DIGITAL SPEED AND POSITION CONTROL SYSTEM INCORPORATING AN INCREMENTAL ENCODER

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ABSTRACT

Nowaday Direct current (DC) motor become an important drive configuration for many applications across a wide range of powers and speeds. The ease of control and excellent performance of the DC motors will ensure that the number of applications using them will continue grow for the foreseeable future. This project focuson DC motor functional applications in term of speed control and position control system by using microcontroller PIC18F4520. Speed control system is a closed-loop real time control system, where optical encoder is coupled to the motor shaft to provide the feedback speed signal to controller. Pulse Width Modulation (PWM) technique is used where its signal is generated in microcontroller. The microcontroller will send PWM signal to motor driver, vary the voltage supply of motor to maintain at constant speed. While position control system are using Propotional Intergral Derivative (PID) controller as control method to get desired position with minimun error. The value of PID are define by using manualy method. Microcontroller acts as proportional, intergral and derivative (PID) controller with Kp =0.6, Ki=0.9 and Kd=0.1 in this study. Meanwhile Visual Basic 6.0 software is developed to provide a graphic user interface (GUI) for the user interfacing at computer. In addtional, it also shows a graph of motor position versus time to let the user monitor the performance of the system easily. Based on the result, the reading of optical encoder built is quite reliable. Through the project, it can be concluded that microcontroller PIC 18F4520 can control motor speed and motor position at desired value.

ABSTRAK

Sejak kebelakangan ini, penggunaan Motor arus terus (DC) menjadi sangat penting dan sering diaplikasi pada pelbagai skala kuasa dan kelajuan. Kawalan yang mudah dengan prestasi cemerlang. Motor DC akan memastikan bilangan penggunaannya akan terus berkembang di masa hadapan. Fokus projek ini adalah, Motor DC akan diaplikasi untuk mengawal kelajuan dan kedudukan dengan menggunakan mikropengawal PIC 18F4520. Sistem pengawal kelajuan merupakan sistem kawalan gegelung tertutup, di mana pengekod optik dipasangkan pada aci motor bagi memberikan bacaan kelajuan dan menghantar maklum balas kepada pengawal. Teknik *Pulse Width Modulation* (PWM) digunakan bagi menjana isyarat dalam mikropengawal. Isyarat PWM akan menghantar signal kepada pemacu motor untuk mengubah bekalan voltan untuk mengekalkan pada kelajuan yang tetap. Dalam kajian ini, sistem kawalan kedudukan menggunakan pengawal PID sebagai kaedah kawalan untuk mencapai kedudukan yang dikehendaki dengan kesilapan yang kecil. Pengawal PID bertindak sebagai *proportional*, *intergral* dan *derivative* (PID) dengan nilai pengawal sebanyak Kp = 0.6, Ki = 0.9 dan Kd = 0.1 yang ditentukan dengan menggunakan kaedah manual. Sementara itu, perisian Visual Basic 6.0 dibangunkan untuk menyediakan perantaraan grafik (GUI) diantara pengguna dengan keseluruhan sistem projek ini. GUI ini juga menunjukkan graf kedudukan motor melawan masa untuk membolehkan pengguna memantau prestasi sistem dengan mudah. Berdasarkan keputusan yang diperolehi, bacaan pengekod optik dibina boleh dipercayai dan dapat disimpulkan bahawa mikropengawal PIC 18F4520 boleh mengawal kelajuan motor dan kedudukan motor pada nilai yang dikehendaki.

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LIST OF SYMBOLS & ABBREVIATIONS

UTHM	-	UniversitiTun Hussein Onn Malaysia
FKEE	-	FakultiKejuruteraanElektrikdanElektronik
P	-	Proportional
I	-	Integral
D	-	Derivative
PID	-	Proportional Integral Derivative
DC	-	Direct Current
PIC	-	Peripheral Interface Controller
CPU	-	Central Processing Unit
RAM	-	Random Access Memory
ROM	-	Read Only Memory
I/O	-	Input Output
IC	-	Integrated Circuit
MCU		Multipoint Control Unit
PWM		Pulse Width Modulation
UART		Universal Asynchronous Receiver/Transmitter
PCB	-	Printed Circuit Board
LED	-	Light Emitting Diode
rpm	-	Rotation Per Minute
R_a	-	Armature resistor
L_a	-	Armature inductor
$I_{a(t)}$	-	Armature current
K_E	-	Constant Value Motor Construction
$Tm(t)$	-	Motor Torque

$Va(t)$	-	Armature Input Voltage
$eb(t)$	-	Back emf
$\omega m(t)$	-	Motor Angular Velocity
$\theta m(t)$	-	Motor Angular Displacement
Jm	-	Moment of inertia of motor + load
Kp	-	Proportional Gain Value
Ki	-	Integral Gain Value
Kd	-	Derivative Gain Value
Tr	-	Rise Time
$\%OS$	-	Percentage Overshoot
Ts	-	Settling Time
e_{ss}	-	Steady-state error
Bm	-	Viscous frictional constant of motor + load
φ	-	Magnetic flux
I_f	-	Field current
R_f	-	Field resistor
L_f	-	Field inductor
K_v	-	Motor constant
K_t	-	Torque constant
T_d	-	Developed torque
T_L	-	Load torque
B	-	Viscous friction constant
J	-	Inertia of the motor
w	-	Motor speed
α	-	Firing angle of thyristor
T_{on}	-	Time ON of switches
T	-	Period
s	-	Standard deviation

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This chapter will focus on the brief introduction of the project to be carried out. The important overview or description including the problem statement, project objectives, project scopes and expected result are well emphasized in this part.

1.1 Project Background

A control system is an interconnection of components forming a system configuration that will provide a desired system response. The main reason to design control system is to producing the desired transient response, reduce steady state error and to achieve the stability. Control system build for four primary reasons as power amplification, remote control, convenience of input form and compensation for disturbances. All of this primary reason is to make precision control for a system that impossible for human to control manually such as electrical motor speed and position.

The modern machines, including the positioning systems, the robots, the flexible manufacturing systems and the application specific machine-tools, require a form of energy conversion toward mechanical energy. Perhaps the most widely used motors are the electric ones because of their high flexibility and reliability as well as of their cost.

The common electric motors can be grouped in four major classes which are DC motors, stepper motors, asynchronous motors and synchronous motors. The mechatronic systems, robots and low to medium power machine-tools often use DC motors to drive their work loads. These motors have rather simple functional and constructive models.

DC motor controls has been used for variable speed and position applications for many decades and historically were the first choices for speed and position control applications. DC motor is an electro-mechanical device in which the electrical input signal controls the motor motion. It is designed for closed loop feedback systems. The output of the motor is coupled to a control circuit as the motor turns, its speed and position are relayed to the control circuit. If the rotation of the motor is impeded for whatever reason, the feedback mechanism senses that the output of the motor is not yet in the desired location.

The control circuit continues to correct the error until the motor finally reaches its proper point. Angular position and velocity information are often required in control system design of electrical machines, because control is applied by using an angular measurement of the position or velocity. Nowadays, the most common device for measurement purpose is the incremental encoder since the majority of precision motion devices are driven by rotary motors. An encoder is a rotary device that outputs digital pulses in response to incremental angular motion. Encoders have many uses in positioning applications. For example, a rotary encoder attached to a DC motor can be used to keep track of the number of revolutions the motor has rotated from its initial position.

DC motor is generally controlled by conventional Proportional Integral Derivative (PID) controllers. PID controller is a feedback loop unit in the industries control. The controller receives the command, subtracts it with the actual value to create a difference. This difference is then used to calculate a new input value which allows the data of system to achieve or maintain at the reference value.

PID controllers which are different from other control method because of its simple structure, easy implementation and easy maintenance. For most kinds of control systems, PID schemes produce high performance to make the system more accurate and stable.

1.2 Problem Statement

Many of the concepts of the digital control are abstract and difficult to fully comprehend. The continuous improvement and research to improve the process and operand of digital control system is a challenge to researchers and system developers. Advanced technology in electronic field currently makes digital control system more complicated. This situation will inconvenience more students to understand the concept and application in digital control system.

Many students have enrolled digital control subject at the undergraduate and postgraduate level. During the lecture, they were exposed with concept, principle and theory of digital control system. Unfortunately while doing the experiment in the laboratory, there no specific equipment that shows the digital time system. Most of equipment use continuous time system and student cannot apply their lesson into practical term.

In present the educational training equipment, the theoretical and real application should be related. Hence to address this problem, we will need more experience in digital control system source. Laboratory equipment for teaching purposes that can relate the theory with the real application is needed. This effort provides an opportunity for the student to increase the quality of learning process during lectures and lab session.

Digital speed and position control system incorporating incremental encoder that using PID as the controller is a good application that can help students to understand the concept of closed loop position and speed control system based on DC motor. The working principle of incremental encoder especially the output response from this kind of sensor is determined.

Last but not least, a graph of position versus time is obtained by using Visual Basic at computer to observe the performance of the system by using PID controller .This equipment shows the direct application that can visualize the theoretical in real time.

1.3 Objective

The main objective of this project is to develop the digital speed and position control system incorporating incremental encoder system that can be used as education training equipment. This project will be built to enhance the teaching and learning quality in digital control subject. It also provides valuable hands-on experience in order to support the theory learned in classroom lectures.

Specific objectives of this project are:

i. To design a speed and position of DC motor by using microcontroller.
ii. To implement PID controller to control position of DC motor.
iii. To analyze output in term of speed and position of DC motor incorporating incremental encoder.

1.4 Scope of Project

The scopes of this project are:

i. The microcontroller that has been used for this project is PIC 18F4520
ii. The PID controller implement on the DC motor by using MPLABX IDE software.
iii. The speed will analyze based on duty cycle waveform and position will determine by output characteristic response using Visual Basic software.

1.5 Thesis Outline

This thesis consists five chapters. In chapter one, it discuss about the project background, problem statement, objective, and scope of this project as long as summary of works. While chapter two will discuss more on theory and literature reviews that have been done. It well discusses about DC motor, incremental encoder, PID controller, microcontroller and MPLABX IDE. In chapter three, the discussion will be on the methodology hardware and software implementation of this project. The result and discussion will be presented in chapter four. Last chapter will discusses the conclusion of this project and future work that can be done.

CHAPTER 2

LITERATURE REVIEW

Literature review was an ongoing process throughout the whole process of the project. It is very essential to refer to the variety of sources in order to gain more knowledge and skills to complete this project. These sources include reference books, thesis, journals and also the materials obtained from internet. This chapter includes theory about the DC motor, incremental encoder, PID controllers, microcontroller and previous work has done.

2.1 Theory of DC Motor

DC motors are used in closed loop control systems as control variable shown in Figure 2.1. The DC motor controller normally control using directs operation by sending velocity command signals to the amplifier, which drives the DC motor.

An integral feedback device (resolver) or devices (encoder and tachometer) are either incorporated within the DC motor or are remotely mounted, often on the load itself. These provide the DC motor position and velocity feedback that the controller compares to its programmed motion profile and uses to alter its velocity signal.

DC motors feature a motion profile, which is a set of instructions programmed into the controller that defines the DC motor operation in terms of time, position, and velocity. The ability of the DC motor to adjust to differences between the motion profile and feedback signals depends greatly upon the type of controls and DC motor used.

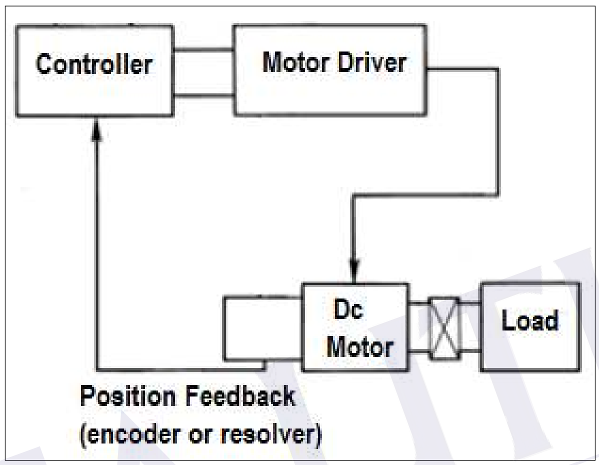

Figure 2.1: Typical DC Motor System with Encoder or Resolver Feedback.

DC motor is one of the devices that have the applications where precise positioning and speed required. The big advantage of the DC motor is it's operated as closed loop system. This means feedback is required from the motor, it make this system is sensitivity to disturbances and have ability to correct these disturbances.

2.2 Theory of Incremental Encoder

Sensors is a device that detects the state of the environment such as energy, heat, light, magnet, supersonic, etc. and convert them to electric signals. An encoder is a sensor for converting rotary motion or position to a series of electronic pulses. Rotary encoders serve as measuring sensors for rotary motion and for linear motion when used in conjunction with mechanical measuring standards such as lead screws, and convert rotary motion which incremental or absolute into electrical signals. They are both effective and low cost feedback devices.

An encoder is an electrical mechanical device that converts linear or rotary displacement into digital or pulse signals. The most popular type of encoder is the incremental encoder also known as optical encoder, which consists of a rotating disk, a light source, and a photo detector (light sensor). The disk, which is mounted on the rotating shaft, has patterns of opaque and transparent sectors coded into the disk shown at Figure 2.2. As the disk rotates, these patterns interrupt the light emitted onto the photo detector, generating a digital or pulse signal output.

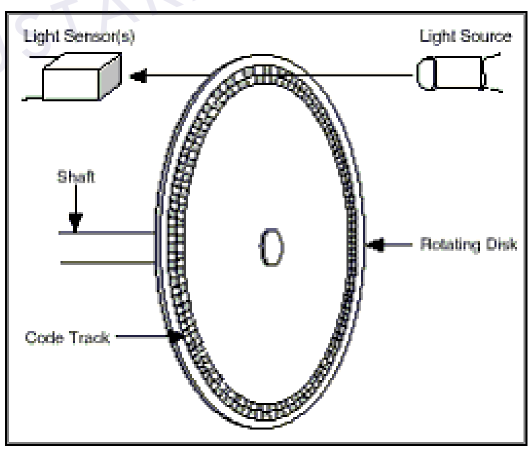

Figure 2.2: Simple Diagram of Incremental Encoder

An incremental encoder generates a pulse for each incremental step in rotation. Although the incremental encoder does not output absolute position, it can provide high resolution at an acceptable price. For example, an incremental encoder with a single code track, referred to as a tachometer encoder, generates a pulse signal whose frequency indicates the velocity of displacement.

However, the output of the single-channel encoder does not indicate direction. To determine direction, a two-channel, or quadrature, encoder uses two detectors and two code tracks. The most common type of incremental encoder uses two output channels A and B to sense position. Using two code tracks with sectors positioned 90° out of phase; the two output channels of the quadrature encoder indicate both position and direction of rotation. If A leads B, for example, the disk is rotating in a clockwise direction. If B leads A, then the disk is rotating in a counter-clockwise direction.

Therefore, by monitoring the number of pulses and the relative phase of signals A and B, the position and direction of rotation can be track. In addition, some quadrature detectors include a third output channel, called INDEX, yield single pulse per revolution, which is useful in counting full revolutions. It is also useful as a reference to define a home base or zero position. This single pulse can be used for precise determination of a reference position as shown in Figure 2.3.

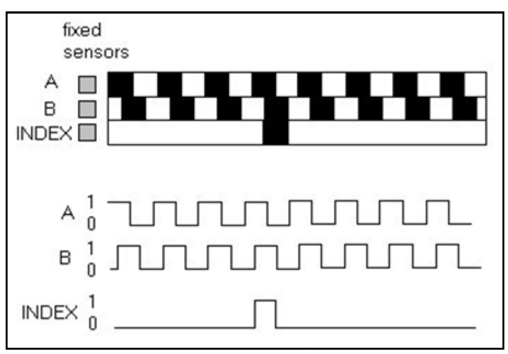

Figure 2.3: Output Pulse from Incremental Encoder

2.3 PID Controller

Controller is equipment introduced to monitor a process and to adjust some variables in order to maintain the system at or near desired conditions. Type of controller are selected to be applied is PID controller. The PID algorithm is the most popular feedback controller used within varied industry field. It has been successfully used for over 50 years. It is a robust easily understood algorithm that can provide excellent control performance despite of the varied dynamic characteristics of process plant.

There are three control modes within the PID algorithm which consists of the Proportional, Integral and Derivative modes as shown in Figure 2.4. When utilizing this algorithm it is necessary to decide which modes are to be used P, I or D and then specify the parameters or settings for the modes that are used. Each control mode needs to be adjusted independently and this will affect other control modes performances. So that, it is complicated to tune the three control modes in order to achieve the minimum error.

Generally, three basic algorithms are used P, PI or PID, but this project adopts the PID controller as the control scheme for the system. It is due to the effectiveness of that three control modes in controlling the position of the DC motor control system.

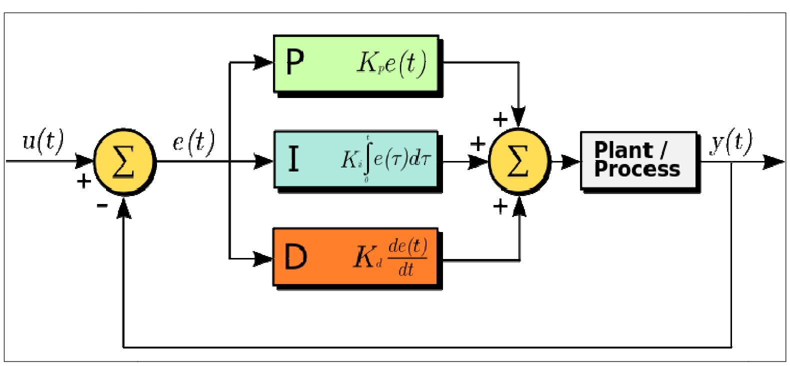

Figure 2.4: Simple Block Diagram of PID Controller.

2.4 Microcontroller

Microcontroller is a highly integrated chip that contains all the components comprising a controller. Typically this includes a 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 which to control a particular system. As a result, the parts can be simplified and reduced, which cuts down on production costs.

Microcontrollers are sometimes called embedded microcontrollers, which just mean that they are part of an embedded system that is, one part of a larger device or system. Microcontroller is the best choice to be the control system in controlling a DC motor because of its ability to store and run unique programs. Besides, the relatively low cost of the microcontroller made it a wise choice in implementing it in the DC motor speed and position control system. The microcontroller’s ability is to run and store unique programs and microcontroller is very flexible to work with. As an example, user can program a microcontroller to carry out a series of functions based on predetermined situations (I/O-line logic) and selections. Its capability on carrying mathematical and logical functions allows it to imitate complicated logic and electronic circuit.

Higher level microchip PIC18F family can be used to integrate large amounts of code in a single IC. PIC microcontrollers are one of the fastest growing parts of the embedded integrated circuit market in recent times and suitable for fast implementation controller and can be programmed for motor control applications.

2.5 MPLABX IDE

MPLABX IDE is a Windows-based Integrated Development Environment for the Microchip Technology Incorporated PIC microcontroller (MCU) and dsPIC digital signal controller (DSC) families [10]. In the MPLABX IDE:

- Create source code using the built-in editor.
- Assemble, compile and link source code using various language tools. An assembler, linker and librarian come with MPLAB IDE. C compilers are available from Microchip and other third party vendors.
- Debug the executable logic by watching program flow with a simulator, such as MPLAB SIM, or in real time with an emulator, such as MPLAB IDE. Third party emulators that work with MPLAB IDE are also available.
- Make timing measurements.
- View variables in Watch windows.
- Program firmware into devices with programmers.

2.6 Previous Works

Science and technology nowadays develop rapidly. Many mechanical systems only need the power to be able to complete the movement. Motors are the kind of most widespread application power source and the present industrial development stresses on motors power primarily [1]. The DC motor is one of the most widely used prime movers in industry today. Generally speaking, DC motor systems can be regarded as a simple low-order as second or third order systems without particular design or implementation difficulties [2].

Dc motor frequently use incremental encoders as position sensor. A digital speed and position control system for a motor with an incremental encoder has been used as a basic system that drives various industrial machines. As the number and type of such applications expand, improvements in response, accuracy, reliability and reduced cost have become more important. The digital speed and position method of a motor that makes a feedback signal is important in order to achieve the above mentioned control performance. In general, an incremental encoder has been used well as a speed detector of the digital speed control system [3].

However, the speed control system is essential because motor need to be accurate, faster, and more efficient. For most kinds of control systems, PID schemes produce high performance and it has dynamic tracking quality and steady precision [4]. PID controller is well known because of simple structure, easy implementation and easy maintenance. Since many control systems using PID control have proved its satisfactory performance, it still has a wide range of applications in industrial control and it has been an active research topic for many years [5].

In order to perform project requirement, the PIC18F4520 microcontroller implements the control algorithm by conditioning the speed and current signals to perform the speed regulation according reference fed through the visual basic software The advantage of PIC 18F4520 microcontroller can incorporate a range of features that can significantly reduce power consumption during operation and high computational performance at an economical price [6].

Comparison of previous works show in Appendix A.

CHAPTER 3

METHODOLOGY

This chapter will describe the method that will be used for this project in order to achieve the desire objectives.

3.1 Gantt Chart

In completing this project, important thing to do are create Gantt chart. Gantt chart shows the detail activity of this project that had implemented in the every semester. It starts with discussing with supervisors on the topic for master project. It was included to discuss on from the project's objectives, until the work flow of this project. Then, when it all comes to agreement, study with literature review to provide a good understanding of the project. Before proceed to implement the PID controller for the DC motor, important to learn how to use software that must be used in this project. Implementation and works of the project are summarized into the Gantt chart, as shown in Appendix B.

3.2 Concept of System

In this project, microcontroller will be used as the controller to control DC motor position and speed at desired value. The block diagram of the system is shown in Figure 3.1. It is a basic structure of a feedback control system.

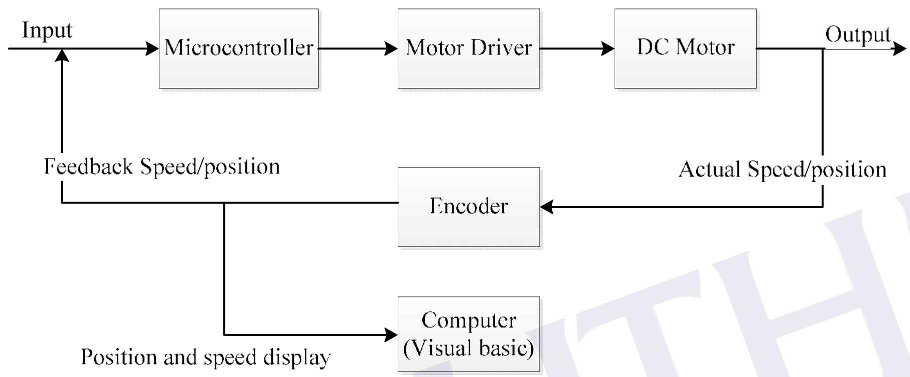

Figure 3.1: Block Diagram of Overall Project

The block diagram of this project consists of the DC motor and an encoder fixed on the motor shaft to measure the angular position. Control algorithms like simple feedback proportional integral derivative are the basic algorithms used for controlling linear time invariant systems. During operation the PID controller will attempt to correct the error and improve the transient response between a measured process variable (output) and a desired set-point by calculating and then outputting a corrective action that can change the process accordingly. While implementing the controller, the microcontroller that used in this project is PIC18F4520. The microcontroller receives the measured position and speed from the encoder. In this project, a motor driver used enhanced 10 Amp DC Motor Driver (MD10C) in order to convert the digital output from the microcontroller into analogue voltage.

3.3 Hardware Implementations

This section will discuss about components that had been used included Main Circuit, DC motor driver, DC motor, incremental encoder, mathematical model of DC motor, microcontroller PIC 18F4520, and pulse-width-modulation (PWM)

3.3.1 Main Circuit

In this project hardware can be divides into three main parts that are main circuit, motor driver and motor with incremental encoder. Figure 3.2 show main circuit of this project. Main circuit consist PIC 18F4520, UART converter, PIC burner connection, ON/OFF switch and power supply input.

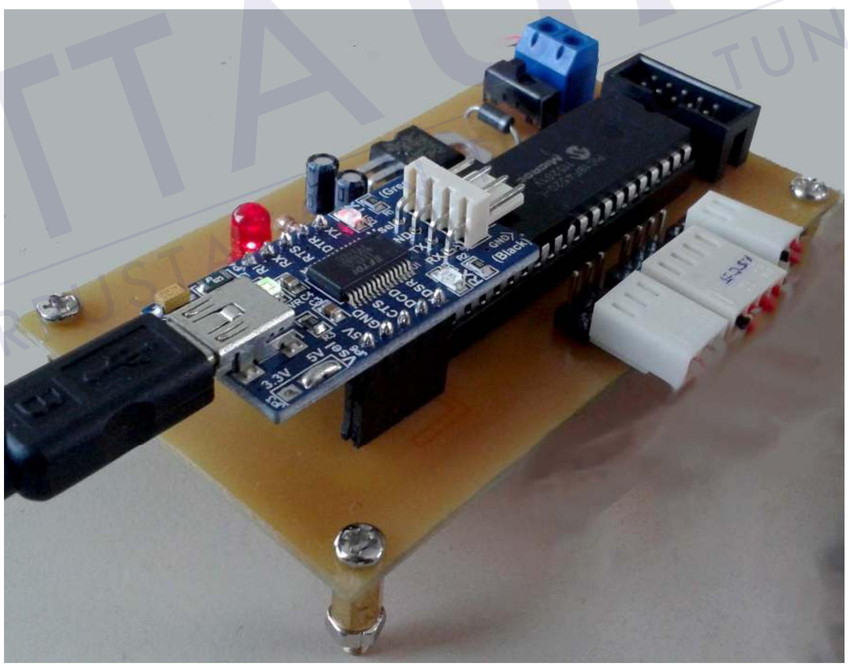

Figure 3.2: Main Circuit

3.3.2 MD10C Motor Driver

MD10C Motor Driver is designed to drive high current brushed DC motor up to 10A continuously. It offers several enhancements over the MD10B such as support for locked-antiphase and sign-magnitude PWM signal as well as using full solid state components which result in faster response time and eliminate the wear and tear of the mechanical relay. The MD10C motor driver show in Figure 3.3. MD10C is compatible with 2 types of PWM operation, which are sign-magnitude PWM and locked-antiphase PWM.

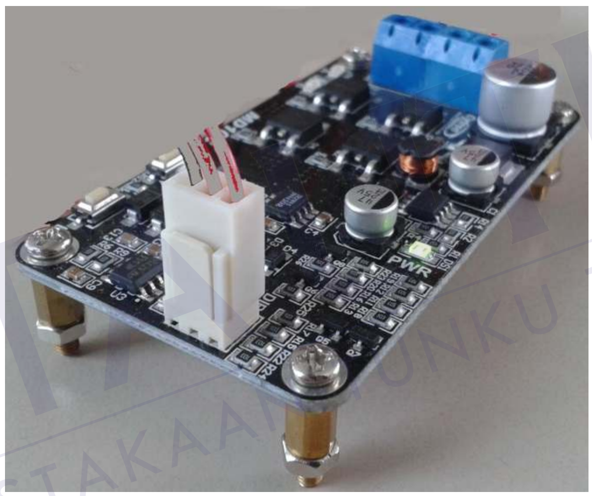

Figure 3.3: MD10C Motor Driver

For this project, the sign-magnitude PWM operation was implemented. 2 control signals are used to control the speed and direction of the motor. PWM is feed to the PWM pin to control the speed while DIR pin is used to control the direction of the motor.

3.3.3 Real Hardware DC Motor.

The project DC motor, which is model RS-365SH-2080 as shown in Figure 3.4 is used. This motor also paired with sensor which an incremental encoder to provide position and speed feedback. In the simplest case, only the position is measured. The measured position of the output is compared to the command position, the external input to the controller. If the output position differs from that required, an error signal is generated which then causes the motor to rotate in either direction, as needed to bring the output shaft to the appropriate position. As the positions approach, the error signal reduces to zero and the motor stops. Using a controller and appropriate control strategies, the error existing between the command and the actual movement can be determined, analyzed, and then corrected.

Figure 3.4: Real DC Motor Model RS-365SH-2080

These motor are designed to run at 6 to 24 volts DC and they draw less than 3 amps rotor. This is normally referred to as the stall current and is usually the maximum current draw for the motor. Motor are rated at 12 volts DC but can be kicked up to 24 volts DC for short periods to get a higher power level if the amplifier used to run the motor can provide the needed power. The specification motor are listed in Table 3.1

Table 3.1: Specification DC Motor Model RS-365SH-2080

Motor Characteristic		**RS-365SH-2080**
At Maximum Efficiency	Rated Voltage (V)	18.0
	Rated Power (W)	11.9
	Rated Torque (mNm)	7.09
	Rated Current (A)	1.06
	Rated Speed (rpm)	16060
No Load Characteristics	No-Load Speed (rpm)	19400
	No-Load Current (A)	0.22
Starting Characteristics	Starting Torque (mNm)	41.2
	Starting Current (A)	5.1
Motor Parameters	Weight (g)	54
	Temperature Range (^{o}C)	-10~55
	Humidity (%)	15~60
	Motor Diameter (inches)	1
	Motor Length (inches)	1.5
	Output Shaft Diameter (inches)	0.093
	Output Shaft Length (inches)	0.375
	Encoder Diameter (inches)	1.25
	Slots In Encoder	35

3.3.4 Incremental Encoder

These DC motor in this project uses two phase (quadrature) incremental encoders to detect the speed of the motor and the distance it has travelled. Incremental Encoders are sensors capable of generating signals in response to rotary shaft movement. In many encoders, the signals contain direction as well as progression information. When used in conjunction with mechanical conversion devices, such as rack-and-pinions, measuring wheels or spindles, incremental shaft encoders can also be used to measure speed and/or position. This shines a beam of light from a transmitter across a small space and detects it with a receiver the other end. If a disc is placed in the space, which has slots cut into it, then the signal will only be picked up when a slot is between the transmitter and receiver. An example of a disc is shown as Figure 3.5.

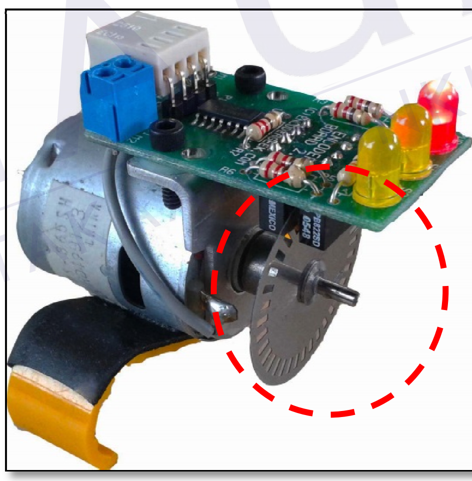

Figure 3.5: Disc of Encoder

Figure 3.6 shows what happens the disc rotates. When the rotation is in a counter-clockwise direction, photo receiver A initially senses the light signal, then both A and B, followed by B only, and finally neither A nor B. in a clockwise direction, the sequence is reversed. Both signals A and B generate four-edge transitions that can be totaled to indicate the disc position. Thus, one revolution of the disc produces 35 pulses.

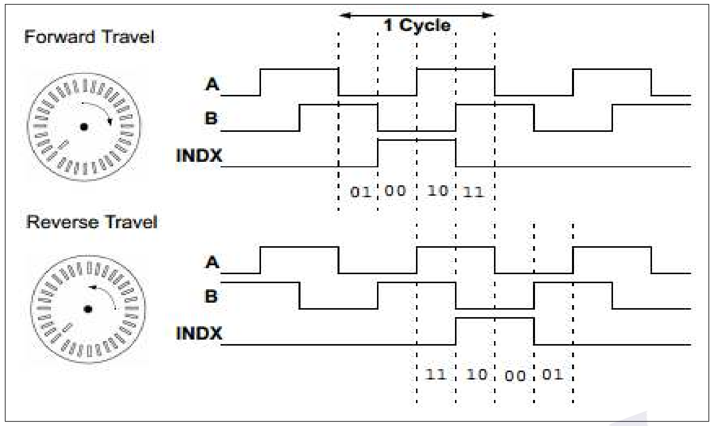

Figure 3.6: Quadrature signal A and B

The frequency of the output waveform is given by,

$$f_{out} = \frac{N\,x\,rpm}{60}$$

So, the speed of DC motor in rpm is given by

$$rpm = f_{out}\,N\,x\,60 \qquad (1)$$

Where f_{out} = frequency of output waveform

rpm = speed in revolutions per minutes

N = number of slots at disc

Calculation speed in coding is:

1 rotation=35 turn convert to rpm speed

Sampling Time,T=0.5sec

rev/m= (x pulse/0.5s) *(60s/1m)*(1 rev/35 pulse) (2)

In coding:

```
Rpm = (int) (3.429*counter[3]);  //counter[3]*60/0.5/35
```

3.4 Mathematical Modeling

A mathematical model of a dynamic system is defined as a set of equation, example differential equation that represents the dynamic of the system accurately or at least fairly well. Note that the a mathematical model is not unique to a given system and may be represent in many different ways, therefore, may have many mathematical model depending on one's perspective. The mathematical models obtain related the outputs of the system to its input. To develop a mathematical model need to use the fundamental physical law of science and engineering. In order to get the model electrical networks Ohm's law & Kirchhoff's law is needed and for model mechanical system is using Newton's Law. In practice, the complexity of the system requires some assumptions in the determination of the mathematical model. The equations of the mathematical model may be solved using mathematical tools such as the Laplace Transform. To control of any power electronics drive system the mathematical model of the plant is required. This mathematical model is required further to design any type of controller to control the process of the plant.

3.4.1 Modeling of DC Motor

A DC motor is used in a control system where an appreciable amount of shaft power is required. This DC motors used in instrument employ a fixed permanent-magnet field, and the control signal is applied to the armature terminals. Figure 3.7 show the DC motor wiring diagram and the Table 3.2 show the parameter of the DC motor

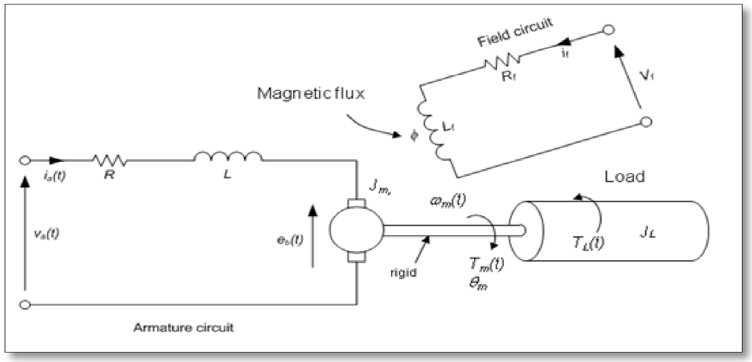

Figure 3.7: DC Motor Wiring Diagram

Table 3.2: DC Motor Parameter

Symbol	Description
Ra	Armature resistance
La	Armature inductance
ia(t)	Armature current
Tm(t)	Motor torque
Va(t)	Armature input voltage
eb(t)	Back emf
ωm(t)	Motor angular velocity
θm(t)	Motor angular displacement
Jm	Moment of inertia of motor + load
Bm	Viscous frictional constant of motor + load

For the given DC servo unit, find $\theta_m(s)/V_a(s)$, assume that $K_t$is torque constant and K_b is emf constant**.** From the system shown above, the equation for the armature circuit is

$$V_a(t) = Ri_a(t) + L\frac{di_a(t)}{dt} + e_b(t) \qquad (3)$$

By rearrange of equation 1, then the following equation is obtained.

$$L\frac{di_a(t)}{dt} = V_a(t) - Ri_a(t) - e_b(t) \qquad (4)$$

The Laplace transform of the equation is

$$LsI_a(s) = V_a(s) - RI_a(s) - E_b(s) \qquad (5)$$

The torque generated by the motor is proportional to the armature current. Motor torque equation is

$$T_m(t) = K_t i_a(t) \qquad (6)$$

Where K_t is defined as torque constant in N-m/A

For the motor, the torques that exist are viscous friction torque is given by this equation

$$T_F(t) = B_m\omega(t) \qquad (7)$$

Where B_m is defined as viscous friction constant in N-m/rad^{-1}

From the Newton's Second Law

$$T_m(t) - T_F(t) = J_m\frac{d\omega_m(t)}{dt} \qquad (8)$$

By substituting equation 7 into equation 8, this following will obtain

$$T_m(t) - B_m\omega(t) = J_m\frac{d\omega_m(t)}{dt} \qquad (9)$$

The Laplace Transform of this equation is

$$J_m s\Omega_m(s) = T_m(s) - B_m\Omega_m(s) \qquad (10)$$

The back e.m.f. $e_b(t)$ is proportional to the angular speed.

$$E_b(t) = K_b\omega_m(t) \qquad (11)$$

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