of DC motor and mechatronic device.
Uran[33]	2008	A virtual web-based laboratory for control design experiments.	Computer- aided control design and structured hands-on experiments (mathematical models).

Educational Principles of Design

Two main directions are taken into account for the design of an engineering course at *Tecnológico de Monterrey*: the 2015 Mission and the *Accreditation Board of Engineering and* Technology (*ABET*[1]) criteria.

Based on a wide survey with industry leaders, students, faculty members, and ex-alumni the new 2015 mission of the *Tecnológico de Monterrey* is to prepare students and transfer knowledge: (1) to promote the international competitiveness of business enterprises based on knowledge, innovation, technological development, and sustainable development, … with this mission (among other objectives), the *Tecnológico de Monterrey* and its community are committed to contribute to the educational, social, economic, and political improvement of México.

ABET[1] is a well known recognized accreditor for college and university programs in applied science, computing, engineering, and technology. *ABET* criteria effective for evaluations during the 2006-2007 accreditation cycle states that engineering programs must demonstrate that their students attain several outcomes (Criterion 3). Through this project, (b) and (e) outcomes will be specifically promoted: (b) ability to design and conduct experiments, as well as to analyze and interpret data, and (e) ability to identify, formulate, and solve engineering problems.

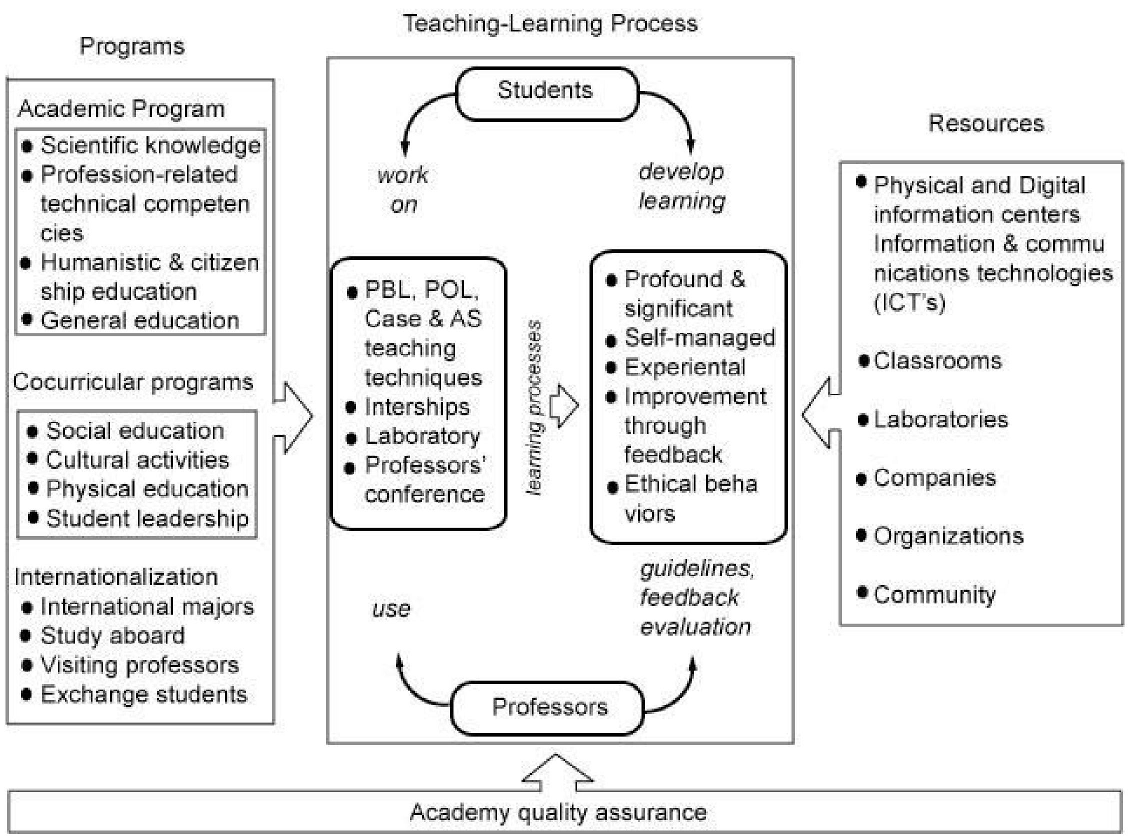

Figure 1. Educational Model of the Tecnológico de Monterrey.

Following these directions, an educational model was developed at the *Tecnológico de Monterrey*, Figure 1. This educational model has been characterized by its richness on information technologies (i.e. *Blackboard suite*[7]) and the systematic incorporation of teaching techniques.
Students assume an active role in their learning process and build knowledge on the basis of their own experience and by reflecting on the same, under the direction and guidance of their professors.

Professors rely on teaching techniques that enrich students' curricular education on the basis of a practical, professional approach achieved through teamwork and active participation. Some of the teaching techniques are: the case method, project-oriented learning, problem-based learning, collaborative learning, and other techniques centered on active learning, such as research-based learning and learning-service.

Figure 2 shows three aspects that are involved with the creation of any course[15]. This paper is primarily focused on the instruction aspect of the educational and research, both software and systems, software which implies the selection and implementation of the teaching techniques combining technology that allows students to reach learning objectives, skills and abilities[27].

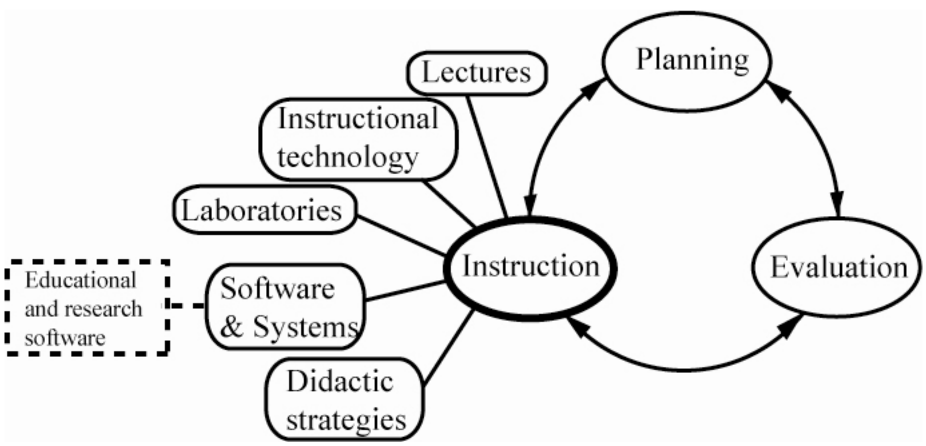

Figure 2. Aspects of course design cycle, leads to continuous improvement. As the quality of the instruction improves, new planning activities may be defined to encompass higher levels of achievement; evaluation should be modified accordingly.

Academic proposal

Special attention was given to the experimental teaching. Several constraints were identified in our previous projects[27]. A research project was started in 2006 looking for a solution of some limitations. The goals of this research project include that students can:

1. *interact* with industrial equipment
2. *avoid* the time that is consumed in the that installation and configuration steps.
3. *design* and *implement* different control strategies

Given that there are several tank-level control stations at *Tecnológico de Monterrey*, a *Drad-and-Drop Graphical User Interface* that communicates a personal computer with an industrial controller was developed.

The tank-level control station is shown in Figure 3 (right picture). The instruments installed in on this station are industrial devices: 2 flow transmitters (FT-101, FT-102), 1 level transmitter (LT-00), and 1 control valve (FV-100). V_1 and V_2 are manual valves that allow us to introduce disturbances at the input and output flow. These characteristics of the tank-level control station met the first aforementioned objective of this research project.

Figure 3 (left picture) shows the architecture of the communication system. The *Drad-and-Drop Graphical User Interface* has a special module designed to monitor and manage communications with controller. The communication is done throughout a RS485 to RS232 converter/ modem connected to a personal computer. The main challenge here was the integration of soft real-time with *Matlab/Simulink* and *ANSI C*.

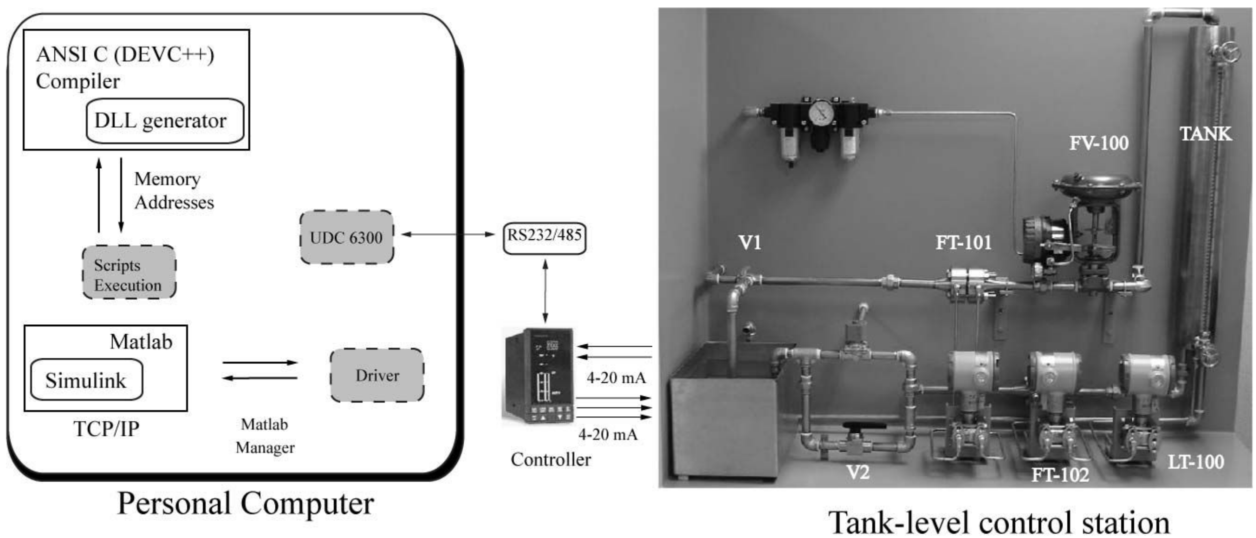

Figure 3. Communication system. The Graphical User Interface communicates with the controller by a serial communication system with a RS232/485 modem. The controller has a standard 4-20 mA communication with sensors and actuators. By TCP/IP the interface interchanges data with Matlab/Simulink software and through the memory; it addresses talks with ANSI C scripts.

The *Drad-and-Drop Graphical User Interface* has two additional interface modules. One interface is dedicated to send and receive data from the software running on *Matlab/Simulink*. The communication is done through a loopback *TCP/IP* connection on the personal computer. Once the simulation is started on *Matlab/Simulink*, the time is controlled by the software.

A *Matlab/Simulink* model containing the variables of the process is provided to the students, Figure 4. Users only have to *plug and play* with this model. The *HMI* meets the second aforementioned goal with these features.

Results.

The *Drad-and-Drop Graphical User Interface* has been tested during one year in a senior automation control systems course. In the first term, three (4-students) teams were working with it. Three different projects were defined, the implementation of (1) a fuzzy logic controller[23], (2) a cascade and feed-forward control strategies and (3) a feedback control strategy with different PID tuning techniques. In the second term, two new projects were defined, designed and implemented: (1) a Smith predictor control strategy and (2) an Internal Model Control (*IMC*) strategy[28].

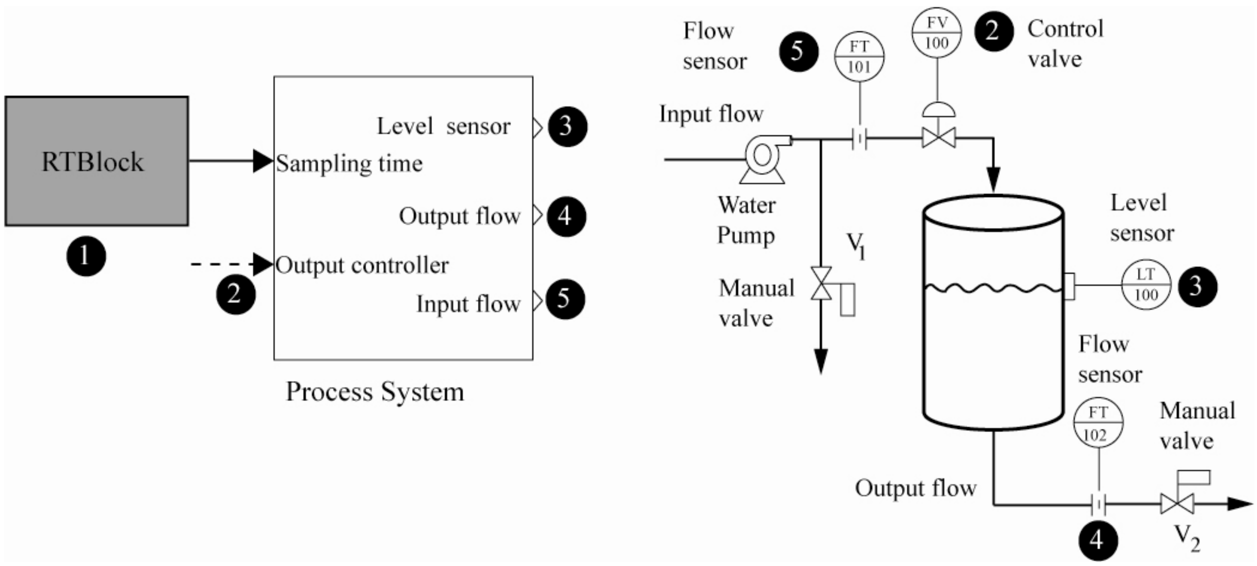

Figure 4. Tank-level Simulink model. Using the left Simulink model, students write the (2) output controller and read the process variables: (3) level, (4) output flow and (5) input flow of the tank-level control station. Using the RTBlock, the sampling time can be defined. The level-tank station diagram shown in the right includes a level-tank system, 2 flow sensor-transmitters (FT101, FT102), 1 level sensor-transmitter (LT100), and 1 control valve (FV100). The numbers show the virtual and physical equivalences.

Right picture in Figure 4 shows a basic instrumentation diagram of the tank-level control station. A cascade control system was implemented Figure 5. Cascade control is widely used within the process industries. There are two nested feedback control system: there is a slave control system (FIC-101) located inside a master control system (LIC-100). The master controller is used to calculate the *SP* for the slave control system. Cascade control is used to improve the response of a single feedback strategy. Figure 6 represents the *Matlab/Simulink* model implementation. This figure shows the simplicity of the implementation; however, students were working hard during the identification process test and PID tuning.

The academic goals were centralized into the experimentation step. Several tests were implemented in order to evaluate the performance of the system. A set point change is shown in Figure 7 as an example of what students developed. The approximated time that a four students (working as a team) dedicated to this 3-weeks project is shown in Table 4.

The students showed high motivation while working in the project, therefore it is important to evaluate the performance of the drag-and-drop graphical user interface as an educational tool. As assessment method, a scoring rubric on learning outcomes was chosen. A rubric is a scoring guide that contains well-defined and systematically applied criteria. Rubrics are useful when a behavioral or subjective issue has to be evaluated such as problem solving as a process, design as a process, student's skills with equipment, team work skills, and leadership abilities. In this course, there are 2-3 design problems in every experimental session where students working in teams must deal with. Detailed rubrics are ideal as an assessment method.

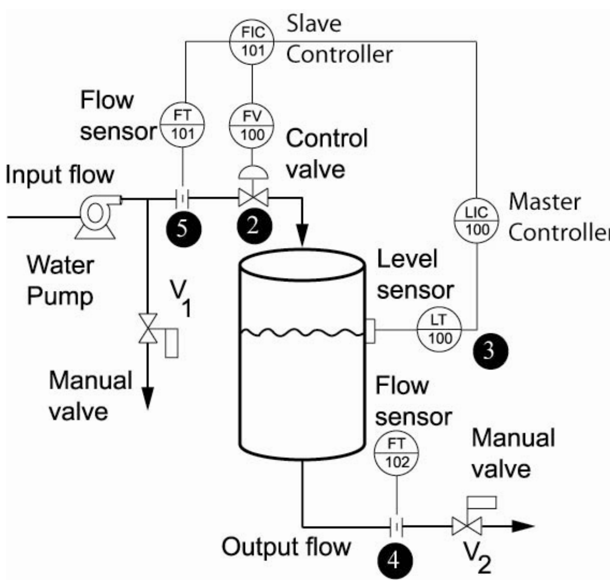

Figure 5. Cascade control system. The master controller LIC-100 must keep the level-tank (LT-100) in the set point by manipulating the set point of the slave controller FIC-101. The slave controller FIC-101 must keep the input flow (FT-101) in the set point by manipulating the control valve (FV-100).

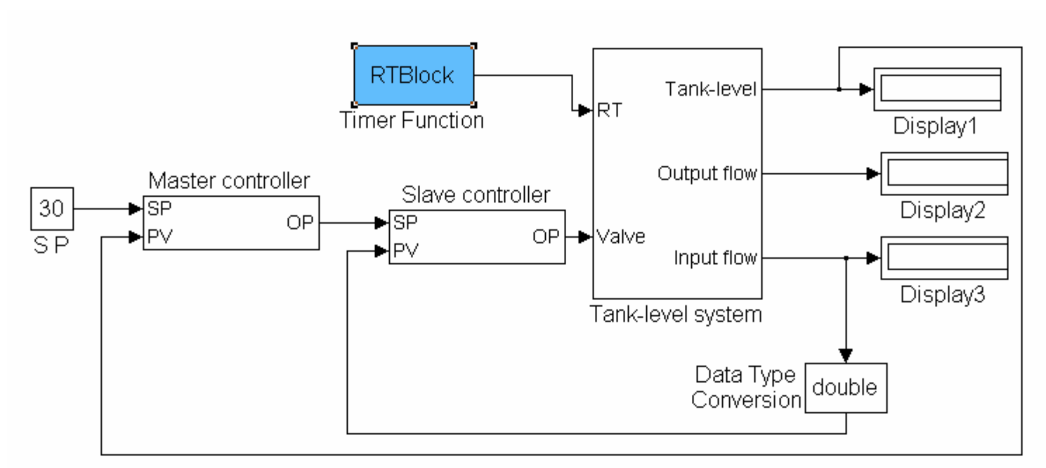

Figure 6. Cascade control model based on Matlab/Simulink.

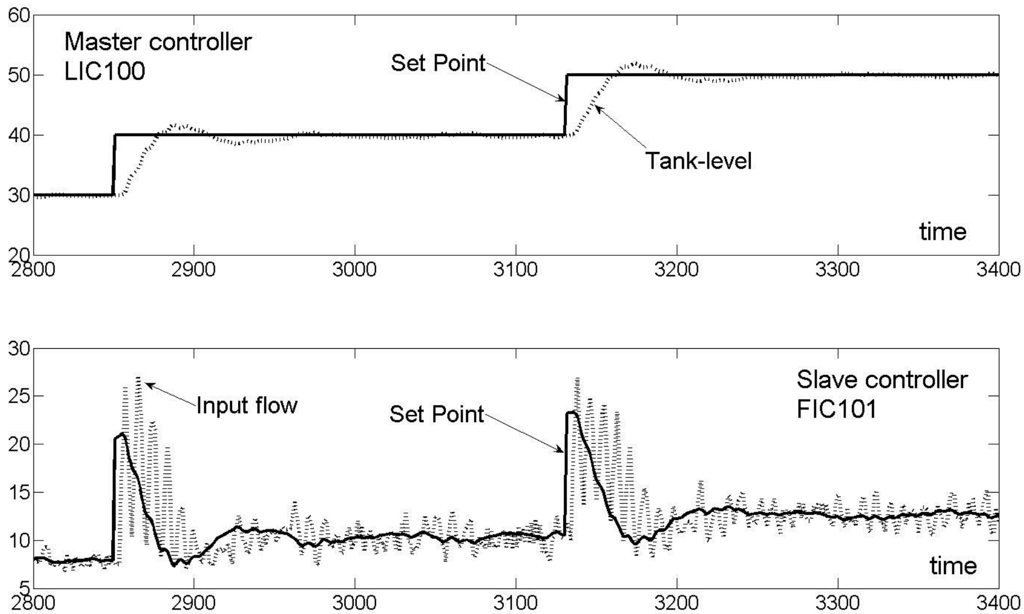

Figure 7. Cascade control system performance. Top plot shows the master control system performance (LIC100); while, bottom plot shows the slave control system.

Table 4. Typical 3-weeks project activities.

Activity	Time (hrs)	Students learn …
Read	3	Cascade control theory
Analyze the process	2	How to analyze…, work with industrial systems…, identify potential problems…, operate real control systems…
Use the Drag-and-Drop Graphical User Interface	2	how to interact with the system (communication, data logging, etc)
Implementation	2	how to design and implement control strategies (physical limitations, operational constraints, dynamic systems, etc)
Experimentation	8	how to tune the PID controllers.., evaluate servo-control and regulator approaches…, implement disturbances…, change operating conditions and evaluate their impact in control systems…, compare theoretical and real results…, etc
Reporting	4	how to analyze and organize information and ideas, identification of performance indexes, write/edit a report, etc

According to *ABET*[1] criteria, Figure 8 shows an example of the Learning Outcome Assessment Rubric for Learning Outcome (b) *Ability to design and conduct experiments, as well as to analyze and interpret data.* With this detailed rubric, each student is assessed in several issues: (1) Problem, process and variables definition, (2) Response variable measurement and operation ranges interpretation, (3) Design of experiments, (4) Experiment planning and data collection, (5) Equipment operation, (6) Safety procedures, and (7) Statistical tools and analysis for improvement.

Each of previous issues has a specific weight (w), and there is a suggested scale (s) for each score. Using this matrix, a better feedback can be obtained. However, sometimes it is recommended to derive a holistic rubric from the detailed rubric. A holistic rubric allows you to asses different skills of the students for accreditation purposes once or twice rather than on each experimental session. For example, sometimes writing skills are more important than designing an experiment or student competencies with laboratory equipment. Certainly, to assess all of the laboratory skills in each experimental session will be overload for everyone.

Conclusions

This academic proposal helps students to develop and operate real control systems. This facilitates the teaching/learning for students with no background in electrical or computer sciences. Also, the gap between theory and practice is eliminated through hands-on laboratory sessions.

Several skills and abilities are promoted as part of the teaching system. Starting from a real problem, students can find the context for significant learning and what they need to find and learn. Working with real problems allows the students to develop concrete abilities. Students, assuming control over their learning process, may evaluate the results. So, theory may be better understood, thus facilitating knowledge transference to other contexts.

Future work. Reduction of sampling time is mandatory. The *Drag-and-Drop Graphial User Interface* can be improved with an OPC interface. This increases the number of devices to communicate with; also, the communication system with them will be more reliable.

Acknowledgement

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Tecnológico de Monterrey

Automation Laboratory

Learning Outcomes Assessment Rubric

Learning Outcome (b): Ability to design and conduct experiments, as well as to analyze and interpret data

Item ↓ (Weight)	Unacceptable (s = 0)	Marginal (s = 1)	Acceptable (s = 2)	Very Good (s = 3)	Points Scored †
Problem, Process and variables (w = 1)	Does not understand the process, operation and response variables. Does not develop a problem statement	Understands the process, operation and response variables. Can develop a problem statement, but critical information is left out	Understands the process, operation and response variables. Can develop a problem statement with some information missing	Very good knowledge of the process, operation and response variables. Uses that knowledge to define a problem clearly	
Response variable measurement and operation ranges (w = 1)	Has severe difficulty setting levels for operation variables, as well as measurement methods for response variables	Has some difficulty in selecting operation levels and measurement methods for the response variables	Can choose operation levels to use. Knows about response variables and measurement methods	Can rank response and operation variables according to their importance. Can choose levels to use, measurement methods and their accuracy	
Design of Experiments (w = 1)	Needs assistance to choose the model to use	Can choose the model, but needs reassurance from the instructor	Can choose model correctly and confidently	Chooses models correctly and knows how to improve the model through sequential experiments	
Experiment Planning and Data Collection (w = 2)	Does not distinguish between repetition and replication. Needs assistance to plan experiments and collect data	Knows the difference between repetition and replication. Needs some assistance to plan experiments and collect data	Determines the need for repetition or replication. Collects data in an organized manner	Determines the need for repetition or replication. Plans and organizes experiments, carefully documenting data collected	
Equipment Operation (w = 2)	Can not operate instrumentation and equipment correctly and requires frequent supervision and help	Operates instrumentation and equipment correctly but fails to follow experimental procedure	Operates instrumentation and equipment correctly. Follows experimental procedure with few mistakes	Operates instrumentation and equipment correctly, following the experimental procedure carefully	
Safety Procedures (w = 1)	Practices unsafe, risky behaviors in laboratory	Unsafe laboratory procedures observed occasionally. Not always uses safety equipment	Very few laboratory procedures observed. Uses safety equipment most of the time	Observes laboratory safety procedures and uses safety equipment correctly	
Statistical Tools and Analysis for Improvement (w = 2)	Makes very little or no attempt to interpret data	Makes errors and omissions in the use of statistical tools for analysis, misinterpret-ting physical meaning of results	Makes few errors and omissions in the use of statistical tools for analysis. Interprets the physical meaning of results	Excellent statistical analysis and physical interpretation of results to make improvements in product or process	
†Points Scored = w×s				**TOTAL POINTS**	

Course Number and Title: ____

Name of Student/Team: ______________________________ **ID Number:** ________

Program: ______ **Reviewer:** _______________________ **Date :** __________________

Figure 8. Learning Outcome Assessment Rubric.

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