DESIGN OF A TEACHING KIT FOR SPEED AND POSITION CONTROL OF DC MOTOR

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ABSTRAK

Motor arus terus (DC), jenis motor pertama yang dibina, masih digunakan secara meluas. Walaupun motor DC lebih mahal jika dibandingkan dengan motor-motor lain, ia adalah sesuai untuk beberapa jenis sistem kawalan berbanding motor-motor lain. Kelebihan utama motor DC ialah kawalan kelajuan dan kawalan posisi. Secara amnya, projek ini dibahagikan kepada dua bahagian: pengaplikasian perkakasan dan pengaplikasian perisian. Pengaplikasian perkakasan adalah di mana isyarat yang dikenakan akan mengawal kelajuan dan posisi oleh pengawal PID dan keluarannya akan dipaparkan pada osiloskop digital. Projek ini juga memerlukan pengaplikasian perisian untuk paparan isyarat keluaran pada panel komputer dengan program mikro-kawalan. Mikro-kawalan tersebut kemudiannya diprogram sebagai penukar ADC dan juga sebagai penghantar data siri, juga melibatkan Borland C++ Builder untuk plot graf isyarat keluaran yang diambil.

ABSTRACT

Direct-current (DC) motors are the first type of motor built and still being used widely. Although, DC motor is more expensive compare to other motors, it is suitable for certain type of control system compare to other motors. The greatest advantage of DC motors is speed control and position control. Basically, these projects are divided into two parts: hardware implementation and software implementation. The hardware implementation is where signal applied will control speed and position by PID controller and the output will be displayed in the digital oscilloscope. This project also requires software implementations to display output signal in the computer panel which involves two microcontroller program. The microcontroller then programmed as an ADC converter and as serial data transmitter, also including Borland C++ Builder to plot a graph of the output signal taken.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Control theory is used for analysis and design of feedback systems (George Ellis, 2000). Generally, the control system is to control outputs in some prescribed manner by the inputs through the elements of the control system. For example, DC motor in control system is one of the most widely used prime movers in industry today (Kuo, 1995). For example, this system is applied such as in Idle-Speed control of automobile and printwheel control system. (Kuo, 1995)

Basically, in this project the speed and position of DC motor are controlled by suitable controller. Eventhough there are few types of controllers, PID controller (P Proportional, I Integral and D Differential) are chosen due to their simplicity and direct design methodology. Analysis will be done to get optimum PID controller to control speed and position of DC motor.

The output signal from this system will be displayed in the digital oscilloscope. Furthermore, another approach taken to display the output signal in the computer panel using microcontroller program. The microcontroller dsPIC30F6014 then programmed as an ADC converter and as serial data transmitter using RS232 pin including Borland C++ Builder to plot a graph of the output signal taken.

1.2 Objective

This project is designed in order to achieve the following objectives:

(i) Understand and analyze the characteristic of operational amplifier on implementing in PID controller circuit.

(ii) Understand and learn the methodology of feedback control using PID controller in DC motor.

(iii) Understand and analyze the characteristic of speed control of a DC motor with optical encoder feedback.

(iv) Understand and analyze the characteristic of position control of a DC motor with potentiometer feedback.

(v) Design PID controller circuit to control speed and position of DC motor.

(vi) Understand and learn the methodology and application of Digital Signal Programmable Interface Controller (dsPIC) as an Analog to Digital Converter (ADC) converter.

(vii) Utilizing Borland C++ Builder as a graphical programming langue to develop a data acquisition for acquiring the output signal.

1.3 Report Organization

There are five chapters in this report. A brief introduction and the objective of the project are given in the first chapter. In chapter two, there will be more explanation regarding theoretical studies. This chapter will discuss about control system, type of controller, DC motor principles and also microcontroller. Chapter three is about the methodology of the project. This chapter discusses the whole process of this project done. This includes hardware development such as speed and position control of DC motor and PID controller circuit. There is also software development for display the signal. Chapter four will discuss about the result obtained from the testing done and also regarding the outcomes of the results. Finally, the last chapter of this project discusses regarding problem faced throughout the project, suggestions for future research and conclusion of the project done.

CHAPTER 2

LITERATURE REVIEW

2.1 Control System

In control system design trial and error method cannot be avoided (Kanno,T et. al, 1994). Control system is to control the outputs in some prescribed manner by the inputs through the elements of the control system (Kuo, 1995). It makes the output *y* behave in a desired way in manipulating the input *u*. Control systems can be classified into two types: open-loop systems and closed-loop (feedback) systems. The controller of an open-loop system determines how to manipulate the input only using the information of the desired output, which is called reference, r, while that of a feedback system also taking advantage of the measurement of the output. A feedback controller calculates the control force from the error e= r-y. Figure 2.1 and Figure 2.2 illustrate the block diagrams of open-loop and closed-loop systems, respectively.

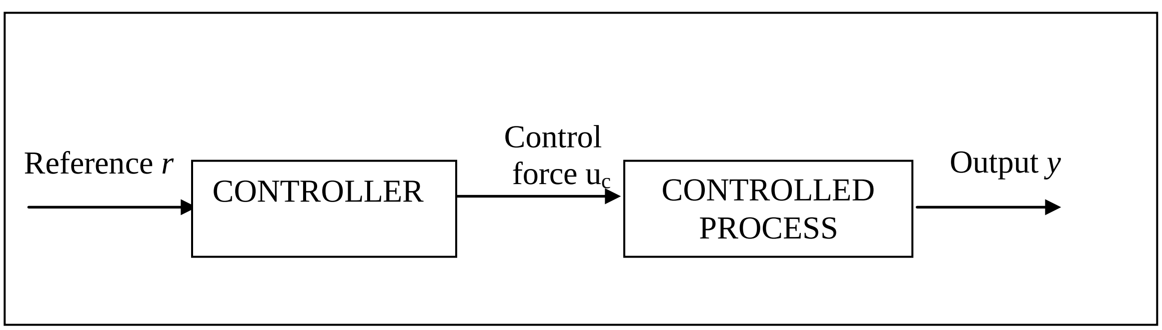

Figure 2.1: An open loop control system

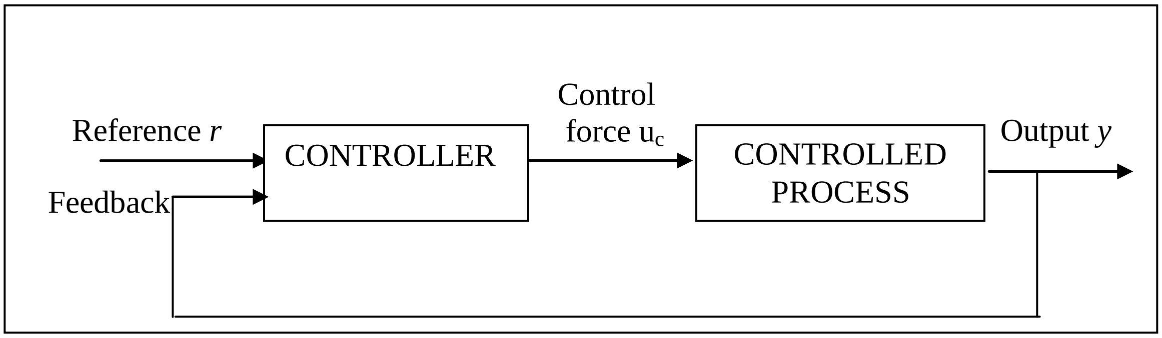

Figure 2.2: A closed – loop control system

Feedback control is the basic mechanism by which systems, whether mechanical, electrical, or biological, maintain their equilibrium or homeostasis. In the higher life forms, the conditions under which life can continue are quite narrow. A change in body temperature of half a degree is generally a sign of illness. The homeostasis of the body is maintained through the use of feedback control (Wiener, 1948). A primary contribution of C.R. Darwin during the last century was the theory that feedback over long time periods is responsible for the evolution of species. In 1931 V. Volterra explained the balance between two populations of fish in a closed pond using the theory of feedback.

Feedback control may be defined as the use of difference signals, determined by comparing the actual values of system variables to their desired values, as a means of controlling a system. An everyday example of a feedback control system is an automobile speed control, which uses the difference between the actual and the desired speed to vary the fuel flow rate. Since the system output is used to regulate its input, such a device is said to be a closed-loop control system.

There are 2 types of feedback in control system; positive feedback and negative feedback. But positive feedback is rarely used. Mostly, negative feedback used in practical. Negative feedback is a type of feedback, during which a system responds so as to reverse the direction of change. Since this process tends to keep things constant, it is stabilizing and attempts to maintain homeostasis. When a change of variable occurs within a stable negative feedback control system, the system will attempt to establish equilibrium. 'Positive' and 'negative' do not refer to desirability, but rather to the sign of the multiplier in the mathematical feedback equation. The negative feedback loop tends to slow down a process, while the positive feedback loop tends to accelerate it. http://www.thefreedictonary.com/_/topad.htm

2.2 Controller

There are many type of controller which implemented in DC motor control system. Eventhough in the modern control system other controller are much more implemented, there is always comparison made with PID controller (Cakir, B et. al, 1999).

PID, although developed in the 1940s, has had staying power as a technique for developing closed-loop process control systems. The reason for its longevity is that PID is easily implemented in software and performs well for linear control problems. PID works very well when the suitable gain values are employed and the system responds smoothly over the range of interest.

A PID Controller is a device that employs each of the three basic feedback control modes: proportional (P), integral (I), and derivative (D) control.

2.2.1 Proportional Control

For proportional control, the controller output, p(t), is proportional to the error signal, e(t), by a factor of K_c, the dimensionless controller gain.

$$p(t) = K_c e(t) \qquad (2.1)$$

The controller gain is adjusted to increase or decrease the sensitivity of the controller output to the deviations between setpoint and the controlled variable.

Taking the Laplace transforms gives the following transfer function:

$$G_c = K_c \qquad (2.2)$$

The advantage of a proportional-only control is its simplicity. If offsets can be tolerated, the use of a proportional controller may be optimal. However, it will not eliminate the steady-state errors that occur after a set-point change or a sustained load disturbance.

2.2.2 Integral Control

Integral control depends on the integral of the error signal over time. The integral time constant, τ_I, is the adjustable controller parameter with units of time.

$$p(t) = (1/\tau_I) \int_0^t e(t^*)dt^* \qquad (2.3)$$

The primary advantage of integral control is that it eliminates offset. This happens because p(t) will change until the error signal is zero, thus eliminating a deviation between the controlled variable and setpoint in the steady-state. The disadvantage of integral-only control is that the controller will not respond until the error signal has persisted.

To counteract this problem, controllers have been developed that combine the use of proportional and integral control. The result is a proportional-integral (PI) controller, which is commonly used because of the immediate acting proportional control coupled with the corrective acting integral control. The PI controller transfer function is

$$G_c = K_c(\tau_I s + 1)/\tau_I s \qquad (2.4)$$

2.2.3 Derivative Control

Derivative control is used to anticipate the future behavior of the error signal by using corrective action based on the rate of change in error signal.

$$p(t) = \tau_D(de/dt) \qquad (2.5)$$

Derivative action is used to stabilize the controlled process. When the error signal is increasing greatly, the controller output is large. The error signal decreases, and the process is eventually stabilized. A disadvantage of derivative control is that controller output is zero when the error signal is constant.

To counteract this problem, proportional-derivative (PD) controllers have been developed to improve the dynamic response of the controlled variable. The transfer function of a PD controller is

$$G_c = K_c(1 + \tau_D s) \tag{2.6}$$

2.2.4 Proportional-Integral-Derivative Control

A three mode proportional-integral-derivative (PID) controller combines the advantages of each individual mode of control. The ideal PID controller output equation is

$$p(t) = K_c[e(t) + (1/\tau_I)\int_0^t e(t^*)dt^* + \tau_D(de/dt)] \tag{2.7}$$

and the transfer function is

$$G_c = K_c(1 + 1/\tau_I s + \tau_D s) \tag{2.8}$$

The PID controller provides quick acting corrective control of most process variables. Adding integral control to a proportional controller will eliminate the steady state error, but will increase overshoot and settling time. But by adding derivative control, the overshoot and settling time can be reduced. A PID controller is not used for highly noisy control variables like flow control, because the derivative response will amplify the random fluctuations in the system.

2.3 DC Motor

In the late 1800s, several inventors built the first working motors, which used direct current (DC) power. After the invention of the induction motor, alternating current (AC) machines largely replaced DC machines in most applications. However, DC motors still have many uses.

2.3.1 DC motor principles

DC motors consist of rotor-mounted windings (armature) and stationary windings (field poles). In all DC motors, except permanent magnet motors, current must be conducted to the armature windings by passing current through carbon brushes that slide over a set of copper surfaces called a commutator, which is mounted on the rotor. The commutator bars are soldered to armature coils. The brush/commutator combination makes a sliding switch that energizes particular portions of the armature, based on the position of the rotor. This process creates north and south magnetic poles on the rotor that are attracted to or repelled by north and south poles on the stator, which are formed by passing direct current through the field windings. It's this magnetic attraction and repulsion that causes the rotor to rotate. Refer Figure 2.3 for DC motor principle.

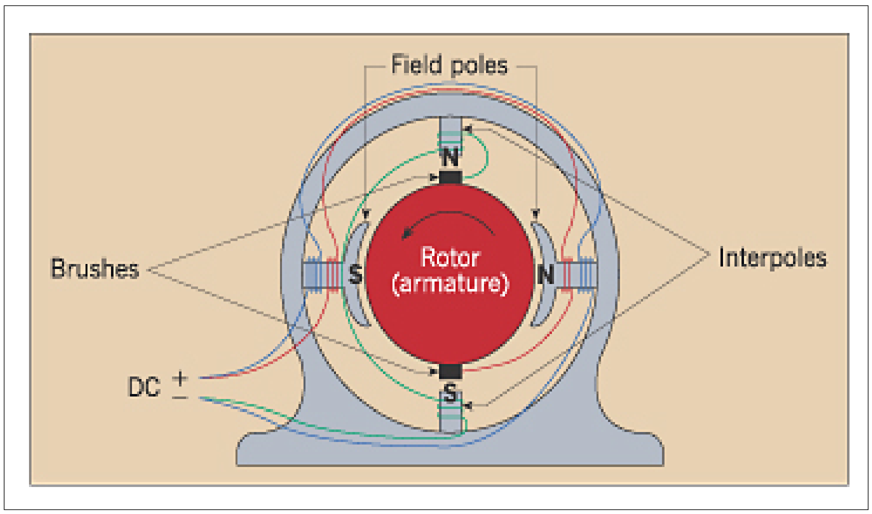

Figure 2.3 : Diagram on DC motor principles

A "DC motor" is designed to operate on direct current. This may be some form of battery, or a DC power supply that runs off of line voltage. The simplest and least expensive DC motors are "permanent magnet" motors as shown in Figure 2.4. This is the smallest D.C. permanent magnet motor in parts box. It has a tiny eccentric weight attached to the shaft. This assembly is used in cell phones and pagers to implement the “vibrate” alert function.

Figure 2.4: The smallest DC permanent magnet Motor

However, the greatest advantage of DC motors may be speed control. Research had been done due to the speed control of DC motor (K.M.Yanev, et. al, 2002). Since speed is directly proportional to armature voltage and inversely proportional to the magnetic flux produced by the poles, adjusting the armature voltage and/or the field current will change the rotor speed. Today, adjustable frequency drives can provide precise speed control for AC motors, but they do so at the expense of power quality, as the solid-state switching devices in the drives produce a rich harmonic spectrum. The DC motor has no adverse effects on power quality.

2.4 Microcontroller

A microcontroller is called a "computer-on-a-chip" or a "single-chip-computer". As indicated by the term "micro" and "controller" a microcontroller is a small device that is used to control objects, processes or events. Besides that, a microcontroller is sometimes called as an "embedded-controller" because it integrates the most commonly used circuitry or a complete microprocessor-based system into a single integrated circuit package in a small chip (Mazidi, 2000). It contains the "brains" of a microprocessor along with

RAM/ROM memory; several I/O ports and other useful support circuits, making it well suited for data acquisition and control functions. On this present day, microcontrollers are the heart and soul of many everyday appliances. A microcontroller can be found inside the devices that measures, stores, controls, calculate or displays information. The largest single use for microcontrollers is in automobile; just about everyday car manufactured today includes at least one microcontroller for engine control and often more to control additional systems in the car. In desktop computers, a microcontroller can be found inside keyboards, modems, printers and other peripherals. In consumer products, microcontrollers are includes in camera, compact-disk players, oven and so on. Microcontroller is becoming more popular because from a point of view of a designer, microcontroller is easy to use and design with. A microcontroller can be interfaced with motors, a variety of displays as output devices, communicate to PCs, read external sensor values, even connect to a network of similar controllers and it can do all that without a lot extra components. This leads to small and compact system that is more reliable and cost-effective.

2.4.1 Microcontroller System

A microcontroller can be defined as a highly integrated chip that contains all in a single chip. Typically, this includes the CPU, RAM, some form of ROM, I/O ports and timers. Unlike a general-purpose computer, which also includes all of these components, a microcontroller is designed for a very specific task to control a particular system. As a result, the parts can be simplified and reduced, which cuts down on production costs.

2.4.1.1 Buffer and converters

The buffers and converters condition I/O signal level necessary. For example, the engine control system has an ignition system requiring high voltage pulses. However, a microcontroller uses TTL logic signals that are normally 0 volts for logic zero and 5 volt for logic one. Therefore, a converter needs to change the microcontroller signals to a higher voltage pulse.

2.4.1.2 Clock circuit

The clock circuit generates a fixed-frequency signal that provides timing information for the entire system. This is necessary for microcontroller operation. Often, the clock circuit is a crystal connected to two pins of the microcontroller.

2.4.1.3 Microcontroller Unit (MCU)

A microcontroller unit (MCU) has three basic parts: the center processing unit (CPU), memory and register. An internal bus connects them. Externally, it has pins for power, input/output (I/O) and some special signals. The block diagram of a typical microcontroller unit is shown in Appendix B.

2.4.2 Microcontroller Architecture

Microcontroller architecture can be classified on the basis of various features. One very common classification is on the basis of a number of instructions: CISC (complex instruction set computer), RISC (reduced instruction set computer) or MISC (minimal instruction set computer). However, these terms have been much muddled by marketing personnel and it is very confusing.

Another classification is the basis of way that the program and data memory is accessed; a unified memory model is called the Princeton or Von Neumann architecture versus the Harvard architecture. Other than that, microcontroller architecture also can be classified on the basis of the way that the internal data is stored and manipulated inside the CPU. A microcontroller's job is to manipulate data with the help of a user program. The way this data is stored and accessed internally in the CPU and the way it processed forms the basis of different processor architectures. This type of classification had come out with four basic models, which are stack machine, accumulator, memory-register and register-register. Early processor architecture used either the stack or the accumulator-model. Today, most processor is based on the register-register architecture. To reduce external memory accesses, a large pool of general-purpose registers is provided for the register-register model. Moreover, register is easier to access for a compiler than stack even though the stack is inside the processor. The basic architecture structure of a typical microcontroller is discussed in detail in this section.

2.4.2.1 Central Processing Unit (CPU)

CPU is the heart of the microcontroller, it fetches the instruction stored in the program memory, decodes these instructions and executes them. The CPU itself is composed of registers, the arithmetic logic unit (ALU), instruction decoder and control circuitry. During the execution of program, the instruction decoder tells the arithmetic and logic unit (ALU) what to do with the data. Then, the control sequencer will transfer instruction and data bytes along the internal data baud. The address bus will select a specified location in memory. The data driver will conditions data signals to be sent to or from memory or I/O registers.

2.4.2.2 Read Only Memory (ROM)

ROM or known as program memory is used to store the instruction that form the program. To accommodate larger programs, the ROM may be partitioned as internal ROM and external ROM in some microcontroller. ROM is usually nonvolatile and is of EEPROM (Electrically Erasable Programmable Read Only Memory) or EPROM (Electrically Programmable Read Only Memory) or Flash of Mask ROM or OTP (one-time programmable) type.

2.4.2.3 Random Access Memory (RAM)

RAM also known as data memory of the microcontroller. It is used by the microcontroller to store data. The CPU uses RAM to store variables as well as the stack. The CPU to return addresses from where to resume execution after it has completed a subroutine or interrupt call uses the stack.

2.4.2.4 Oscillator (OSC)

Oscillator is a circuit that produces a constant frequency square wave that is used by the microcontroller as timing or sequencing reference. It is used to determine the rate of the microcontroller executes the program out of the ROM. The oscillator could be an internal RC-oscillator or an oscillator with an external timing element, such as a quartz crystal, an LC resonant circuit or even an RC circuit. The dsPIC30FXXXX can be operated in three different oscillator modes. The clock mode is primarily chosen based on the desired frequency of the crystal oscillator. The main difference between the XTL Low Power/Low Frequency mode, XT Medium Power/Medium Frequency mode and HS Highest Frequency mode is the gain of the interval inverter of the oscillator circuit, which allows the different frequency range. In XTL, XT and HS modes, a crystal or ceramic resonator is connected to the OSC1 and OSC2 pins to establish oscillation. The dsPIC30F oscillator design requires the use of a parallel cut crystal. Using a series cut crystal may give a frequency out of the crystal manufacturers specifications. The oscillators will start operating when power is applied to the microcontroller.

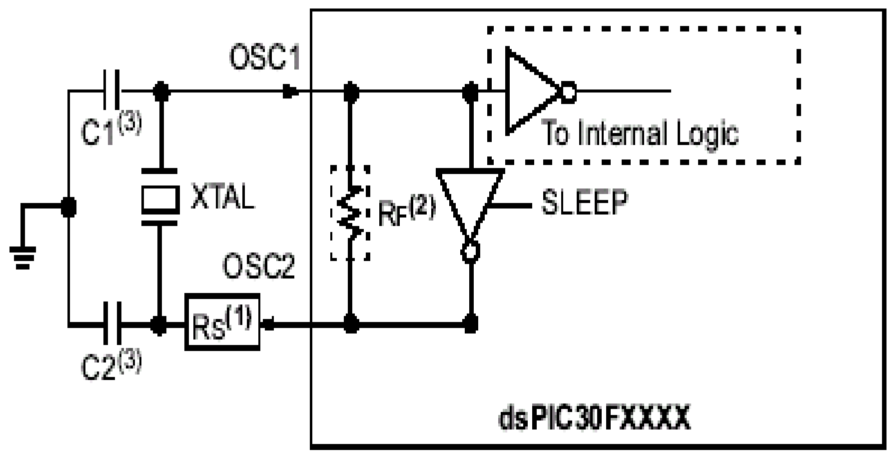

Figure 2.5 : Crystal/ Ceramic Resonator Operation

2.4.2.5 Bus control

Bus control is used to control the flow of signal inside the microcontroller. Basically, there are three types of signals that can be transferred by bus, which are the data signal, address signal and control signal. Data signal represents instructions and values of different variables, such as voltage. Address indicates where data is stored. Control signals coordinate microcontroller operation with associated chips.

2.4.2.6 I/O Port

I/O ports are the connections to the process, which are controlled by the microcontroller. Normally, the ports are bit-programmable in both directions. The I/O port is used to exchange data between the microcontroller with the outside world. Basically there are two types of I/O port that is digital I/O port and analog I/O port. The microcontroller uses the digital I/O ports components to exchange digital data with the outside world. Compared to the serial port, which transfer data serially one bit at a time, the data on the digital I/O ports is exchanged as bytes.

2.4.2.7 Serial Port in the microcontroller

The serial port is a very useful component in the microcontroller. It is used to communicate with external device on a serial data basis. The serial port can operate at any required data transfer speed. The serial port takes data bytes from the microcontroller and shifts out the data one bit by one bit at time to the output. Similarly, it accepts external data a bit at a time, makes a byte out of 8 bits and presents this to the microcontroller.

Serial ports are of two types: synchronous and asynchronous. Synchronous data transfer need an accompanying clock signal with each data bit for timing information, while the asynchronous data transfer does not need the clock signal and the timing information, synchronization is embedded in the data bit itself by way of duration of data bits as well as additional start and stop bit on the data path.

2.4.3 Asynchronous Transmission

Serial transmission of data means that data is transferred over a single signal path rather than a parallel set of lines, which is common with I/O devices and internal computer signal paths. With serial transmission, signaling elements are sent down the line one at a time. Serial communication is popular because most computers have one device to the computer.

The strategy of asynchronous transmission scheme is to avoid the timing problem by not sending long, uninterrupted streams of bits. Instead data are transmitted one character at a time, where each character is five to eight bits long. The number of bits that comprise a character depends on the code used. Timing or synchronization must only be maintained within each character and the receiver has the opportunity to resynchronize at the beginning of each new character. Serial transmission requires the specification of four parameters, which is the baud rate of transmission, the number of data bits encoding a character, the sense of the optional 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 optional parity bit and the stop bits.

Baud rate is a measure of data speed between instruments that uses serial communication. RS-232 uses only two voltage states called MARK and SPACE. In such a two state coding scheme, the baud rate is identical to the maximum number of bits of information, including 'control' bits that are transmitted per second.

MARK is a negative voltage and SPACE is positive. The output signal level usually swings between +12V and –12V. The "dead area" between +3V and –3V is designed to absorb line noise. A start bit signals the beginning of each character frame. It is a transmission from negative (MARK) to positive (SPACE) voltage and its duration in second is the reciprocal of the baud rate. If an instrument is transmitting at 9600 baud, the duration of the start bit each subsequent bit will be about 0.104ms. The entire character frame of eleven bits would be transmitted in about 1.146ms.

Data bits are transmitted upside down and backwards. It is a case of inverted logic is being used and the order of transmission is from least significant bit (LSB) to most significant bit (MSB). The data bits in a character frame must be read from right to left, with 1 representing negative voltage and 0 for positive voltage. An optional parity bit follows the data bits in the character frame. The parity bit if present also follows inverted logic (1 for negative voltage and 0 for positive voltage). This bit is included as a simple means of error checking. Ahead specification of time is determined whether the parity of the transmission is even or odd. If the parity is chosen to be odd, the transmitter will then set the parity bit in such a way as to make an odd number of 1's among the data bits and the parity bit.

The last part of a character frame consists of 1, 1.5 or 2 stop bits. A negative voltage always represents these bits. If no further characters are transmitted, the line stays in the negative (MARK) condition. The transmission of the next character frame is heralded by a start bit of positive (SPACE) voltage.

CHAPTER 3

METHODOLOGY

3.1 Proposed Project

The project is basically to develop a system to control the speed and position of DC Motor using PID Controller. An input voltage is supplied through the PID controller that will generate a signal. This signal is then being transmitted to the DC motor. As a result, the DC motor generates mechanical movement. The input represents the voltage that will act as a reference signal to the controller. The summing element subtracts the feedback from the reference signal to form an error signal. The error signal is scaled by the controller and fed to the motor so that the speed and position of output shaft can be modified. The output signal then will be displayed using digital oscilloscope. This project also requires software implementations for display output signal in the computer panel. Therefore, for display the output signal, microcontroller program are used. The dsPIC30F6014 microcontroller then programmed as an ADC converter. The digitized data are converted into as serial data complying the RS232 standard and also including Borland C++ Builder to plot a graph of the output signal taken. This project will be carried out based on the block diagram shown in Figure 3.1.

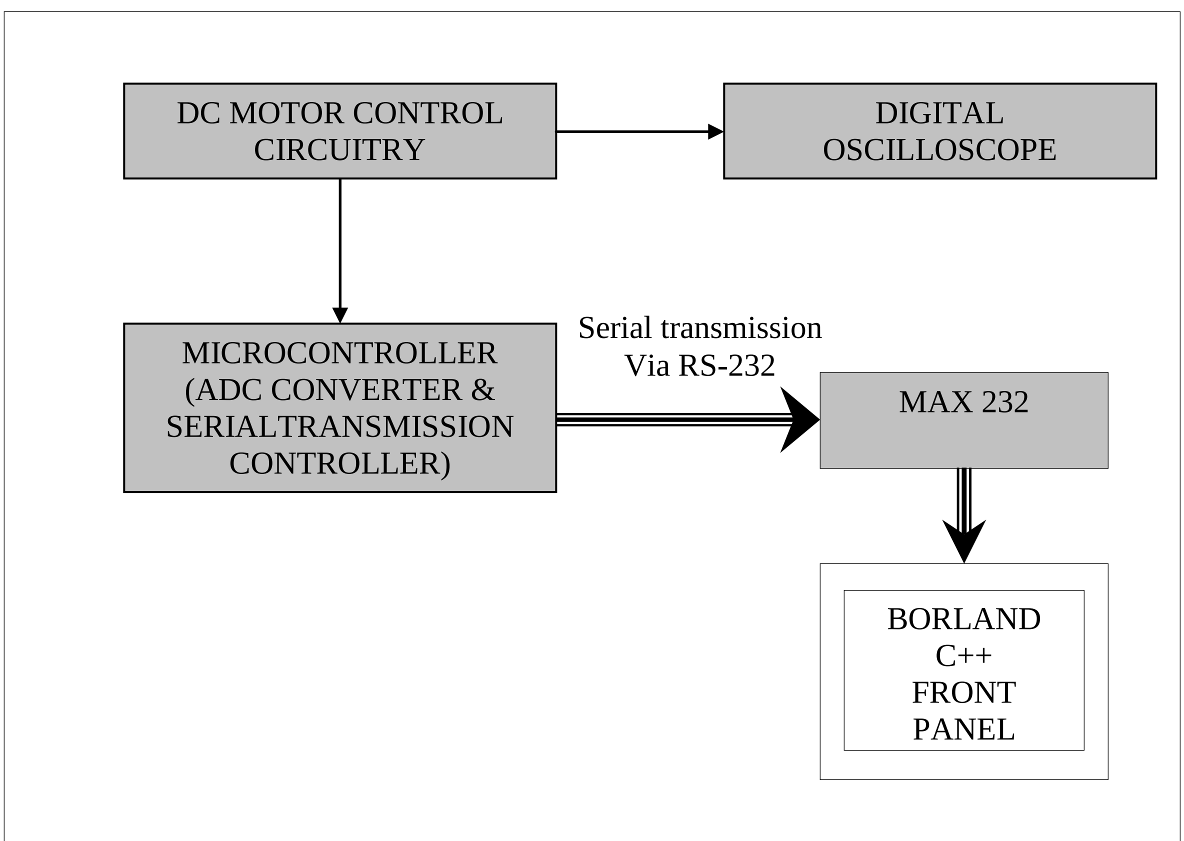

Figure 3.1: Block diagram of speed and position control of DC motor

3.2 Hardware Development

3.2.1 DC motor feedback control system

Generally, there are two types of DC motor control which are speed control and position control. The Figure 3.2 shows a typical DC motor feedback control system. The input represents the voltage that will act as a reference signal to the controller. The summing element subtracts the feedback from the reference signal to form an error signal. The error signal is scaled by a controller and fed to the motor. Eventually, I used DC motor which is available in USM Control Lab for my project.