International Journal of Electronic and Electrical Engineering.
ISSN 0974-2174 Volume 4, Number 1 (2011), pp.107-116

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Design and Development of Virtual Instrumentation based PID Control of Bar & Ball System

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Abstract

Virtual instrumentation is the use of customizable software and modular measurement hardware to create user-defined measurement systems, called virtual instruments. This paper presents a real-time application of Bar and Ball controlled by PID controller designed based on Lab VIEW program and the real - time position control of the DC motor was realized by using NI-ELVIS. Bar and Ball is a common feedback control system application, due mostly to its ease in construction and its use in learning. The system includes a ball, a bar, a motor and several sensors. The basic idea is to use the torque generated from a motor to control the position of the ball on the bar. The mathematical model for this system is inherently nonlinear, so linearization was done in order to improve the controllability of the system. Data acquisition using ELVIS, signal processing and analyzing can be completed by virtual instrument based on Lab VIEW.

Keywords: Proportional-Integral-Derivative (PID), NI-ELVIS, LabVIEW, Bar and Ball arrangement.

Introduction

Closed loop control systems classified for two types of control, analog and digital. Analog and digital control have a relation between each other that can convert analog to digital and vice versa which gives the control world more flexibility for controlling any device. Figure (1) show the cycle of converting analog signal to digital signal and applying digital signal to computer then converting the digital signal back to analog signal.

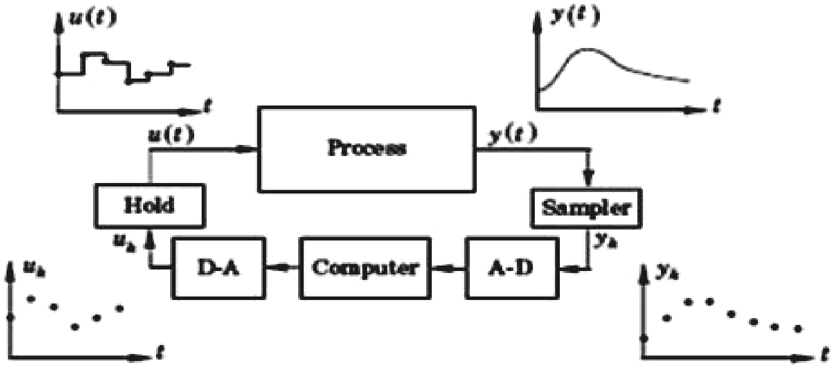

Figure 1: Cycle of analog and digital signal.

The Bar and Ball is a common feedback control system, due mostly to its ease in construction, and its use in learning for applying control to stabilize an unstable system. This system is extremely unstable and needs compensation to stabilize. The ball moves freely along the length of the bar. Sensors are placed on one side of the bar to detect the position of the ball. An actuator must drive the bar to a desired angle, either by applying a torque at the center, or in our case, a force at one of the ends.

The physical hardware of the system is simple, a steel ball rolling on the top of a long wooden bar. The bar is mounted on the output shaft of an electrical motor and so the bar can be tilted about its center axis by applying an electrical control signal to the motor amplifier. The position of the ball on the bar can be measured using a special sensor. Figure 2 shows the simple diagram for bar and ball.

When the angle is changed from the horizontal position, gravity causes the ball to roll along the bar. The objective of this paper is to design a digital PID controller using Lab VIEW, and ELVIS for this system so that the ball's position can be manipulated.

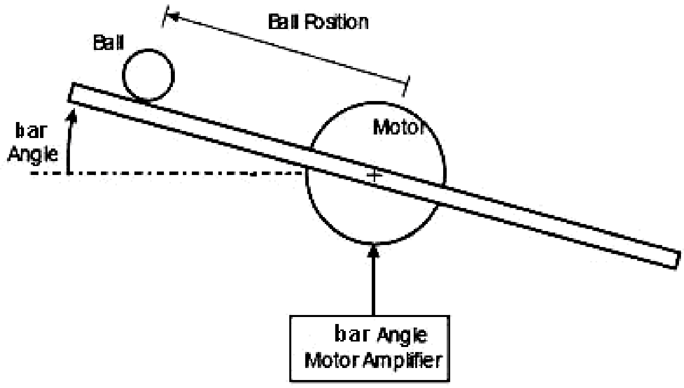

Figure 2: Bar and Ball system.

Dynamic Model

Physical systems are modeled and manipulated in software, and realized in hardware to demonstrate what differences may occur with real-life applications. By solving control problems using software-based virtual instruments and actual hardware, students gain an appreciation of the interaction of process instrumentation and computers [4]. The complete description of the dynamics of the ball system design a simplified derivation is used to give a model that is good for controller design. The system consists of two motional parts, the bar which rotate with the shaft of the motor, and the rotating ball which roll on the bar according to its angle. Figure (3) describe the behavior of ball and bar system [2].

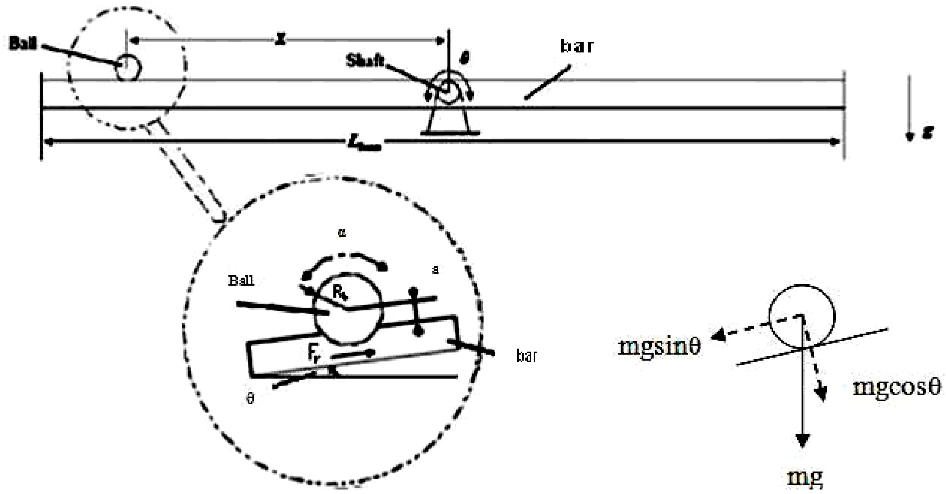

Figure 3: Bar and Ball System and free body diagram of the ball.

Rolling ball on the bar equations

Applicant the motion laws on the motor and the bar rotation

$$m_{ball} g \sin\theta - F_r = m_{ball} x'' - b_1 x' \tag{1}$$

Where,

F_r - The rolling constraint force on the ball

b_1 - Damping between ball and wires (may be neglect)

m_{ball} - The mass of ball

g - Gravity acceleration

θ - Angular displacement of bar

x - Displacement of ball

Electromechanical system Equations

Applicant the motion laws on the motor and the bar rotation

$$KI - J_{bm}\theta'' - b\theta' - xm_{ball}\, g\cos\theta = 0 \tag{2}$$

$$J_{bm} = J_{bar} + J_{motor} \tag{3}$$

$$J_{bar} = \frac{1}{12} m_{bar} L_{bar}^2 \tag{4}$$

Where

J_{motor} = The moment of inertia of the motor

J_{bar} = The moment of inertia of the bar

m_{bar} = The mass of bar

L_{bar} = The length of bar

The nonlinear state space model of bar and ball is: as shown in equation (5):

$$\begin{pmatrix} x' \\ x'' \\ \theta' \\ \theta'' \\ \theta''' \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & g/\left(1+\frac{2}{5}\left(\frac{R_b}{a}\right)^2\right) & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ -\frac{Rm_{ball}g}{LJ_{bm}} & -\frac{m_{ball}g}{LJ_{bm}} & 0 & -\left(\frac{Rb+K_eK}{LJ_{bm}}\right) & -\left(\frac{R}{L}+\frac{b}{J_{bm}}\right) \end{pmatrix} \begin{pmatrix} \cos[\theta]x \\ \cos[\theta]x' \\ \sin\theta \\ \theta' \\ \theta'' \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \frac{K}{J_{bm}} \end{pmatrix} v \tag{5}$$

$$y = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} \cos[\theta]x \\ \cos[\theta]x' \\ \sin\theta \\ \theta' \\ \theta'' \end{pmatrix}$$

A precise mathematical of the bar and ball system is complicated. Fortunately approximate models are sufficient to analyze stability of closed loop system [3]. Now will derive linear approximate model of the bar & ball system using linearized method. Assume θ too small, then $\sin\theta \approx 0, \cos\theta = 1$, the linearized model of bar and ball system is a good approximation to real system dynamics. The linearized model of closed loop system will be as shown in equation (6)

$$\begin{pmatrix} x' \\ x'' \\ \theta' \\ \theta'' \\ \theta''' \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & g/\left(1+\frac{2}{5}\left(\frac{R_b}{a}\right)^2\right) & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ -\frac{Rm_{ball}g}{LJ_{bm}} & -\frac{m_{ball}g}{LJ_{bm}} & 0 & -\left(\frac{Rb+K_eK}{LJ_{bm}}\right) & -\left(\frac{R}{L}+\frac{b}{J_{bm}}\right) \end{pmatrix} \begin{pmatrix} x \\ x' \\ \theta \\ \theta' \\ \theta'' \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \frac{K}{J_{bm}} \end{pmatrix} v \quad (6)$$

$$y = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} x \\ x' \\ \theta \\ \theta' \\ \theta'' \end{pmatrix}$$

PID Control

One of the simplest kinds of controllers is the PID, which stands for proportional-integral and derivative. Each of the three elements is multiplied by its own constant, and then sum is used to determine the new inputs for the actuator. The mathematical model formula for the PID control algorithm is [5]:

$$u(t) = K_P e(t) + K_I \int e(t)dt + K_D \frac{de(t)}{dt} \quad (7)$$

With the correct choice of signs for K_P, K_I and K_D, a PID controller is shown in Figure (4) will generate an actuator command that attempts to drive the error to zero with the proportional gain, remove the steady state error with integral gain and damp the response with derivative gain. Implementing PID controller to unstable Bar & Ball will make the closed loop system stable PID controllers are designed based on LabVIEW program and real time position control of the ball on the bar was realized by using a device named ELVIS.

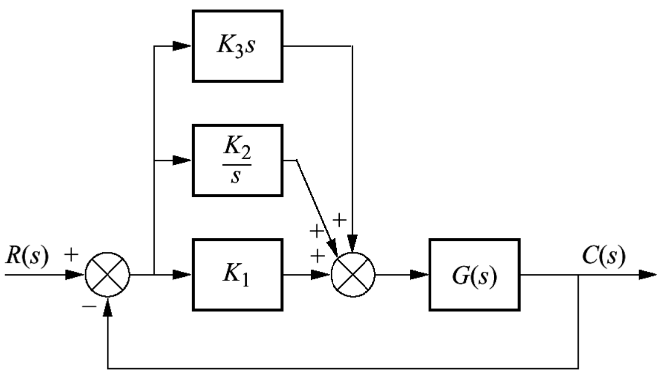

Figure 4: Bar and Ball System and free body diagram of the ball.

LabVIEW and NI- ELVIS

(Laboratory Virtual Instrumentation Engineering Workbench) is a graphical programming environment, developed by National Instrument (NI), which is well suited for high-level or system-level design. LabVIEW, developed by National Instruments, is a graphical programming environment suited for high level or system level design. This programming approach is based on building blocks called Virtual Instruments (VIs) [6, 7]. This software package is one of the first graphical programming products, and is currently used in academia and industries for data acquisition, remote control, simulation, and analysis [1]. LabVIEW uses dataflow programming, where the flow of data determines execution. LabVIEW programs are called virtual instruments, or VIs, because their appearance and operation imitate physical instruments, such as oscilloscope and millimeters

A VI contains the following three components [9]:

- Front Panel: serves as the user interface.
- Block Diagram: contains the graphical source code that defines the functionality of the VI.
- Icon and connector panel.

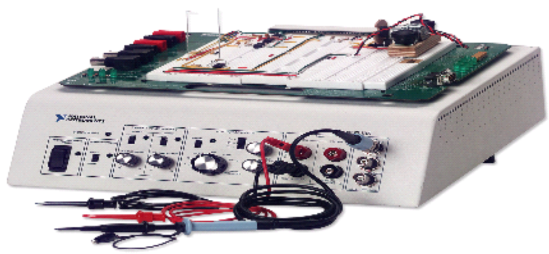

Figure 5: ELVIS.

NI ELVIS environment consists of the hardware workspace for building circuits and interfacing experiments, and the NI ELVIS software. The NI ELVIS software, all created in LabVIEW has two main types: the soft front panel (SFP) instruments and LabVIEW APIs, which are just additional LabVIEW VIs for custom control and access to the features of the NI ELVIS bench top workstation. Thus ELVIS acts as data acquisition device. Where Data acquisition is the process by which physical phenomena from the real world are transformed into electrical signals that are measured and converted into a digital format for processing, analysis, and storage by a computer.

Design & Simulation

DC Motor and Driver Circuit

The direction and the torque of the motor are needed to be controlled. In order to meet these requirements, a driver circuit is built which receive low power control signal and turn it to high power to switch the motor. High power Darlington transistor was used to control the torque of the motor by PWM technique. H-bridge circuit (as shown in Figure (10) was used to control the direction of the motor. Figure (6) show the schematic connection of the driver circuit.

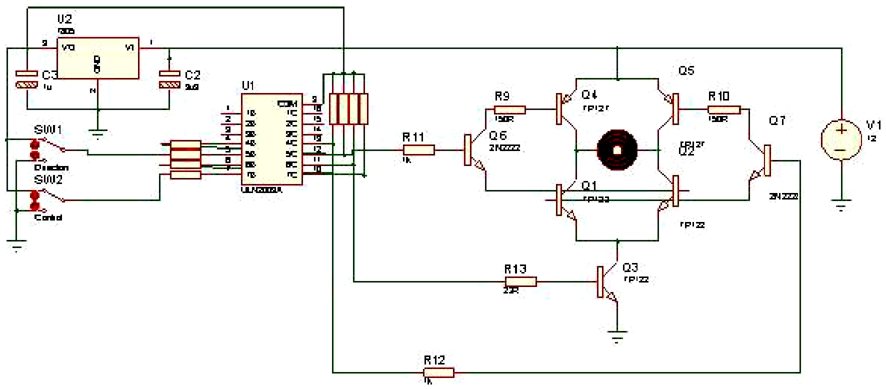

Figure 6: Schematic connection of the driver circuit.

PWM signal was generated using LabVIEW and digital output of the ELVIS. Figure (7) shows the programming method to generate PWM. The constant frequency of the PWM = 1/Ts. The value of the duty cycle is changing according to the programmed logical circuit.

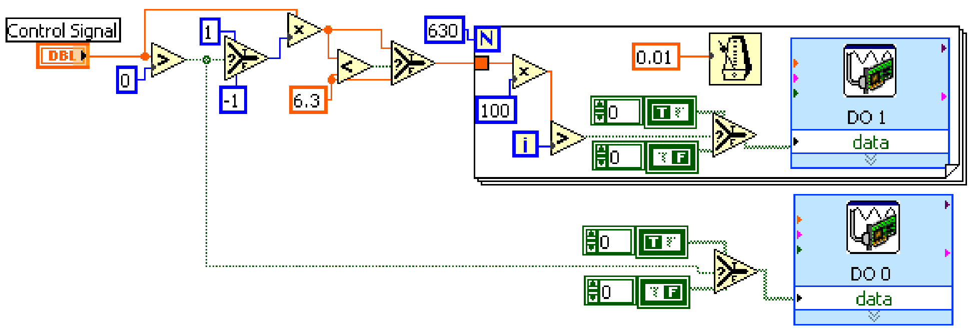

Figure 7: Block diagram of Controlling direction and generation PWM using LabVIEW

Linear resistive wire is used as position sensor since it has a relative large resistance of about 2.15 ohm/m. A series resistor is added to the circuit in order to divide the voltage. To avoid unwanted heat. According to the position (X) of the ball, the voltage will linearly vary from 0.1 V to 0.74 V. Schematic of the resistive wire circuit is shown in Figure (7).

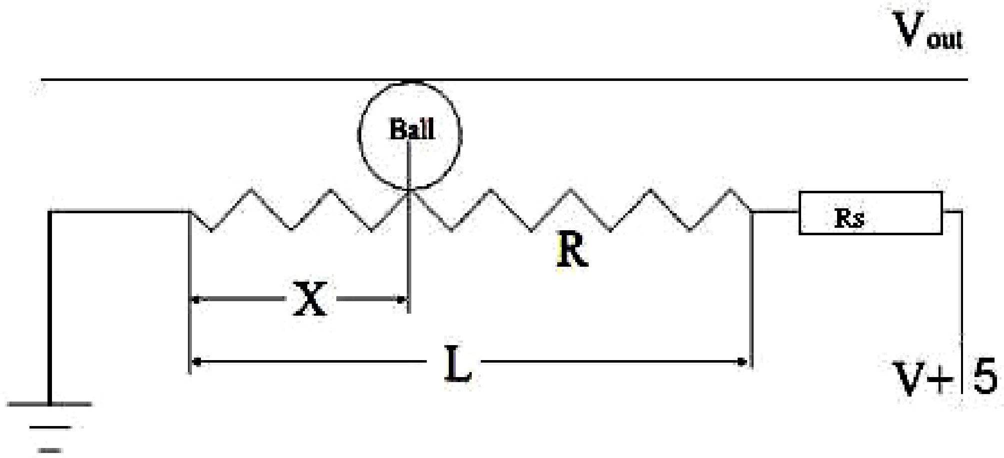

Figure 7: Schematic of the linear resistive wire circuit 'position sensor'.

A linear resistive wire is used as a position sensor & conducting ball moving along it, acting as a voltage divider. By moving the ball along the wire and taking the reading using analog input of ELVIS, the result signal has non continuity. So it needed filtering. Using low pass filter, we take array of sample at every sampling time & then calculate the average of these samples to make signal smoother as shown in figures (8a & 8b).

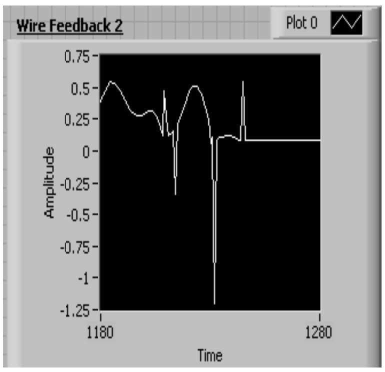

Figure 8(a): Before filtering.

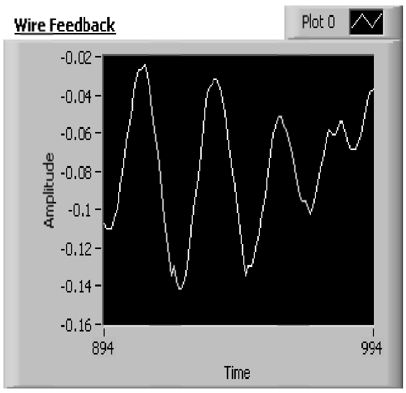

Figure 8(b): After filtering.

After handling the feedback signal, the PID controller is ready to be design and gains (K_P=6, K_I=2 and K_D=6) were gotten using Ziegler Nichols tuning method .Figure (9a & 9b) shows the block diagram and front panel of PID controller respectively.

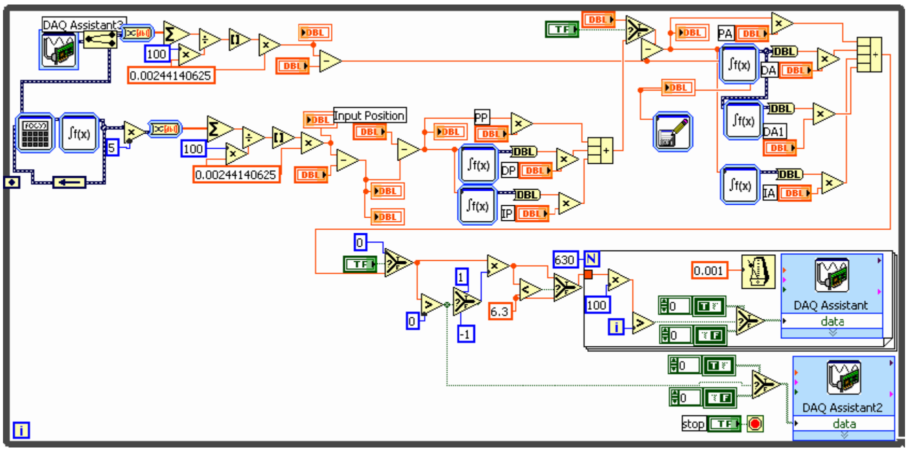

Figure 9(a): Block diagram of PID controller.

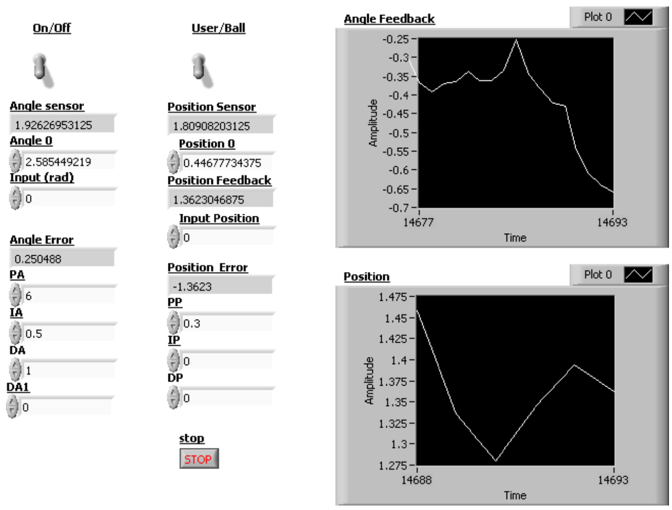

Figure 9(b): Front panel of PID cont.

To reach acceptable speed when the ball acts on the bar, PID controller is applied to the ball & bar system.

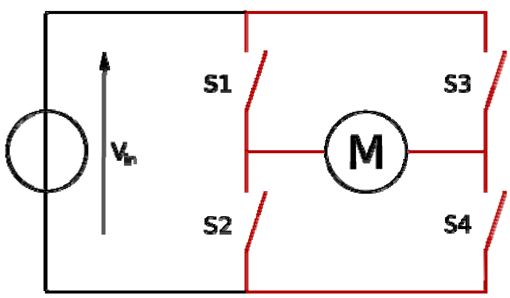

Figure 10: Schematic of H-bridge.

Table 1: H-bridge Operation summary.

S1	S2	S3	S4	Result
1	0	0	1	Motor moves right
0	1	1	0	Motor moves left
0	0	0	0	Motor free runs
0	1	0	1	Motor brakes
1	0	1	0	Motor brakes

Conclusion

The LabVIEW based ELVIS system is used to control the bar and ball system. ELVIS was used for measuring the feedback signals and converting them into a digital format for processing, analysis, and storage on a computer. To drive the DC motor and control its direction, H-Bridge driver circuit was designed and implemented. PWM was programmed using LabVIEW to control the motor speed. The flexibility of digital control makes it easy to change the gains values without the need of new components. The application of virtual instruments makes data analyzing more accurate, and decreases the measuring time significantly. This system has been used for demonstration in the classroom to the students and the system is stable, and works properly.

References

[1] Korrapati R.; Anderson, J.A; Swain, N.K; Swain M; “System Modeling Using Virtual Instruments” Southeast Con, 2002. Proceedings IEEE Digital Object Identifier:10.1109/.2002.995570 Publication Year: 2002, Page(s): 121 – 126.
[2] http://www.mecheng.adelaside.edu.au/Novell/projects/2007/Ball-Bar, Oct’08
[3] Li Qiu, and Kemin Zhou “Introduction to Feedback Control”. 2010, Prentice Hall.
[4] Elmerabete, J. Hong Li Rafi, Y.” Application of Real-Time Control System Using LabVIEW in Distance-Learning” International Conference on Measuring Technology and Mechatronics Automation (ICMTMA), Volume.1, 2010, 663 – 666.
[5] Benjamin C Kuo and Farid Golnaraghi, “Automatic Control System”, 8th Edition 2003, John Wiley & Sons Inc.
[6] Chance Elliott, Vipin Vijayakumar, Wesley Zink, and Richard Hansen:National Instrument LabVIEW: A programming environment for laboratory automation and measurement, The association for Laboratory Automation, 2007.
[7] N. Kehtarnavaz, N. Kim, and I. Panahi, Digital signal processing system design using LabVIEW and TMS320C6000, IEEE Digital Signal Processing Workshop, 2004.
[8] John Park and Steve Mackay. “Practical Data Acquisition for Instrumentation and Control Systems”. Copyright © 2003, IDC Technologies.
[9] LabVIEW User Manual, April 2003 Edition, National Instruments.