Implementation of Discrete PID on Inverted Pendulum

Faiza Faizan, Faizan Farid, Muhammad Rehan, Shoaib Mughal, M Tahir Qadri
Department of Electronics Engineering, Sir Syed University of Engineering & Technology,
Karachi, Pakistan.
Email: miss_naz786@hotmail.com, fayzan786@hotmail.com, murehan@hotmail.com, mughalshoaib@hotmail.com, mtahirq@hotmail.com

Abstract—**The objective here is to implement the discrete PID on pendulum. The idea is to balance an Inverted pendulum electro-mechanically using Proportional Integral Differential (PID) Control. The heart of the system is a PIC micro-controller (PIC18F4520). Controller commands the motor through PWM signal, which drives the cart to balance the pendulum in an inverted position. Pendulum's angular position is fed back by an incremental encoder mounted on its base, which is read by controller. Controller then calculates error and runs the PID algorithm to generate a new command signal. The exact position of pendulum with the value of its gains are sent to the attached Personal Computer (PC) using RS-232 protocol. The front panel is built in LabVIEW software.**

Keywords- Inverted pendulum; Discrete PID; PWM control; Close loop system

I. INTRODUCTION

A Control System is a device, or a collection of devices that manage the behavior of other devices [1]. A control system is an interconnection of components connected or related in such a manner as to command, direct, or regulate itself or another system [2]. Control systems which operate on discrete data are called digital control systems. These systems being discrete suffer from granularity, thus they have a theoretical limit on accuracy, but as there is a great benefit of processing power in current generation digital processors. Proportional Integral Differential (PID) is a control strategy that scales, tracks and estimates the error to generate a command signal. This method is simple yet effective at controlling highly unstable systems. This work uses its discrete implementation. Most practical systems exhibit nonlinear behavior [3].

The inverted pendulum is a common, interesting control problem that involves many basic elements of control theory [4]. It is a typical example of an unstable nonlinear system and is often used to test the performance and efficiency of control methods [5].The inverted pendulum control problem is very important because it describes many systems very exactly [6]. It is a regulation problem, so it can be adopted easily to nay regulation problem and also the tracking problem which can be reduced to this type [6]. The goal of the control process is to move the pendulum from the lower (stable) equilibrium position to the upright (unstable) equilibrium position and keep it in this position [5]. It has been widely used in both linear and nonlinear control education with applications to other mechanical systems [7]. The PID controller is simple and easy to implement. It is widely applied in industry to solve various control problems [8]. PID and its variants have been well established not only in textbooks and research papers but also witnessed by their dominant roles in industrial applications [9].

The work comprises of four major parts. The embedded PID system, motor drive circuitry, inverted pendulum assembly and user interface in LabVIEW.

The embedded PID system is based on PIC18F4520 micro-controller. The object is to run the PID fast within ~10ms, so this micro-controller is selected for an optimal response. The micro-controller is also responsible to execute the PID routine. This is done by using a timer interrupt at a constant interval of 10ms. The Quadrature Decoder is also used to translate the incremental output of PID into absolute positional values. The bridge driver is also used to drive the motor connected with the pendulum. It also delivers PWM signal to the MOSFET Bridge to protect the circuit against any spikes produced by fast switching MOSFET or motor inductance. The micro-controller also sends the data to the Personal Computer (PC) serially for user display.

Secondly, the full bridge inverter circuit is used to drive the motor in both directions. The inverter consists of four transistors and they are arranged in pairs. The transistors in each pair are switched in such a way that when of them is in ON state, the other is OFF and vice versa. For this purpose IR2130 High Frequency H-Bridge Driver IC is used which can operate from 10VDC to 600VDC.

The inverted pendulum assembly consists of a cart mounted on a ball screw with 2D freedom, driven by motor. Pendulum is mounted on the cart. The movement of cart depends on the angle of pendulum. If pendulum is on zero degree then cart remain still and when pendulum moves clockwise, cart moves on right side and when pendulum moves counter clockwise, the cart moves on left.

Finally, for user interface on PC, LabVIEW software is used. LabVIEW has very good front panel interface and provides serial communication. The current angle of pendulum, values of P, I and D with their gains 'kp', 'ki' and 'kd' are sent through RS-232 serial communication protocol using 115.2kbps baud rate from micro-controller.

The rest of the paper is organized as follows: section 2 will present the software and hardware models of the system. Section 3 will present the working of the system. Section 4 is the discussion and results and finally section 5 will end the paper with conclusion and future works.

II. SYSTEM MODEL

The overall system can be divided into the software model and hardware model.

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A. Hardware Model

The hardware model consists of sensor (incremental encoder) to sense the position of pendulum, motor to drive the cart and circuit boards of discrete PID. The block diagram of the hardware model is given below.

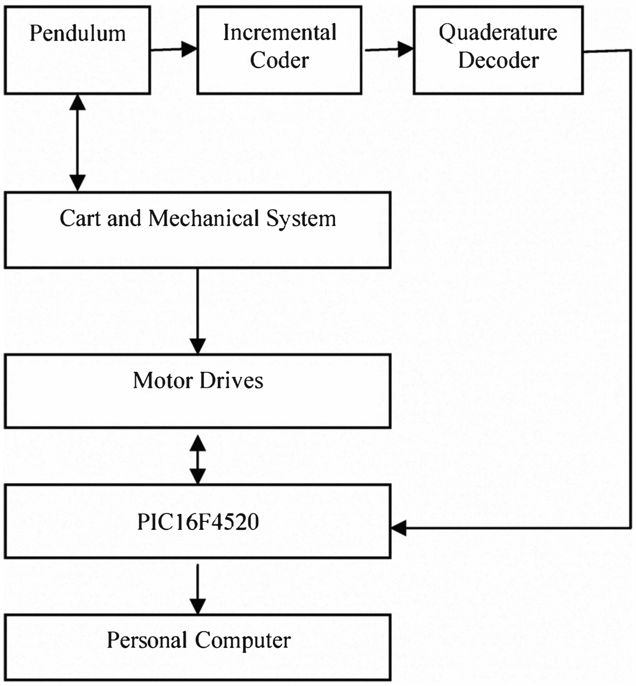

Figure 1. System block diagram

The heart of the hardware is the micro-controller PIC18F4520. It drives the motor with respect to the feedback signal. It is also serially interfaced with the PC to display the real time stability status of the pendulum with the PID gains. These values are also displayed on PC interfaced with the micro-controller.

The DC motor drive acts as an interface between micro-controller and the motor. The drive produces power conversion, amplification and sequencing of waveform signals. The motor is attached with mechanical assembly to move the cart vertically. Pendulum is mounted on the shaft of the incremental encoder. Further, incremental encoder is interfaced with the Quadrature Decoder to decode the pulses into absolute position values and feed to PIC18F4520 micro-controller.

Angular sensor consists of two parts one is incremental encoder and other is quadrature decoder.

Incremental encoder is the feedback element that closes the loop of system. It does this by being attached to the base of pendulum. It feeds back the angular position of the pendulum through two channels of quadrature pulses.

Quadrature decoder starts working when it receives index pulse from incremental encoder. Pulses are decodes into absolute values and feed to PIC18F4520 micro-controller.

Additionally, the photo coupler is also used between micro-controller and motor drive to isolate micro-controller from back spikes of motor drive.

B Software Model

The system communicates with PC through serial communication. Serial communication is a popular means of transmitting data between a computer and a peripheral device [10]. Serial communication requires specifying the following four parameters [10]:

The baud rate of the transmission. The number of data bits encoding a character. The parity bit and the number of stop bits. Each transmitted character is packaged in a character frame that consists of a single start bit followed by the data bits, the parity bit, and the stop bit or bits [10].

The National Instruments LabVIEW is used for user interface. The *com1* port is used with a baud rate of 115.2 kbps to send the current location of the pendulum with its PID gains. A discrete and unique data packet protocol was developed for passing information between the System and GUI. In this full-duplex serial communication, PC acts as an active device that can issue system commands, and microcontroller acts as passive, thus can only transmit state information. Both sides transmit 8-bytes packet. System's GUI has ON/OFF control, Kp, Ki, Kd Gain adjustments, Real time P, I, D states and current Pendulum's angle. The System running/halted indicator and Error out of bounds indicator is also shown on screen. The LabVIEW based front panel of the system I shown in figure 2.

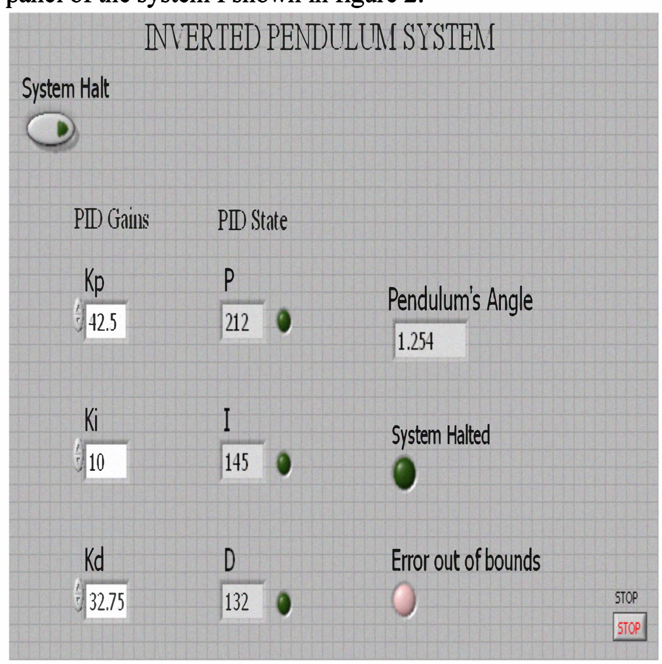

Figure 2. LabVIEW Based Front Panel of the System

III. WORKING OF THE SYSTEM

The system starts working when the sensor detects the set point from the Index signal of incremental encoder. Once PID starts then it generates commands for driving the Inverted Pendulum System on behalf of the angle of Pendulum.

A Proportional–Integral–Derivative Controller (PID Controller) is a generic control loop feedback mechanism widely used in industrial control systems [11]. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly [11]. The block diagram of the PID is shown in figure 3.

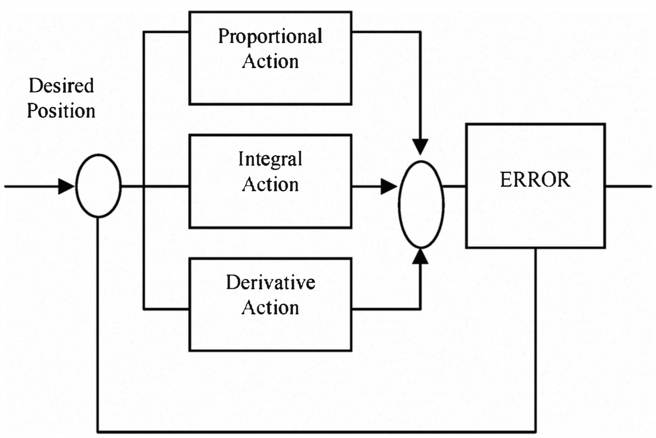

Figure 3. General Block Diagram of the PID

Discrete PID requires that the error signals be processed digitally, in a digital processing device. For any such system, the best number crunching device would logically be an FPGA or FPAA, but these systems are very costly. For cost effective system, high speed 8-bit controller is used. Therefore, PIC18F series is selected as it has built-in CCP (Capture Compare PWM) module and has peak performance of 10 MIPS (Million Instructions per Second), high enough speed to carry out PID routine update within 5ms.

Pendulum is attached with the cart and the movement of the cart is controlled by full bridge inverter. Figure 4 shows the function of full bridge inverter circuit. The micro-controller PIC18F4520 generates PWM signals for full bridge inverter. PWM duty cycle depends on the angle of pendulum. The full bridge consists of two parts one is H-Bridge driver and other includes H-bridge.

The H-Bridge consists of four transistors Q1, Q2, Q3 and Q4 shown in figure 4. Commonly, the transistors are arranged to switch in pairs (Q1, Q4) and (Q2, Q3). The transistors in each pair are turned off and on simultaneously. Also, the pairs are switched in such a way that when one of them is in its ON state, the other is OFF. In figure 5, is also included anti-parallel protection diodes connected to the transistors. The use of these diodes is highly recommended since they provide a path to the reverse current. The reverse current can be named a "reactive" current, because it would not be present with a purely resistive load (the arc). Under some conditions the reverse current is neither present nor harmful, but in other circumstances it is; since many times the operating conditions are totally unpredictable, protection diodes should always be used.

The IR2130 High Frequency H-Bridge Driver is used. This H-Bridge driver IC provides the ability to operate from 10VDC to 600VDC busses for driving H-Bridges. The IR2130 has high speed power MOSFETs and IGBTs.

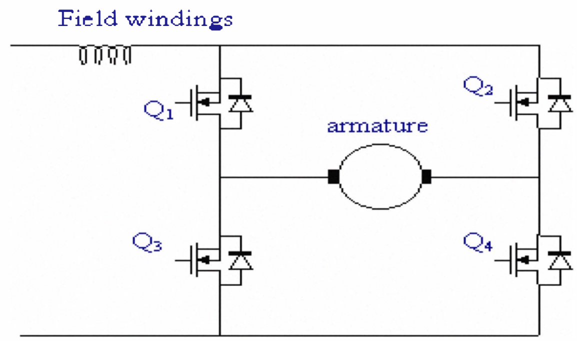

Figure 4 General Block Diagram of the PID

IV. DISCUSSION AND RESULTS

The system starts when it senses its set point which provides manually by standing the pendulum. Once the PID starts it cannot let the pendulum down. If the pendulum is disturbed, the incremental encoder senses the change and it sends pulses to PID. The PID generates another error free command to stabilize the pendulum again in vertical position. The complete process is done in 10 milliseconds. The system is limited in 10 degree span i.e. it can only destabilized only if it is under its limit (-5 to +5 degree). The snapshot of the system is shown in figure 5.

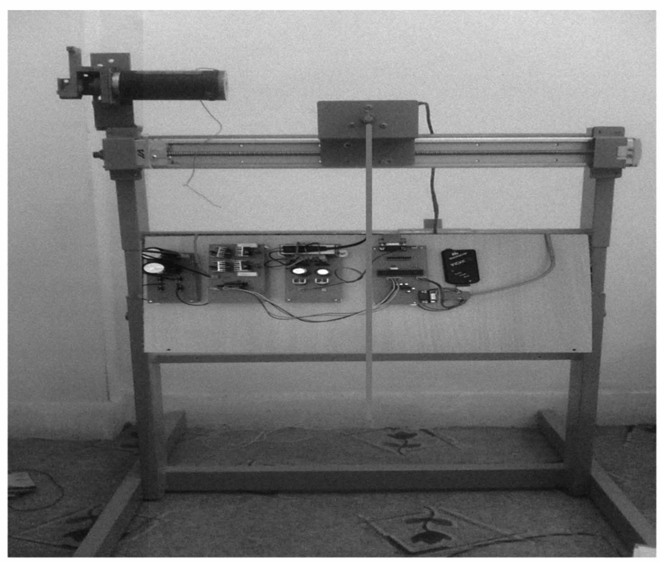

Figure 5. Snapshot of the System

CONCLUSION AND FUTURE WORK

The work is centered on control systems, but the wide variety of tools that it uses to accomplish the given task, are invaluable to any electronic engineering practitioner as they are in high demand in industry. This exercise provides a chance of designing a controller for a system that has a good dynamic behavior and hence the consideration for the transient response is accentuated. The power of MATLAB and Simulink becomes more evident to one as all these designing would not have been possible without these tools. The simulation of PID is done on Matlab and simulink. The implementation of the PID algorithm is done on PIC18F4520 micro controller. GUI for this system is designed on National Instrument LabVIEW. The incremental encoder used in this project is 0.175 degree sensitive and by using Quadrature decoder it is increased by four times which is 0.044 degree. The Ball screw is also used in this work to move the cart. It covers the distance of 1cm by 10 revolution of motor.

The implementation works quite well however, there is still room for improvement. PID control module can be swapped for Fuzzy control or AI, and likewise this PID control module can be used in any feedback based system. Feedback mechanism can be also be upgraded to accommodate better accuracy.

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