

An Educational Level Control System

J. JAIMES-PONCE, R. ALCÁNTARA-RAMÍREZ, I. I. SILLER-ALCALÁ, I. RAMÍREZ-ALPÍZAR,
N. NÁJERA-RAMOS.

Departamento de Electrónica

Universidad Autónoma Metropolitana

Av. San Pablo No. 180, Col. Reynosa Tamaulipas, Del. Azcapotzalco CP 02200 D.F.
MEXICO

Abstract: - In this paper, a level control system is presented, which is composed of a level system, data acquisition hardware and a graphical tool. The main target of this prototype is to provide students with an environment, where theoretical concepts can be applied. Thus, students can connect control theory with practice. The control level system has the advantage to allow implementing classical controllers through a friendly user interface with minimal effort. Another advantage is the low cost compared to similar commercially available products. Implementations of classical controllers in real time are made in order to show the effectiveness.

Key-Words: - control education, classical control, process control, graphical tool, sensor electronics, microcontroller.

1 Introduction

In [1], the authors examine a common experiment (ball and beam) and conclude that virtual labs (model simulation) are good to assimilate theory, but they cannot replace real process since a model is only an approximation which cannot reproduce all the aspects of the process. To avoid these issues, laboratories that allow a student to interact directly with real process should be used.

The modernization of the laboratories (as [2], [3], [4], [5]) has been based on the following goals: creating a motivation environment for the practice of basic control laws, allowing experimental verification of fundamental concepts; providing opportunities for immediate correlation between theoretical and experimental results.

Matlab and Simulink [6] are standard tools in the control community, and they are adopted in many basic and advanced courses, the Matlab environment is used in [7] and [8]. Although Matlab is very useful, there is a problem: its cost, this kind of software is so expensive, in addition the need for an acquisition board in order to communicate the systems and the computer, the assembler language software, C++ compiler and a last generation computer to satisfy software computer requirements. All of this increases the cost of the equipment. In the control laboratory, it is necessary to have at least ten complete kits, due to the previous reasons it is impossible to acquire this kind of equipment.

In the process control laboratory, the use of Matlab has facilitated the implementation of classical and modern control [9], [10] and [11], the friendly

user interface, allows the user concentrates on the analysis and design of the control system.

This experience led to the idea of the development of a digital control system, which is presented in this paper.

On the other hand, the process offered by manufacturers like Feedback, TecQuiment, Quanser Consulting, etc. can be used effectively for any course, but the costs are prohibitive, almost nothing being available under U. S. \$3000 per item. The previous limitations had impelled to develop a low cost prototype composed of a level system, data acquisition hardware and a graphical tool.

2 Process Description

The tank apparatus is designed for the teaching of process control principles. As shown in Fig. 1, it consists of a tank mounted above a reservoir. The level of water in the tank can be read from the scale in front of the tank.

The tank is fitted with an outlet which is in turn connected to a plastic hose for returning water to the reservoir. Also, the tank apparatus has a pump RESUN model SP-2500, which is used to feed the tank and a proportional valve AALBORG INSTRUMENTS AND CONTROLS, INC. model PSV-5, it is used to open or close in a proportional form, as required by control signal.

The water level in the tank is monitored by a pressure sensor MOTOROLA model MPX2010DP along with electronic circuits, provides an output signal proportional to the level of water in the tank.

3 Level control system

The level control system is shown in Fig. 2. It is composed by a control graphical tool and electronic subsystems used to signal processing of the sensor and controller.

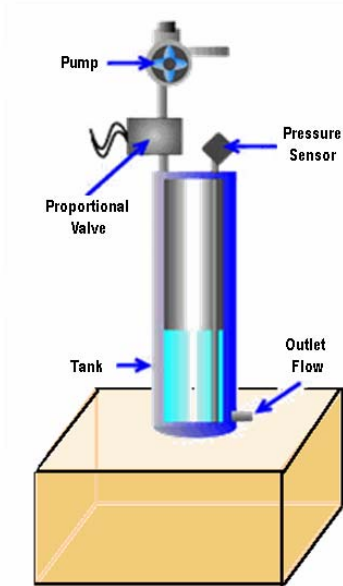


Figure 1. The tank apparatus

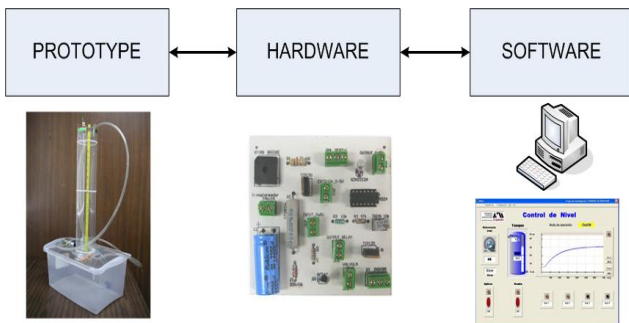


Figure 2. Tank level control system

3.1 Hardware of the system

The electronic subsystems are: a data acquisition hardware shown in Fig. 3, a sensor signal amplifier, a power stage and the modulation of energy by PWM.

The data acquisition hardware is connected to the computer using a serial port, this device is composed of a PIC micro controller 16F876, -see [12] and [13]-, and a C1 MAX232 which is used to make compatible the signals transmitted by the PIC to the computer, in others words it translates the binary signal sent by the PIC into RS232 protocol. The data acquisition hardware has four digital inputs, four analog inputs, four digital outputs and one analog output.

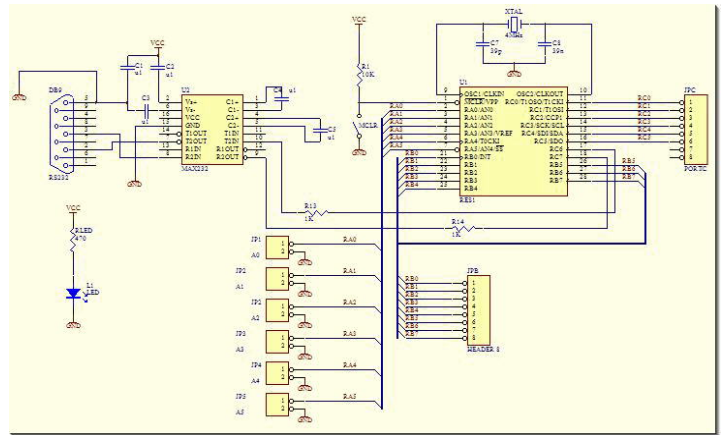


Figure 3. Data acquisition hardware

The sensor signal amplifier is shown in Fig. 4. It processes the measured pressure signal through an instrumentation amplifier. The power stage allows converting the analog control signal given by the control tool, from 0 to 5 volts into a variable signal that varies from 0 to 30 volts. This signal is used to manipulate the valve as required by the control signal. The power stage is shown in Fig. 5.

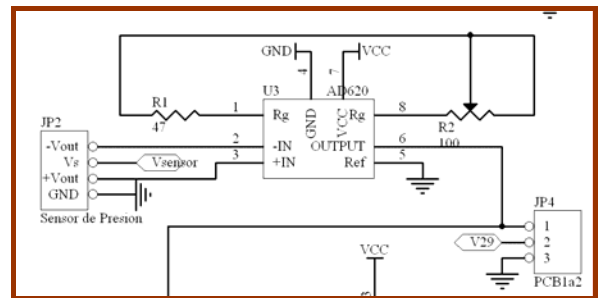


Figure 4. Sensor signal amplifier

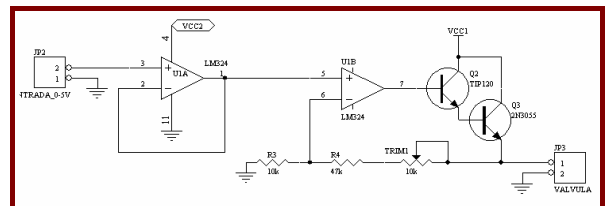


Figure 5. Power stage

The circuit shown in Fig. 6 is used to generate four digital signals to handle different logical control devices, such as data acquisition (DAQ) through a PC, PLC's (Programmable Logic Controllers) or any other electronic circuit designed for this purpose.

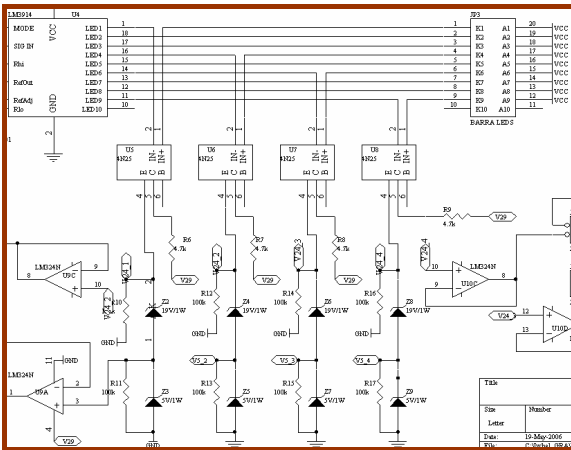


Figure 6. Circuit to generate the four digital signals

3.2 Control Graphical tool

Visual basic was the programming language chosen to develop the graphical user interface, due to its advantages was easy to develop an user interface that can be used by everyone, and the user can focus his/her efforts on interacting with the experiment.

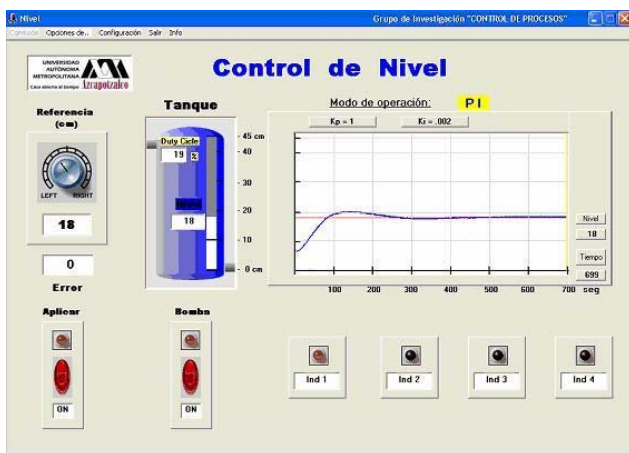


Figure 6. Main window

The Graphical User Interface (GUI) is composed of a main window with analog and digital virtual controls, virtual led, numerical and graphical displays, which are shown in Figs. 6, 7 and 8.

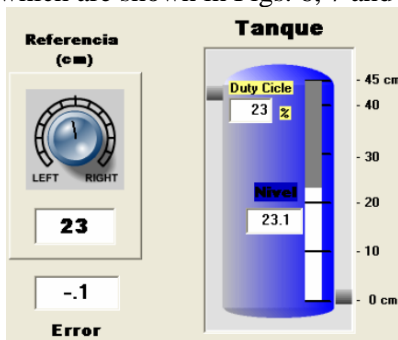


Figure 7. Reference control display and button, tank with numerical and graphical display, and error display

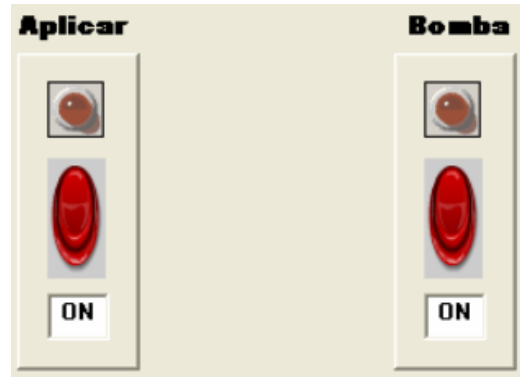


Figure 8. Stopping and starting of process and pump.

In the main menu three different controllers can be chosen by double clicking **Opciones de** (PID, On/Off and On/Off with hysteresis) see Fig. 9. After the selection of the controller a second window for controller parameter will appear Fig 10.

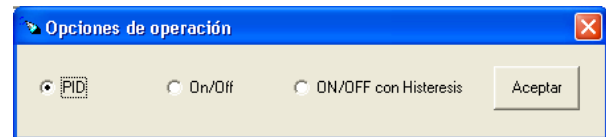


Figure 9. Implementation of Controllers

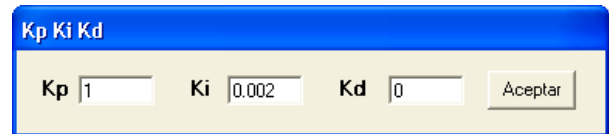


Figure 10. Parameters of controllers

4. Controller Implementation

The control graphical tool presented here, is powerful and versatile, allows to implement PID, ON/Off and On/Off with hysteresis, by just selecting a controller. In this section, a brief description of the implementation aspects is provided as well as responses obtained by applying the three different controllers.

4.1 PI Controller

The PI parameters chosen are $K_p=1$, $K_i=0.002$ and $K_d=0.05$, the set point is 23 cms. As is shown in Fig. 7, the reference and controller parameters can be changed, on line. In both Fig. 7 and Fig. 11 can be observed the system response in a virtual and graphical form, respectively. The controlled variable (tank level) achieved the reference with a small overshoot.



Figure 11. System Response using a PI controller

The equation used to implement the blocks PID is described below. The PID controller Transfer Function is given by the following equation

$$\frac{U(z)}{E(z)} = K_p \left[1 + \frac{T}{T_i(1-z^{-1})} + \frac{T_d(1-z^{-1})}{T_i} \right] \quad (1)$$

$$U(z) = U(z)z^{-1} + K_p \left[E(z) - z^{-1}E(z) + \frac{T}{T_i}E(z) + \frac{T_d}{T}E(z) - \frac{T_d}{T}2z^{-1}E(z) + \frac{T_d}{T}z^{-2}E(z) \right] \quad (2)$$

In the time domain, the signal control is given by

$$u(k) = u(k-1) + K_p e(k) \left(1 + \frac{T}{T_i} + \frac{T_d}{T} \right) - K_p e(k-1) \left(1 + 2\frac{T_d}{T} \right) + K_p \frac{T_d}{T} e(k-2) \quad (3)$$

This equation was used to build the PID implementation.

4.2 On/Off Controller

The system response with this controller is shown in Fig. 12. The response reached the set point with a good behavior.



Figure 12. System Response using an On/Off controller

4.3 On/Off with hysteresis Controller

The hysteresis levels are introduced in a window like the Fig. 13. The system response is shown in Fig. 14, it is observed the hysteresis band.



Figure 13. Hysteresis limits



Figure 13. System Response using an On/Off controller with hysteresis

5. Impacts of level control systems in teaching.

The control system described in this paper is currently being utilized in the teaching of undergraduate courses in the Departamento de Electrónica, Universidad Autónoma Metropolitana Unidad Azcapotzalco. The laboratory sessions consist of: finding the Transfer Function of the tank system by using the step response in open loop, understand the concept of closed loop feedback control (in contrast to open loop), observe the effects of controller gain on the response, predict the steady error of the Proportional Controller, and understand the reason for its existence, as well as designing a PID controller.

During these sessions, students seem to be very excited, basically because they can put in practice their control theory knowledge through a real-world problem. Since the mathematical model generally catches the main features of the system, students can evaluate the differences between the model and the actual plant and can tune on-line some parameters to obtain a controller which works better with the real process.

6. Conclusion

This paper has described the design and development of a level control system composed by a level system, data acquisition hardware and a graphical tool. As well as it is discussed its impact from a teaching point of view.

The main advantages of the present system are: versatility, controller design flexibility and low cost compared to similar commercially available products. In order to show its effectiveness strategies as On/Off, On/Off with hysteresis and PID controller have been implemented. It is considered that this prototype has an impact in the Control Theory Teaching allowing that abstract concepts would be visualized, making easy its comprehension. The author's impression with the educational control level system, is that students are motivated to approach abstract concepts with more positive attitude.

Also, the authors consider that this system is a platform on which a more powerful kit can be developed in the future.

Another advantage of this control level system is that the hardware has been designed to handle different devices of control, such as data acquisition (DAQ) devices (through a PC), PLC's (Programmable Logic Controllers) or any other electronic circuit designed for this purposes

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