Experimental Platforms based LabVIEW for teaching Electronics Engineering Courses

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Abstract— Linking control theory and instrumentation to the real world is an essential part in engineering teaching laboratories, but high cost of equipment is a big problem, especially with equipment that present real problems encountered in the industry. Additionally, it is necessary to consider in additional costs: maintenance, security and the physical space occupied by the process, for these reasons this kind of plants are prohibited for the university laboratories. An alternative is remote laboratory but it has the inconvenience of the separation between the students and the laboratory. However, different technologies have emerged which considerably reduce the costs of this learning process without using real industrial components. In this paper the subject of teaching engineering control and instrumentation from three different approaches applied the language of LabVIEW graphical programming and emulation process is addressed. The first one, based exclusively in simulation; the second, is by means of the use of Arduino; and the third, is by applying the commercial hardware from National Instrument. These strategies are well within public universities budgets.

Keywords— **G**raphical Programming, Process Simulation, Arduino, Classical Control.

I. Introduction

HANDS-ON experience is an essential requirement in engineering, as it is a practical discipline. But you should also consider the teaching of scientific principles and how to apply them to real problems, i.e. reach a balance and a link between theory and practice. Teaching control engineering or instrumentation using industrial devices or components may result highly costly even with the use of equipment specifically designed for educational purposes. When the lack of economic resources is a reality, a common practice to overcome the deficiency of industrial components is: the development of own Low Cost Experiment Kits, the use of digital simulations or the development of own software, mainly based on C language, Visual Basic, etc. as in [1]-[4]. Although, the development of software is an excellent alternative it may takes a considerably long time A second option is to acquire a LabVIEW license [5], as it is well known that LabVIEW has been widely used in universities for the purpose of teaching data acquisition, instrumentation and control [6]-[12]. This software can be used for teaching purposes by creating software applications (Virtual Laboratory). For instance, the development of Virtual Instruments (VI) applications to simulate industrial devices such as fluid containers, pressurized tanks, furnaces, engines, etc. or temperature, flux and pressure sensors. Another alternative is to use commercial systems based on microcontrollers like Arduino, which is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software [14]. Arduino is supported by Matlab, Simulink and LabView, it is a very economic microcontroller for which already exist many LabVIEW applications allowing the substitution of the data acquisition hardware. A final option is the use of the National Instruments software, from which the modulus for USB data acquisition are the cheapest and sufficient enough for many applications.

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II. Approaches General Description

A. Simulation of Process using LabVIEW

One of the most important aspects of the use of LabVIEW for process simulation is that it is possible to implement the mathematical model of a process in a SubVI [13], such that its dynamical behavior can be simulated under different operating conditions or several parametrical configurations. Moreover, this model simulation can be used for control purposes using ON/OFF or PID controllers. In the same way, a sensor can be also simulated. With the use of several of these VI's it is possible to simulate more complex systems which can include real industrial conditions for voltages, currents, pressures and fluxes, making the simulations more realistic.

B. Control and Instrumentation of Process using LabVIEW and Arduino

Arduino has become a very popular and powerful system despite its limitations in speed and capacities for data processing compared to other microcontrollers, [14].

Nonetheless, it represents a low-cost helpful option due to all the support available to create interfaces with LabView. The A/D converters, digital E/S and PWM generation make Arduino a good device for the control and instrumentation for applications not demanding high capabilities for data processing.

Several tools or functions are available for serial connections and A/D – D/A converters linked to the generation of PWM signals, Figure 1. These functions can be used to implement different and interesting projects.

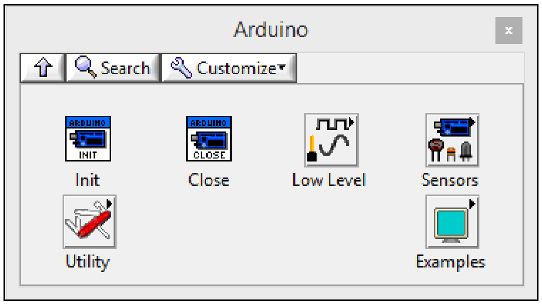

Fig. 1 Arduinos tools for LabVIEW

C. Control and Instrumentation of Process using LabVIEW

A third relatively economic option is to use National Instrument Data Acquisition Boards (NIADQ). In the market of the process instrumentation and control there are several data acquisition boards for general purposes with USB communication. In this case a real process or at least a prototype is required. A real industrial process may be really expensive; however, it is possible to construct a prototype at a considerably lower cost than a real process. The prototype of a Level process, depicted in Figure 2, consists of an acrylic tank of 50cm deep, a submerge water pump, a MPX2010DP pressure sensor -Figure 3- to indirectly measure the liquids level, and the PSV-5 proportional valve shown in Figure 4.


Fig. 2 Prototype of a Level process


Fig. 3 MPX2010DP pressure sensor


Fig. 4 PSV-5 proportional valve

III. Approaches Development

A. Simulation using Graphical Programming

The aim of creating SubVIs for the simulation of several industrial devices is to induce the students to the analysis of the dynamical models and data sheets of such devices. This will enable them to face real industrial conditions. For example, by consulting the data sheet of a humidity sensor the students must deduce that this variable depends on the environments temperature or with the dynamical model of a level system it must be also concluded that the liquids flow depends on the density and level of the liquid.

By analyzing the data sheet of the temperature sensor PT100 it can be assumed that it has linear behavior, [4]. Based on this characteristic it can be also determine how to condition its output signal using electronic components to generate measurements within industrial standards such as *0* to *5 volts* or *4* to *20 mA*. The SubVI of a PT100, in Figures 5 and 6, show the output voltage, proportional to the resistance, assuming a *1 mA* input current.

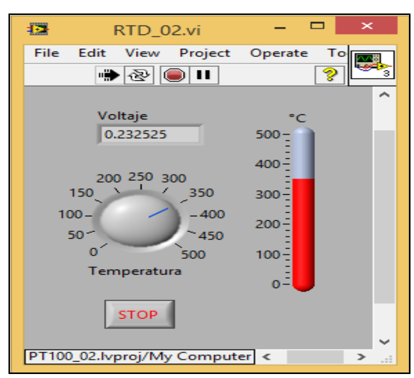

Fig. 5 SubVI frontal panel of the PT100

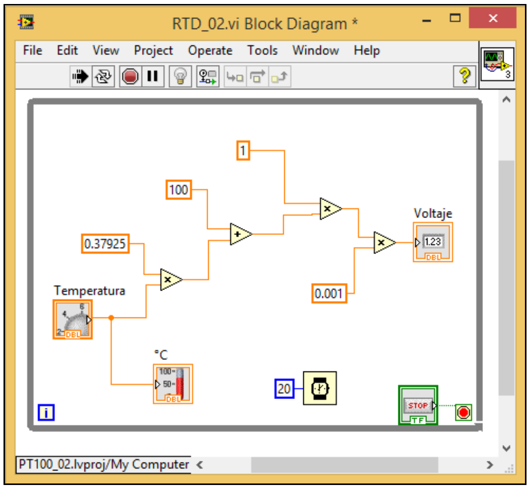

Fig. 6 PT100 SubVI program

With the SubVI of the PT100 it is possible to use it, as a specific function, in the implementation of a block diagram of some process which requires sensing the temperature, Figure 7.

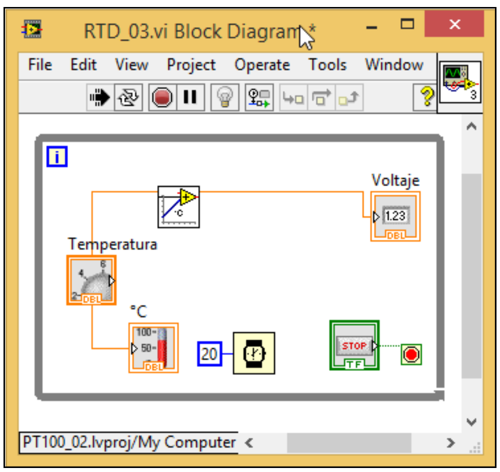

Fig. 7 Application of the PT100 SubVI

Other example consists in the implementation or simulation -Figure 8 and 9- of differential equations describing the dynamical behavior of a level system with output flow.

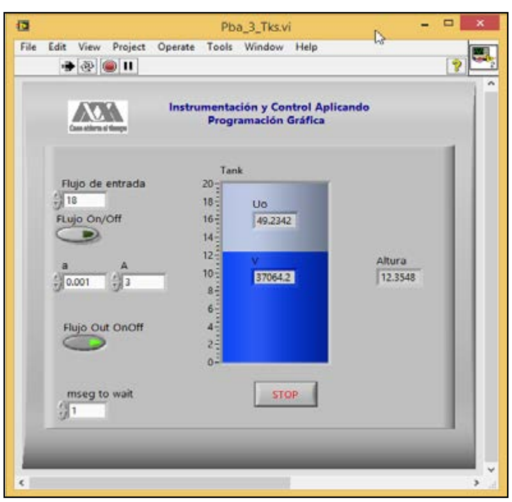

Fig. 8 Level System simulation

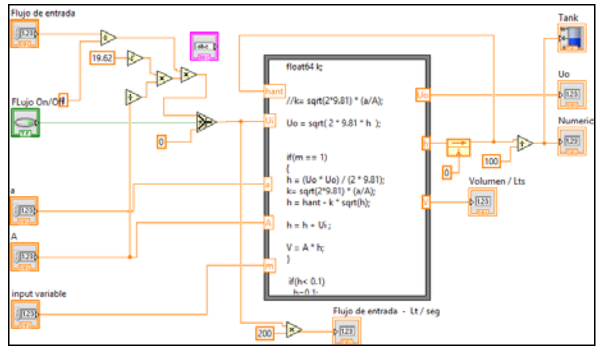

Fig. 9 Block diagram of a Level System model

Similar to the previous example, with the SubVI of the Level System it is possible to develop a VI to simulate a Level Control System which can include several interconnected tanks, Figures 10 and 11. The digital simulations have become an excellent tool to improve the comprehension and understanding of the control theory. Digital simulations allow the user to experiment using a mathematical model the effects of changing the conditions and parameters in the object of study; also, the user can evaluate the consequences of his decisions and hence to infer how the real process will behave. Therefore, the student takes an active role in the teaching-learning process by recognizing the effects of his own decisions. Also, it can be conclude that digital simulations promote the creativity, individualized learning process and auto evaluation, save time and money and even more it allows learning by discovery.

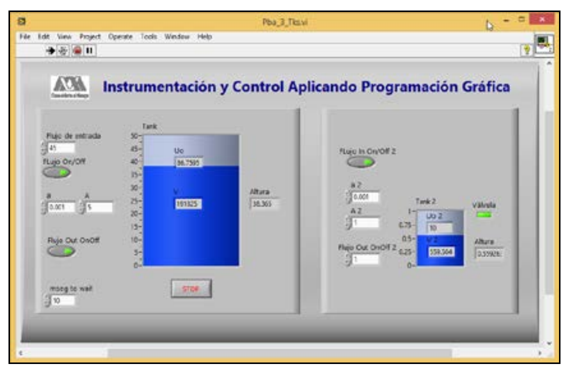

Fig. 10 Control Level System VI with two tanks

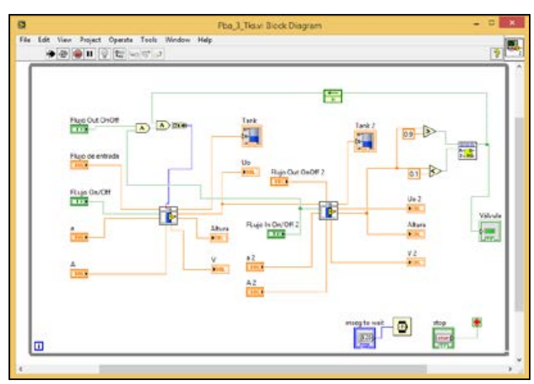

Fig. 11 Control Level System VI block diagram with two tanks

B. LabVIEW and Arduino

As mentioned above, Arduino includes a connecting or communication toolbox just like a typical USB data acquisition boards has, Figure 12. Obviously, Arduino doesn't have the resolution of industrial data acquisition boards; nevertheless, for some applications it is a powerful and economic alternative.

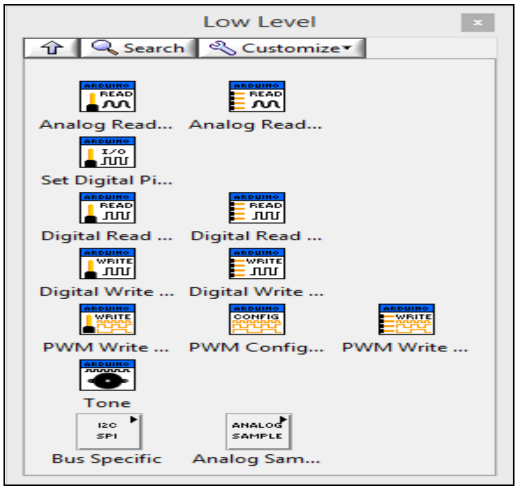

Fig. 12 Arduino communication toolbox

If a real process or a prototype is not available it is possible to emulate some simple processes using RC circuits. For example, to emulate a Level System with output flow a parallel RC circuit can be used as shown in Figure 13. In this case when switch S1 is off the capacitor C1 will discharge, and when switch S1 is on the capacitor will charge.

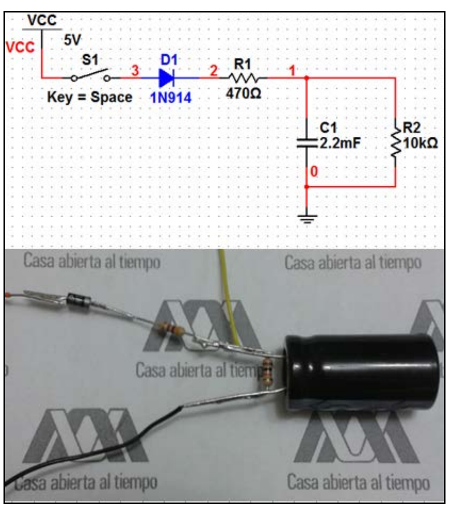

Fig. 13 RC Simulation of a Level System with output flow

Figures 14 and 15 show the charge and discharge [4] of the capacitor showing a similar response to the level system with output flow. This VI displays the control panel from which it is possible to change the level of the liquid in the tank emulating the real tank.

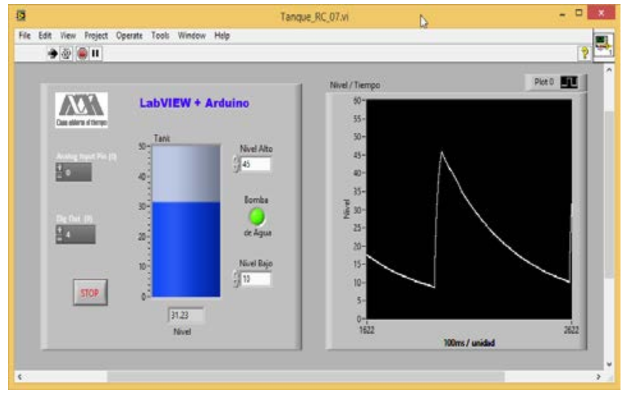

Fig. 14 VI using a RC circuit and Arduino

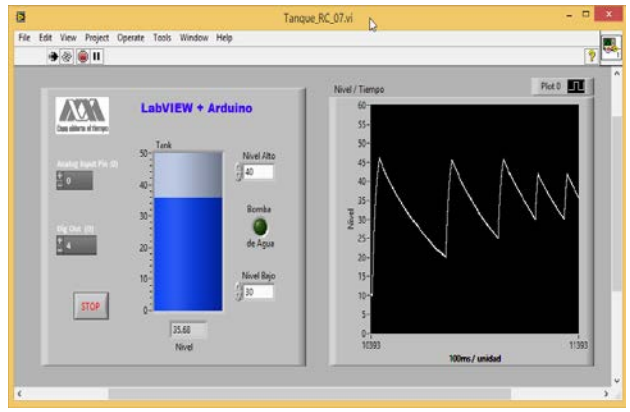

Fig. 15 VI using a RC circuit and Arduino with different control limits and hysteresis

The VI shown in Figure 16 is identical to anyone designed for a commercial data acquisition board; it only requires to substitute the Arduinos tools of data acquisition and signal generation for the specific functions of the commercial data board.

A relatively more complex application is the emulation of a Level system in which a largest tank is connected in series to two smaller tanks. This means that the largest tank feeds the two smaller tanks.

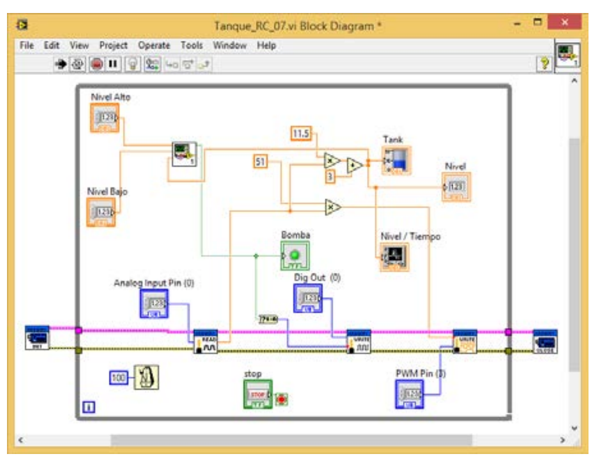

Fig. 16 Block diagram of the Level Control System with hysteresis of two tanks

Figures 17 and 18 show the diagram and the actual RC circuit that emulate the three tanks level system.

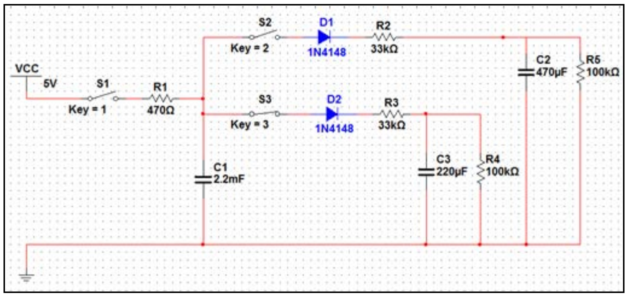

Fig. 17 Diagram of the RC circuit to emulate the three tanks system

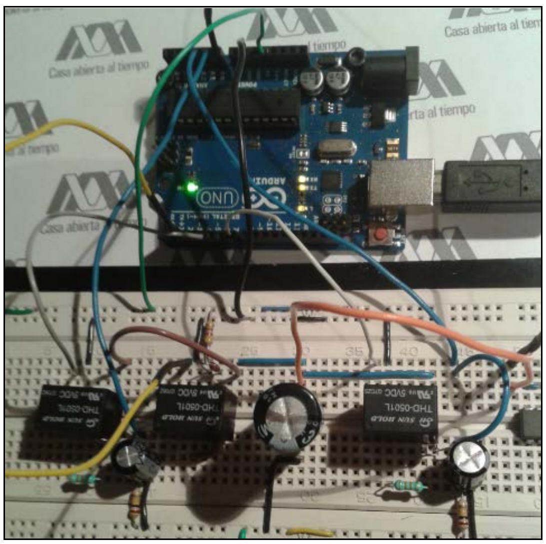

Fig. 18 Actual diagram of the RC circuit to emulate the three tanks system

The control panel of the three tank level system is shown in figure 19.

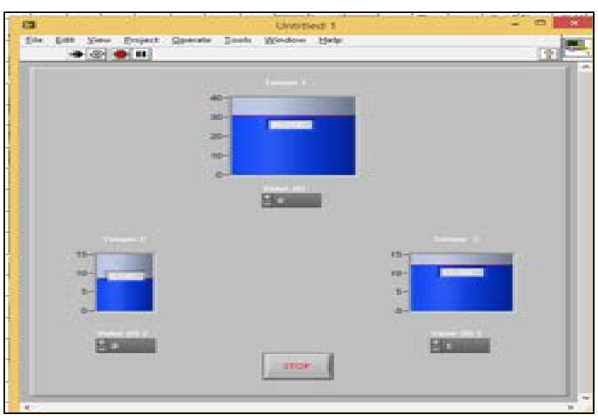

Fig. 19 Frontal Panel for the three tanks system

Finally in Figures 20, 21 and 22 three responses of the control of the level system emulated by the RC [15] circuit are shown. In this case, the controller is based on the classical PID with a block diagram depicted in Figure 23.

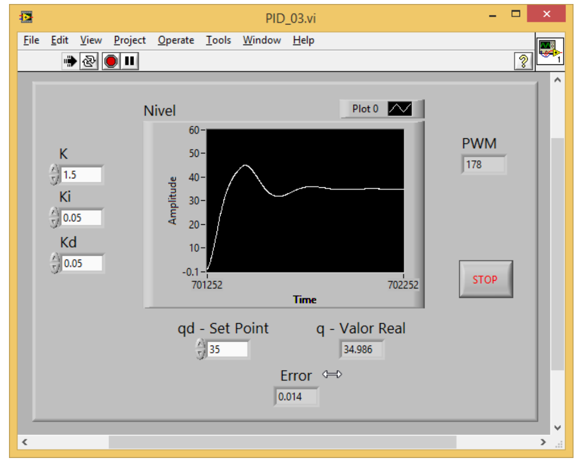

Fig. 20. Level System response with a PID controller (K_p = 1.5, K_i = 0.05 and K_d = 0.05.)

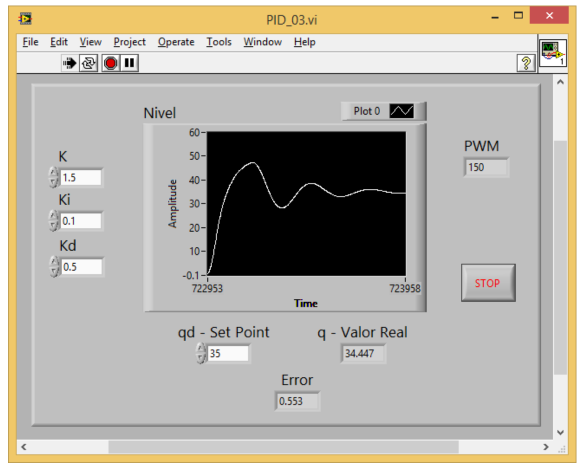

Fig. 21 Level System response with a PID controller (K_p= 1.5, K_i = 0.1 and K_d = 0.5.)

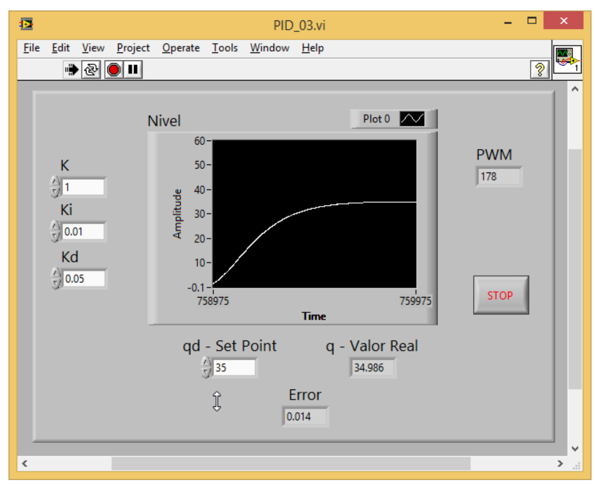

Fig. 22 Level System response with a PID controller (K_p= 1, K_i = 0.1 and K_d = 0.5.)

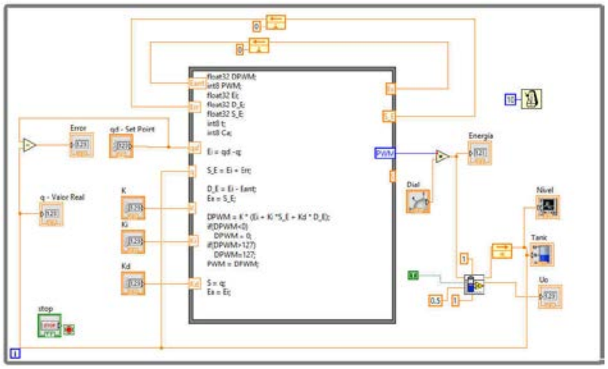

Fig. 23 Block Diagram of the PID controller

The need to control more complex systems has led us to use more complex electronic systems for example, a microcontroller-based system, in which a program developed to simulate the process and therefore can have a greater number of tanks, or furnaces and emulation conveyors. As an example you have a simple system of filling and packaging bottles. Each element of the process is a subprogram within the microcontroller, so that the digital system can receive both analog and digital signals for controlling the internal elements, and also the digital system responds with analog or digital signals based on the values of the variables of the elements programmed into the microcontroller. An example is a tank, which is programmed similarly to subVI of LabVIEW, emulating one or several tanks, as well as level or temperature sensors, etc. The process is shown in Figure 24, where each element is programmed into the microcontroller PIC18F4550. In this process, bottles are carried on a conveyor belt until reaching the correct position, by stopping the conveyor belt to be filled from two tanks, to a first level with a first fluid tank, and to a second level with other liquid. The dosage is controlled by opening two valves at different times. Furthermore the tank level is controlled based on a control with hysteresis. The programming language for the microcontroller is MIKROBASIC sufficient to reproduce the behavior of the devices.

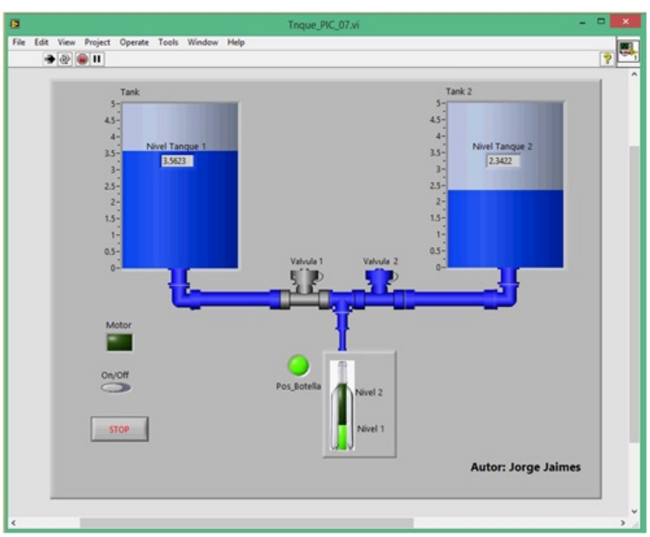

Fig. 24 System of filling bottles.

For example, the subroutine that emulates the advance of the conveyor belt of the bottle and which indicates when it reaches the filling position is:

```
'*****   SUBRUTINA PARA ENERGIZAR MOTOR     *****
sub procedure MOTOR
    M = PORTB.5
  If M = 1 then
     If (Avance >= 4) and (Avance <= (Distancia[indicador] - 4)) then
          PORTC.5 = 0     'Nivel_1 de botella = Off
          PORTC.6 = 0     'Nivel_2 de botella = Off
          Sens_Pos = 0    'La botella no está en la posición correcta
          Nivel1 = 0
          Nivel2 = 0
     end if
  'Avanzar botella, y activar sensor de "posición correcta"
     if camina >= 150 then
        camina = 0
        Avance = Avance + 1
          if Avance >= (Distancia[indicador]-3) then
             Sens_Pos = 1
             PORTC.0 = Sens_Pos      'Posición corrects de Botella
             if Avance >= Distancia[indicador] then
                    Avance = 0
                    indicador = indicador + 1   'Apuntar a la distancia siguiente
             end if
             if indicador >= 20 then
                indicador = 0              'Inicializar apuntador
             end if
          else
              Sens_Pos = 0  'No hay botella en pocisión de llenado
              PORTC.0 = Sens_Pos
              if Avance >= 50 then    'Inicializar avnce
                 Avance = 0
              end if
          end if
      else

      end if
   end if
end sub
```

Part of the program to determine the filling of a bottle to a first level is:

```
'Llenar Botella si Válvula_1 está abierta
V_1 = PORTB.1
V_2 = PORTB.2
if (V_1 = 1) and (V_2 = 0) and (Sens_Pos = 1) then

   if Cont_Niv_1 >= 250 then
        Nivel1 = Nivel1 + PWM_UNO/100
        Cont_Niv_1 = 0

        if Nivel1 >= 80 then
             PORTD.5 = 1        'Señal del Nivel_1 de botella
        end if

        if Nivel1 >= 180 then
           PORTD.6 = 1        'Señal del Nivel_2 de botella
        end if

    end if
else
   Nivel1 = 0
   Cont_Niv_1 = 0
end if
```

The subroutine to fill the tank 2 when the filling valve opens is programmed as follows:

```
'*****   SUBRUTINA DE TANQUE_2   *****
sub procedure Tanque_2
    Flujo_2 = PORTB.4
      If Flujo_2 = 1 then
      'Llenar Tanque 2
      'Una unidad de incremento cada 18 mseg / 220 unidades / llenado en 3.95 seg
              if llenar_T2 >= 200 then
                 PWM_DOS = PWM_DOS + 1
                 Pwm2_Change_Duty(PWM_DOS)
                 llenar_T2 = 0

                 if PWM_DOS >= 225  then
                     ANiv_T2 = 1     'Alarma de tanque desbordado
                     PORTC.4 = ANiv_T2

                     PWM_DOS = 225  'No aumentar el nivel
                     'Pwm2_Change_Duty(PWM_DOS)
                 else
                     ANiv_T2 = 0
                 end if
              end if
      else
          'inicializar  contador de pausa para llenado
          llenar_T2 = 0
      end if
```

C. Instrumentation and Control using LabVIEW and the NI USB-6009 Data Acquisition Board

The electronic circuits and prototypes described in the previous sections can be controlled using the data acquisition board NI USB-6009 from National Instrument getting exactly the same results. The only difference is the exchange of the function blocks for those specifically designed to the USB-6009. For the level control of the single tank system shown in Figure 2 the PID [16] controller programmed in the *Formula Node* to control the RC circuit tank emulator was used. It only requires a retuning using the actual parameters of the process.

Once the system or process has been characterized the PID [16] parameters can be tuned in the *Formula Node* getting the closed loop responses shown in Figures 25-28.

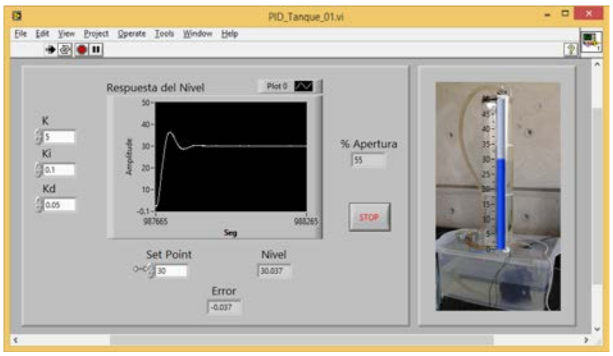

Fig. 25 Level System response with a PID controller (K_p = 5, K_i = 0.1 and K_d = 0.05.)

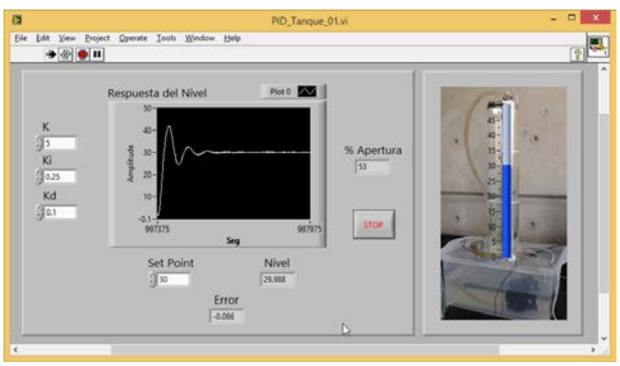

Fig. 26 Level System response with a PID controller (K_p = 5, K_i = 0.25 and K_d = 0.1.)

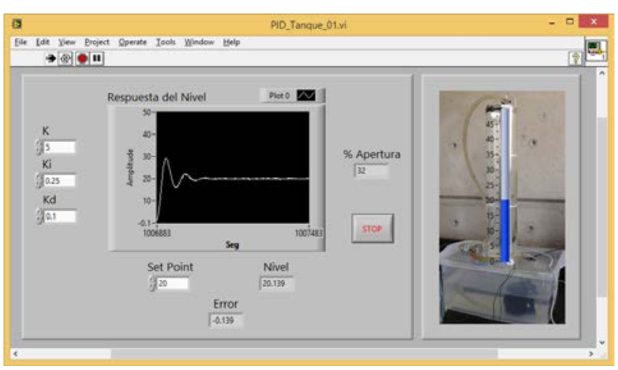

Fig. 27 Level System response with a PID controller (K_p = 5, K_i = 0.25, K_d = 0.1 and Set Point = 20.)

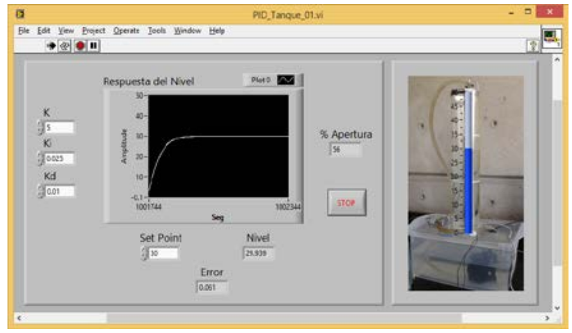

Fig. 28 Level System response with a PID controller (K_p = 5, K_i = 0.025 and K_d = 0.01.)

The teaching approaches have been used in the laboratory control with great success, complementing the theoretical class through the five sequential laboratories activities:

- Find the transfer function;
- Obtain a closed-loop transfer function that satisfies the system performance requirements;
- Design the control law.
- Implementation of the control law.
- Test classical control algorithms and compare simulation and real results.

IV. Conclusion

In this paper three different teaching approaches that help to overcome the lack of real industrial process or components in control and instrumentation lectureships are presented. This approaches aid in the comprehension and understanding of these complex topics that otherwise must be treated in a pure theoretical context. We consider that equilibrium between practice and theory is a must. On the other hand, to get access to costly real industrial process is not always possible. In this sense the use of Arduinos represent a good alternative especially with the development of new economical sensors that can be used to construct non expensive prototypes capable to emulate real industrial processes. This has also been possible due to possibilities that LabVIEW and Arduino offer. With the use of commercial of Data Acquisition Boards the possibilities of better experiments increase. The educational approaches are used as the hands-on experience in order to link the practice with theoretical concepts as Transfer function, disturbance, time constant, final value, steady state error, proportional control as well as integral proportional control. During the practices, students seem to be very excited, basically because they can put in practice their control theory knowledge through real process. The authors consider that the present article provides interesting ideas for those who are teaching the Control Systems.

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