SCALED CONTROL OF DC MOTORS

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"I hereby declare that I have read through this report entitle "Scaled Controled of DC Motors" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronics Engineering"

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Date :

SCALED CONTROL OF DC MOTORS

NG CHO LIANG

A report submitted in partial fulfillment of the requirements for the degree of Mechatronics Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

I declare that this report entitle "Scaled Controled of DC Motors" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :……………………………………………….

Name : Ng Cho Liang

Date : 18^{th} June 2015

To my beloved mother and father

ACKNOWLEDGEMENT

The route in completing this project, I had encountered many obstacles and problems. Firstly, I would like to thank my supervisor, Dr Ahmad Zaki bin Hj Shukor who had guided me through the whole two semesters in providing me various solutions to the problems that arise. The other panels that I went through to look for the unanswered question and discussion, I am greatly appreciated and thankful. Without forgetting University Technical Malaysia Melaka (UTeM) for giving me this opportunity to do my final year project here. Last but not least, I would like to express my gratitude to those who had helped me through this project. Thank you.

ABSTRACT

Scaling of DC motors using a control system can be used in many applications such as robotics, pneumatic or even in the industry. The importance of this scaling control of DC motors can save a lot of time and energy for the user. In many applications, scaling control of DC motors causes a lack of performance in the delay time when the motor rotated to the desired set point and the deviation error when each of the motors being rotated to the specified angle. The delay time and deviation error are crucial for the whole development of the process in order to increase the smoothness and efficiency of the system. The main objective is to scale the smaller motor or the larger motor respectively, which act as an actuator under a standard force on one of the motors, the larger motor or smaller motor respectively will scaled the torque to become smaller or larger. Other than that, to calculate the delay for the DC motors and the deviation of the error in the motors. For the methodology, the first part is to take the encoders reading for both motors in order to calculate the time delay for both of the motors. Second part comprises of measuring the beginning angle and last angle of the motor in order to know the exact error after the scaling being done. Hence, the parameter of each of the results tabulated need to be calculated accordingly in order to know the scaling factor which will relate to the torque parameters which the current and force that being applied on the DC motors. The error in time delay is about 5.0s. The deviation of the angle that produces is around 5˚. Lastly, the scaling factor around the range of 10.

ABSTRAK

Motor DC menggunakan skalar sistem kawalan boleh digunakan dalam pelbagai aplikasi seperti robotik, pneumatik atau dalam industri. Kepentingan kawalan skalar ini dengan menggunakan DC motor boleh menjimatkan banyak masa dan tenaga untuk pengguna. Dalam banyak penggunaan, kawalan mendaki DC motor menyebabkan kekurangan prestasi dalam masa tunda apabila motor berputar ke titik set yang diingini dan kesilapan sisihan apabila setiap satu daripada motor yang berputar dengan sudut tertentu. Masa tunda dan kesilapan sisihan adalah penting untuk pembangunan keseluruhan proses bagi meningkatkan kelancaran dan kecekapan sistem. Objektif utama adalah untuk skala motor yang lebih kecil atau motor yang lebih besar, masing-masing yang bertindak sebagai penggerak di bawah satu kuasa standard di salah satu motor, motor yang lebih besar atau lebih kecil motor masing-masing akan diskalakan tork untuk menjadi lebih kecil atau lebih besar. Selain daripada itu, untuk mengira tunda bagi motor DC dan sisihan ralat dalam motor. Untuk kaedah ini, bahagian pertama adalah untuk mengambil pengekod membaca untuk kedua-dua motor untuk mengira kelewatan masa untuk kedua-dua motor. Bahagian kedua terdiri daripada mengukur sudut bermula dan sudut terakhir motor untuk mengetahui ralat sebenar selepas skalar yang telah dilakukan. Oleh itu, parameter setiap keputusan perlu dijadualkan akan dikira sewajarnya untuk mengetahui faktor penskalaan yang berkaitan dengan parameter tork yang semasa dan kuasa yang sedang digunakan pada motor DC. Kesilapan kelewatan masa adalah dalam 5.0 saat. Sisihan bagi sudut yang menghasilkan sekitar 5˚. Akhir sekali, faktor bersisik di sekitar lingkungan 10.

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LIST OF ABBREVIATIONS

cpm	-	Cubic feet per minute
s	-	Seconds in Time
Nm	-	Newton metre
^{o}	-	Degree
V	-	Voltage or Voltage unit
I	-	Current
A	-	Ampere unit
RPM	-	Revolution per minute
α	-	Angular acceleration
P	-	Power
τ	-	Torque
ω	-	Angular velocity
k	-	Constant
Hz	-	Hertz
J	-	Inertia
N	-	Force
k	-	Scaling factor

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Motivation

DC motors are widely used nowadays no matter in a small or big industry. The usage of DC motor advantage over AC motor is the starting torque. This advantage is important for the processor to save the delay time occurred when measuring the speed. DC motor steady state speed can be achieved in just less than 5 seconds while AC motor tends to use longer than 5 seconds. DC motor is a very useful application in robotics and industrial. For examples in robotics, as shown in Figure 1.1 below. The arm uses for microsurgery in the surgery for complicated surgery. Doctor just needs to move the robot assisted microsurgery (RAMS) and the other end of the micro forceps will apply the small and precise force [1].

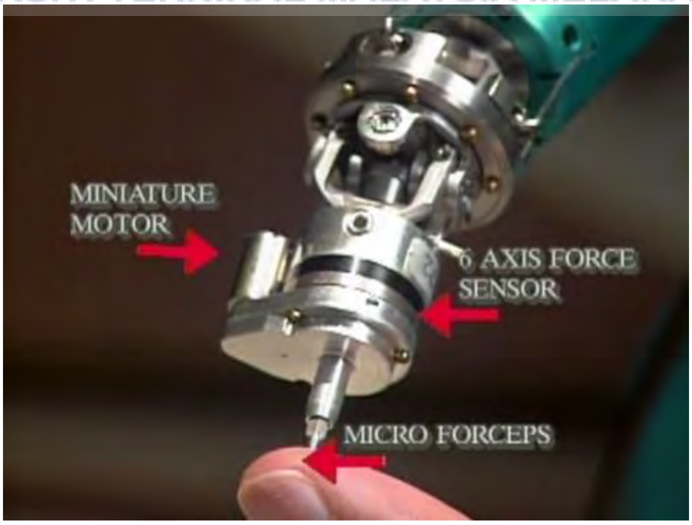

Figure 1.1: Robot Assisted Microsurgery (RAMS) arm [1]

In a pneumatic system, the DC motor used for scaling from small to big motor as shown in Figure 1.2 below. The pneumatic system with 40 head rotary fillers can produce speed up to 400 cpm. The motor can turn from the PLC Allen Bradley controller to the 40 head rotary filler using the provided motor.

Figure 1.2: Pneumatic Filler Liquid (PNEUMAFLOW) [2]

DC motor with higher torque can amplify the torque with a DC motor with a smaller torque as a reference. This shows that the performance of the whole system will improve tremendously and hence given me, an aspiring idea to do this project. Examples of application can be used in this project will be electric cars, robotics parts and pneumatic cylinder in car manufacturing industry. The diagram below Figure 1.3 and Figure 1.4 shows the simple illustration of the project:-

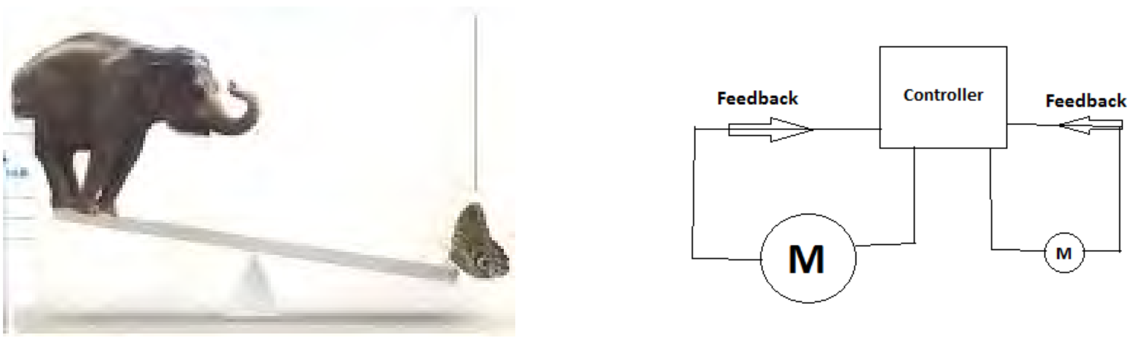

Figure 1.3 and 1.4: Illustration of scaling using a small motor to a bigger motor

1.2 Problem Statement

Due to the lack of performance when running two DC motors together synchronously, the value of the encoder in the motor varies a lot from the actual value. This cause a lot of problems to the user and the system. The system might breakdown or the whole operation will suspended. The problem arises is the deviation of values between the two motors when running together in which, causes the desired setpoint cannot be achieved. Secondly, the deviation to the error percentage of both the DC motor when being rotated and the delay time for the primary motor to the secondary motor response time which causes the motor to operate improperly. The force amplication of the small motor to the large motor need to be known in order to get the exact value after the small motor being rotated. The value of the force decrement from the large motor to the small motor also needs to be found out in order to get the correct decrement of force in the system. However, the tuning of the control parameter from the Proportional Intergral Derivative controller (PID) can reduce the deviation of angle and time delay in the motors.

1.3 Objectives

The objectives for this final year project are:-

1. To implement motion and force amplification for small DC motor to large DC motor which can replicate the movement of each other at different torque and scaling.

2. To implement motion and force decrement for large DC motor to small DC motor which can replicate the movement of each other at different torque and scaling.

3. To analyse the time delay and deviation error from the encoders of both the motor.

1.4 Scope

The scope of this project covers mainly about hardware and software. The hardware, DC motor range of torque between 0.1Nm and 2.0Nm. The power supply for both DC motors consists of 12V only. The microcontroller that using will be Arduino Uno. All the components will be fixed to a board that can hold the motor from dislocated from its position. The small and large motor rotation only limits to less than 270º which the link cannot exceed the 360º rotation. Since the voltage input is fixed at 12V, the current for the motor need to be varies for the large and small motor. Large motor will need at least 2.0A current supply which the maximum current can go up to 5.0A while small motor need around 0.5A current supply. The current sensor only can sense up to 5A based on the ACS712 model. This is suitable for both the motor which carries only 0.5A and 5.0A maximum current based on the current input. The encoder for the motor having clockwise and anticlockwise rotation produces in four phases that are 90º, 180º, 270º 360º and it is continuous.

CHAPTER 2

LITERATURE REVIEW

2.1 Background Study

Main characteristics of the DC motor depending on the motor current, magnetic field, voltage, torque, load and power. Each of the motors differs by the most important features that is torque and power. In AC motor characteristics, the starting torque will be more than 5s and this will cause time consuming. The steady state for the motor must be as short as possible in order to make the starting torque increase [6].

In DC motors, the speed (RPM) can be easily controlled and change in the desired speed that wanted while in AC motor, the speed hardly manageable due to the changing of the waveform from positive to negative or negative to positive. Normally in the industry, AC motors are being applied because they need a very fast start up speed which can increase the profit of the industry [6].

2.2 Theories and basic principles of the DC motor

There are many types of DC motor in the market with different types of specifications. Most of the motor used in the industry to operate their production and use for moving a larger item with just a controller. In this particular section, some theories and basic principles for the scaled control DC motor will be discussed here. DC motor works with a direct current supply that is always positive.

2.3 Types of Sensors

Current sensor

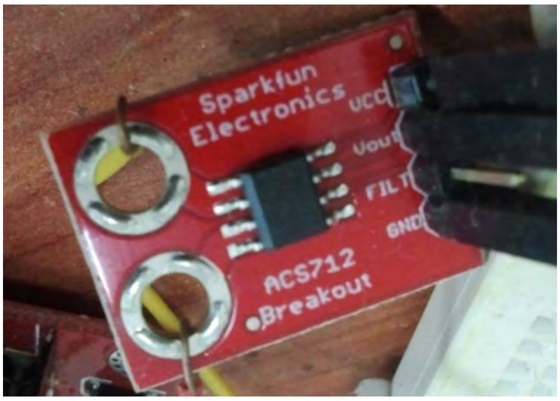

Figure 2.1: ACS-712 Breakout

The current can sense up to 5Amp with model of xx05b version. The low noise analog signal path makes it easier to get the current data. Device bandwidth is the filter pin. 1.5% output error at 25 ºC. Output voltage proportional to AC or DC currents. Extremely stable output offset voltage which makes the graph stable [7].

Force Sensitive Resistor

Figure 2.2: Force Sensitive Resistor

The maximum mass can be withstood by this force sensitive resistor is 100kg and minimum is about 0.1kg. Overall length is 3.5 inches and width is 1.75 inches and sensing area is 1.75 inches x 1.75 inches. [17]

2.4 Types of Actuator

Smaller torque motor

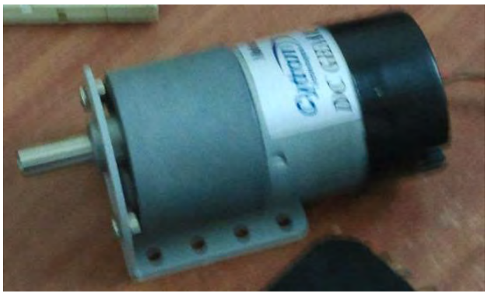

Figure 2.3: SPG30E-150K

Input voltage is DC12V. Output Power for this motor is 1.1 Watt. The rated speed is 26RPM. The rated current will be 410mA while the rated torque is 0.588Nm [8].

Large torque DC motor

Figure 2.4: IG42E-49K [9]

The voltage input is 12V DC and the rated torque is 1.76 N.m. The speed of this motor is 120 RPM. Rated current is 5.5A and power output is 41.3W. [9]

Motor driver

Figure 2.5: Motor driver MD10C

The motor driver which can support up to 25V of voltage in the DC motor. The current that can be input inside the motor driver can up to maximum 13A and 30A peak, which can only hold for 10 seconds. The motor driver provides a bi-directional way of turning. [15]

Figure 2.6: Motor driver L298N

The operating voltage can be up to 46V from the input supply. The maximum current can hold for this motor driver is about 4A maximum.

2.5 Reviews of previous related works

DC Motor and Control Technique

Application of the DC motors can be controlled by many types of controller. One of it was using an emotional intelligent controller. Based on the article by Daryabeigi in [1], he concluded that the speed of the DC motor can be controlled using an emotional intelligent controller. The controller uses a brain emotional learning based intelligent controller. This intelligent controller inspired by the limbic system of human or animal brain especially in the amygdala. This intelligent controller had a design which looks simple and high auto learning feature. By using Matlab, the results of the simulation show that steady state and fast transient speed responses to a wide range of 20 to 300 rpm. The controller had been compared with a conventional PID controller [1].

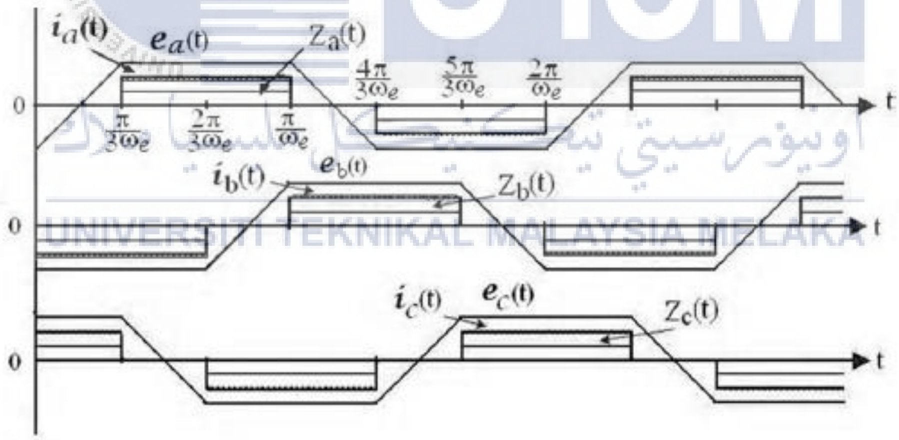

Figure 2.7: Waveforms of the EMFs, phase currents and commutating signal for brushless DC motor [1]

$$\frac{\omega_r(s)}{i_{eq}(s)} = \frac{\sqrt{2}\, k_c \emptyset}{Js + B} \qquad (2.1)$$

Based on above Figure 2.7, the equation 2.1 formed and proven that three phase brushless DC motor equivalent to DC brush motor with equal back EMF and equal armature current which proportional to the torque of the system. Therefore, all this parameter can be reduced to a simple scalar control. [1]

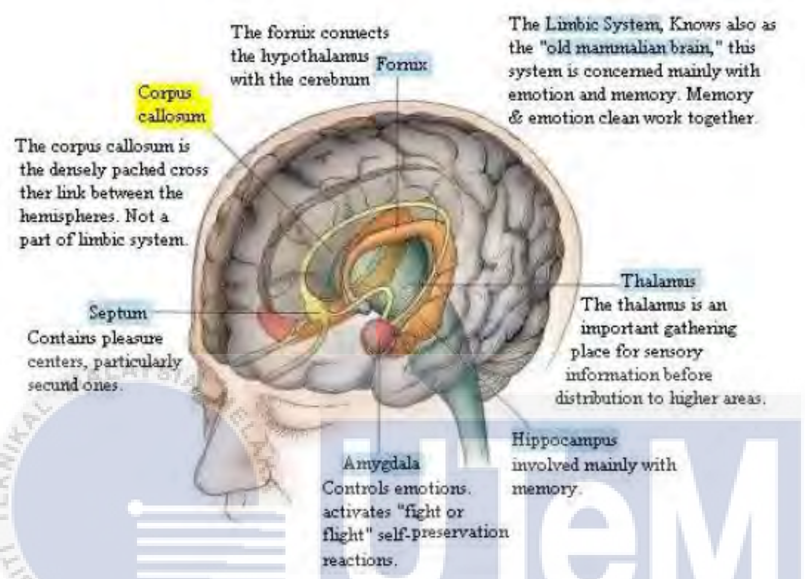

Figure 2.8: The sectional structure of the brain, which amygdala shown [1]

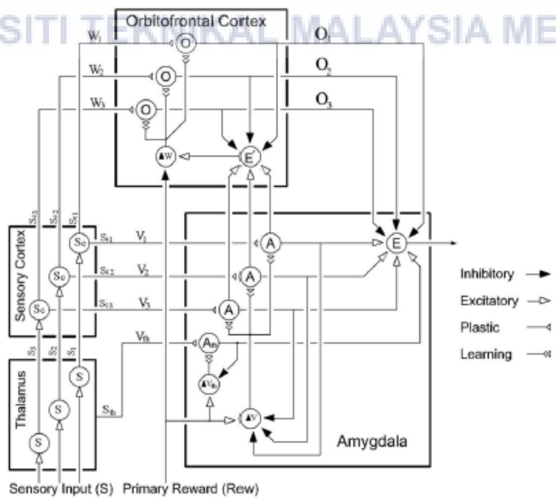

Figure 2.9: Graphical presentation of the computational model of brain emotional learning [1]

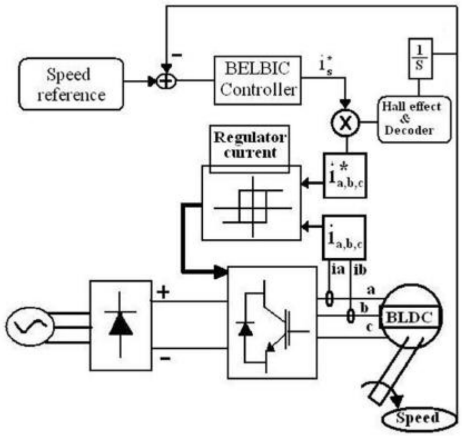

Figure 2.10: Control structure of the brushless DC motor using BELBIC [1]

Table 2.1: Speed command and load torque [1]

Time [sec]	0	0.2	0.5	1
ω_r^* [rpm]	300	300	300	300

Time [sec]	0.2	0.4	0.4	1
T_L [Nm]	1	1	11	11

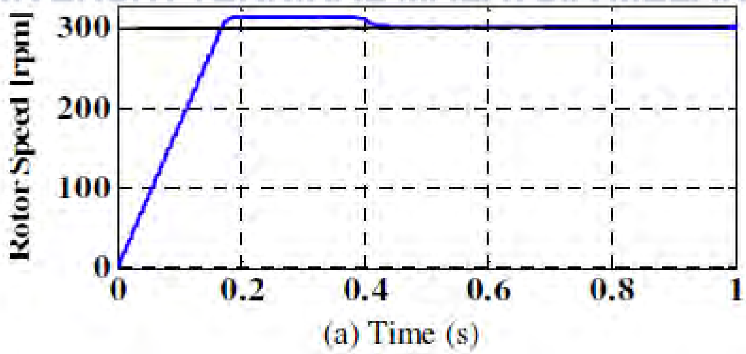

Figure 2.11: Simulation using conventional PID controller [2]

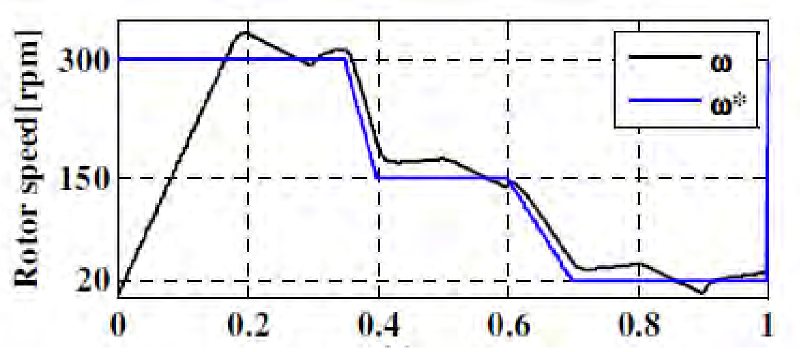

Figure 2.12: Simulation of control speed [2]

Based on this Figure 2.11, the simulation using PID has a significant ripple in speed curve. Figure 2.12 shown that the curve was not constant throughout the time and therefore proven that PID cannot operate at a wide range of work points and environment which having disturbance [2].

For the fuzzy control algorithm, DC motor can be controlled by the variable scale factor. Increase in scale factor increases the dynamic responses when the frequency and set up error was very big. To reduce the overshoot, the scale factor will be reduced respectively [3].

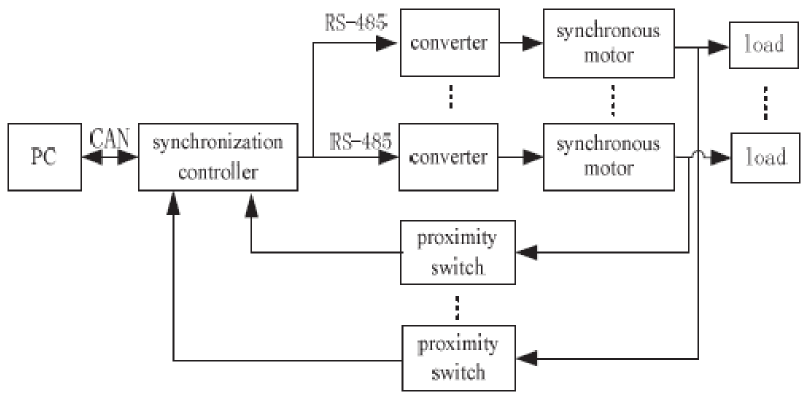

Figure 2.13: Multi motor synchronization control system [3]

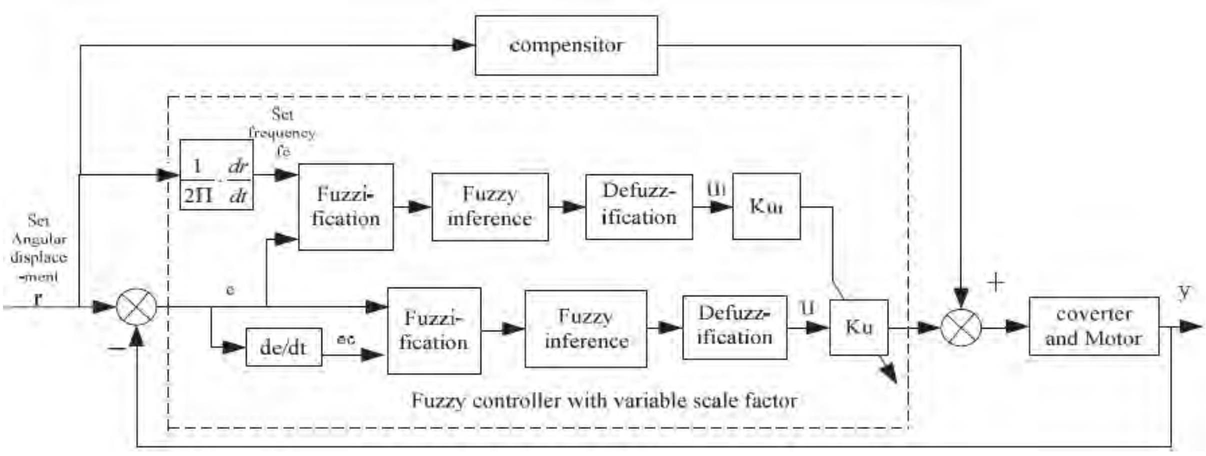

Figure 2.14: Fuzzy control with variable scale factor [3]

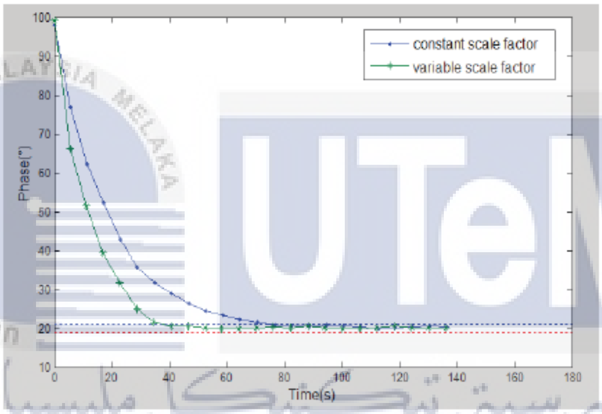

Figure 2.15: Adjustment of phase at 33.33Hz [3]

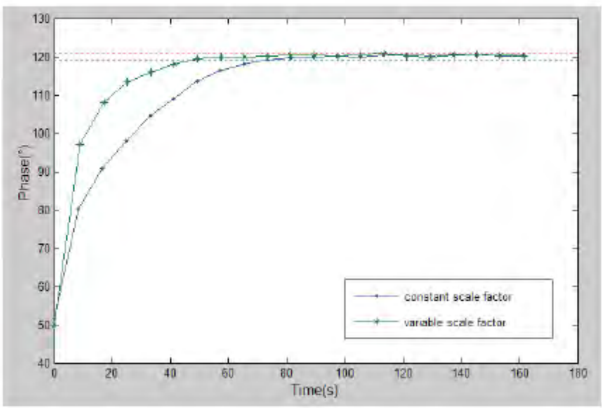

Figure 2.16: Adjustment at phase 25Hz [3]

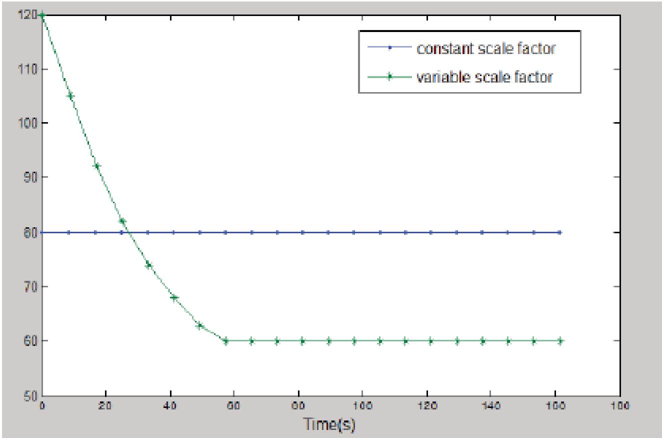

Figure 2.17: Adjustment process of scale factor [3]

Based on Figure 2.15 and Figure 2.16, shown that the system designed with fuzzy control algorithm can fulfil synchronization control tasks at different frequency level. In Figure 2.17, the scale factor was larger when the error was big. Therefore, the system had faster response and the scale factor was reduced when the phase is close to set phase [3].

Another type of control of DC motor will be using sensorless Kalman filter in [4]. Kalman filter was designed to the machine tool and precision system control design for the DC motor as the machine mover. This intelligent control design where the speed control of DC motor was applied to stochastic time varying system to achieve high accuracies. Kalman filter was robust to external disturbances and had ability to predict states and parameter which were not simple to measure.

According to researcher in [5], speed control of a DC motor using the multi-level DC-DC converter. By using this, there were two feedback loops. The first will be armature current control for DC motor while the second DC motor speed control was maintained. The major controller used was proportional-integral (PI) controller.

The fifth controller for the DC motor was a non-linear PD controller. The PID controller used to be poor due to large overshoot, so the PD controller was a good choice to overcome such a problem. The PD controller having lower overshoot for integrating processes with delays compared to PID. Most of the industries having a time delay. Therefore, having a lower overshoot and faster settling time was preferred in the industries. In robotics field, a lot of PD controller was applied, but very little of the number reported tuning relations in the conventional control. Some of the base rule state that using a fuzzy tuner rather than scaling for both PI and PD fuzzy controller. The scaling factors of the fuzzy PD controller were continuously synchronous with the fuzzy rules depending on the environment [5].

2.6 Summary and discussion of review

The comparison between the controllers are listed below table 2.1 and the application of each involved in the industry area.

Table 2.2: Comparison between controllers used

Types of Controller	Emotional Intelligent	Fuzzy Control	Kalman Filter	Proportional Differential	Proportional Integral
Improvement	Fast transient speed	Variable scale factor	Speed control	Auto-tuning Scheme	Speed control
Number of DC motor	1	1	1	1	2
Application involved	Heating, Ventilation	Printing, paper making	CNC machine	Robotics	Semi-conductor Industry

Based on the five articles, the proportional integral derivative controller is the best controller. This is because of the easy implementation in the system. Besides that, the overshoot will be lower and faster settling time.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology which has been carried out cover most parts in the project. The parts being discussed here is the motion sensing, controlling one motor without moving another motor and relate each of the parameters to the torque.

3.2 Flow Chart

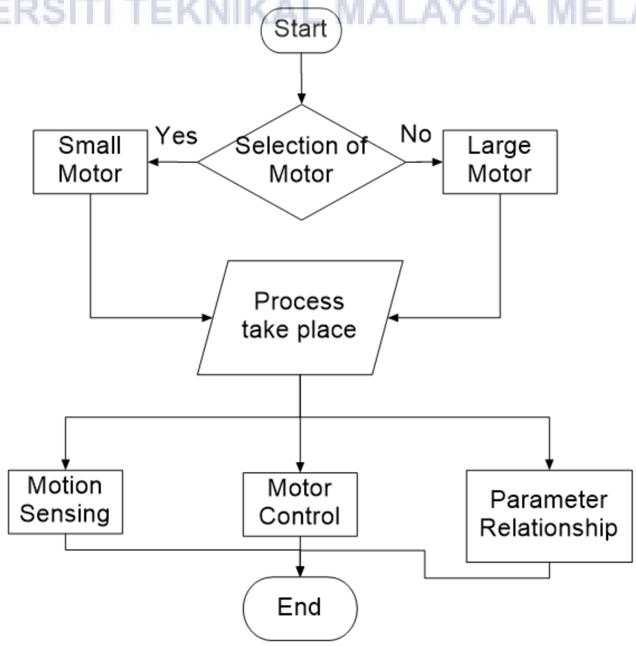

Figure 3.1: Overall flow chart process

This flow chart explains the flow of the system and the process involve when detecting motion and scaling takes place. The process started with the selection of motor that is either small or large motor. After that, the motor being applied force to it. The force applied will either amplify or decrease based on the motor that being picked. If large motor is picked, the force will decrease while small motor is picked, the force will amplify. The process of amplification, motor control and relationship for each parameter are further discussed.

3.3 Block Diagram

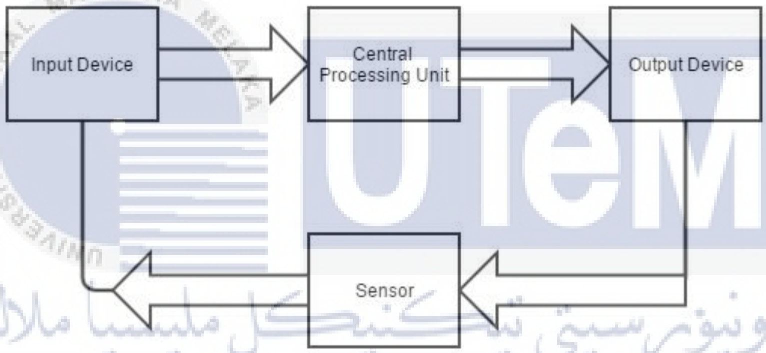

Figure 3.2: Overall system block diagram

The input device will be the current and motion from the DC motor. The CPU is by using Arduino Leonardo. The output device is the torque produced and finally sensors are current sensing breakout.

3.4 Calibrating the current sensor

The current sensor used is ACS712 which can support up to 5Ampere of current. The current sense of the current sensor is being recorded down in the serial monitor of Arduino. With this value, the torque can be calculated out since:-

$$P = \tau\omega \tag{3.1}$$

where P = Power

$\tau = Torque\ (Nm)$

$\omega = angular\ velocity\ (rads^{-1})$

$$\tau = \frac{P}{\omega} \tag{3.2}$$

$$\tau = \frac{IV}{\omega} \tag{3.3}$$

where I = Current (A)

V = Voltage (V)

$$\tau\ \alpha\ k.I \tag{3.4}$$

where k = constant

With the amount of current get can get the torque produced. This will be further clarified with the reading taken using a multimeter. The multimeter sensitivity is approximately ±1% based on the XL830L model.

The apparatus set up as below:

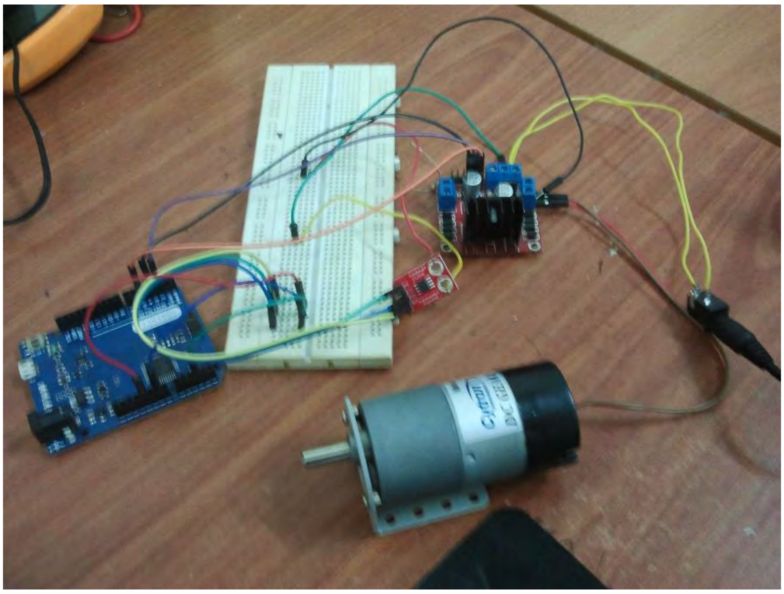

Figure 3.3: Apparatus setup to calibrate the current

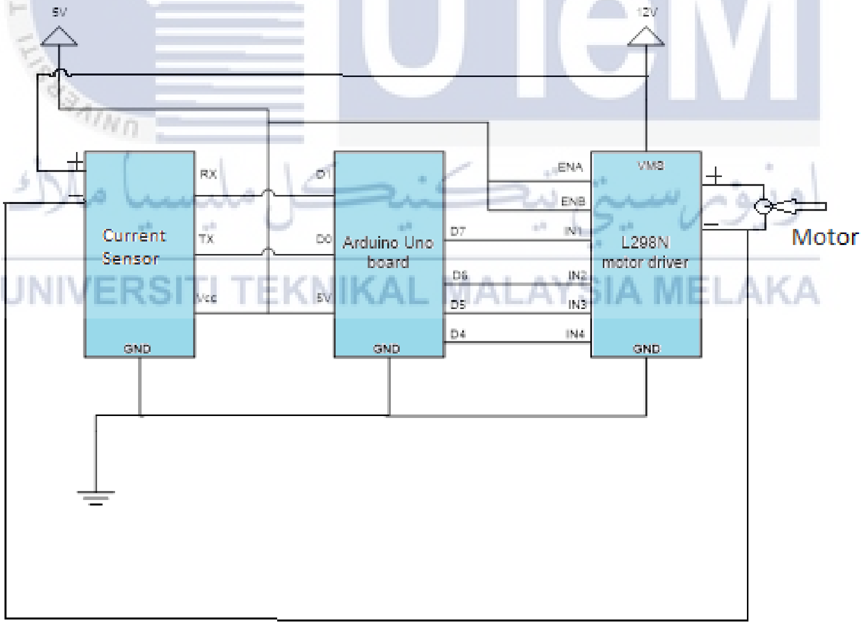

Figure 3.4: Electric circuit for current sensing

Firstly, the current sensor is used to read the current for the no load. The data obtained was tabulated. This is follow up by the reading of current with the SPG30-150k (τ =0.588Nm) motor. The data obtained also is tabulated in a table. A graph is drawn to see the difference between the data obtained between the data from current sensor and the multimeter readings. This process is repeated using the IG42E-49K (τ =1.76Nm) motor. A table of current versus time was tabulated in Table 3.1 and graph was plotted in Figure 3.5.

Table 3.1 Time and current table

Time (second)	**Current (Ampere)**
1	
2	
3	
4	
5	

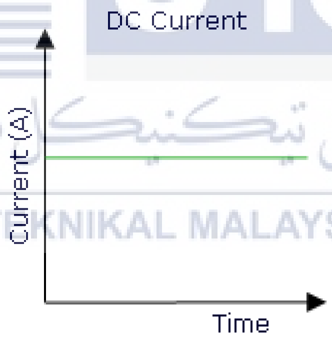

Figure 3.5: Current versus Time graph [13]

Coding for the calibration:

```
const int currentPin = 3;
const unsigned long sampleTime = 100000UL;                    // sample over 100ms, it is an exact number of cycles for both 50Hz and 60Hz mains
const unsigned long numSamples = 250UL;                       // choose the number of samples to divide sampleTime exactly, but low enough for the ADC to keep up
const unsigned long sampleInterval = sampleTime/numSamples;
const int adc_zero = 510;                                     // relative digital zero input from ACS712
void setup()
{
 Serial.begin(9600);
}
void loop()
{
 unsigned long currentAcc = 0;
 unsigned int count = 0;
 unsigned long prevMicros = micros() - sampleInterval ;
 while (count < numSamples)
 {
  if (micros() - prevMicros >= sampleInterval)
  {
    int adc_raw = analogRead(currentPin) - adc_zero;
    currentAcc += (unsigned long)(adc_raw * adc_raw);
    ++count;
    prevMicros += sampleInterval;
  }
 }
 float rms = sqrt((float)currentAcc/(float)numSamples) * (50 / 1024.0); //P in hertz
 Serial.println(rms);
}
```

Figure 3.6: Coding for current sensing

3.5 Project Process

3.5.1 Relation of torque parameter

Objective

1. To implement motion and force amplification for small DC motor to large DC motor which can replicate the movement of each other at different torque and scaling.

2. To implement motion and force decrement for large DC motor to small DC motor which can replicate the movement of each other at different torque and scaling.

Apparatus

1) Arduino software
2) Arduino controller
3) Multimeter/ current sensor
4) 12 DC motors (Large and small motor)
5) Motor driver (MD10C)
6) Force sensitive resistor pad

Procedure:

Figure 3.7: Apparatus set up for two DC motors

1) The apparatus was set up in Figure 3.7.
2) Torque can be derived in many ways, the torque used in these DC motors was related to force, angular velocity and current.

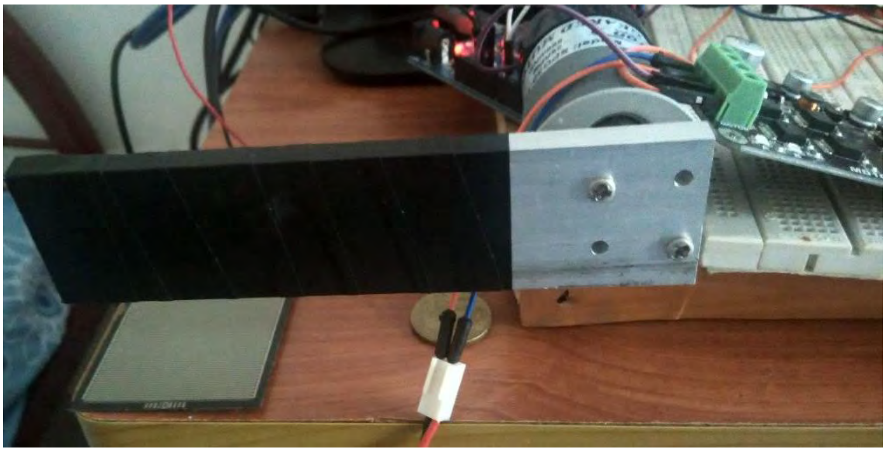

Figure 3.8: Motor link rotates and going touch the force sensor pad

Figure 3.9: Motor link touched the force sensor pad

3) Inertia present when the motor link was pressed with a certain force. This force will cause a fixed value of inertia to the system. In this project, the applied force is defined using the force sensor to the link of the motor when the rotating link hit the force sensitive resistor pad as shown in Figure 3.8 and Figure 3.9.

Table 3.2: Force Sensitive Resistor Value for both DC motors

Setpoint(˚)	Small Motor Force(N)	Large Motor Force(N)

4) A Table 3.2 as shown above was tabulated for the force sensitive resistor value when the linkage of motor hit the force sensitive resistor pad. The setpoint of 180˚ was repeated eight times to get the force of small and large motor.
5) For the angular velocity, while the motor is turning in a specific RPM, the angular velocity will change. By assuming the constant RPM in this project, the desired RPM for the small motor is 24RPM while the large motor is 120RPM.
6) In order to get the accurate torque, the current from the multimeter that detect the current in the motor was measured. The current for both motors was tabulated when the motor runs by using a multimeter.
7) Since inertia (force) is directly proportional to the current, by finding the current the inertia (force) was known. The complete table for all the parameters for the motors was tabulated.
8) The scaling factor and current of the motors was tabulated.
9) The force amplication and force decrement factor was calculated based on the provided data.

3.5.2 Motion Sensing

Objective

3. To analyse the time delay and deviation error from the encoders of both the motor.

Apparatus

1) One small torque motor with encoder
2) One large torque motor with encoder
3) Arduino controller with software
4) Motor driver MD10C
5) 12V DC adapter (0.3A and 5.0A)
6) Coupling for the motor.

Procedure

1) Based on the small motor and large motor, the reading of the motion recorded from the build in encoder. The motion can be represented by the Figure 3.10 below:

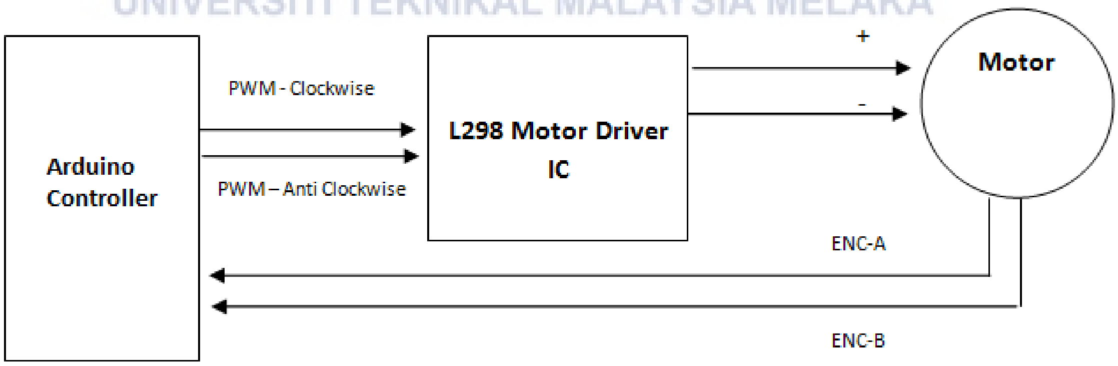

Figure 3.10: Connection of motor driver and encoder [14]

2) The encoder reading can be taken into two sets of data. By either clockwise or anticlockwise, each of the pulse at a given time will be different and finally the RPM can be calculated.

3) The value of encoder reading was recorded based on the serial monitor of Arduino software.

Figure 3.11: Measuring the angle of the motor link

4) The difference in the reading from a serial monitor of Arduino and hardware as shown in Figure 3.11 was calculated and shown in a Table 3.3, Table 3.4 and Table 3.5.

Table 3.3: Reading of Encoder from Arduino Serial

Setpoint(˚)	Reading from Arduino Serial			
	Small Motor		Large Motor	
	Clockwise position(˚)	Anti-Clockwise position(˚)	Clockwise position(˚)	Anti-Clockwise position(˚)
0				
50/-50				
100/-100				
150/-150				
200/-200				
250/-250				
300/-300				
360/-360				

Table 3.4: Reading of Rotation by Protractor

Setpoint(˚)	Reading from manual protractor			
	Small Motor		Large Motor	
	Clockwise position(˚)	Anti-Clockwise position(˚)	Clockwise position(˚)	Anti-Clockwise position(˚)
0				
50/-50				
100/-100				
150/-150				
200/-200				
250/-250				
300/-300				
360/-360				

Table 3.5: Overall Results of the Calculation

Setpoint(˚)	Small Motor	Large Motor	Small Motor	Large Motor
	Difference of position clockwise (˚)	Difference of position anticlockwise (˚)	Difference of position clockwise (˚)	Difference of position anticlockwise (˚)
0				
50/-50				
100/-100				
150/-150				
200/-200				
250/-250				
300/-300				
360/-360				

5) The mean, variance and standard deviation for the data is calculated.

3.5.3 Control Parameter Relationship

Objective

3. To analyse the time delay and deviation error from the encoders of both the motor.

Apparatus

1) One small torque motor with encoder
2) One large torque motor with encoder
3) Arduino controller with software
4) Motor driver MD10C
5) 12V DC adapter (0.3A and 5.0A)
6) Coupling for the motor
7) Matlab

Procedure:

1) The type of control for the motor is by either PID, PI or PD.
2) PID was chosen based on the effectiveness in minimising the error in the motor.
3) The error of the values in PID was calculated between the motor desired points to the setpoint.
4) The graph of the PID controller as shown below in Figure 3.12 is a general error and a calculation based on the reference of K_p =0.5, K_i =1.1, and K_d =1.6.

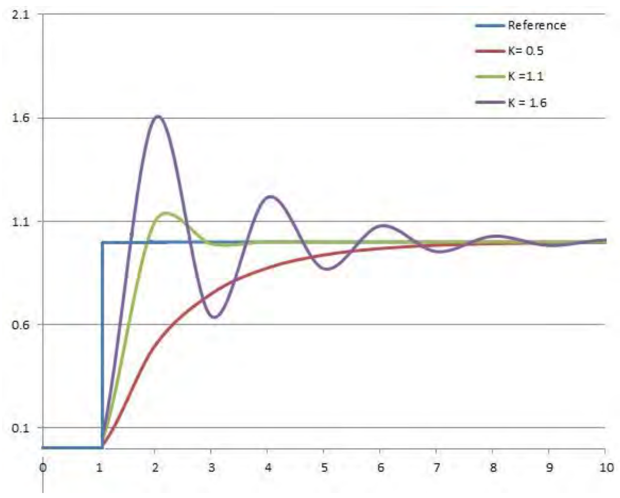

Figure 3.12: PV vs time for PID controller [12]

5) From the equation,

$$u(t) = MV(t) = Kp(e) + Kd(\frac{d(e)}{dT}) + Ki(\frac{d^2(e)}{dT^2}) \quad (3.5)$$

Where,

K_p: Proportional gain, a tuning parameter

K_i: Integral gain, a tuning parameter

K_d: Derivative gain, a tuning parameter

e: Error = SP - PV

The error u(t) of K_p, K_i, and K_d was calculated and being adjusted to the desired value.

6) When moving the second motor, the first motor error was corrected by implementing the calculation u(t) and tune back to the value wanted.
7) A set of ranges of values for the PID controller was formed to get to correct to the desired setpoint.
8) Three sets of values were tested using Matlab and the graphs were shown.

3.5.4 Time delay parameter

Objective

3. To analyse the time delay and deviation error from the encoders of both the motor.

Apparatus

1) One small torque motor with encoder
2) One large torque motor with encoder
3) Arduino controller with software
4) Motor driver MD10C
5) 12V DC adapter (0.3A and 5.0A)
6) Coupling for the motor
7) A stopwatch

Procedure:

Figure 3.13: Set up of apparatus with stopwatch

1) The apparatus was set up as Figure 3.13.
2) A setpoint of 360˚ was set to the program.
3) The time lapse for the small motor to stop completely was taken and recorded in a table.
4) The step is repeated for the large motor and the data were recorded in a table.
5) The difference in time was calculated and shown in the Table 3.6.

Table 3.6: Time delay for small and large motor

Small Motor		Large motor		Difference in Time(s)
n	Time(s)	n	Time(s)	

6) Step 2 to 5 was repeated for 8 times in order to get a more accurate reading.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The expected results in this chapter show the objective being fulfilled and analysis of the scaled control of DC motors

4.2 Calibration results for current sensor

The sensor tested and the data were collected in a table 4.2 with the multi meter reading as shown below:

Table 4.1 Current and time data

Current Sensor reading		**Multi meter reading**		**Difference (%)**
Time(s)	**Current(A)**	**Time(s)**	**Current(A)**	
1	2.37	1	2.50	5.49
2	2.37	2	2.55	7.59
3	2.38	3	2.52	5.88
4	2.37	4	2.50	5.49
5	2.36	5	2.54	7.63
6	2.37	6	2.60	9.70
7	2.36	7	2.54	7.63
8	2.37	8	2.52	6.33
9	2.38	9	2.53	6.30
10	2.38	10	2.54	6.72
		Mean Difference=		6.88

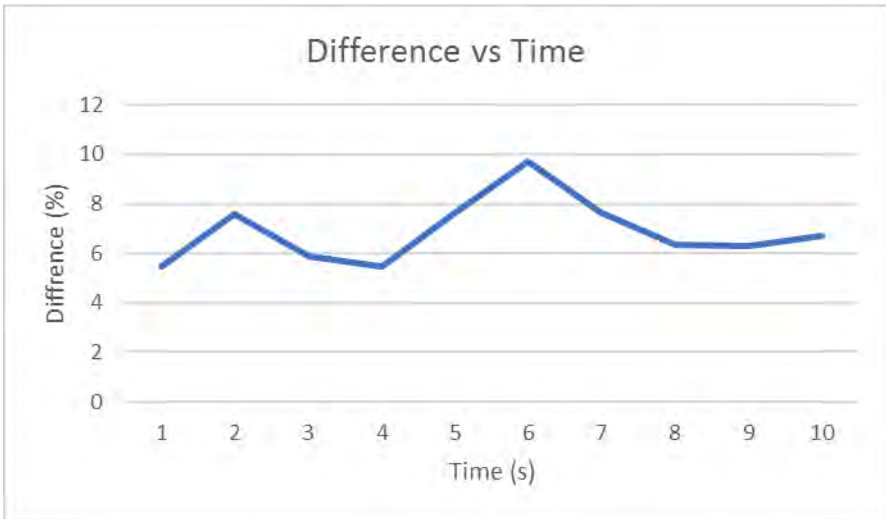

Figure 4.1: Difference (%) over time (s) graph

The results in Table 4.1 show that a difference of 6.88% from the multimeter as reference to the current sensor. However, the value of the multimeter cannot obtain in the steady value due to several unavoidable factors such as human error and device error. The current sensor value almost linear all the time, which is a trustable value compare to the multimeter value. In Figure 4.1 shows that the difference of error over time, the deviation of current between multi meter and current sensor.

4.3 Project Results

4.3.1 Relation of torque parameter

Below are the relation of torque equations based on theory:

Considering the power in electrical:

$$P_e = VI \tag{4.1}$$

where P_e = Electrical Power (W)

V = Voltage (V)

I = Current (A)

Then, considering the power in mechanical:

$$P_m = \tau\omega \tag{4.2}$$

where P_m = Mechanical Power (W)

τ = Torque (Nm)

ω= Angular velocity (rads^{-1})

Equates both the equation together when applying electrical and mechanical power conservative.

$$P_e = P_m \tag{4.3}$$

$$VI = \tau\omega \tag{4.4}$$

Based on the equation 4.4, since the voltage supply is in constant 12V,

$$\tau = \frac{VI}{\omega} \tag{4.5}$$

Considering RPM for small motor is 26 rev/min and RPM for large motor is 120rev/min

$$\omega_s = \frac{24}{60} = 0.4 \text{ rad/s}^{-1} \tag{4.6}$$

where ω_s = small motor angular velocity

$$\omega_L = \frac{120}{60} = 2.0 \text{ rad/s}^{-1} \tag{4.7}$$

where ω_s = large motor angular velocity

From equation 4.4, the torque is directly proportional to current over angular velocity.

$$\tau \propto k\frac{I}{\omega} \tag{4.8}$$

By comparing the torque, τ produces for both small and large motor,

$$\tau_s = \tau_l \tag{4.9}$$

where τ_s = torque of small motor(Nm)

τ_l = torque of large motor(Nm)

$$\frac{I_s}{0.4} = \frac{I_l}{2.0}$$

$$I_s = 0.2I_l \tag{4.10}$$

where I_s = Small motor current(A)

I_l = Large motor current(A)

$$I_l = 5I_s$$

Since $I_l \alpha k.I_s$, based on theoretical calculation in equation 4.10, the value of scaling, k is 5 from small motor to large motor.

For the comparison between force amplification:-

By using Newton's second law,

$$F = ma \tag{4.11}$$

where F = force (N)

m = mass(kg)

a = acceleration (ms^{-2})

$$F\Delta t = m\Delta v \tag{4.12}$$

where Δt = change in time (s)

Δv = change in velocity (ms^{-1}

Applying conservation of momentum through Newton's second law,

$$m\Delta vr = F\Delta tr \tag{4.13}$$

where r = radius (m)

$$\frac{m\Delta vr}{\Delta t} = Fr \tag{4.14}$$

$$\text{Torque, } \tau = Fr \tag{4.15}$$

For the small motor and large motor of radius is constant,

$$\tau \ \alpha \ kF \tag{4.16}$$

From equation 4.8,

$$\tau \propto k\frac{I}{\omega} \tag{4.17}$$

$$F \propto k\frac{I}{\omega} \tag{4.18}$$

By equating both small and large formula,

$$\frac{Fs}{F_l} = \frac{Is/\omega_s}{I_l/\omega_l} \tag{4.19}$$

where F_s = force of small motor (N)

F_l = force of large motor (N)

$$\frac{F_s}{F_l} = 1.25\frac{I_s}{I_l} \tag{4.20}$$

At the maximum current of operating system, and assuming Fs is at 10N,

$$F_l = \frac{5.0(10)}{(0.5)(1.25)} = 80N \tag{4.21}$$

Therefore, from the calculation of theory in equation 4.21, the amplification of force from a small DC motor to a large DC motor is 8 times. Meanwhile, the decrement of force also using the same calculation from equation 4.20 which will result of 0.125 times.

From the experiment done in the relationship with torque parameter:

The value of the gains of K_p, K_d, and K_i is set for small motor is K_p= 0.325, K_d = 0.0000001, and K_i = 0.3 while the gain for large motor of K_p, K_d, and K_i is set at K_p= 0.335, K_d = 0.00000001, and K_i = 0.001. The force exerted to the small motor and force exerted to the large motor in 180˚ is based on Table 4.2.

Table 4.2: Force Sensitive Resistor Value

Setpoint(˚)	Small Motor Force(N)	Large Motor Force(N)
180	4.4	44.30
180	4.0	45.30
180	4.8	43.95
180	4.2	44.25
180	4.4	45.20
180	4.4	44.25
180	4.5	44.00
180	4.4	44.05

The average value of small motor force is, F_s = 4.388N

The average value of large motor force is, F_l = 44.41 N

Table 4.3: The encoder reading and current reading for both DC motors

Small Motor		Large Motor	
Encoder Reading (˚)	Reading of Current (A)	Encoder Reading (˚)	Reading of Current(A)
0	0	0	0
7.50	0.075	8.50	0.79
17.00	0.072	22.50	0.74
31.00	0.069	65.50	0.70
50.50	0.060	93.00	0.66
93.00	0.055	141.00	0.60
139.00	0.050	208.50	0.62
206.00	0.043	254.00	0.55
266.50	0.040	280.00	0.40
34.00	0.010	320.00	0.20
360.00	0	360.00	0

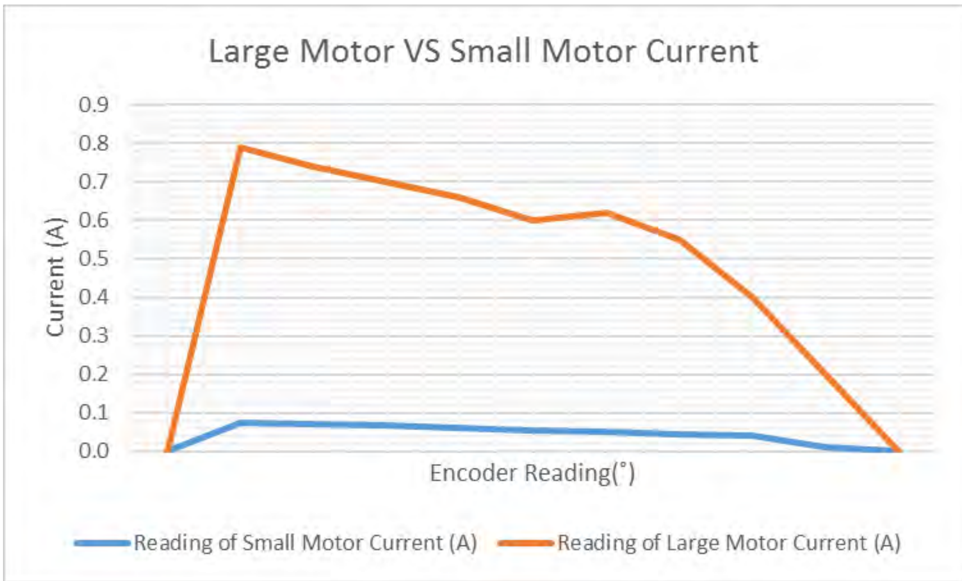

Figure 4.2: Graph of comparison of current for both DC motors

Based on the Figure 4.2, the scaling factor, k shows around 10. In which, when a 0.045A DC motor run with a 0.61A DC motor will produce a scaling factor of around k = 10. For the force amplification, by taking the force applied to the small motor is 4.40N from the force sensitive resistor data and encoder reading at 180˚, the value of force in the large motor based on equation , $\frac{F_s}{F_l} = 1.25\,\frac{I_s}{I_l}$ is

$$F_l = \frac{4.388 \times 0.61}{0.045 \times 1.25}$$

$$= 47.59\text{N}$$

Therefore, the force amplification factor, $j_1 = \frac{47.59}{4.388} = 10.84$ times of the small motor force.

For the decrement of force for the large motor to small motor, $\frac{F_s}{F_l} = 1.25\,\frac{I_s}{I_l}$

$$F_s = \frac{1.25 \times 0.045 \times 44.41}{0.61}$$

$$= 4.095\text{N}$$

The decrement factor, $j_2 = \frac{4.095}{44.41} = 0.0922$.

Hence, the decrement factor, j_2 = 0.0923 meaning the value of the force will decrease by 0.0922 times the force of the large motor.

Table 4.4: Comparison between Theory and Measurement

Elements	Calculation	Measurement	Error	Percentage of Error(%)
Force Amplification	8 times	10.844 times	2.844	35.55
Force Decrement	0.125 times	0.0922 times	0.0327	26.16

Based on the above Table 4.4, the percentage of error in the force amplification process through theory and measurement is about 35.55% and the force decrement process error is about 26.16%. One of the reasons due to the error occur based on theory is because of the current lost to the wiring. Other than that, the motor which contains magnetic features will make the current lost because of Eddy's current. However, the way to overcome this is by minimising the wire use and calculate the Eddy current error to tune it right.

The significance in this experiment is to amplify or decrease the force of the motor with a scaling factor of k or decrement factor of j respectively. The amplification and decrement force is very crucial in any field which uses robotic application in their workspace. Human strength only can operate machine which uses less force to compare to machine operating with tonnes of loads. With this application of scaling, user can operate the small motor in order to move a large load through the larger motor.

4.3.2 Motion Sensing Result

Below are the data taken for the encoder reading in the Arduino Serial and Protractor reading as shown in Table 4.5 and Table 4.6.

Table 4.5: Reading of Encoder from Arduino Serial

Setpoint(˚)	Reading from Arduino Serial			
	Small Motor		Large Motor	
	Clockwise position(˚)	Anti-Clockwise position(˚)	Clockwise position(˚)	Anti-Clockwise position(˚)
0	0	0	0	0
50/-50	50.5	-49.5	48.0	-51
100/-100	100.5	-99.0	99.0	-102
150/-150	151.0	-150.5	149.0	-152
200/-200	200.5	-200.0	198.0	-202
250/-250	250.5	-249.5	249.0	-252
300/-300	300.5	-300.5	298.0	-302
360/-360	360.5	-359.5	358.0	-363

Table 4.6: Reading of Rotation by Protractor

Setpoint(˚)	Reading from manual protractor			
	Small Motor		Large Motor	
	Clockwise position(˚)	Anti-Clockwise position(˚)	Clockwise position(˚)	Anti-Clockwise position(˚)
0	0	0	0	0
50/-50	56.0	-44.0	53.0	-49
100/-100	106.0	-95.0	102.0	-102
150/-150	157.0	-146.0	153.0	-152
200/-200	207.0	-194.0	203.0	-202
250/-250	258.0	-245.0	255.0	-255
300/-300	309.0	-295.0	305.0	-302
360/-360	367.0	-355.0	362.0	-360

The data shown below Table 4.7 is the overall results of the calculation from the Arduino Serial and protractor reading.

Table 4.7: Overall Results of the Calculation

Setpoint(˚)	Small Motor	Large Motor	Small Motor	Large Motor
	Mean Difference of position Arduino (˚)	Mean Difference of position Arduino (˚)	Mean Difference of position Protractor (˚)	Mean Difference of position Protractor (˚)
0	0	0	0	0
50/-50	0.5	1.5	6.0	2.0
100/-100	0.8	1.5	5.5	2.0
150/-150	0.8	1.5	5.5	2.5
200/-200	0.3	2.0	6.5	2.5
250/-250	0.5	1.5	6.5	5.0
300/-300	0.5	2.0	7.0	3.5
360/-360	0.5	2.5	6.0	1.0

1- Refer to data position in Arduino for small motor
2- Refer to data position in Arduino for large motor
3- Refer to data position using Protractor for small motor
4- Refer to data position in Protractor for large motor

The mean of the difference in position is, $x_n = \frac{\sum_i xi}{n}$ (4.22)

$x_1 = 0.469^\circ$

$x_2 = 1.563^\circ$

$x_3 = 5.375^\circ$

$x_4 = 1.833^\circ$

Average mean for Arduino reading and protractor reading,

$$x = \frac{x_1 + x_2 + x_3 + x_4}{4} \tag{4.23}$$

Accuracy = ± 2.31˚

The variance of position Arduino reading and protractor reading is,

$$\sigma_1{}^2 = \frac{1}{n}\sum_{i=1}^{i=n}(xi - mean)^2 \tag{4.24}$$

$\sigma_1{}^2 = 0.054$ ˚

$\sigma_2{}^2 = 0.465$ ˚

$\sigma_3{}^2 = 4.359$ ˚

$\sigma_4{}^2 = 1.996$ ˚

The standard deviation for Arduino reading and protractor reading,

$$\sigma_n = \frac{1}{n}\sqrt{\sum_{i=1}^{i=n}(xi - mean)^2} \tag{4.25}$$

$\sigma_1 = \sqrt{0.054} = 0.232$ ˚

$\sigma_2 = \sqrt{0.465} = 0.682$ ˚

$\sigma_3 = \sqrt{4.359} = 2.088$˚

$\sigma_4 = \sqrt{1.996} = 1.413$ ˚

Based on the mean difference of the project, the mean for Arduino reading for small motor is 0.469˚ while the mean for large motor through Arduino is 1.563˚. This is followed by the manual protractor reading of small motor is 5.375˚ and large motor is 1.833˚ respectively. The value of standard deviation, the standard deviation angle of the project in a range of 0 degrees to 3 degrees in Arduino is 0.232˚ and 0.682˚ respectively. For the manual calculation using a protractor, the standard deviation for smaller motor and large motor is 2.088˚ and 1.413˚ respectively. All the deviation from the desired values need to be corrected using the correct gain in the control parameter. Mean, standard deviation of both Arduino and protractor reading is 0.707˚

The main reason to do this experiment is because the angle deviates from the setpoint which is set by the user is very important. For example, in a robotic industry, the operator controlling the machine in the control room and to send signals to the machine to the operation line. When the signal is sent to the operation line, the deviation of 2.088˚ and 1.413˚ respectively from the small motor and large motor is very vital. Any small error causing the robotic machine to wrongly calculate the movement will make the whole system collapsed.

4.3.3 Control Parameter Relationship

Let SP = setpoint, PV = present value,

Error = SP – PV, (4.26)

Assume the value of SP = 120˚ and the PV = 10˚,

Sampling time, $T_s = T_P$ (present time) – T_L(last time) (4.27)

Error sum += (T_s x Error) (4.28)

$$\frac{d(E1)}{dt} = error \quad (4.29)$$

$$\text{Output} = \text{Kp(error)} + \text{Kd}\left(\frac{\text{d(error)}}{dT}\right) + \text{Ki}\left(\frac{d^2\,(\text{error})}{dT^2}\right) \quad (4.30)$$

For the small motor control PID gain Kp, Kd and Ki when the Kp value changes,

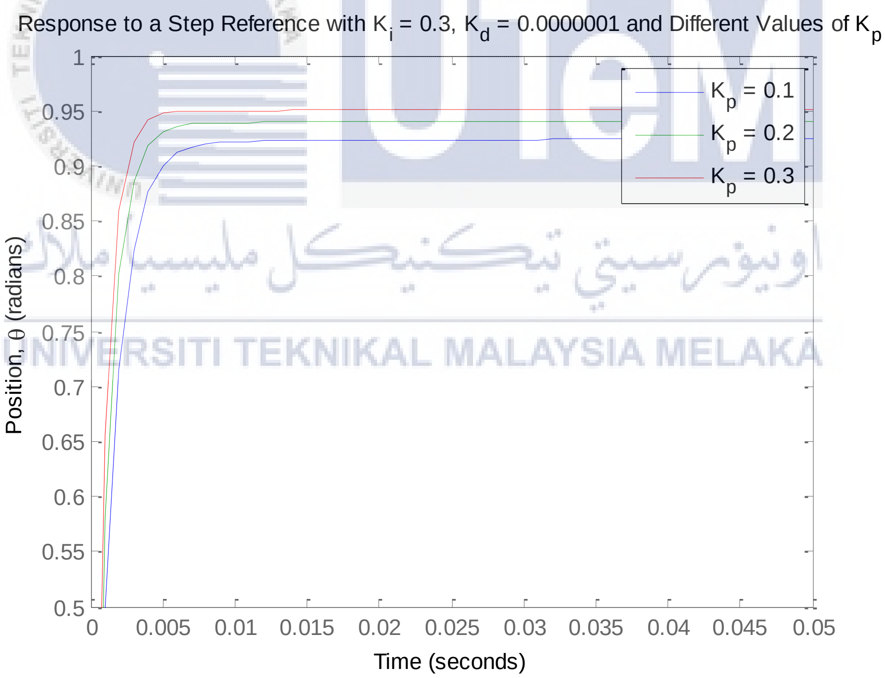

Figure 4.3: Changing of Kp value of small motor in simulation

Based on the Figure 4.3, the graph shown the values of gain in Kp changes with the setpoint of 1 radian which is equivalent to about 57˚. When the gain in Kp increases, the graph shifted nearer to position one in radian while the gain Kp decreases, the graph shifted lower to the steady-state of around 0.92 (52˚). The value of Kp must be in a range of 0<Kp<10 in order to get a graph that is near to the desired value. If the gain of Kp is too large >100, the desired value of angle will fall a lot below the desired value which causing the system to fail.

For the small motor control PID gain Kp, Kd and Ki when the Kd value changes,

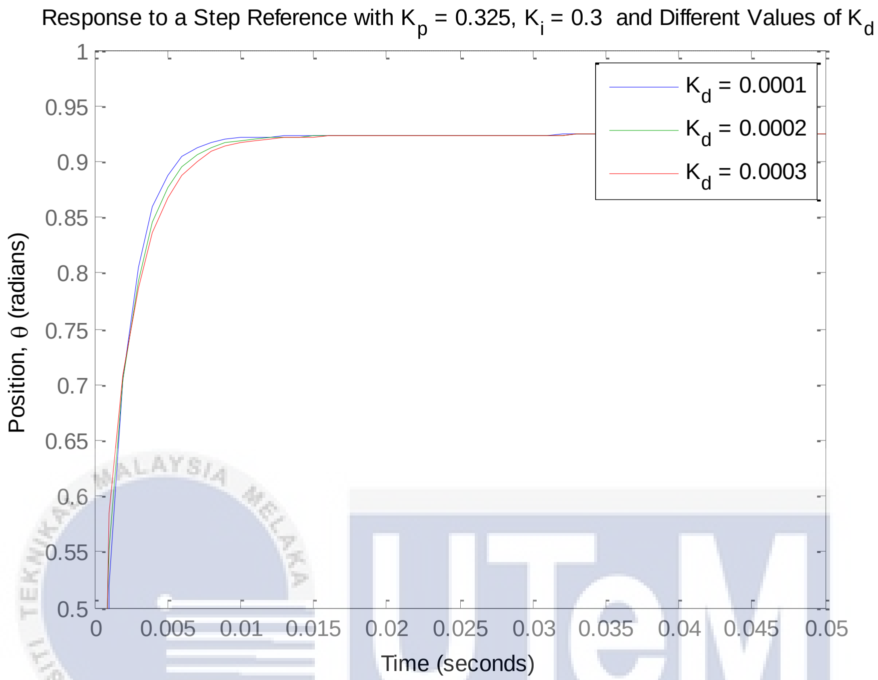

Figure 4.4: Changing of Kd value of small motor in simulation

For the Figure 4.4, the graph shown that the value of Kd = 0.0001 is at 0.92 to the steady state value while the other value is not recommended as they are too far apart from the desired value. If the value of Kd is 0.0002, the difference it is very small but the time to reach the desired angle of 0.92 rad is faster. The value of Kd must fall in a range of 0<Kd<1 because if the value is less than zero and Kd >1, the graph will be shifted to the negative and to the infinity respectively that is the position will not fall on the desired setpoint.

For the small motor control PID gain Kp, Kd and Ki when the Ki value changes,

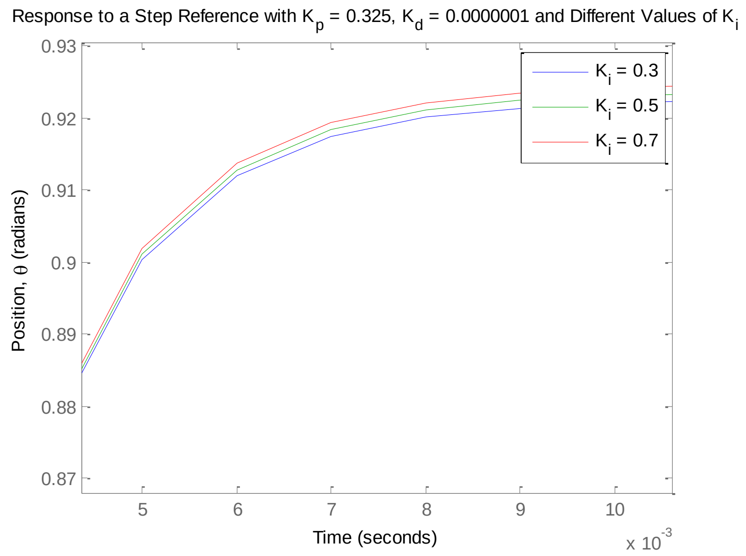

Figure 4.5: Changing of Ki value of small motor in simulation

Based on the Figure 4.5, the changes of Ki is very small as the range of Ki can be 0<Ki<1. The changes in the gain of Ki only shifted the graph a bit. The system can still stable in the range of gain as shown in Figure 4.5. The time for the higher Ki to reach the desired angle in radian is faster compared to the lower Ki which is 0.3. If the value is too small or too large the graph will be shifted to negative region and infinity respectively that is the position will be too small or too big that is not compatible to the system requirement.

For the large motor control PID gain Kp, Kd and Ki when the Kp value changes,

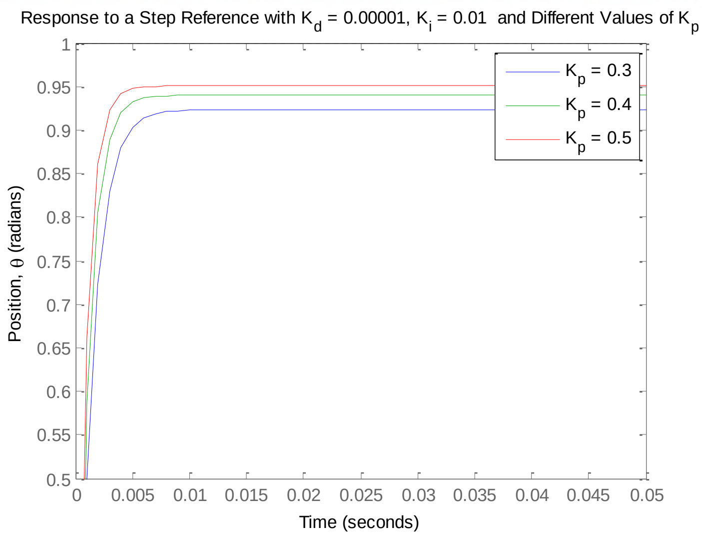

Figure 4.6: Changing of Kp value of large motor in simulation

Based on the graph of Figure 4.6, the desired value is 0.93 which is near to the value of gain of Kp of 0.3 and 0.4. The value of Kp must not be too large which exceed 10 because the graph will be shifted to the infinity. If the Kp value set is too small, the value of position get will be too small which is not recommended for the system.

For the large motor control PID gain Kp, Kd and Ki when the Kd value changes,

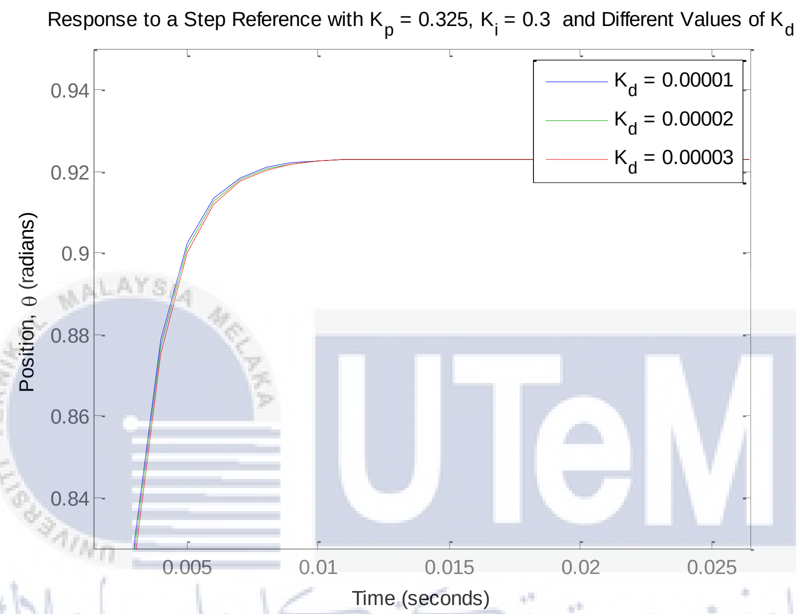

Figure 4.7: Changing of Kd value of large motor in simulation

The changes of Kd in the above Figure 4.7 is not so obvious, but the value of larger gain in the Kd contributes to the faster time to reach the desired position. If the Kd is too big such as Kd = 1, the system will fail due to the sudden increase of power surge that might spoil the whole equipment or machine. If the Kd value is too small, the time to reach the desired time will increase and this will cause the system to have a lot of delay.

For the large motor control PID gain Kp, Kd and Ki when the Ki value changes,

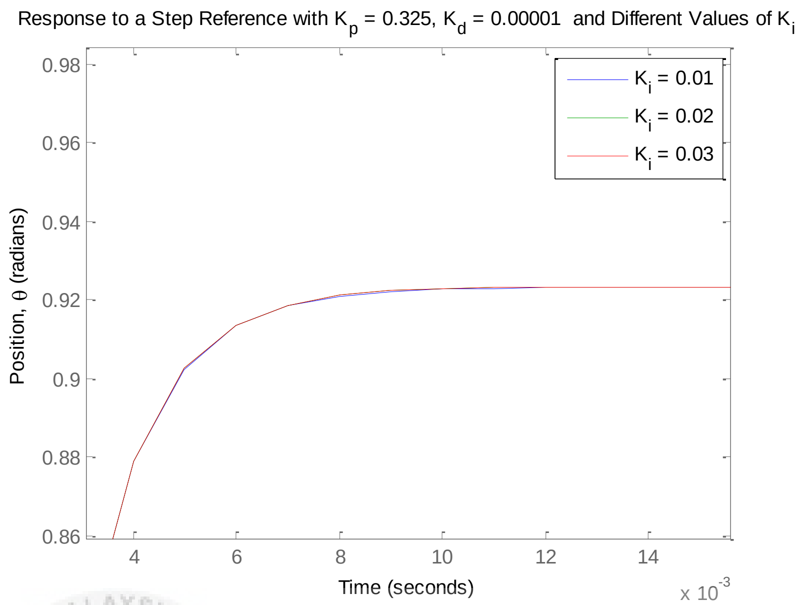

Figure 4.8: Changing of Ki value of large motor in simulation

The value of Ki gain shown in the graph is a smooth straight line after time reaches, t=0.02s. Before the time reaches 0.02s, the gain happens to cause some minor underdamp situation. This only applies to the gain which is Ki>0.01. Therefore, in order to get a steady output of the system, the Ki must be in a range of 0.01<Ki<0.1.

Summary of Control Parameter Relationship

The value of each Kp, Kd and Ki must be a logical value that is 0 < Kp <10, 0 < Kd < 1, and 0.01 < Ki < 0.1 respectively as shown in the small motor of Figure 4.3, Figure 4.4 and Figure 4.5 above so as large motor of Figure 4.6, Figure 4.7 and Figure 4.8 above. There is an assumption made that is no disturbance for this system. The values set for each of the parameters needed in that range because to obtain the minimum deviation of angles after the setpoint been set. However, the values need to be tuned again if other factors such as load or changes of power input is added to the motor.

4.3.4 Time delay parameter

The data collected in the experiment is shown at Table 4.8,

Table 4.8: Time to complete each rotation

Small Motor		Large motor		Difference in Time(s)
n	Time(s)	n	Time(s)	
1	7.6	1	2.6	5.0
2	7.8	2	2.7	5.1
3	7.9	3	2.5	5.4
4	7.5	4	2.8	4.7
5	7.5	5	2.7	4.8
6	7.6	6	2.7	4.9
7	7.6	7	2.6	5.0
8	7.7	8	2.7	5.0

Based on the Table 4.8, the mean of the each rotation is

$$x = \frac{5+5.1+5.4+4.7+4.8+4.9+5.0+5.0}{8}$$

$= 5.0$ s

The variance of the each rotation, $\sigma^2 = 0.0386$

Standard deviation of each rotation, $\sigma = 0.196$

The mean of the setpoint of 360° is 5.0s which meaning the small motor moving slower than the large motor and the delay time for it is 5.0s. The variance for the delay time is around 0.0386s from 5.0s and the standard deviation is 0.196s. There are a few reasons why the time delay happening, one of it because the motor is not lubricated enough. Another reason is because the gain for either Kp, Kd or Ki is set wrongly. The method to overcome this situation is apply grease and trial and error until the most desired gain was found.

The main reason doing this time delay experiment is because the time delay in a machine or application is a life-deciding and cost-saving experiment. In a pneumatic industry, when applying a force to a small pneumatic cylinder, there is some delay to transfer to the other larger pneumatic cylinder. The time delay is calculated and with the time delay, the operator of the system can know exactly when to stop or start the whole system without waiting for the system to complete the whole process. Other than that, the operator can estimate the time for the larger pneumatic cylinder to finish its operation and continue with the following process. This will save a lot of time through the time delay period.

CHAPTER 5

CONCLUSION

5.1 Introduction

The scaled control of DC motors will be concluded in this chapter. The limitation and the future development will be further discussed in this section.

5.2 Conclusion and Recommendation

There are three objectives that need to be achieved in this project. The first objective is to implement the motion and scaling for a small motor to large motor with different torque and scaling. The second objective is to implement the motion and scaling for large motor to small motor with different torque and scaling. Lastly, the objective is to analyse the accuracy and delay time of the motor. The first and second objective is achieved by getting the scaling factor of k which is about 10. The force amplification is 10.84 for the small motor force to large motor force and force decrement of 0.0923 for the large motor force to the small motor force. The last objective is achieved by knowing the accuracy of the rotation is $\pm 5.03^{\circ}$ and the time delay of about 5.0s.

For the recommendation, the hardware need to be use on real application such as in robotics to test the performance of the prototype. This is because without the real testing, all the parameters will be keep changing and need to tune to the optimum performance. For the methodology part, few sensors need to add to the project in order to get more accurate data such as encoder sensor for the motor. The sensor is useful to detect the turning of an angle in the linkage of the motor rather than using manual measurement of the protractor. Besides that, the working principles for the motor can be increased to three or four motors subsequently.

5.3 Limitation of Project

There are few limitations for the scaled control of DC motors. One of it is the direction of link to move. The link can only move clockwise and anticlockwise in a one way direction. The second limitation is the maximum motor torque. The motor used only can manage to achieve a torque of about 0.1Nm and 2.0Nm. Lastly is the input power supply. The current supplied to the motor is fixed to around 0.5A to 3.0A and 12V-DC.

REFERENCES

[1] E. Daryabeigi, H. Sadeghi, G. R. A. Markadeh, and C. Lucas, "Speed control of brushless DC motors using emotional intelligent controller," *IECON 2010 - 36th Annu. Conf. IEEE Ind. Electron. Soc.*, 2010.

[2] W. Qian, H. Cha, F. Z. Peng, and L. M. Tolbert, "55-kW variable 3X DC-DC converter for plug-in hybrid electric vehicles," *IEEE Trans. Power Electron.*, vol. 27, pp. 1668–1678, 2012.

[3] C. Dey, R. K. Mudi, and D. Simhachalam, "A simple nonlinear PD controller for integrating processes," in *ISA Transactions*, 2014, vol. 53, pp. 162–172.

[4] F. He, W. Tong, and Q. Wang, "Synchronization control strategy of multi-motor system based on profibus network," in *Proceedings of the IEEE International Conference on Automation and Logistics, ICAL 2007*, 2007, pp. 3029–3034.

[5] S. Praesomboon, S. Athaphaisal, S. Yimman, R. Boontawan, and K. Dejhan, "Sensorless speed control of DC servo motor using Kalman filter," in *Information, Communications and Signal Processing, 2009. ICICS 2009. 7th International Conference on*, 2009, pp. 1–5.

[6] Faiz Hassan, *Speed Control of CESB conveyor belt*, in thesis writing for Faculty of Electronic and Computer Engineering UTeM on 2007.

[7] "SN-ACS-712 – Current Sense Breakout Board." [online] Available: http://www.cytron.com.my/viewProduct.php?pcode=SN-ACS712&name=Current%20Sense%20Breakout%20Board/ (Accessed: 8th Nov 2014)

[8] "SPG30E – 150K – DC Geared Motor with Encoder." [online] Available: http://www.cytron.com.my/viewProduct.php?pcode=SPG30E-150K&name=DC%20Geared%20Motor%20with%20Encoder/ (Accessed: 8th Nov 2014)

[9] "IG42E-49K Planetary Geared Motor (42mm)." [online] Available: http://www.cytron.com.my/viewProduct.php?pcode=IG42E-

49K&name=Planetary%20DC%20Geared%20Motor%20(42mm)/ (Accessed: 8th Nov 2014)

[10] "The Ram Arms." [online] Available: https://www-robotics.jpl.nasa.gov/systems/systemVideo.cfm?System=9&Video=66/ (Accessed: 8th Nov 2014)

[11] "Pneumatic Scale Filler Liquid Grav/Press PNEUMAFLOW Rotary, 40-hd, 5" centers5E1670." [online] Available: http://www.fraingroup.com/products/pneumatic-scale-filler-liquid-gravpress-pneumaflow-rotary-40-hd-5-centers/ (Accessed: 8th Nov 2014)

[12] V. Aggarwal, M. Meng, and U. M. O'Reilly, "A self-tuning analog Proportional-Integral-Derivative (PID) controller," in *Proceedings - First NASA/ESA Conference on Adaptive Hardware and Systems, AHS 2006*, 2006, vol. 2006, pp. 12–19.

[13] "Physics 30." [online] Available: http://physics30.edcentre.ca/elect/lessoniii_2_2.html/ (Accessed: 9th Nov 2014)

[14] "PID based DC motor Control." [online] Available: http://thetechnicalbrain.com/electronics/elec_pid.php/ (Accessed: 9th Nov 2014)

[15] "Enhanced 10Amp DC Motor Driver." [online] Available: http://www.cytron.com.my/p-md10c/ (Accessed: 18th May 2015)

[16] "L298 Dual Full Bridge Driver." [online] Available: http://www.st.com/web/en/catalog/sense_power/FM142/CL851/SC1790/SS1555/PF63147/

(Accessed: 18th May 2015)

[17] "Force Sensitive Resistor – Square" [online] Available: http://www.sparkfun.com/products/9376/ (Accessed: 27/5/2015

APPENDICES

GANTT CHART FOR FINAL YEAR PROJECT 1 AND 2

Task	Semester 1 / 2014																Semester 2 / 2015																							
	Sep				Oct				Nov				Dec				Jan				Feb				Mar				Apr				May				Jun			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1) Initial stage																																								
Project title selection																																								
Planning of project																																								
2) Literature review stage																																								
Study on the DC motor																																								
Study on the previous review done by researcher																																								
Study on the hardware																																								
Study on the current sensor																																								
Study for motion sensor																																								
Study on the rotation of motor																																								
Study on control in motor																																								
Study on the error and delay time																																								
3) Research introduction stage																																								
Identify the problem statement, objective and scope FYP 1																																								

Identify the problem statement, objective and scope FYP 2
4) Research methodology stage
Planning for methodology FYP 1
Planning for methodology FYP 2
5) Prototype preparation stage
Construct the prototype
Insert programming
6) Analysis and result stage
Result analysis for FYP 1
Result analysis for FYP 2
7) Report writing stage
Final FYP 1 report writing
Final FYP 1 submission
Final FYP 2 report writing
Final FYP 2 report submission
8) Presentation stage
Presentation FYP 1
Presentation FYP 2

Coding for Matlab

```
Kp = 0.335;
Ki = 0.001;
Kd = 0.00001;

for i = 1:3
   C(:,:,i) = pid(Kp,Ki,Kd);
   Kd = Kd + 0.0001;
end

sys_cl = feedback(C*P_motor,1);
t = 0:0.001:0.1;
step(sys_cl(:,:,1), sys_cl(:,:,2), sys_cl(:,:,3), t)
ylabel('Position, \theta (radians)')
title('Response to a Step Reference with K_p = 0.325, K_i = 0.3  and Different Values of K_d')
legend('K_d = 0.0001', 'K_d = 0.0002', 'K_d = 0.0003')
```