DESIGNING A REAL TIME EMBEDDED CONTROLLER USING DATA ACQUISITION SYSTEM FOR A DC MOTOR SPEED CONTROL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

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Under the Guidance of
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CERTIFICATE

This is to certify that the thesis entitled, **"DESIGNING A REAL TIME EMBEDDED CONTROLLER USING DATA ACQUISITION SYSTEM FOR A DC MOTOR SPEED CONTROL"** submitted by **Mr. Prashant Sharma(107EC001)** in partial fulfillment of the requirements for the award of **Bachelor of Technology** Degree in **Electronics & Communication Engineering** at **National Institute of Technology, Rourkela** (Deemed University) is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university / institute for the award of any Degree or Diploma.

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ABSTRACT

Speed of a DC motor varies proportional to the input voltage. With a fixed supply voltage the speed of the motor can be changed by switching the supply on and off so frequently that the motor notices only the average voltage effect and not the switching operation. This thesis focuses on controlling the speed of a DC motor using PWM technique (varying duty cycle of a square wave) and Data Acquisition Systems.

Virtual instrumentation is defined as the combination of measurement and control hardware and application software with industry-standard computer technology to create user-defined instrumentation systems. DAQ card along with LabVIEW are used to create the virtual instrument for designing a real time embedded controller for controlling the speed of a DC motor in an open loop control system. The DAQ card used is NI PCI 6221 along with daughter board CB-68LP. A ZX-03 IR reflector type sensor is used to study the speed of the motor.

Chapter 1

INTRODUCTION TO CONTROL SYSTEM

Control system represents a very common class of embedded systems. A control system seeks to make a physical system's output track a desired reference input by setting physical system inputs.Control system consists of subsystem and process assembled for controlling the output of the process.

Control systems are an integral part of today's society. Many applications are all around us: such as aself guided vehicle delivering materials to workstations in an aerospace assembly plant glides along the floor seeking its destination, the rockets fire, the space shuttle lifts off to earth orbit etc. There is control in every aspects of life such as a policeman controlling the traffic, a fireman trying to bring fire under control. In contrast digital cameras, video games and cell phones are not examples of control system as they do not seek to track a reference input.

1.1 TYPES OF CONTROL SYSTEM

There are basically two types of control systems:

- **Open loop control system-** Open loop system is a type of control system in which uses only the current state as well as its model of the system for computing its output.It is controlled directly, and only, by an input signal, without the benefit of feedback.The basic units of this system are a transducer, an amplifier, a controller and the plant. It starts with a subsystem called an input transducer, and this transducer convert the input signal in the form that can be used by the controller.The amplifier receives a low- level input signal from the transducer and amplifies it enough to drive the plant to perform the desired job. Open-loop control systems are not as commonly used as closed-loop control systems because they are less accurate.

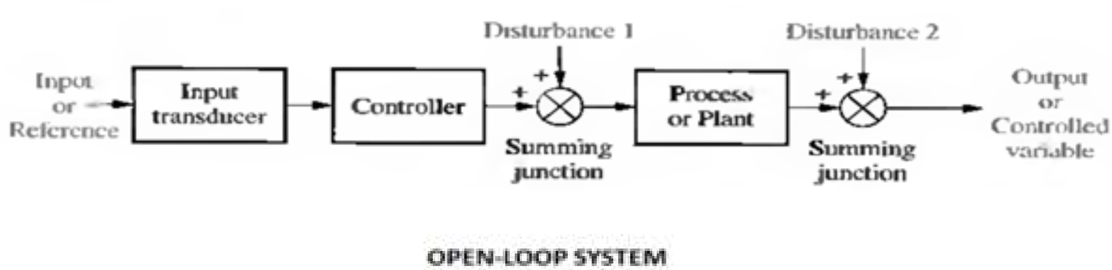


FIG: 1.1: OPEN LOOP SYSTEM

- **Closed loop control system-** A closed-loop control system is one which determines an input forcing function in part by the system response. It them compares the measured response of a physical system to the desired response. Actions will be initiated by the difference between the two responses to make the actual response of the system approach the desired response. Hence, the difference signal drives towards zero. Basically closed loop systems use two transducers. One transducer convert the input signal to a form that can be used by the controller and the other one measure the output response of the plant and convert it into a form that can be used by the controller. These systems measures the output response and then it provides the measurement result through a feedback path to the input where the output is compared with respect to a desired response and this error signal is then used to drive the plant via an actuating signal provided by the controller. A closed-loop system has the ability to regulate itself when disturbance or variations in its own characteristics are present. In this regard, a closed-loop system offers a distinct advantage with respect to an open-loop system.

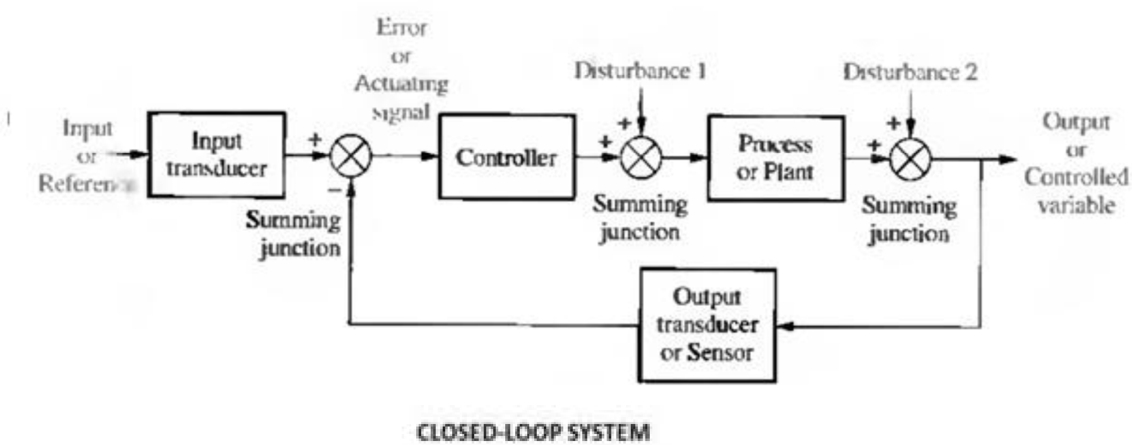


FIG: 1.2: CLOSED LOOP SYSTEM

1.2 OBJECTIVES OF CONTROL SYSTEM

- **Transient response -** transient response is important for any control system. E.g. in an elevator a slow transient response makes passengers impatient whereas an excessively rapid response makes them uncomfortable. The transient response of a plant must be appropriate.A control system is designed to achieve a desired transient response by adjusting various design parameters or design components.
- **Steady state response-**this response resembles the input and is usually what remains when transients have decayed to zero.e.g this response may be an elevator stopped near the fourth floor. We are concerned about the accuracy of the of the steady state response. An elevator must be at level enough with the floor for the passengers to exit. Control system design must take into account the steady state errors and corrective action must be taken to reduce the steady state error.
- **Stability-**total response of a system is the sum of the natural response and the forced response. Natural response describes the way the system dissipates or acquires energy and is dependent only on the system and not input. On the other hand the form on nature of the forced response depends on the input. For a control system to be useful the natural response must approach zero leaving only the forced response or oscillate but in some systems the natural response grows without bound rather than diminishes to zero or oscillate. This situation when natural response becomes much greater than the forced response is called instability and may lead to physical device destruction if limit stops are not part of the design. E.g. the elevator crash through the door or exits through the ceiling. So control systems must be designed to be stable i.e. their natural response must decay to zero with time or oscillate.
- **Finance –** control systems are designed to meet the desired needs in proper budget. So control system designers must take into account the economic impact of the design.
- **Robustness –** design should be robust so that the system will not be sensitive to parameter changes.

1.3 CONTROL STRATEGIES

- **Feedback control:** This technique compensates for all disturbances. If any disturbance affects the controlled variable and once the variable deviates from its set point or desired point then the controller takes an action such that it changes its output in such a way as to bring the variable back to its desired value. This system does not know which disturbance enters the system it only tries to maintain the variable to be controlled at its set point and in doing so it compensates for the entire disturbance. The major disadvantage of this type of control is at it can compensate for the noise only after the controlled variable has deviated from the set point.
- **Feed-forward control:** Feed-forward controller works by first measuring the disturbance and then compensating for it before the controlled variable deviates from the set point. In this type of control the deviation of controlled variable is minimized as compare to that of feedback control.

To have a better control over the system and to minimize the noise some feedback compensation is provided to minimize the noise that occurs during the process.

1.4 BASIC COMPONENTS OF A CONTROL SYSTEM

- **Sensor-Transmitter:** The output of the process is sensed or measured by the sensor. Usually the sensor is physically connected to the transmitter, which takes the output of the sensor as its input and converts the signal to a form that can be transmitted to the controller.
- **Controller:** It is the brain of the control system. The controller receives the signal transmitted by the transmitter and compares it with the desired value. Depending upon the result of the comparison the controller decides what to do to maintain the output at the desired value.
- **Final Control Element:** It receives the signal from the controller. Also known as Actuators these do the translation of the control signal into action on the control element.

Thus if a valve is to be operated then the actuators is a device that converts the control signal into physical action of opening or closing the valve.

All these components together perform 3 basic operations**:**

- **Measurement:** Measurement is basically done by sensor- transmitter combinations.
- **Decision:** The controller decides what to do on the basis of the measurement to maintain the variable to be controlled at the desired value.
- **Action:** On the basis of decision taken by the controller the system take an action and this is usually done by the final controlling element.

1.5 PARTS OF A CONTROL SYSTEM

The control system consists of several parts such as:

1. **Plant:**The plant is also known as the process and it is the physical system to be controlled. In our case DC Motor is the plant.
2. **Output or the Controlled Variable:** It is the signal or the plant output which we need to control. In our case the speed of the DC Motor is the controlled variable which is to be control.
3. **Manipulated Variable:** The manipulated variable is used to maintain the controlled variable at the desired set point. In this thesis the output of the controller is the manipulated variable.
4. **Reference:**It is the desired value that we want to see at the output. In this thesis set point or reference is the desired speed of the DC Motor.
5. **Actuator:**It is the device that we use to control the input to the plant. Here PWM Generator is the Actuator.
6. **Controller:**It is the system that we use to control the outputs of the plant for the desired functionality. In this thesis, PID Controller is used for controlling the motor's speed by providing the signal to the PWM Generator that will change the pulse width of the PWM output so as to bring the speed of the motor to the desired or to the set-point.

7. **Lag Time:** It is the time required for returning to its set point after there is a change in the variable to be measured by a control system.
8. **Dead Time:** It is the elapsed time between errors occurs and when the corrective action takes place.
9. **Transient:** It is the temporary variation in the load parameter after which the parameter which is to be measure returns to its desired value.
10. **Offset:**It is the difference between the set point and the measured variable after a new controlled variable level is reached.
11. **Disturbance:**It is the additional undesirable input to the plant that tries to deviate the controlled variable from its set point and it is the signal which is to be compensated by the controller.

1.6 PERFORMANCE OF A CONTROL SYSTEM

It describes how well the output tracks a change in the reference input. Performance has several aspects which are:

1. **Rise Time:** It is the time required for the response to shift from 10% to 90% of the signal from the initial value to the final value.
2. **Peak Time:** It is the time required by the response to reach its first peak.
3. **Settling Time:** It is the time required by the system to settle down within 1% range of the final value.
4. **% Overshoot:** It is the percentage by which peak of the response exceeds the final value.

1.7 CLASSIFICATION OF A CONTROL SYSTEM

Many different ways can be used to design a control system. The manipulated variable can be generated from the error by one of the following ways:

- **Mechanically or Electrically**
- **Analog or Digitally**
- **With or without Auxiliary Energy**

These differences have almost no impact on the control response, although they significantly influence the controller selection The manipulated variable is the main criteria for determining the control response. Therefore, controllers are classified according to their control signal response.

Depending upon the output of the controller the control signal can be continuous or discontinuous.

1. **Continuous controller:** In continuous controller the output of the controller or the Manipulated Variable can have any value within the controller output range. The continuous controllers can be either proportional (P), integral (I) or differential (D) action, or is a sum of these individual elements.
2. **Discontinuous controller:**In discontinuous controller the manipulated variable can only have discrete values. Depending upon the different states of the manipulated variable, a distinction is made between two-position, three positions and multi position controllers. Compared to the continuous controllers discontinuous controllers operate on very simple, switching final control elements.

1.8 CONTINUOUS CONTROLLERS

- **P controller:** Proportional controller is the most common among all the continuous controllers. In proportional controller the amplitude of the output of the process is measured by a suitable sensor and converted into an electrical signal by a suitable transducer. This signal is then compared to a set point or a reference point. If there is any difference between the two then this difference is amplified by multiplying the error or the difference with a constant gain called a proportional gain and then the amplified signal is fed to a final controlling element. In our case it will be a PWM Generator. The final controlling element controls the input to the process whose value changes in accordance with the error input to the final controlling element until the output of the process is equal to the reference signal or error is equal to zero. In proportional controller the manipulated variable y is proportional to the error signal i.e.

Y=Kp*e

Where

Y= controller output

Kp= Proportional gain

e= error

- The controller gain determines how much a given change in error changes the output from the controller.
- Proportional controller has only one tuning parameter but the main disadvantage is that it operates with an offset value.
- The proportional controller reduces the Rise Time but never eliminates the steady state error.
- The larger the value of Kp, smaller the offset but more is the proportional gain and more will be the oscillation in the output signal. There is a maximum value of Kp beyond which the process becomes unstable.

- **PD Controller:** The basis function of adding a derivative term to a proportional controller is to reduce the correction time or the settling time that would have occurred using a proportional action alone.

➢ In PD Controller, a pure differentiator is added in the forward path of the feedback control system.

To understand the derivative action let us assume error undergoes an initial large change, differentiation of this change yields a large value that drives the plant or the process. At this point the output of the differentiator is much larger than the integral or proportional gain. This results in the faster response of the system. The output from the derivative decreases with time and become negligible as the error approaches zero.

➢ Differentiation is a noisy process whose amplitude is small but frequency is quite high.

➢ Adding Derivative action to the proportional controller increases the stability of the system, reduces the % Overshoot, reduces the Rise Time and Settling Time and improves the transient response of the system.

➢ In PD Controller the output of the controller results from the addition of P and D control elements.

The mathematical expression of the PD Controller is

$$y = K_P \cdot e + K_D \frac{de}{dt}$$

PI Controller: Since most of the process cannot work with an offset, they must be controlled at their set points and in order to achieve this, extra intelligence must be added to proportional controller and this is achieved by providing an integral action to the original proportional controller. So the controller becomes proportional –integral controller.

- Under PI Controller as long as error is present the controller keeps changing its output and once the error is zero or it disappears the controller does not change its output.
- Integration is the mode that removes the offset or the error but sometimes it may make transient response worse
- In PI Controller the output of the controller is changed proportional to the integral of the error.

The mathematical expression of the PI Controller is:

$$\mathbf{y = Kp.e + Ki \int e\, dt}$$

Where

Ki = Integral gain of the PI controller.

PI Controller has the following disadvantages:

- The response is sluggish at the high value of the integral time Tn.
- The control loop may oscillate at the small value of integral time Tn.

- **PID Controller**: PID Controller includes all the three control actions i.e. proportional, integral and derivative.

- A PID controller calculates and outputs a corrective action, which corrects the error between the process output and the desired set point, that adjusts the process accordingly and rapidly.
- The output of the controller or the manipulated variable is obtained by adding P,I and D components and their associated coefficient.

The mathematical expression of the PID Controller is:

$$y = K_p \cdot e + K_i \int e\, dt + K_D \frac{de}{dt}$$

1.9 DISCONTINUOUS CONTROLLERS

- **ON_OFF Controller:** In this control process the output of controller changes from one fixed condition (ON) to another fixed condition (OFF). Set point is used as control adjustments.

➢ The output of the controlled variable is compared with a set point or the reference. When the controlled variable is above a set point then the system is turned ON and when below the set point the system is turned OFF or vice-versa.

➢ It cannot be used for a process with small time constant.

➢ It is used in control of Home Appliances such as Refrigerator temperature control, Oven temperature controls Dish-washer water level control etc.

- **Two-Position Controller:** Two Position Controller is an improvement over ON-OFF Controller. In this controller also the output swing between 0 to 100% but in this case an additional hysteresis element is added.

➢ Neutral Zone is the region of error over which the controller does not change its output

➢ Two Position control is basically used in home heating systems, air conditioning systems, refrigerator, tank fluid level control etc.

- **Multi-Position Control System:** In this the controller can have 3 or more level of output. It basically reduces the controller cycling rate.

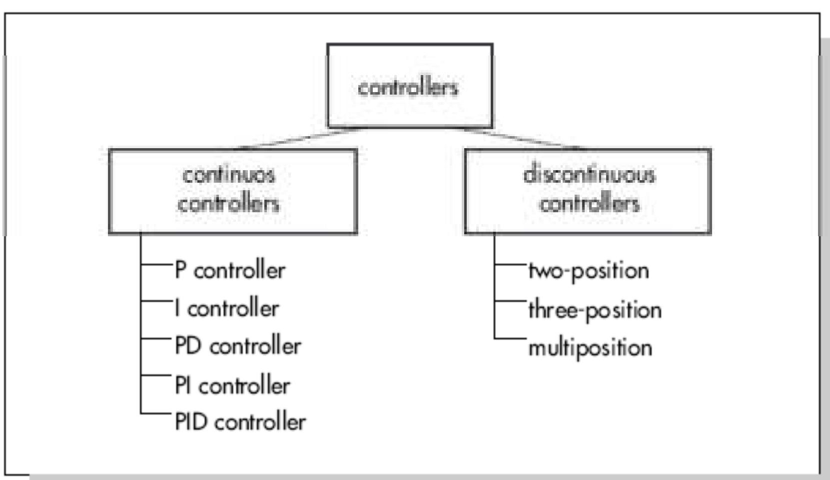


Fig1.3: Classifications of the controllers

1.10 <u>SELECTING A CONTROLLER</u>

To solve a control task it is required that

a. The control system be analyzed and

b. A suitable controller be selected and design

Listed below are the most important properties of the widely used **P,PI,PD** and **PID**controllers:

Control Element	*Offset*	*Operating Point Adjustment*	*Speed of Response*
P	Yes	Recommended	High
PD	Yes	Recommended	Very high
I	No	N/A	Low
PI	No	N/A	High
PID	No	N/A	Very High

TABLE:-1.1 Different Modes of Control

Which controller to select depends on following factors:

a. Whether the system is based on integral or proportional control action.
b. Process lag.
c. Speed of the error correction
d. Acceptability of steady-state error.

According to the above table, controllers and systems can be assigned to each other as:

- For easy-to-control systems where steady-state errors are acceptable, P controllers are used
- In systems with great lag where offset is tolerable PD controllers are used
- For applications with low requirement to control dynamics and where the system does not exhibits great lags, I controllers are used
- For a dynamic control response without exhibiting the steady state error, PI controllers are used
- If it is required that the speed of the response is as high as possible, regardless of the great lag, PID controllers are used.

Chapter 2

Data Acquisition System

2.1 INTRODUCTION

Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition systems (abbreviated with the acronym DAS or DAQ) typically convert analog waveforms into digital values for processing.

2.2 COMPONENTS OF A DATA ACQUISITION SYSTEM

The components of data acquisition systems include:

- Transducers and sensors
- Signals
- Signal conditioning
- DAQ hardware
- Driver and application software

2.2.1 Transducers

The physical phenomenon to be measured is the starting point of the data acquisition process.The temperature inside a room, the intensity of light by a light source, the pressure inside of a chamber, the force applied to an object are some examples of a physical phenomenon. All of these different phenomena can be measured by an effective data acquisition system.

A transducer can be used to convert a physical phenomenon into voltage, current or any other measurable electrical signal. The ability of a transducer to convert physical phenomena into signals that can be measured by the data acquisition hardware greatly affects the ability of a data acquisition system for measuring different phenomena. Transducers are similar to sensors in data acquisition systems. Each different application, such as measuring temperature, pressure or fluid flow uses a specific transducer.

2.2.2 Signals

Physical phenomena can be converted into measurable signals by the appropriate transducers. However, different ways are required to measure different signals.So, understanding the different types of signals as well as their corresponding attributes is important. Signals are basically categorized into two groups:

- Analog signals
- Digital signals

Analog signals:

It is a signal that exists at any value with respect to time. Voltage, sound, temperature, and load are some examples of an analog signal.

The following are the three primary characteristics of an analog signal :

- **Level:** As an analog signal can possess any value, the level imparts vital information about the analog signal that is being measured. The signal generally does not change rapidly with respect to time, as we measure the level of a signal,. However, the accuracy of the measurement is very important.
- **Shape:** The shape of signals – sine, square, sawtooth, and triangle, are sometimes used for naming them. The shape of an analog signal is very important because we can further analyse the signal by measuring the shape of an analog signal, including peak values, slope, and DC values. Generally, signals where shape is of interest, seem to change rapidly with respect to time, but importance of system accuracy is still high. Some applications involving shape measurements the analysis of video signals, sounds, heartbeats, circuit responses and vibrations.
- **Frequency:** Frequency can be used to categorize all analog signals. Unlike the shape or level of the signal, frequency cannot be measured directly. The signal is analysed using software for determining the frequency.

  Both accuracy and acquisition speed need to be considered when frequency is the most important information. Although the acquisition speed required for the frequency of a signal is relatively less than the speed for obtaining the shape of a signal, we must, still, acquire the signal quickly so as not to lose the pertinent information while the analog signal is acquired. Some applications where the frequency of the signal is important are telecommunication, speech analysis and earthquake analysis.

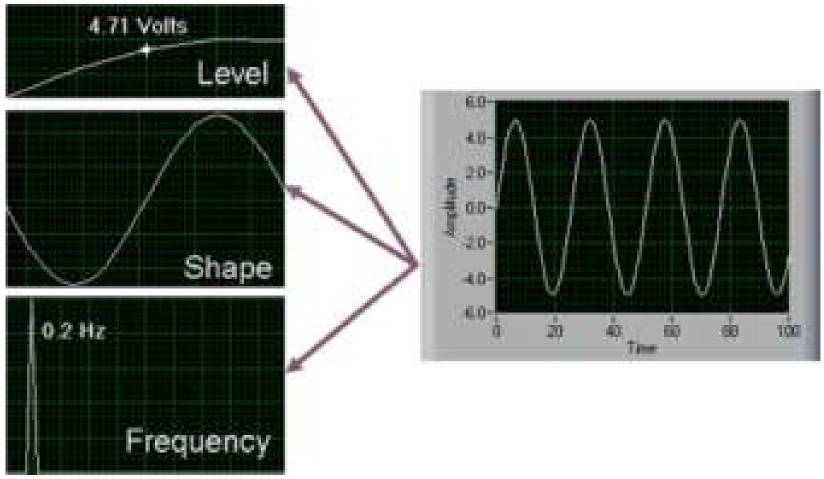


FIG 2.1:Analog Signals

Digital signals:

A digital signal cannot take on any value with respect to time. On the contrary, it has two possible levels: **high** and **low.**

When its level falls within **0-0.8V,** a digital signal is considered **low** and it is considered **high** between **2-5V**.

State and **rate** are the useful information that we can measure from a digital signal.

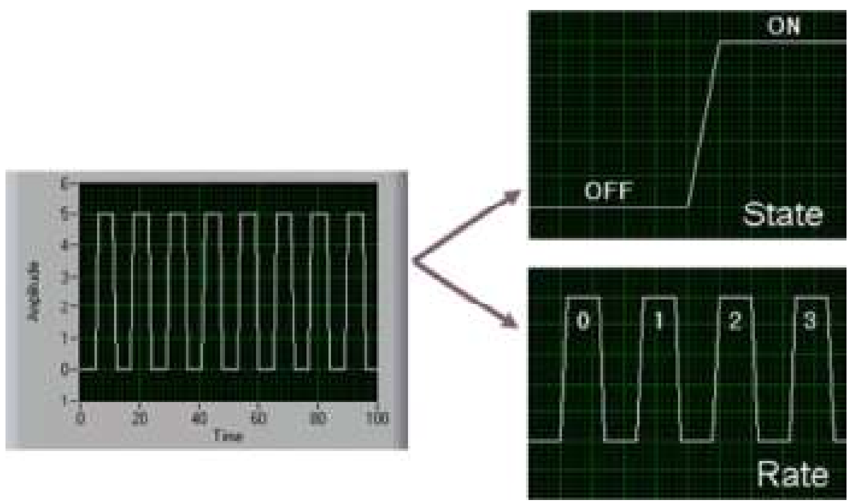


FIG 2.2:Digital Signals

State: Any value with respect to time is not possible for a digital signal. The state of a digital signal is basically the level of the signal- **on** or **off**, **high** or **low**.

Rate: How the digital signal changes state with respect to time defines the rate of a digital signal.

2.2.3 Signal conditioning

Sometimes the signals generated by are too difficult or too unsafe to measure directly with the help of a data acquisition device. For instance, signal conditioning is essential for an effective data acquisition system, when dealing with extremely high and low signals, noisy environments, high voltages or simultaneous signal measurement. The accuracy of a system is maximized, safety is guaranteed and sensors operate properly with the help of signal conditioning. Various operations included in signal conditioning are isolation, amplification, simultaneous sampling, attenuation, sensor excitation etc.

2.2.4 Data Acquisition Hardware

Data acquisition hardware acts as the interface in between the computer and the outside world. It primary function is to helping the computer interpret analog signals by digitizing them. It could be in either of the two forms - modules that can be connected to the computer's ports (parallel, serial, USB, etc.) or cards connected to slots (S-100 bus, ISA, MCA, PCI, PCI-E, etc.) in the mother board. Usually an external breakout box is required because the space on the back of a PCI card is too small for all the connections needed. Other functionalities of data acquisition are as follows:

- **Analog input/output**
- **Digital input/output**
- **Counter/timers**
- **Multifunction** - combines analog, digital, and counter operations on a single device

2.2.5Driver and Application Software

Driver Software : The PC and the data acquisition hardware are transformed into a complete data acquisition, analysis, and presentation tool by software. The data acquisition device does not work properly without software to control or drive the hardware. Driver software can be defined as the layer of software for easily communication with the hardware. It acts as the middle layer between the application software and the hardware.

Application Software: Application software allows the full control and view of various data operations that can be done on the input signals. It provides a graphical view of the whole system and provides an ease of access to the data processing.

2.3 DAQ HARDWARE

Usually interfacing between the signal and a PC is done by DAQ hardware. Multiple components (multiplexer, ADC, DAC, TTL-IO, high speed timers, RAM) are contained within a DAQ card. These can be accessed via a bus by a microcontroller, which can run small programs.

Some common terms related to DAQ hardware are:

- **Analog-to-digital convertor (ADC)**
  An electronic device that converts analog signals to an equivalent digital form. The analog-to-digital converter is the heart of most data acquisition systems.
- **Digital-to-Analog Converter (D/A)**
  An electronic component found in many data acquisition devices that produce an analog output signal.
- **Digital Input/output (DIO)**
  Refers to a type of data acquisition signal. Digital I/Os are discrete signals which are either one of two states. These states may be on/off, high/low, 1/0, etc. Digital I/Os are also referred to as binary I/O.
- **Differential Input**
  Refers to the way a signal is wired to a data acquisition device. Differential inputs have a unique high and unique low connection for each channel. Data acquisition devices have either single-ended or differential inputs, many devices support both configurations.

- ## 2.3.1Resolution

The smallest signal increment that can be detected by a data acquisition system is known as resolution. It is also defined as the number of bits ADC of the DAQ uses to represent the signal.

No of levels= $2^{resolution}$

For example a resolution of 12 gives $2^{12} = 4096$ levels

While a 3 bit resolution gives 8 levels.

Thus, higher the resolution, greater is the number of levels and hence more precise the representation of the signal.

Code width represents the smallest change in the signal that a DAQ system can detect.

Code width = voltage range (peak to peak)/total no of levels

Example of resolution

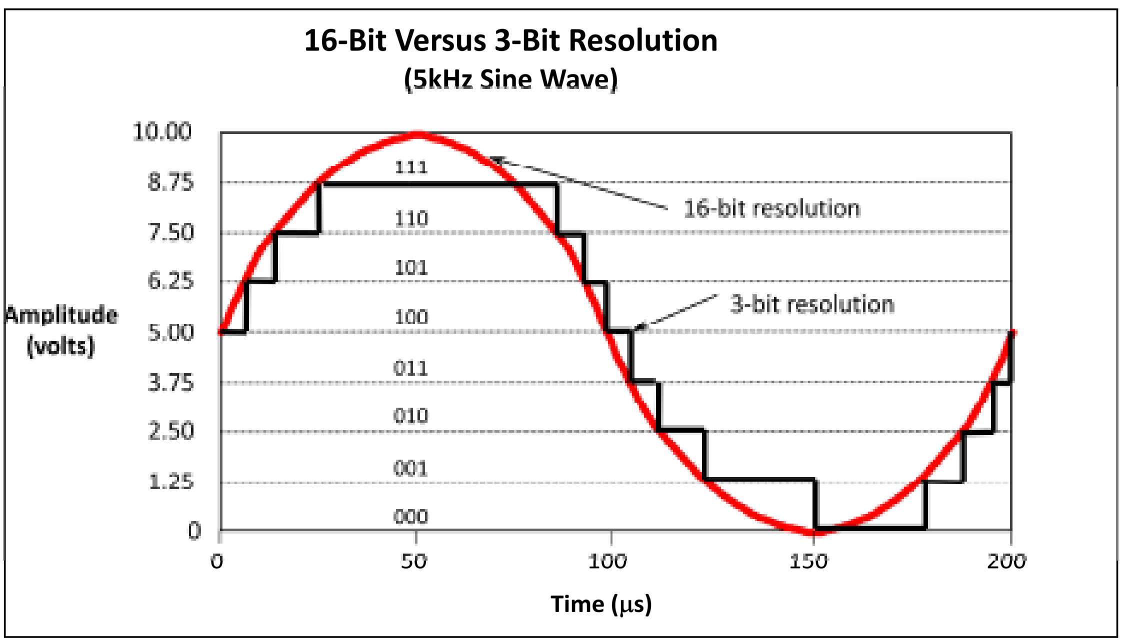


FIG 2.3: Analog to Digital Conversion

2.3.2 Sampling rate

The number of samples obtained in one second, i.e. the speed at which a data acquisition system collects data is called sampling rate. The speed is normally expressed in samples per second.

The sampling theorem guarantees that band limited signals (i.e., signals limited by a maximum frequency), if sampled at a sampling rate more than twice the maximum frequency, can be reconstructed perfectly from their sampled version. This theorem is known as Nyquist-Shannon sampling theorem.

A phenomenon known as **aliasing** arises when sampling rate is below Nyquist rate of sampling (under sampling). It results in wrong prediction of the signal.

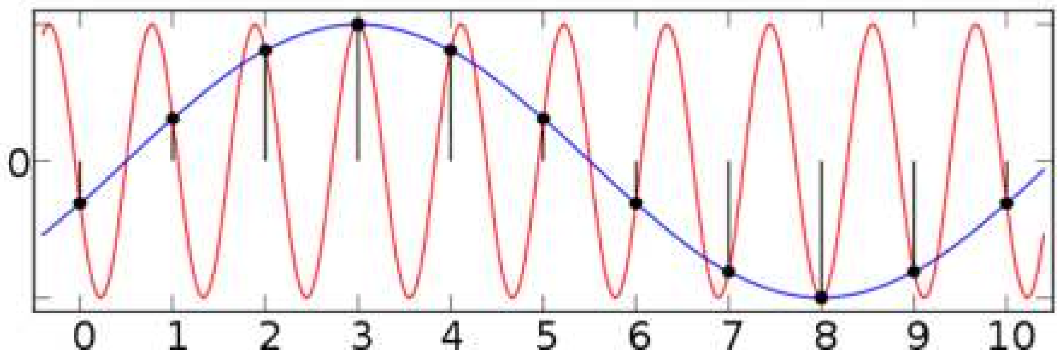


FIG 2.4: Aliasing

2.3.3 DAQ Hardware Used

1. **NI PCI-6221** data acquisition card is used as the hardware device. It has a total of 68 pins for various input/output purposes. Various characteristics of the card are:
    - 16-Bit, 250 kS/s, 16 Analog Inputs
    - Two 16-bit analog outputs (833 kS/s); 24 digital I/O; 32-bit counters.
    - Correlated DIO (8 clocked lines, 1 MHz)
    - NI-MCal calibration technology for increased measurement accuracy
    - **NI-DAQmx** driver software and **NI LabVIEW V8.5** interactive data-logging software

2. **NI CB-68LP** is the daughter board used along with the **PCIcard.** It is a low-cost termination accessory with 68 screw terminals for easy connection.

The following are the connections for the PCI 6221 card:

68 ACH0	61 ACH12	15 DGND	08 +5V	01 DIO6P2
34 ACH8	27 AIGND	49 DIO2P0	42 DIO3P1	35 DGND
67 AIGND	60 ACH5	16 DIO6P0	9 DGND	2 DIO4P2
33 ACH1	26 ACH13	50 DGND	43 DIO2P1	36 DGND
66 ACH9	59 AIGND	17 DIO1P0	10 DIO1P1	3 DIO1P2
32 AIGND	25 ACH6	51 DIO5P0	44 DGND	37 DIO0P2
65 ACH2	58 ACH14	18 DGND	11 DIO0P1	4 DGND
31 ACH10	24 AIGND	52 DIO0P0	45 DIO2P2	38 DIO7P1
64 AIGND	57 ACH7	19 DIO4P0	12 DGND	5 DIO6P1
30 ACH3	23 ACH15	53 DGND	46 DIO3P2	39 DIO7P2
63 ACH11	56 AIGND	20 RESERVED	13 DGND	6 DIO5P1
29 AIGND	22 DAC0OUT	54 AOGND	47 DIO3P0	40 DIO5P2
62 AISENSE	55 AOGND	NA NA	14 +5V	7 DGND
28 ACH4	21 DAC1OUT	NA NA	48 DIO7P0	41 DIO4P1

2.3.4 DAQ software used

NI LabVIEWis used as the application software for controlling all the processes and functioning of the system. **LabVIEW**(Laboratory Virtual Instrumentation Engineering Workbench) is a graphical programming environment used to develop sophisticated measurement, test, and control systems using intuitive graphical icons and wires that resemble a flowchart. It provides integration with thousands of hardware devices as well as provides hundreds of built-in libraries for advanced analysis and data visualization for creating virtual instrumentation.

A **LabVIEW** program is called a **virtual instrument (VI).** Each VI consists of a **front panel** and **a block diagram**. The front panel works as the user interface. Buttons, switches, graphs, tables, and more can be placed on the front panel. On the block diagram, you develop graphical code to acquire and analyze your measurement data, branch and repeat code, and interface with elements on the front panel.

Data acquisition applications usually include acquiring signals, displaying data in a chart or graph on the front panel, as well as saving the data to a file. All of these elements are easy in LabVIEW which also has several features for configuration and getting started.

Chapter 3

CONTROLLER , ACTUATOR AND SENSOR

3.1 INTRODUCTION

PID Controller is basically designed to control the output of the process to a fixed value called the set point or the reference. The controller produces an output according to the difference between the controlled variable and the set point and that signal is given to the process input through an Actuator and that causes some corrective effort to be applied to the process so as to drive the controlled variable towards the set-point. The figure 3.1 shows the feedback control block diagram.

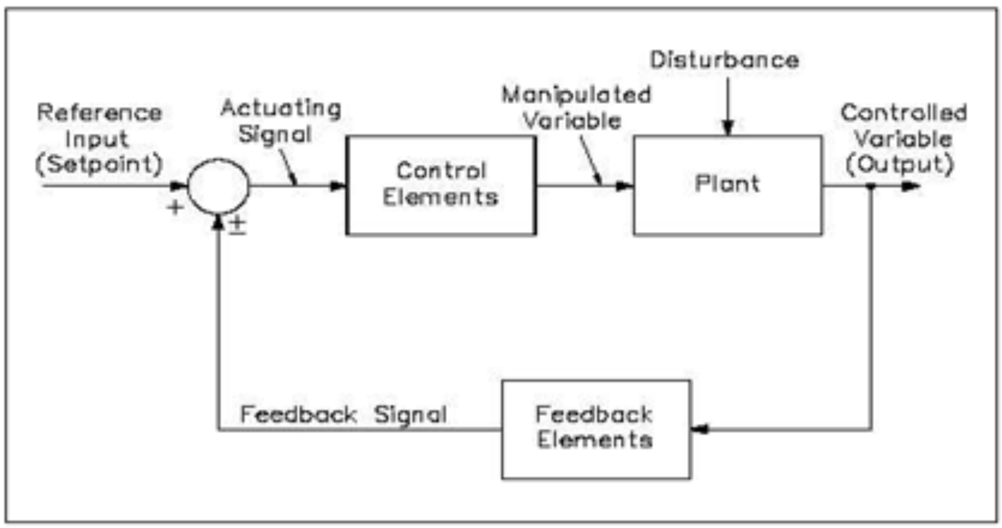


Fig: 3.1: Feedback Control System

In the above block diagram control element is the controller which is used to control the output of the process. In this thesis we have used a P Controller to do the task.

Plant is the system or the DC Motor whose speed is to be control.

Feedback elements consist of a sensor and a DAQ card. In this thesis we have used an infrared reflector sensor to sense the speed of the motor and NI PCI 6221 configured in a PC as a transducer to provide the digital output to the controller input. The controller is designed in NI LabVIEW with which the DAQ card is configured.

The overall block diagram for the motor speed control is shown in figure 3.2

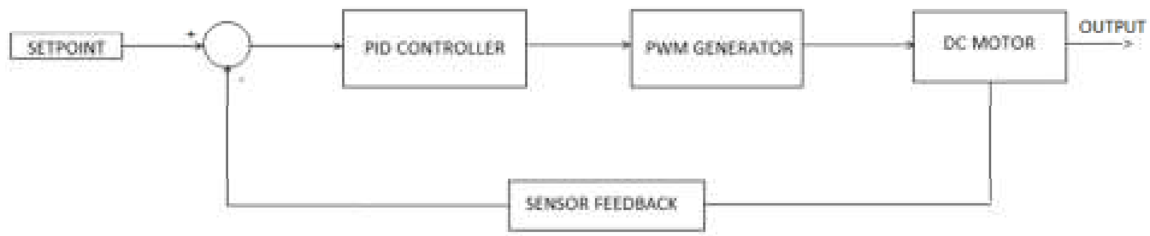


Fig:- 3.2 Block diagram for motor speed control.

The output of the controller is used by the PWM Generator to produce the PWM waveform which will be the input to the system which in our case is a DC Motor. The PID controller (which is actually configured as a P controller for an open loop system) gives output as the duty cycle of the PWM waveform which is generated by the PWM generator.

3.2 <u>PID CONTROLLER</u>

A PID Controller algorithm involves a parallel combination of proportional integral and derivative control. The Proportional term determines how the controller responds to a current error, the Integral term determines the response based upon sum of recent errors and finally derivative term determines the response of the controller, based on the rate of change of the error. The weighted sum of all the actions is then used to adjust the process via a final controlling element such as PWM Generator, control valve etc. Since we are dealing with an open loop system, hence the controller will be reduced to a P controller with I and D components set to zero.

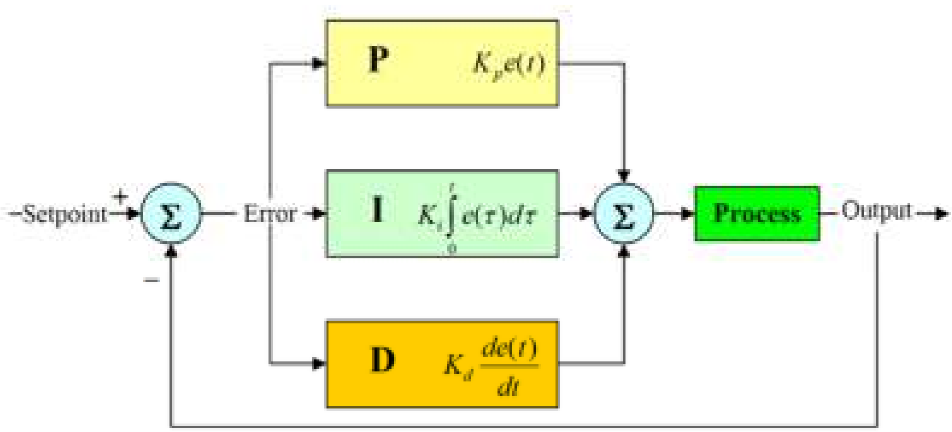


Fig: 3.3: A Block Diagram of PID Controller

3.2.1Proportional term: The proportional gain changes the output in such a way that the change is proportional to the current error.

The proportional term is given by:

$$P_{\text{out}} = K_p e(t)$$

Where

Pout: Proportional output

Kp: proportional gain

e: error

t: Time or instantaneous time (the present)

The following figure shows how the output of the proportional controller changes with a change in gain of the controller.

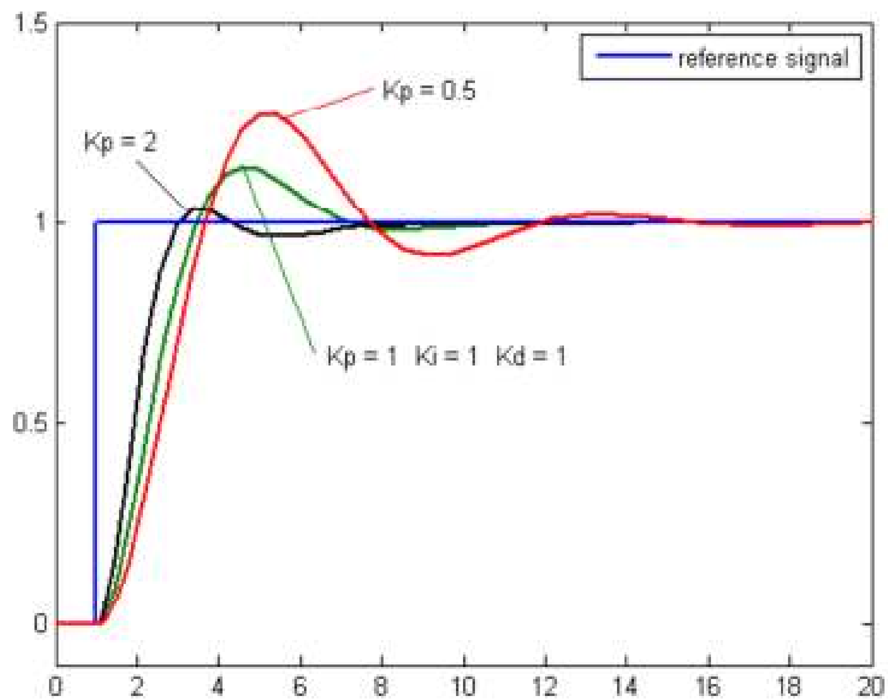


Fig 3.4: Step response of P controller

As shown in the figure 3.4 as the value of the proportional gain increases the sensitivity of the system with respect to a change in the error value increases i.e. the rise time of the system decreases but if the proportional gain is too high, then the system can become unstable.

3.2.2Integral term: The integral term makes a change to the output that is proportional to both the error magnitude and the error duration. The error is accumulated over the time and this error is then multiplied by a constant known as integral gain and then it is added to the controller output. The integral term is given by

$$I_{\text{out}} = K_i \int_0^t e(\tau)\, d\tau$$

Where

Iout: Integral output

Ki: Integral gain, which is a tuning parameter

e: Error

t: Time or instantaneous time

τ: a dummy integration variable

The integral term reduces or even completely eliminates the steady state error and reduces the response time for a change in error but it can cause the output of the controller to overshoot the set point value.

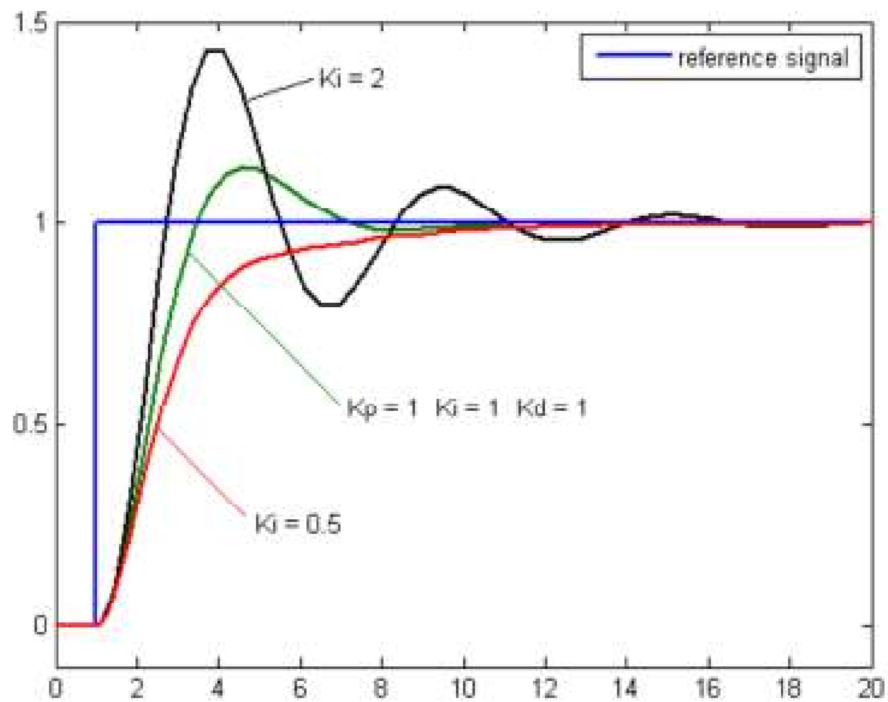


Fig 3.5: Step response of PI controller

3.2.3 Derivative term: The derivative term is calculated by determining the slope of the error with respect to time and multiplying the derivative gain Kd with the rate of change of error.

The derivative term is given by

$$D_{\mathrm{out}} = K_d \frac{d}{dt} e(t)$$

Where

Dout= derivative term of output

Kd= derivative gain

e = error

t= Time or instantaneous time

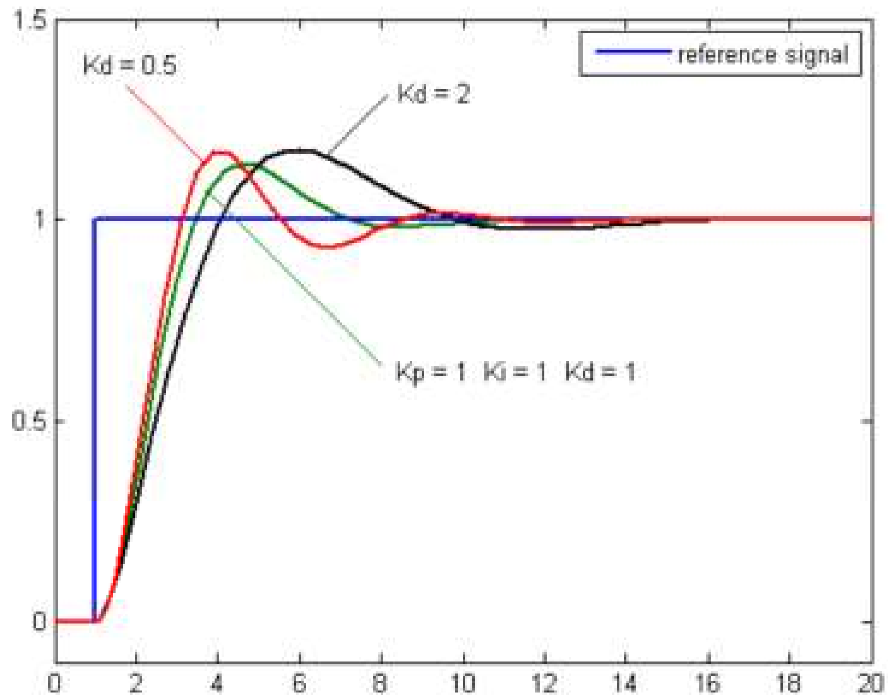


Fig: 3.6: Step response of PD Controller

To calculate the output of the PID Controller the proportional, integral and derivative terms are summed together.

Let u(t) be the controller output , then the final form of the PID algorithm is

$$\mathrm{u(t)} = \mathrm{MV(t)} = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{d}{dt} e(t)$$

In this thesis we are using a PID controller configured as a P controller for open loop system.

3.3 PWM GENERATOR

Pulse width modulation is a technique to provide a logic'0' and logic '1' for a controlled period of time. Analog voltages and current can be used to control processes directly but as simple it seems its not always practical and economical to do so because analog circuits tend to drift over time and can therefore be very difficult to tune.Controlling an analog circuit digitally can greatly reduce cost as well as power consumption. PWM is a powerful technique for controlling analog circuits digitally.

PWM is a way of digitally encoding analog signal levels. The duty cycle of a square wave can be modulated to encode a specific analog signal level. However the PWM signals are always digital because at any instant the DC supply is either fully on or fully off. Voltage or current sources are applied to the analog load by means of repeating series of on and off pulses. The "on-time" is the time during which DC supply is given to load while the "off-time" is the time during which it is switched off. Given a sufficient bandwidth, an analog value can be encoded with PWM. Figure below shows various PWM waveforms of different duty cycles:

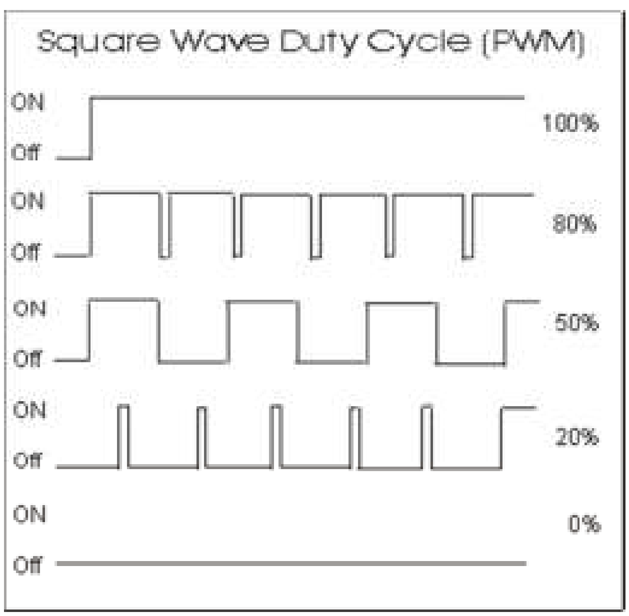


Fig 3.7 : PWM with various duty cycles

Duty cycle of a PWM is the ratio of "on time" to "pulse period".

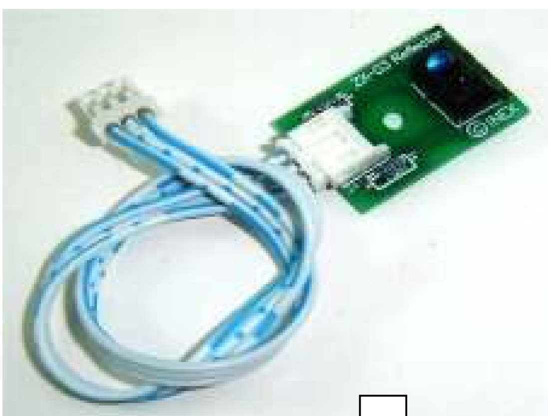
3.4 SENSOR

The IR Reflector sensor senses the speed of the DC motor and gives series of on/off pulses according to the speed of the DC motor. These signal act as the feedback input for the PID controller.

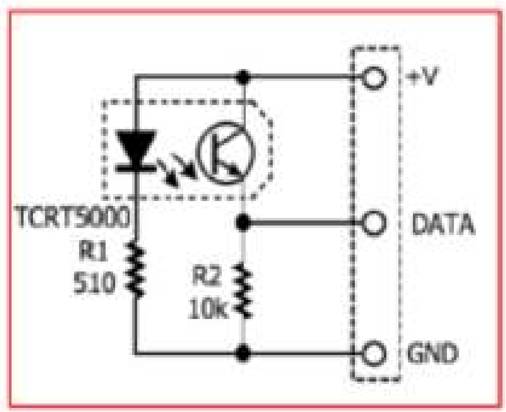
The sensor is made of the infrared reflector LED and a photo resistor, when infrared rays from the LED hits the black surface, it absorbs most of the light falls on it so reflection is less as a result of which the resistance of the photo diode is high and when the light falls on the white surface, it reflect most of the rays falls on it so reflection is more and therefore resistance of the photo diode decreases. The infrared reflector has two parts: -

1. Emitter – emits the light.

2. Detector–detects light for further processing.



a



b

Fig 3.8: (a) ZX-03 IR reflector sensor (b) sensor schematic

In this thesis a ZX-03 IR reflector sensor (shown above) has been used. An infra-red LED in the sensor will continually receive voltage from a +V voltage power supply. A 510 Ω resistor is connected to limit the electric current. The infra-red receiver uses a phototransistor in a parallel line with a 10 kΩ resistor. The amount of the electric current that flows in the circuit depends upon the intensity of the reflected light. The DATA terminal will have the sensor output voltage ranging from 0.5- 5 V.

Chapter 4

IMPLEMENTATION OF LABVIEW BASED CONTROLLER

FOR DC MOTOR SPEED CONTROL

4.1 INTRODUCTION

Motor control is a very old field but interesting development has been done recently by making the use of digital technology for motion control. Sophisticated motor controllers are being used for wide range of application for much complex and accurate motion control. However development time and the cost factor have increased due to error in design and integration which can be detected only when the code is run on the actual hardware.

4.2 DC MOTOR - AN OVERVIEW

A DC motor is a machine that converts electrical energy into mechanical energy.The operation is based on simple electromagnetism, i.e. “when a current carrying conductor is placed in a external magnetic field it experiences a force which is proportional to the current and the external magnetic field.” A torque is generated by the magnetic reaction and the armature revolves and this induces a voltage in the armature windings which is opposite in direction to the outside voltage applied to the armature, when current is passed through the armature of the DC motor, and hence is called back voltage or counter e.m.f. The back voltage rises till it becomes equal to the applied voltage as the motor rotates faster,

The speed at which the DC motor rotates depends on two factors - the armature current as well as the strength of the magnetic field acting on the armature. The stronger the field, the slower is the rotation rate required to produce a back voltage huge enough to counteract the applied voltage. Hence, the speed of the DC motor can be controlled by varying the field current.

Every DC motor consists of six parts: axle, stator, rotor, commutator, field magnet and brushes. The stator holds the motor casing as well as the two permanent magnets which helps to generate the external magnetic field. The rotor rotates with respect to the stator; it has windings which are electrically connected to the commutator.

4.3 DC MOTOR SPEED CONTROLLER

The function of a DC motor speed controller is to take as input a signal representing the demanded speed and to drive a motor at that speed. The controller may or may not measure the speed of the motor to use it as a feedback for the purpose of error reduction. If it does so, it is called a closed loop system else an open loop system. In this thesis we have implemented an open loop system with no feeding of the sensor output to the controller input.

The dc motor speed in general is directly proportional to the supply voltage, so if reduce the voltage from 12 volts to 6 volts then our speed become half of what it originally had. But in practice, for changing the speed of a dc motor we cannot go on changing the supply voltage all the time. So how to change the speed of the motor with input voltage fixed led to the development of systems known as speed controllers.

The speed controller for a DC motor works by varying the average voltage supplied to the motor (PWM is one such speed controller were we can get varying voltage according to the duty cycle of the PWM output signal). Rather than simply adjusting the voltage sent to the motor, we can switch the motor supply on and off where switching is done so much fast that the motor only notices the average effect.

The time it takes a motor to speed up slow down under switching conditions depends on the inertia of the motor. The graph below shows the speed of a motor that is switched on and off fairly slowly. If switching is done fast enough the motor does not have time to change speed and it gives an almost constant speed. Thus the speed is set by Pulse Width Modulation (PWM).

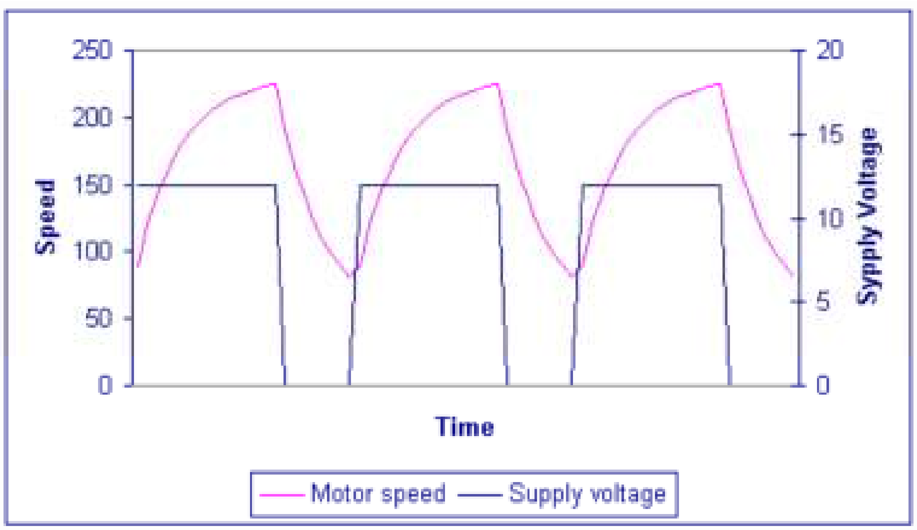


Fig4.1: DC motor speed v/s supply voltage

4.3.1 DC motor speed control using PWM

PWM or duty-cycle variation method is commonly used in DC motor speed control. Duty cycle is defined as the percentage ratio of the pulse HIGH to pulse HIGH + LOW during a PWM period. The average DC value for a 0% duty cycle is zero; with 25% duty cycle its 1.25(for a 5V DC supply). For 50% the average value is 2.5V and 3.75V for a 75% duty cycle and so on. Thus by varying the pulse width we can vary the average voltage across the DC motor and hence the speed.

4.4 DC MOTOR INTERFACING WITH DAQ CARD: IC L293D

L293D is a quadruple high current half-H driver for the DC motor.The L293D is designed to provide bidirectional drive currents of up to 600mA at voltages from 4.5 V TO 36 V. All the inputs are TTL compatible. Drivers are enabled in pairs, with drivers 1 and 2 enabled by 1,2EN and drivers 3 and 4 enabled by 3,4EN. L293D is used to drive the motor. Basically the output of the PWM Generator is given to the EN1 pin of the L293D. When the PWM Generator output is high it enables the driver. 1A and 2A are two inputs; 1Y and 2Y are the outputs. The output terminal of the L293D is connected to the dc motor input. When 1A is high and 2A is low the motor will rotate in anti clock wise direction and when the polarity is reversed then the motor will rotate in clock wise direction.

The pin and the block diagram of L293D IC are shown below:

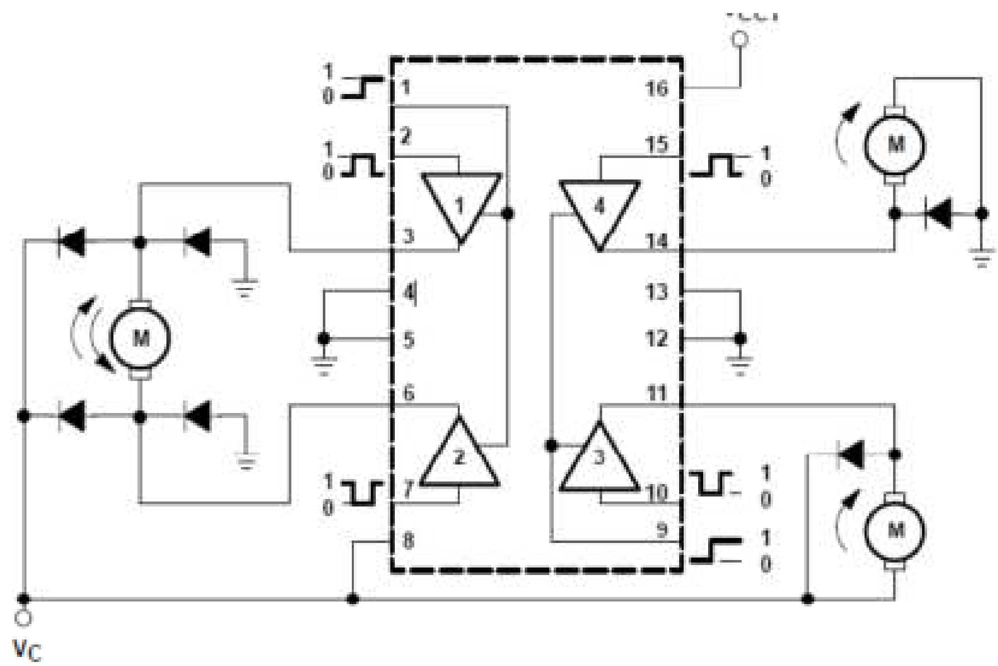


Fig4.2: Block Diagram ofL293D

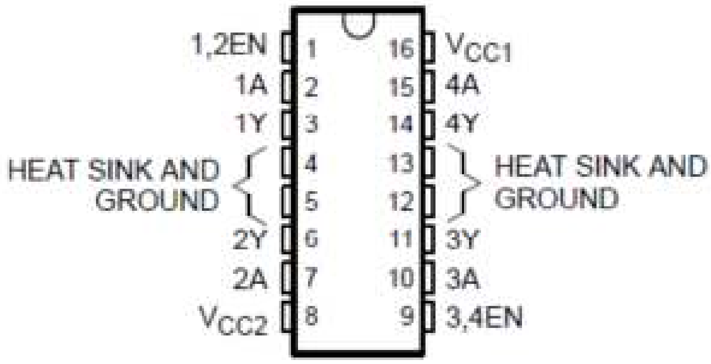


Fig 4.3:Pin Diagram of L293D

4.5 OPEN LOOP SYSTEM FOR DC MOTOR SPEED CONTROL

In open loop system the speed of the DC motor can be changed by varying the duty cycle of the PWM which depends on PID input. Increasing the duty cycle will run motor faster and vice versa. The driving voltage of the motor is incremented a quantity proportional to the speed of the motor according to a proportionality factor that is adjusted to compensate the back voltage.If a motor runs at 600 rpm at a duty cycle of 50% then making it 60% increases the rpm and reducing it to 40% decreases the motor speed.

Open loop control is useful for well defined systems where the relationship between the input and the resultant state can be modelled by using some simple mathematical formula. An open loop controller is used in simple processes because of its simplicity and low cost, especially where feedback is not important. In an open loop system the controlling parameters are fixed or set by an operator and the system finds its own equilibrium state. In our case of a DC motor the equilibrium state is the desired or reference value speed of the motor.

4.6 EXPERIMENTAL SETUP

4.6.1 DC motor hardware setup

Fig. 4.4 shows the hardware setup of our DC motor speed control process. Here a wheel is connected to the motor with a code sticker attached to it. The circular shaped code sticker has alternate black and white portions with a total of nine black and nine white portions. The ZX-03 IR reflector sensor is attached to the setup so that the IR radiations from the emitter falls on the code sticker which eventually gets reflected and are sensed by the sensor and an equivalent signal of on – off pulses is generated at the DATA terminal (middle port) of the sensor. When light rays falls on the black portion of the wheel, most of them gets absorbed giving out a LOW pulse. On the other hand when rays falls on the white portion most of them gets reflected giving out HIGH pulse. The other two terminals of the sensor are used to provide the power supply (0 and 5V) to the sensor.

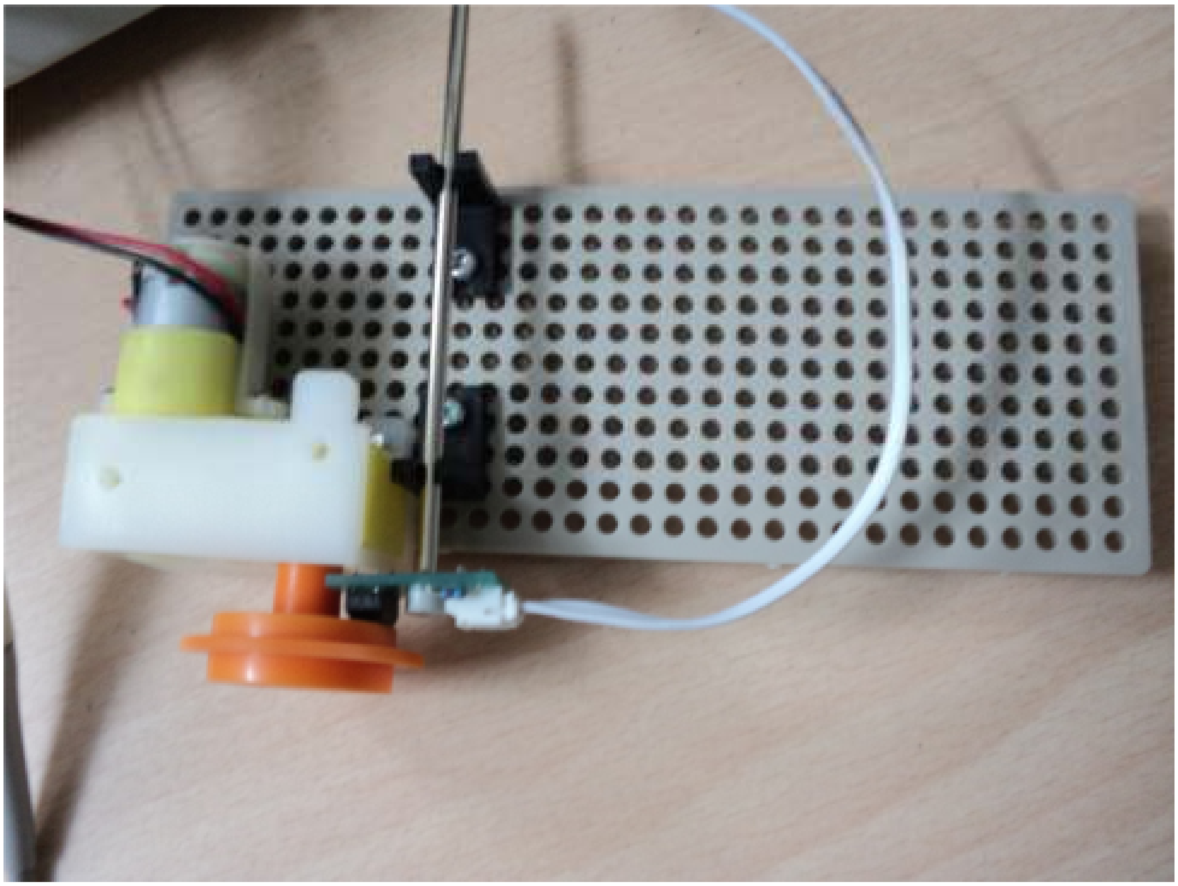


Fig 4.4: Hardware setup showing DC motor with wheel and sensor attached

The output signal is a square waveform whose frequency varies proportional to the speed of the motor. This signal is observed in a CRO to measure the RPM of the motor by doing the calculation as

RPM = (sensor_freq/9)*60

Since nine on-off pulses corresponds to one revolution of the motor.

The DC motor is driven by the driver IC L293D. The following figure shows the connection of the DC motor with IC L293D:

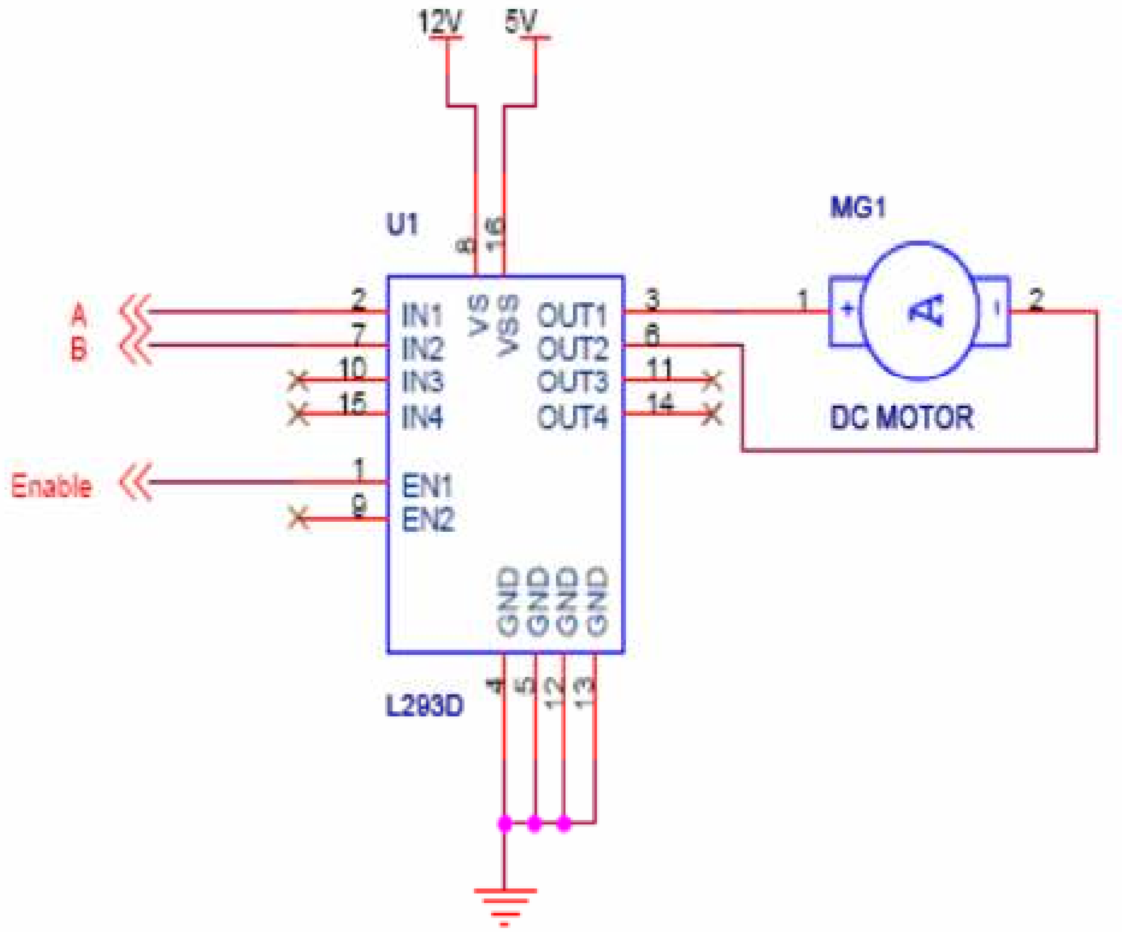


Fig. 4.5: schematic for showing the interfacing of the DC motor with L293D

From the circuit we can see that the motor in connected at terminals 3 and 6 and terminals 1,2 and 7 i.e. Enable , A and B are used to control the motor. The output of the PWM generator is fed to the Enable input and inputs A and B controls the direction of running of the DC motor as:

EN	1A	2A	FUNCTION
H	L	H	Turn right
H	H	L	Turn left
H	L	L	Fast motor stop
H	H	H	Fast motor stop
L	X	X	Fast motor stop

L = low, H = high, X = don't care

Fig 4.6 : Truth table for the IC inputs

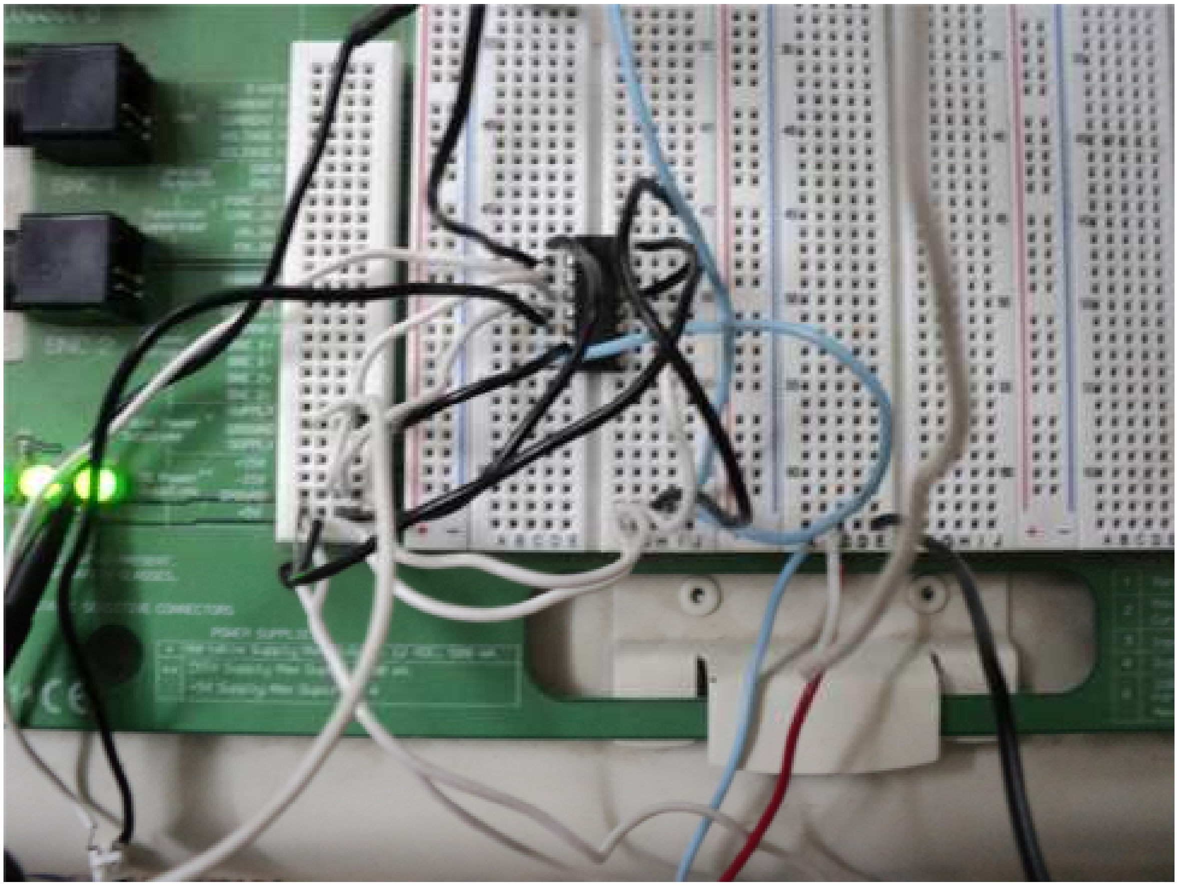


Fig. 4.7 : Physical connections of IC L293D

4.6.2 Software setup in LabVIEW

The controller (P controller) is implemented in LabVIEW with a reference point control as the desired RPM of the motor. The output of the controller which is the duty cycle of the required PWM is fed to the input of the PWM generator. The PWM generator generates the desired PWM of the input duty cycle at one of the counter output port of the DAQ card i.e. NI PCI 6221 inserted in the PCI slot of the PC. The daughter board of the DAQ card, CB-68 LP provides the interfacing with the physical world and the PWM signal is obtained from the equivalent slot of the daughter board. This PWM signal is then given as the input at the ENABLE pin of IC L293D.

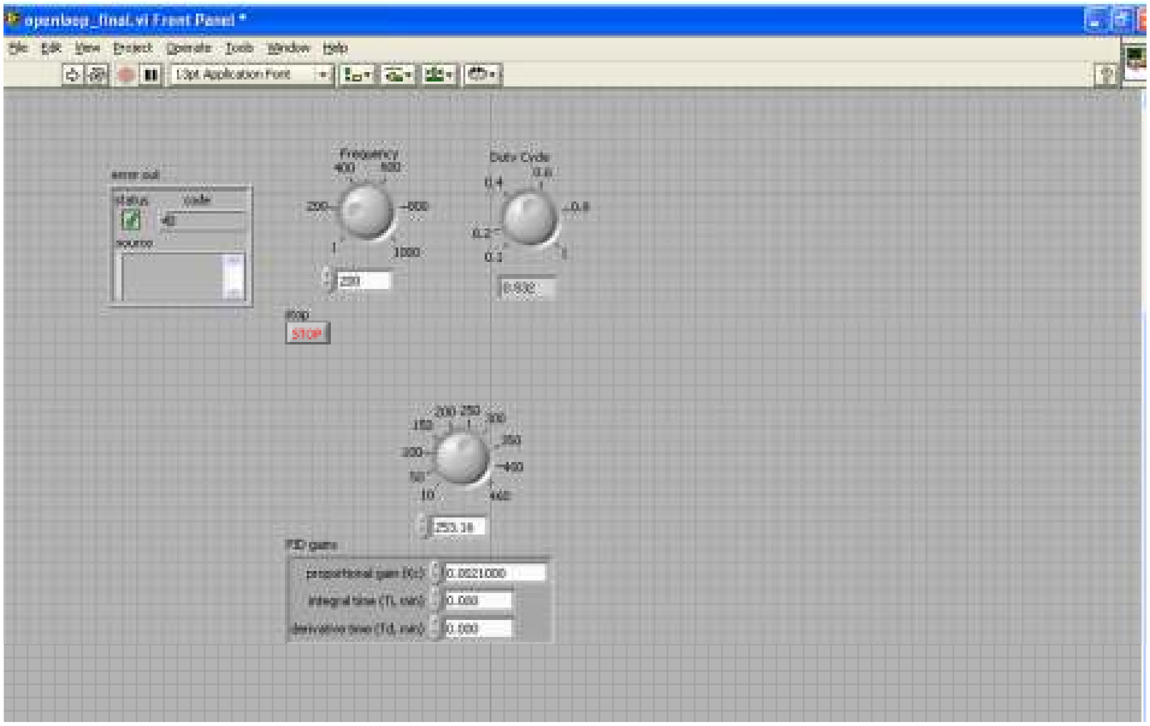


Fig. 4.8 : Front panel of the LabVIEW window

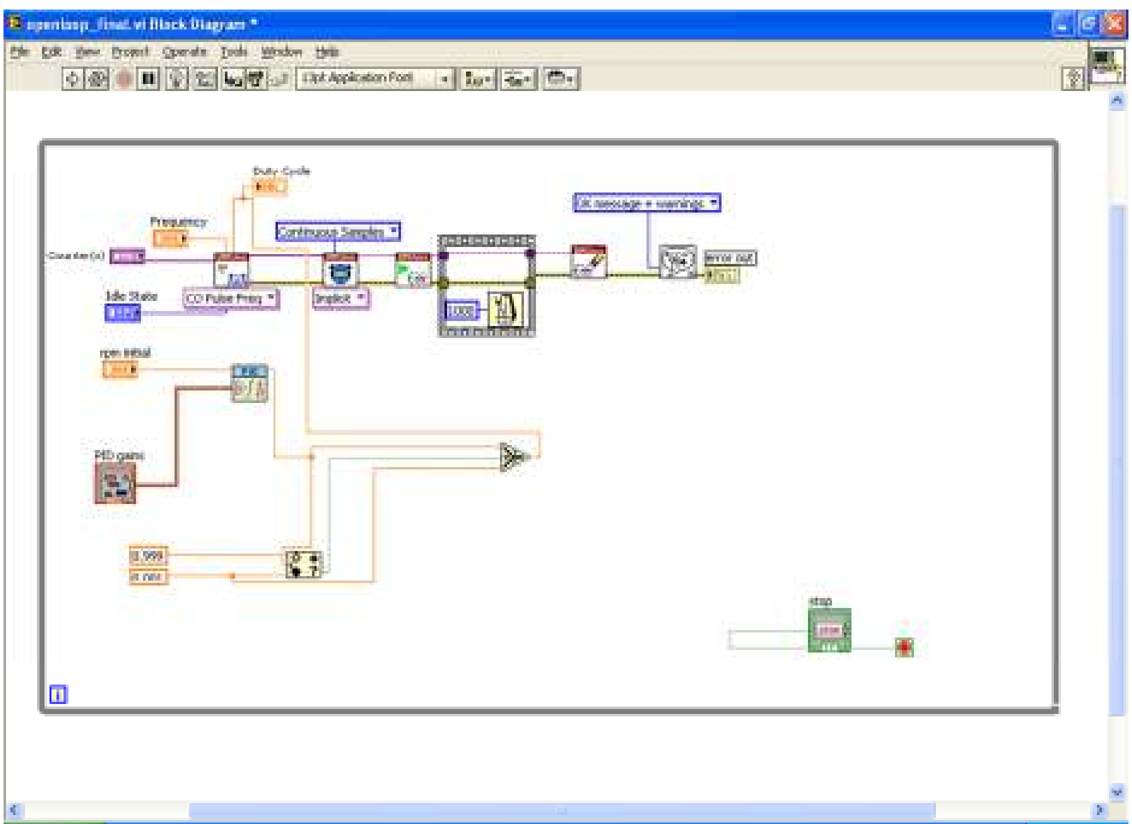


Fig.4.9 : Block Diagram of the LabVIEW window

Hence the desired RPM is set as the reference point of the P controller which generates the required duty cycle of the PWM to be generated by the PWM generator at a preset frequency of 200 Hz. The PWM thus generated is used as an enable signal to the driver circuit which drives the motor at the desired reference speed. A tachometer is used to measure the speed of the motor. The sensor output can also be used to measure the speed using a CRO.

This completes our open loop hardware and software setup and connections and working.

4.7 RESULTS AND DISCUSSION

Various observations were taken for a varied range of input or reference RPM . The following table and graph shows the observations:

REFERANCE RPM	DUTY CYCLE	OUTPUT RPM
50	.105	68
80	.168	88
100	.21	105
150	.315	140
180	.378	172
200	.42	198
220	.462	221
250	.525	250
275	.578	271
300	.63	294
325	.682	320
350	.735	346
375	.787	364
400	.84	382
425	.892	393
450	.945	402
475	.997	406

Table 4.1: Observation Table for Reference and Observed RPM and Corresponding Duty Cycle

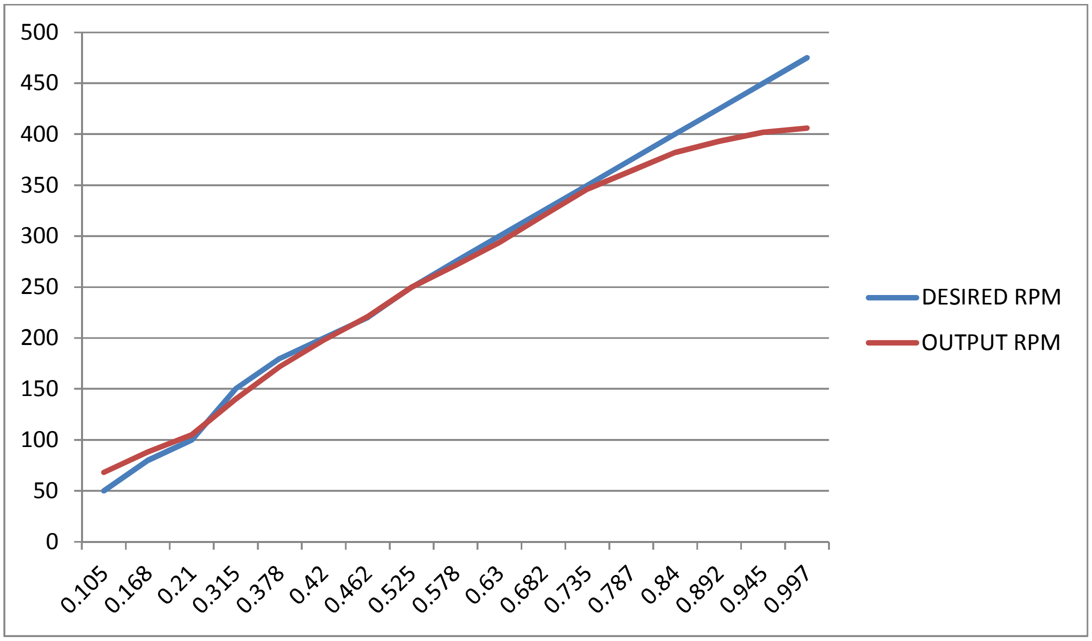


Fig 4.10 Graph Showing the Reference and Output RPM for the Observed Values (X-Axis Shows The Corresponding Duty Cycles)

The open loop control system for DC motor speed control was successfully designed. It was observed that the system works fine up to a speed of 300 RPM beyond which significant error was observed. The error might be because of inexperienced handling or inaccuracy of the tachometer.

CONCLUSION AND FUTURE WORK

The LabVIEW based DAQ system is used to control thespeed of a DC motor. NI PCI 6221 DAQ card was used for generating the actuating signalsto drive the DC motor and control its direction, quadrupleH-Bridgedriver circuit was designed and implemented. PWM wasprogrammed using LabVIEW to control the motor speed.The flexibility of digital control makes it easy to change thegains values without the need of new components. Theapplication of virtual instruments makes data analyzingmore accurate, and decreases the measuring timesignificantly. This system has been tested for various input values and works properly.

The work done can be further extended in future to design a closed loop system which could control the speed to a more précised value and error can be easily reduced by giving feedback signal form the sensor to the controller using the DAQ card.

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