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PROJECT REPORT

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Design and Development of Turning Motion Trajectory for Limb Assisting Device

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Bachelor of Mechatronics Engineering

2013/ 2014

I hereby declare that I have read through this report entitle "Design and Development of Turning Motion Trajectory for Lower Limb Assistive Device" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronic Engineering.

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Date : ______________________

DESIGN AND DEVELOPMENT OF TURNING MOTION TRAJECTORY FOR LIMB ASSISTIVE DEVICE

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A report is submitted in partial fulfillment of the requirements for the degree of Bachelor of Mechatronic Engineering

Faculty of Electrical Engineering

UNIVERSITY TEKNIKAL MALAYSIA MELAKA

2013/2014

I declare that this report entitle *"Design and Development of Turning Motion Trajectory for Limb Assistive Device"* 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: ……………………………………………………………..

Date: ……………………………………………………………….

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ABSTRACT

Nowadays, the number of disorders such as stroke, spinal cord injury and traumatic brain injury is increasing drastically in the society. For every year, there are about 40 million people around the world suffer for mobility disorder and cannot perform their daily life activity. By improved architecture of lower limb assistive device (LAD) in hip for turning motion, patients can have more perfect motion in walking. However, the angle and torque for turning trajectory still have not been discover fully and need to be test. The accuracy and stability for the lower limb devices is importance in order to avoid the excessive turning that might hurt the user. The design of exoskeleton robot is follows the turning trajectory of a normal person. The performance of the hip turning motion is analyzed in term of stability, accuracy and repeatability. Position analysis is done and the suitable angle for turning motion is tested in few positions. Method of accuracy tracking and stability test has been conducted in order to improve the performance of the device. The expected result and the actual result for turning motion is different and need to be improve. The testing will be conducted by using a higher torque motor in order to get an accurate result for turning motion. In FYP2, it is important to improve the performance of the prototype and thesis. For the different type of turning trajectory, it having different of accuracy. The accuracy of the prototype is tested by using 2 method of turning trajectory. There are totally different phases of turning motion that analyzed in the each motion of turning. The results are plotted and show the error of turning, standard deviation and mean error. The result shows that the method one has a higher accuracy of turning which is 98.5% and standard deviation for 0.436 in 45 degrees of turning. For method two, the accuracy and standard deviation are 98.39% and 0.500 respectively. It is prove that method 1 is easier to control and have a higher accuracy as compared to method 2.For the future work, the error of output turning angle should be reduce. The turning angle should be accurate as to improve the safety for the user. For the hardware part, the higher torque motor is needed for the next step. By this, the hardware can attach to a real human body and get a better analysis based on the performances.

ABSTRAK

Pada masa kini, bilangan gangguan seperti strok, kecederaan saraf tunjang dan kecederaan otak trauma semakin meningkat secara drastik dalam masyarakat. Bagi setiap tahun, terdapat kira-kira 40 juta orang di seluruh dunia mengalami sakit pergerakan dan tidak boleh melakukan aktiviti kehidupan harian mereka.(LAD) di pinggul untuk menukarkan gerakan dapatbmelakukan pergerakan yang lebih sempurna dalam berjalan. Walau bagaimanapun, sudut dan tork untuk bertukar trajektori masih belum menerokai sepenuhnya dan perlu dikaji. Ketepatan dan kestabilan bagi peranti anggota badan yang lebih rendah adalah kepentingan untuk mengelakkan perubahan yang berlebihan yang mungkin akan membawa pengguna. Reka bentuk robot Exoskeleton adalah berikut trajektori perubahan daripada orang biasa. Prestasi gerakan perubahan pinggul dianalisis dari segi kestabilan, ketepatan dan kebolehulangan. Analisis kedudukan dilakukan dan sudut yang sesuai untuk menjadikan gerakan diuji dalam beberapa jawatan. Kaedah mengesan ketepatan dan ujian kestabilan telah dijalankan untuk meningkatkan prestasi peranti. Hasil yang dijangka dan hasil sebenar untuk menukarkan gerakan adalah berbeza dan perlu memperbaiki. Ujian ini akan dijalankan dengan menggunakan motor tork yang lebih tinggi untuk mendapatkan hasil yang tepat untuk menukarkan gerakan. Untuk jenis yang berbeza menjadikan trajektori, ia mempunyai kejituan. Ketepatan prototaip diuji dengan menggunakan 2 kaedah bertukar trajektori. Terdapat fasa-fasa berbeza menjadikan gerakan yang dianalisis dalam setiap gerakan perubahan. Keputusan diplotkan dan menunjukkan kesilapan membelok, sisihan piawai dan min ralat. Hasilnya menunjukkan bahawa satu kaedah yang mempunyai ketepatan yang lebih tinggi perubahan yang 98.5% dan sisihan piawai bagi 0,436 di 45 darjah perubahan. Untuk kaedah dua, ketepatan dan sisihan piawai adalah 98.39% dan 0.500 masing-masing. Ia membuktikan bahawa kaedah 1 adalah lebih mudah untuk mengawal dan mempunyai ketepatan yang lebih tinggi berbanding dengan kaedah 2. Bagi kerja masa depan, kesilapan output sudut bertukar harus mengurangkan. Sudut bertukar ini tepat untuk meningkatkan keselamatan untuk pengguna. Perkakasan boleh melampirkan kepada badan manusia yang sebenar dan mendapatkan analisis yang lebih baik berdasarkan prestasi.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Nowadays, the number of neurological disorders such as stroke, spinal cord injury and traumatic brain injury is increasing drastically in the society. Every year, there are estimated about 40 million people all around the world suffer from the problem. From the research, most of the patients are in the age group of 20 to 25[1]. Most of the patient affected by permanent movement disorder, such as hemiplegia, paraplegia or tremor.[2, 3]

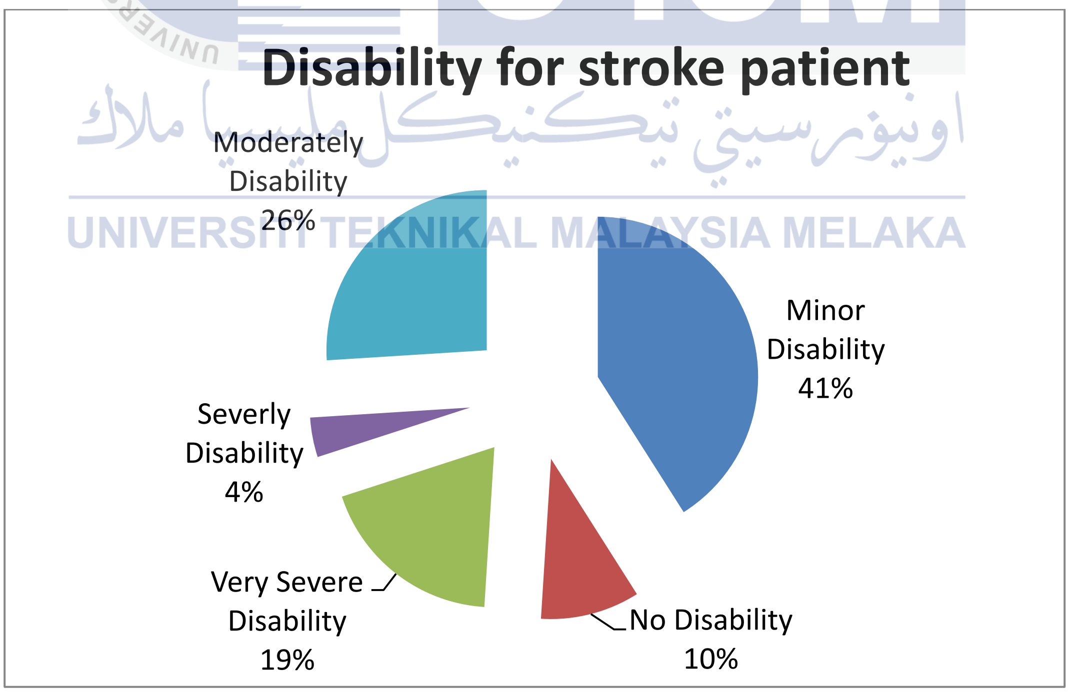

Figure 1: Chart for disable person

The victim of the disease will cause mobility disorder and limit their movement. Most of them could not able to walk normally. Although the facilities and technology in rehabilitation and neuron rehabilitation is getting improved, the presence of mechatronic systems design is still in small amount. For the early 60's, most of the researches are done by created powered hip exoskeleton devices to increase human strength[4, 5].

In summary, the thesis presents an improved architecture in hip exoskeleton unit. The theses mainly focus in the motion of turning trajectory on the hip. The turning trajectory is the motion of medial and lateral rotational on the hip. This enable the patient have more perfect movement in turning motion while walking.

Besides, the performance of the exoskeleton will improve as it concerns more on the other aspect like turning other than walking trajectory. It is helpful for the disable person and help them in daily life activity.

1.2 Problem Statement

Development of a wearable lower limb exoskeleton robot must obey the physical human robot interaction fields (PHRI). The fields that focus are power, size, torque and safety. Suitable actuators that obey the movement of lower limb are electric motor. For safety, the size of the motor has to be compact and small which fulfill with the design of the wearable lower limb assistive devices. However, it has to be producing enough torque for the turning motion trajectory.

Stroke patient have limited degree of rotational for the lower limb part. The lower limb assistive device in the hip helps the patient in the turning motion. A suitable motor is needed to give enough torque for turning motion. The accuracy of the turning angle is important as well in turning motion trajectory. However, the suitable trajectory torque and angle for the turning motion are still not known. Especially, the particularly design for one leg assistive device for half body impaired person is still does not assist.

Besides, the design needs a high accuracy mechanism in term of rotational as the patient need to use the devices repeatedly. It is also avoid the excessive turning that might hurt the patient. Therefore, the maximum turning angle for the lateral and medial rotational has to be finding out. A suitable actuator is needed as it is design for the patients that are under rehabilitations.

Moreover, the controller of motor has to be precise and give fast response which does not need a steady-state error of 0. It must achieve the suitable angle for turning trajectory. The pattern for the turning trajectory must be suitable and obey the cubic polynomial which get the best performance and does not hurt the user.

1.3 Project Objectives

I. To design an exoskeleton robot that follows the turning trajectory of a normal person.
II. To analyze the phase of turning trajectory according to the cubic polynomial.
III. To analyze the performance of the hip turning motion in term of accuracy and repeatability and the phase of turning.

1.4 Scope of the Project

I. The design is limit for two degree of freedom for the purpose of turning motion.
II. The motion of turning trajectory is only focus on medial and lateral rotation
III. The motion of the motor is control by Arduino Controller.
IV. The use of the dc motor only can attach to the prototype but not human.
V. For hardware part, the turning motion trajectory is tested by using a DC motor and feedback by encoder.
VI. The design of the turning trajectory for turning motion only for one side of leg.
VII. The prototype is not attach to a real person as the design is smaller due to the torque supply and safety for the user.

1.5 Outline of the Dissertation

The thesis includes several chapters and the road map of this thesis process as follows:

- Chapter 1: Introduction

Include project motivation and the problem that happen in design the turning motion trajectory for lower limb assistive device. The project objective and the scope are listed in the chapter.

- Chapter2: Literature review

It includes the theory regarding the turning trajectory. The system block diagram is present in the chapter as the overview of the project. The chapter also introduces the background of human gait and cubic polynomial. Performances indices and comparison among the solution trade of is also being explained in the chapter.

- Chapter3: Research Methodology

In the chapter, the design of procedure is discussed. The analysis is also done to test the performance of the device in term of accuracy, repeatability and stability.

- Chapter4: Result

The accuracy for motor and prototype has been finding out and analyze. The error is calculated and being analyze. The phase of turning for 2 methods is plotted in term of the turning trajectory.

- Chapter5: Discussion

The chapter is discussing the result for the experiment. The deviation of the turning angle is discussed. All the error and phase of turning is discuss.

- Chapter 6: Conclusion and Recommendation

Conclude the current progress and plan for FYP2 and give recommendation for future plan.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory of Turning Trajectory

2.1.1 System block diagram

For the study of turning motion trajectory of lower limb assisting device, a simple block diagram is draw based on the requirement needed. First, a desire input (error) is act as a source and send to the controller which is signal conditioning. Then, the output will send to the actuator. The position will definitely deviate from the desired position. In order to make correction to the deviate, an encoder feedback is used to send a feedback signal to the signal conditioning. Then, the desire input can be fulfilling after the correction.

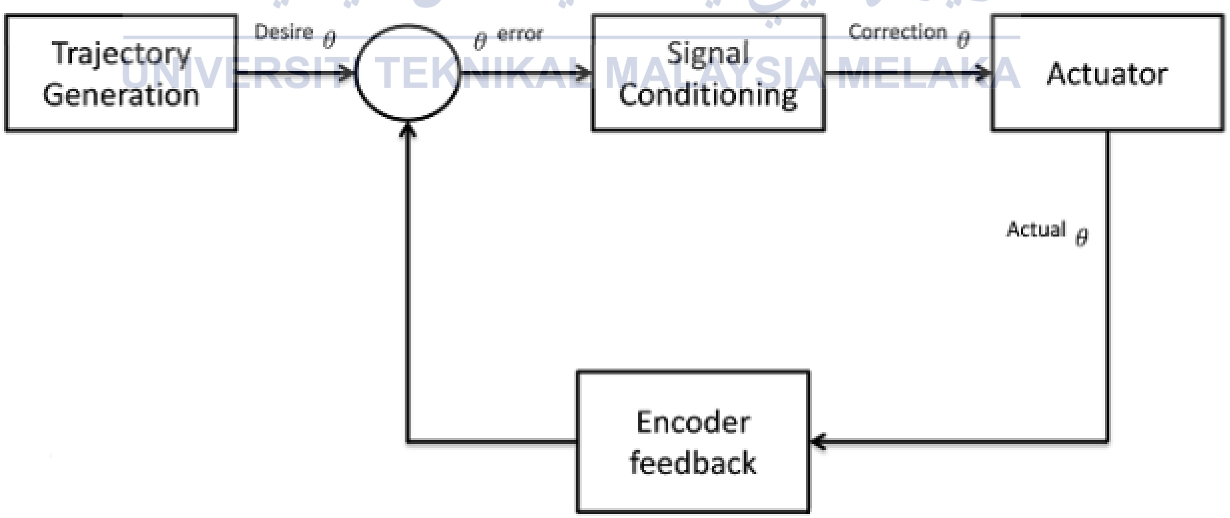

Figure 2: Simple block diagram for the system

θ_{Desire} : Desire angle of the trajectory

θ_{error} : Difference of trajectory angle between desired angle and actual output angle

$\theta_{Corrected}$: Corrected signal which make correction at actual output angle to meet desired angle

θ_{Actual} : Actual output angle

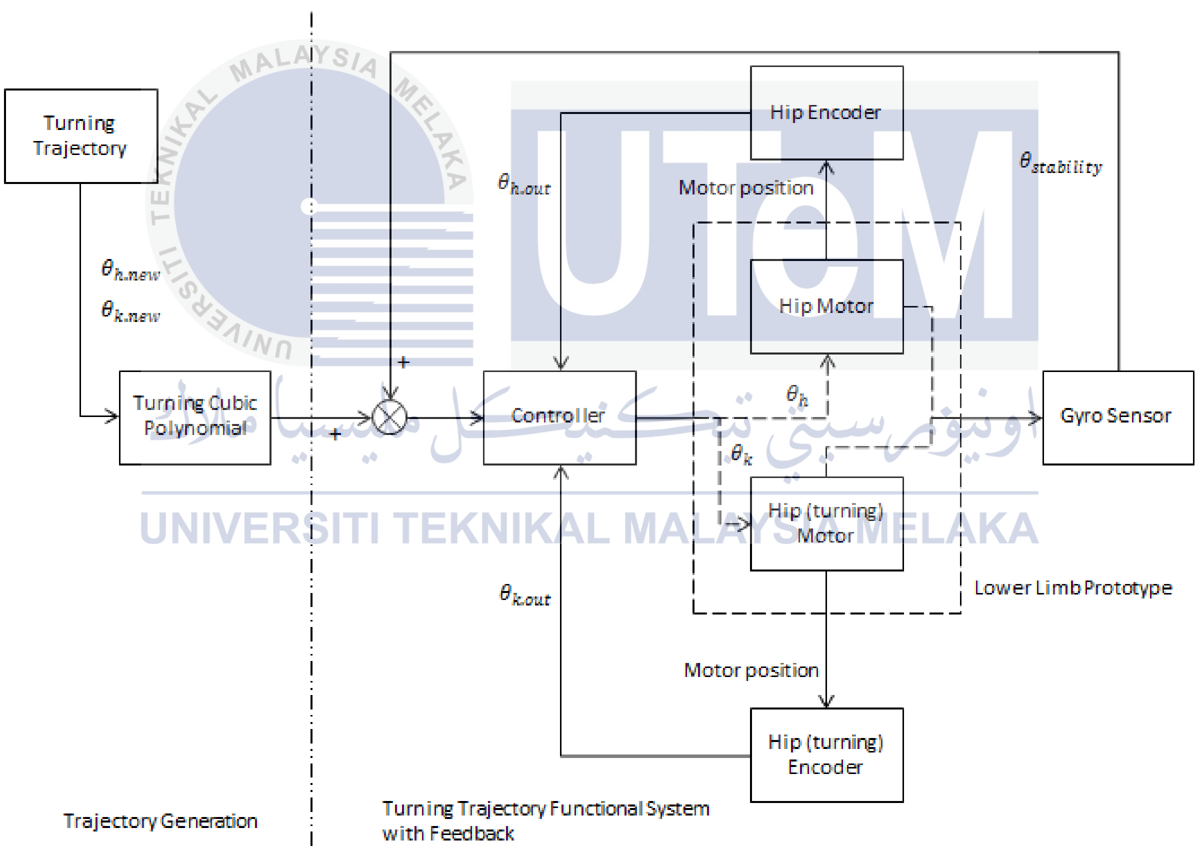

Figure 3: detail flow chart for the system

2.1.2 **Human Gait**

Human walking is in series with repeated motion in 3 dimensions. The hip exoskeleton unit should be able to accommodate the hip's basic motions which are flexion and extension, abduction and adduction, and medial and lateral rotation (3-DOFmotion)[6]. For the understanding of human body's joints, a Cartesian coordinate system can be used to display the relation of a human body.

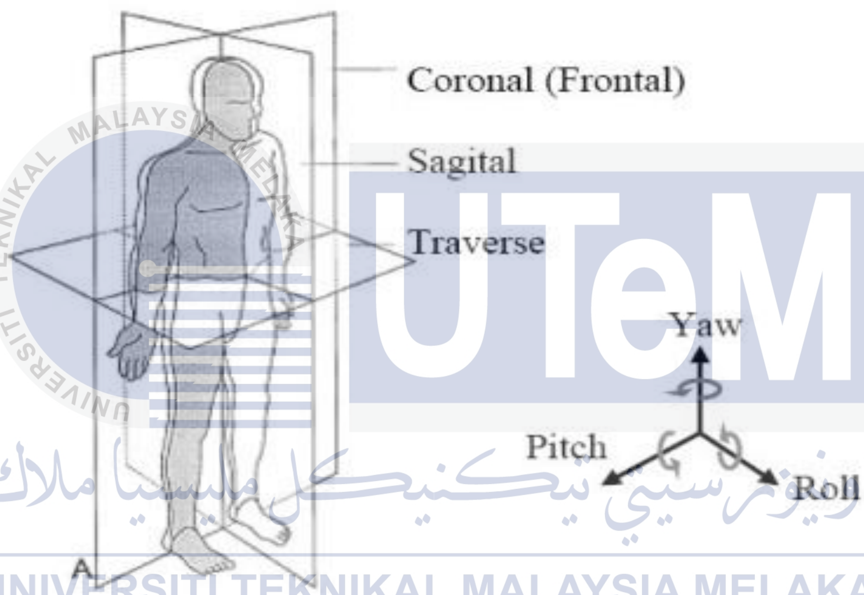

Figure 4: Cartesian coordinate system

- Sagittal Plane- Bisects the body from front to back, dividing it into right and left symmetrical halves. Movements which generally occur in this plane are flexion, extension, and hyperextension.

- Coronal Plane- It is referred to the frontal plane. Bisects the body from side to side and divides the body into equal front and back halves. Abduction and adduction are movements commonly performed in this plane.

- Transverse Plane- It is referred to as the horizontal plane divides the body horizontally into superior (upper) and inferior (lower) halves. Rotational movements such as spinal rotation and supination and pronation of the forearm occur in the transverse plane.[7]

For the thesis, the main focus is on the medial and lateral rotational of the lower limb. The rotational to the inner and outer is different in term of the limit of the maximum angle.

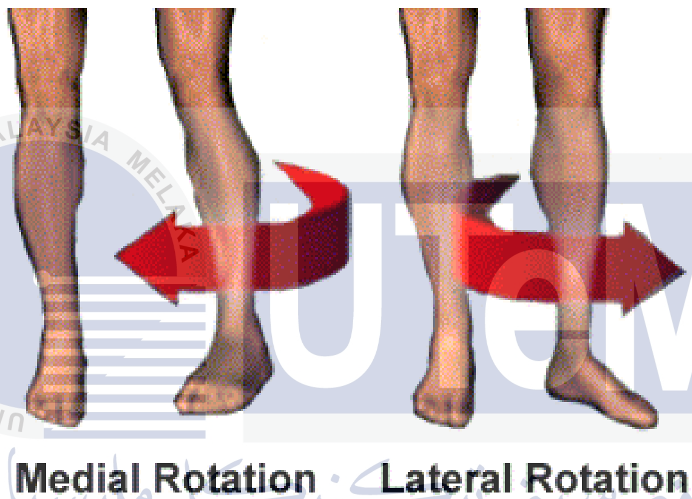

Figure 5: Medial and lateral rotational

2.1.3 **Anatomy of turning trajectory**

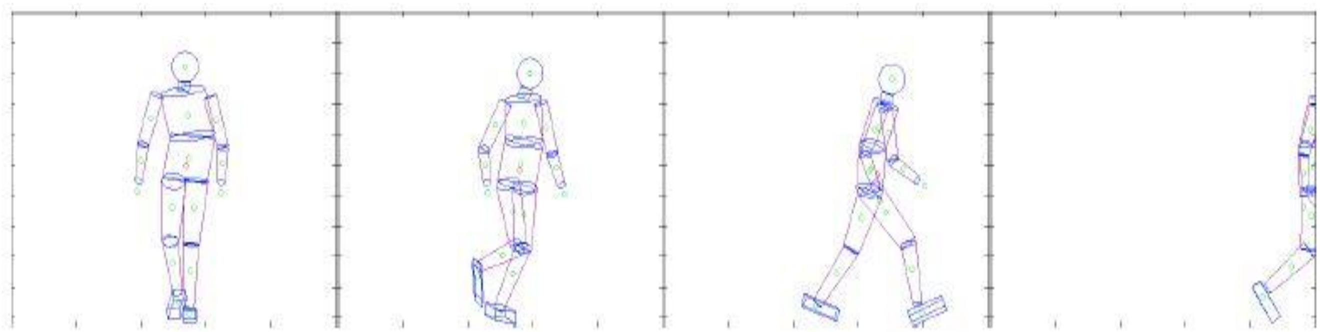

Figure 6: Human Turning pattern

There are four phase in turning motion during walking[8]

i.) Normal walking

ii.) Start to turn

iii.) Landing the swing foot

iv.) Back to normal walking

There are two types of turning pattern generally during walking. Two types of turning pattern have different of turning angle.

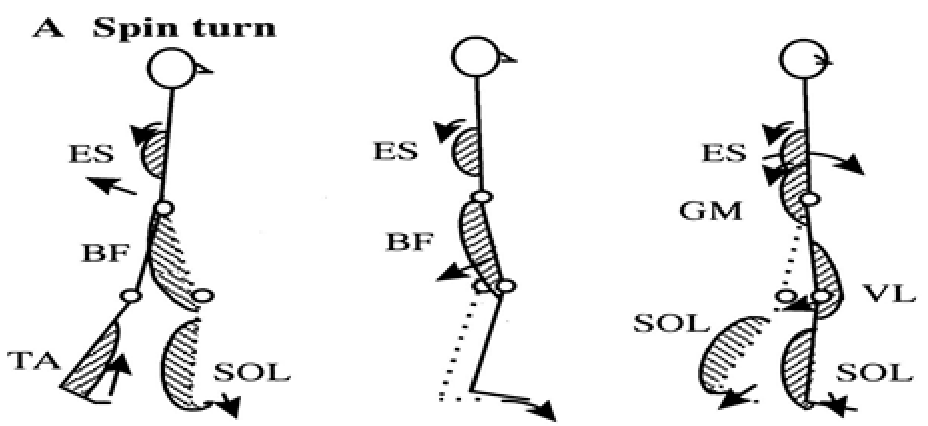

Figure 7: Spin turn pattern

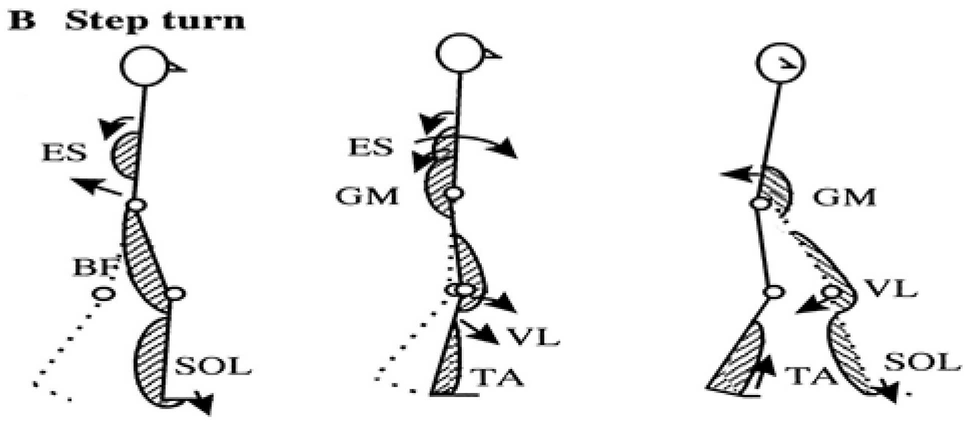

Figure 8: Step turn pattern

2.1.3.1 Spin turn

This strategy allows the body to spin on the forward leg while producing a braking force (axial leg). The torso is kept behind the axial leg presumably to balance the centrifugal force caused by rotating the body and to step toward the new direction. As a result the subjects could not use this strategy after the COM passed the stance foot. The existence of push-off power is also advantageous to put spin on the body so the spin turn is restricted to less of the cycle than the step turn. [9]

2.1.3.2 Step turn

This strategy is easier and more stable for the patient that having disability. This is because the base of support while changing in direction is much wider than for the spin turn. We can see a constant step rhythm during changing direction in the subjects who always used the step turn.

2.1.3.3 Comparison between spin turn and step turn

(a) Spin turn on the right on right foot (b) Step turn to the right of the left foot

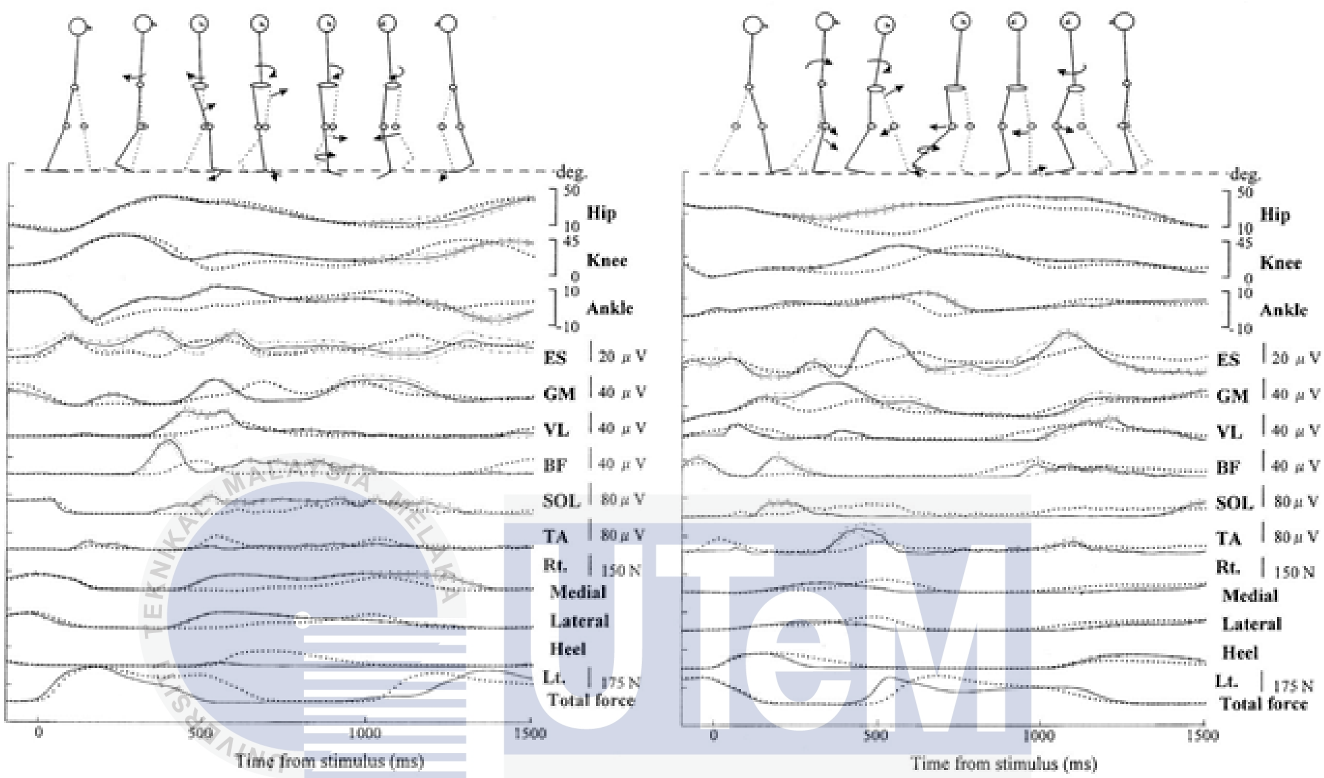

Figure 9: Graph of spin turn and step turn

2.1.4 Cubic Polynomial

For turning motion trajectory, the actuator has to follow the theory of cubic polynomial which is position, velocity, and acceleration. The initial position of the manipulator is also known in the set of joint angle. The function of each joint where t_0 is the initial position and t_f is the desired position of the joint is required.

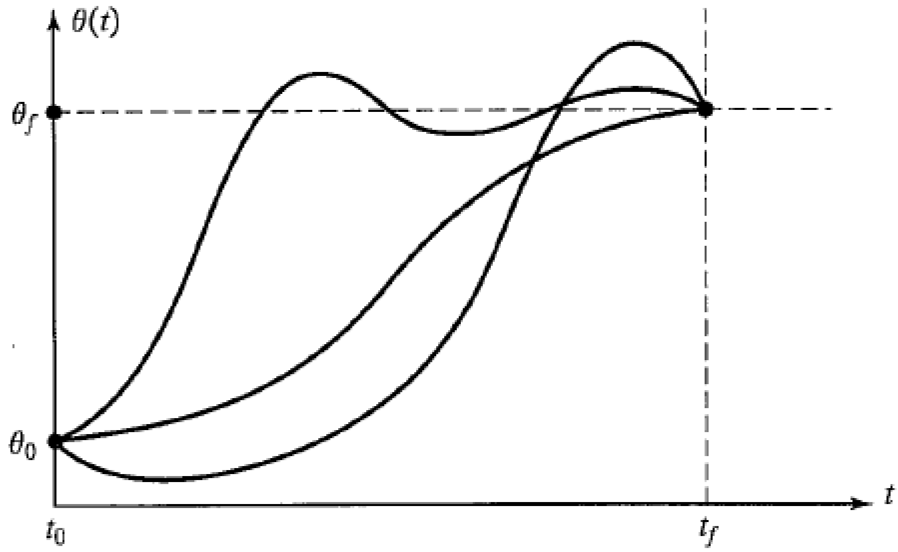

Figure 10: Graph of cubic polynomial

The joint position, velocity and acceleration can be defined as:

$$\theta = a_0 + a_1 t + a_2 t^2 + a_3 t^3$$

$$\theta' = a_1 + 2a_2 t + 3a_3 t^2$$

$$\theta'' = 2a_2 + 6a_3 t \quad (2.1)$$

Where, $\theta(t)$: Joint angle

a_i : Constant

t^i : Time taken

Finding the value of constant when θ_0 and θ_f:

$$\theta_0 = a_0$$

$$\theta_f = a_0 + a_1 t_f + a_2 t_f^2 + a_3 t_f^3$$

$$\theta'_0 = a_1 = 0$$

$$\theta'_f = a_1 + 2a_2 t_f + 3a_3 t_f^2 \quad (2.2)$$

Solving this equations for $a_1, a_2, and\ a_3$:

$$a_0 = \theta_0$$

$$a_1 = \theta'_0$$

$$a_2 = \frac{3}{t_f^2}(\theta_f - \theta_0)$$

$$a_3 = -\frac{2}{t_f^3}(\theta_f - \theta_0) \quad (2.3)$$

By using the equation (2.3), the cubic polynomial that connects initial joint angle position with the desired final position can be calculated. The solution requirement is the velocity of joint start and finishes are at zero.[10]

2.1.5 **PD controller**

For the controller for the motor in the system, PD controller has been chosen. PD controller is also known as Proportional-Derivative control. It is a motivated derivative control system inherent in a motor system. This controller is a very useful and fast response regulator that does not need a steady-state error of 0. The PD controller is use in the programming to avoid the fluctuation of the motor when perform a turning motion.

$$u(t) = K_p e(t) + K_d \frac{d}{dt} e(t) \quad (2.4)$$

K_p: Proportional gain, a turning parameter

K_d: Derivative gain, a turning parameter

e : Error (desire - actual)

t : Time

2.2 Turning Trajectory Problems

2.2.1 The desire angle for a turning motion

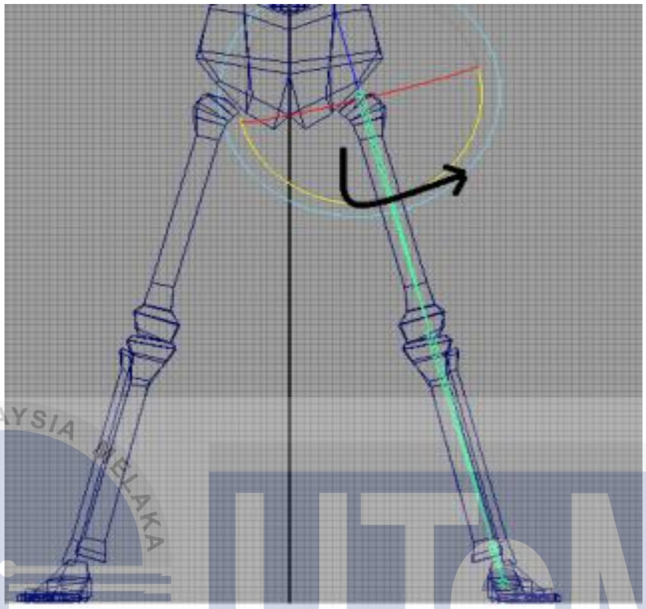

Figure 11: Turning angle for lower limb

The angle for human turning motion when walking is needed to discover. It is important to know the angle for turning motion to make sure the user does not lost balance when he make a turning motion. The suitable angle for turning trajectory is important to avoid excessive turning for the user.

2.2.2 Angular velocity for turning motion

The angular velocity for the actuator has to be discovering to make sure that it has a high accuracy when turning. A suitable actuator has to be choosing to fulfill the repeatability used for the user. The angular velocity should be obeying the human motion trajectory.

2.3 Position analysis

Position analysis is to find the most suitable angle for the medial and lateral rotational angle for the half body impaired patient. The movement of the hip for a regular walking motion is considered as a three degree of freedom (3DOF) motion in three motion planes (x-y plane, y-z plane, and x-z plane). These three planes can be called as transverse plan, coronal plane, and sagittal plane.

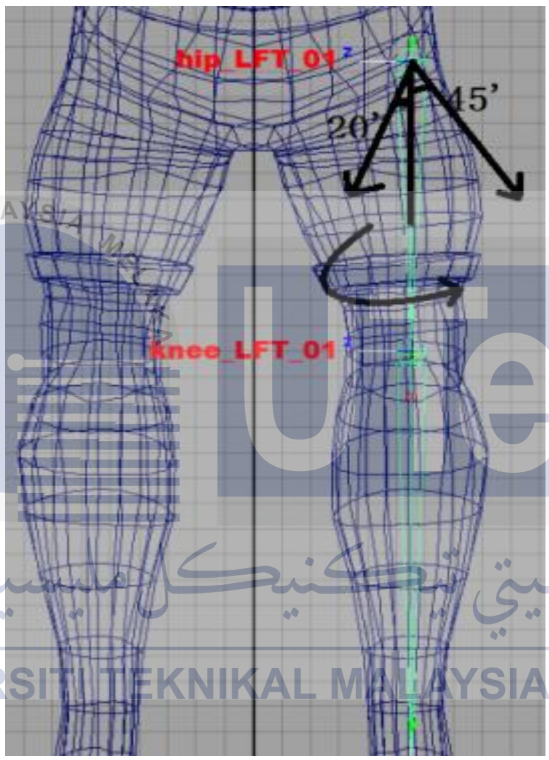

Figure 12: The rotational angle for medial and lateral rotational

The table below shows the maximum displacement of movement plane respectively. Different motions have the different limit angle of rotational for lower limb. Thus, the designed exoskeleton has to meet the following possible position ranges in table below in order to help the half body impaired patient to achieve the possible average daily activities.

Table 1: Limit angle of rotational[11]

Movement Plane	Movement	Motion	Maximum Displacement
Sagittal Plane	Forward Backward	Extension Flexion	60 degree 30 degree
Coronal Plane	Up-Down	Abduction & Adduction	10cm
Transverse Plane	Outside Inside	lateral rotation medial rotation	45 degree 20 degree

2.3.1 **Comparison of the medial and lateral rotational angle**

For different position, it has different limit of rotational angle.

- Prone hip rotational

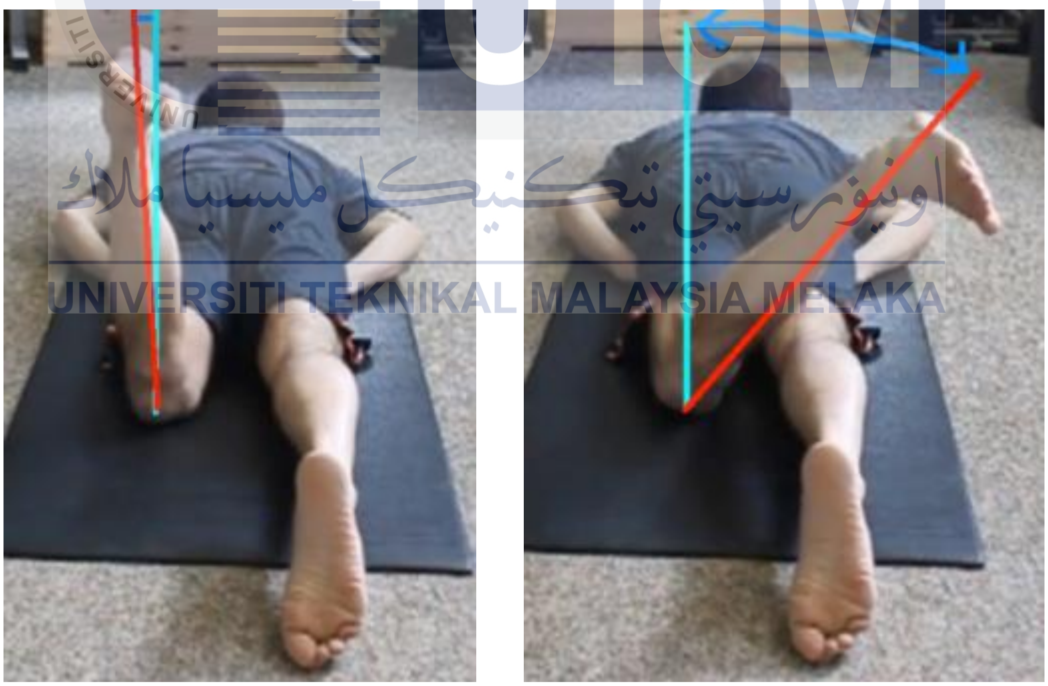

Figure 13: Prone hip rotation

In this section, we can clearly see the different of the angle between the different directions. Teal is the midline, red is the rotation. The hip which can laterally rotate 60 degrees but only medially rotate 10 degrees should cause one’s ears to perk up.

- Laying down

Figure 14: Laying position rotational

For laying down position, the lateral rotational angle can up to almost 90 degrees. The leg has the maximum rotational when the leg is straight. This is the same same the person in standing position.

- Sitting

Figure 15: Sitting position rotational

For sitting position, now you don't have the asymmetry in rotation. Therefore, it has limited rotation for both medial and lateral directions. By putting a person in a seated position, it is no longer fully on stretch when the hip is significantly flexed.

2.4 Performance indices

2.4.1 Accuracy

The accuracy of the motor is important as the lower limb assistive device is use repeatability. The angle of rotational must be accurate to avoid injured for the patient. It should not over the maximum angle of the lateral and medial rotational angle. By make sure the high accuracy of the turning angle, the repeatability test on motor is carried out by using Arduino controller. The desire angle should achieve in the least time and does not fluctuate.

Besides, the accuracy of the turning trajectory also analyze in the thesis. The trajectory should follow the normal human turning pattern and obey the cubic polynomial. In each phase of turning, it must accurate and follow to the equation that proposed.

2.4.2 Stability

The stability of the user is important when a turning motion has been made. The angle of turning trajectory has to be suitable to ensure that the user would not lost balance when make a turning motion. The stability test is design to test it performance in stability to ensure it is always maintain its balance while turning.

2.4.3 Torque

The torque for the turning motion trajectory should enough for a complete turning motion. The require torque for handle a human leg have to be calculated as it is the criteria for choosing a right motor. By this, it can ensure that the design does not over design. It is important to consider the mass, size and length of the prototype to choose a right motor so that it is sufficient to perform turning motion.

2.5 Comparison among available solution- trade off

2.5.1 The historical exoskeleton

The idea of using exoskeleton exists since the year of 1890. Some of the past exoskeleton design are lacked of degree of freedom as compared to actual human motion. There are some complex exoskeleton designs that are existed to help the disable in walking motion as shown in figure below.

Figure 16: The historical exoskeleton unit

(A) (B) (C) (D) (E)

(A) Yagn’s apparatus to facilitate walking, running, & jumping. It implemented a bow spring interconnecting the hip and ankle which stored energy when compressed. It did not allow for the knee to bend[12].

(B) The ‘Kinematic Walker’, circa 1969, was an exoskeleton with 2 degrees of freedom at the hip and ankle. It was pneumatically actuated at the hip. The knee remained locked straight. [13]

(C) The ‘Partial Exoskeleton,’ circa 1970, was the first 3 degree of freedom exoskeleton with a degree of freedom for each the hip, knee, and ankle joints It had 7 pneumatic actuators and 14 valves.

(D) The ‘Active Suit,’ circa 1978, was a self-contained, microcomputer controlled active exoskeleton powered by servo electric drives. It had a 100W servo electric drive for the hip and a 50W servo electric drive for the knee.

(E) The ‘Spring Walker’, circa 1991, was a complex, human powered, kinematic exoskeleton. The passive spring legs were in series to the human legs. It allowed the human to achieve a moderate running pace.[14]

2.5.2 Present exoskeleton with hip turning motion trajectory

Besides, there is many other exoskeletons design that keeps improved to assist human walking. It is created according to the human walking pattern with more degree of freedom. Furthermore, the design for hip turning motion trajectory has become an important issue to help disable have a better motion when walking. It enables them to make turning motion during walking.

Table 2: Comparison of the design in turning motion

Present project	**Actuator of medial and lateral rotational**	**Total Degree of Freedom**	**Sensor**
Berkeley Lower Extremity Exoskeleton (BLEEX)	Compliant actuator	7- DOF	Encoder
Hybrid Assistive Leg	Servo motor	10-DOF	EMG
Nurse Assistive Exoskeleton	Direct-drive pneumatic rotary	10-DOF	Potentiometer
Quasi-Passive Parallel Leg Exoskeleton	Revolute joint and Igus bearing	7- DOF	None

Table 3: Available solution tradeoff for turning motion

	Available solution and comparison of the design in turning motion				
Trajectory Planning	Human Behavior		Feedback Mechanism		
Method	Mimic Human Behavior	According to user's intention	Power assist	Inertial Navigation System (INS)	Considering Center of Pressure (CoP)
Instrumentation	-	electromyography sensor	Laser Sensor	Sensor is placed at crutch	Sensor is embedded in the exoskeleton
Data Collected	Position, velocity and acceleration of user performing turning motion	Measuring the biological signal such as myoelectricity from muscles	Position of x, y and z plane	Position of x, y and z plane	estimates the location of the user's (CoP) and ground plane
Performance	Position, velocity and acceleration of user is recorded and	Estimating user's intention and mimic the trajectory of	laser sensor is placed on hips area to sense the angle of	Crutch is used to sense turning angle and can provide feedback to the controller	Control system estimates the location of the user's (CoP). Use distance between CoP and ground plane estimate forward step

	follow the data collected to turning motion	turning motion	turning	for turning motion	
Limitation	Limited to specific height and depth of stairs	Easily effected by environment factors such as sweat and noise	Slow response time	limited to normal crutch gait walking	System is unstable and need holder to perform stairs climbing trajectory
Controller	Zero Moment Point Calculation		Fuzzy Logic Controller		PD controller with gravity compensation
Performance	accurate positioning and provides virtue wall areas and additional torques to prevent the user from falling down and semi-automatically to avoid losing the balance		Allow flexible engineering design		Suitable for mathematical modeling
Limitation	user's motion of this method is not always natural motion, it may bring uncomfortable to the		do not consider the balancing while performing turning motion		The parameters change as user's weight and size change.

	user		
Design	Exoskeleton	Power wear	
Performance	Exoskeleton structure which can support the motion provided.	Power wear is a structure like trouser and can assist human without an exoskeleton. Hence, the weight is the lighted among all designs and it able to decrease the restriction that exoskeleton structure has	
Limitation	Heavier than power wear and restriction on certain motion.	-	
Actuator	Electric Actuator	Pneumatic actuator	
Performance	Accurate, small, light in weight and provide enough torque for performing stairs climbing	Accurate, small, light in weight and provide enough torque for performing stairs climbing	
Limitation	-	Noisy	

2.6 Summary of literature review

After study and gather the data for the turning trajectory, few important parts have to be concern in the project. The turning angle and torque have to be suitable and follow the turning motion of a normal human. In controller, PD controller is used. This controller is a very useful and fast response regulator that does not need a steady-state error of 0. The performance of the lower limb assistive device is tested in term of accuracy, repeatability and stability.

The actuator has to be choosing wisely in order to have a more accurate turning angle. Besides, the torque for turning motion has to be enough for whole leg of the user. DC motor and encoder feedback is chosen to get the output of the angle of turning trajectory.

After the position analysis, the lateral rotational is designed to turn for 45 degrees. It is the most suitable angle to perform a turning motion. The motor is decided to put on the hip in order to make a rotational for leg. The pattern of turning trajectory has to be concern in order to make the design easier to be controlled. There are 2 methods available for the turning trajectory. The phase of each trajectory is being analyzed to get the better turning pattern and turning trajectory.

CHAPTER 3

METHODOLOGY

3.1 Turning motion trajectory

Appropriate turning trajectory is chosen for experiment purpose. The DC motor and Arduino board are used to generate the desire output for the turning motion trajectory in the experiment. The turning motion is occur during a person walking in straight line make a turn in another direction. [15]

Figure 17: Turning motion while walking

There are 2 available turning trajectories to analyze in this section. The accuracy of this 2 trajectories pattern is compared after the experiment is conducted. There are 2 figures are shown in below to show the turning trajectory pattern when perform turning motion.

Turning trajectory 1

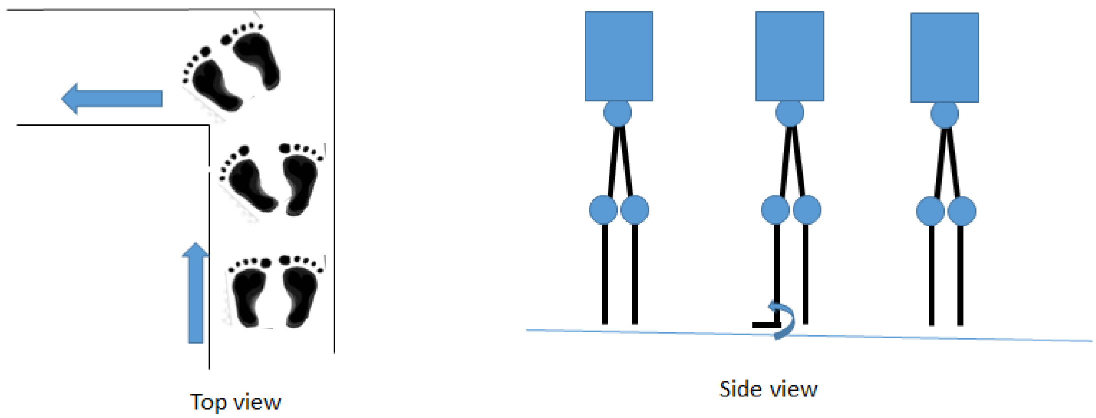

Figure 18: Method 1 of turning trajectory

For turning trajectory 1, it is a simpler trajectory for turning motion. It only need to turn one side of the leg in a stationary position while perform turning motion. After the desire angle is achieve in turning, then the other leg only have to follows and step to the same level. Then, the person can continue the walking. As the exoskeleton only design for one side for the user, the turning trajectory pattern only been program and help one side of the leg to turn to the desire angle. The user needs to move the other side of leg as to complete a turning motion.

Turning trajectory 2

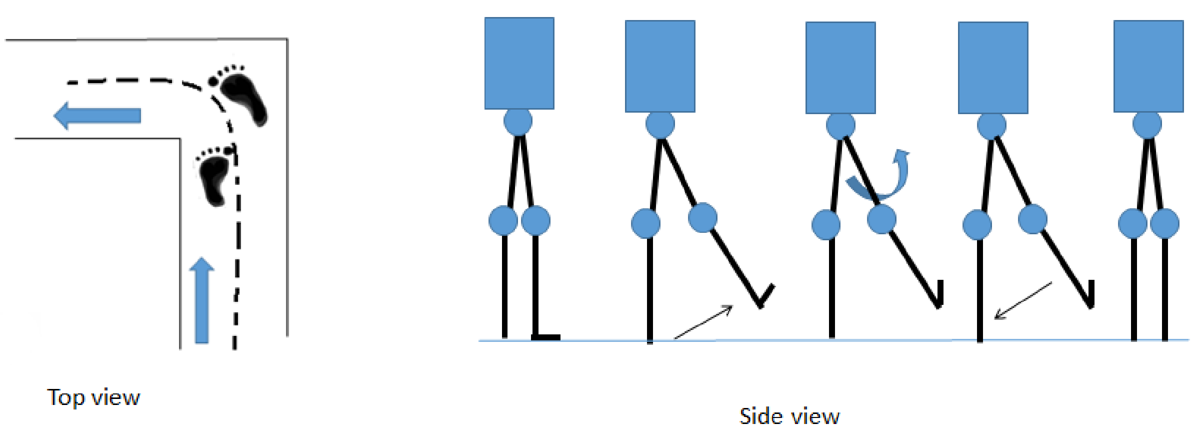

Figure 19: Method 2 of turning trajectory

For turning trajectory 2, it is a complex trajectory as compare to turning trajectory 1. It had 2 degree of freedom while perform the turning trajectory. The user needs to lift up the hip first in a stationary position. Then, it was turn to a desire angle that had been programmed. Then, the other leg also follows and step to the same level. Next, the person can continue the walking. As the exoskeleton only design for one side for the user, the turning trajectory pattern only been program and help one side of the leg to turn to the desire angle. The user needs to move the other side of leg as to complete a turning motion.

3.1.1 Applying theory in calculation

In this chapter, the turning motion is focus on hip turning motion while a person is walking or in standing position. Foot of the person is the base of the turning motion trajectory. In the experiment, the leg is turning for 45 degrees outward to the body.

As to perform turning motion for the leg assistive device, it has to obey the theory of cubic polynomial. The formula is calculated as below.

The joint position, velocity and acceleration can be defined as:

$$\theta = a_0 + a_1 t + a_2 t^2 + a_3 t^3$$
$$\theta' = a_1 + 2a_2 t + 3a_3 t^2$$
$$\theta" = 2a_2 + 6a_3 t \quad (2.1)$$

Where, $\theta(t)$: Joint angle = 45°

a_i : Constant

t^i : Time taken = 1.5°

$$a_0 = \theta_0$$
$$a_1 = \theta'_0$$

$$a_2 = \frac{3}{t_f^2}(\theta_f - \theta_0)$$

$$= 60$$

$$a_3 = -\frac{2}{t_f^3}(\theta_f - \theta_0)$$

$$= 26.67$$

Therefore, the equations are:

$$\theta = 60t^2 + 26.67t^3$$

$$\theta' = 120t + 80t^2$$

$$\theta'' = 120 + 160t \qquad \text{(Calculated)}$$

3.2 Validation of the proposed turning trajectory

This section shows the validation of the idea. Then, the experiment is carried out to test the validation of the idea. The experiment is conducted for 20 times to get the average value of output angle of the motor. During the experiment, there are no extra load is attached. The angle of turning is observed from the view on the hip.

Besides, the environment factor, human error factor and systematic error must also take into the consideration as to get a reliable data.

1.) Environment factor - The place to conduct the experiment must be in a sufficient space. Besides, the experiment have to be conduct in indoor to avoid other environment factor like wind speed and weather.

2.) Human error - The human error like parallax error and random error have to be avoided.

3.) Systematic error - The protractor must place exactly in the middle of the motor to ensure the data is reliable. Besides, we must make sure the railway of the experiment is put on a flat surface by using a water level ruler.

In order to obtain reliable data from the experiments, there are two considerations. The first consideration is to prevent the position error of rotation from the actuator. The error is being tuned using microcontroller before the experiment start. The second consideration is the actuator must being placed at the middle of protractor to ensure that the data that recorded is reliable and accurate.

By avoiding random error, average value from the experiments is conducted and a comparison graph between desire result and experimental result is drawled. During synthesis of data, the result is obtained by using mean method. Means method is best measuring tool for analysis of data. Besides, parallax error is avoided during collecting data. It is a precaution that is taken during obtaining raw data from the experiment of accuracy tracking for DC motor on the leg assistive device. The sight must be perpendicular to the reading in order to avoid unnecessary error.

3.2.1 Objective of experiment

Purpose of the experiment of accuracy tracking and stability test

- To implement turning motion trajectory into hardware configuration
- To test the different between the desire and the actual turning angle
- To analyze the data get from the angle of turning trajectory
- To analyze the turning angle of the turning trajectory that suitable for the device to remain its stability

3.2.2 Flow chart of turning trajectory generation

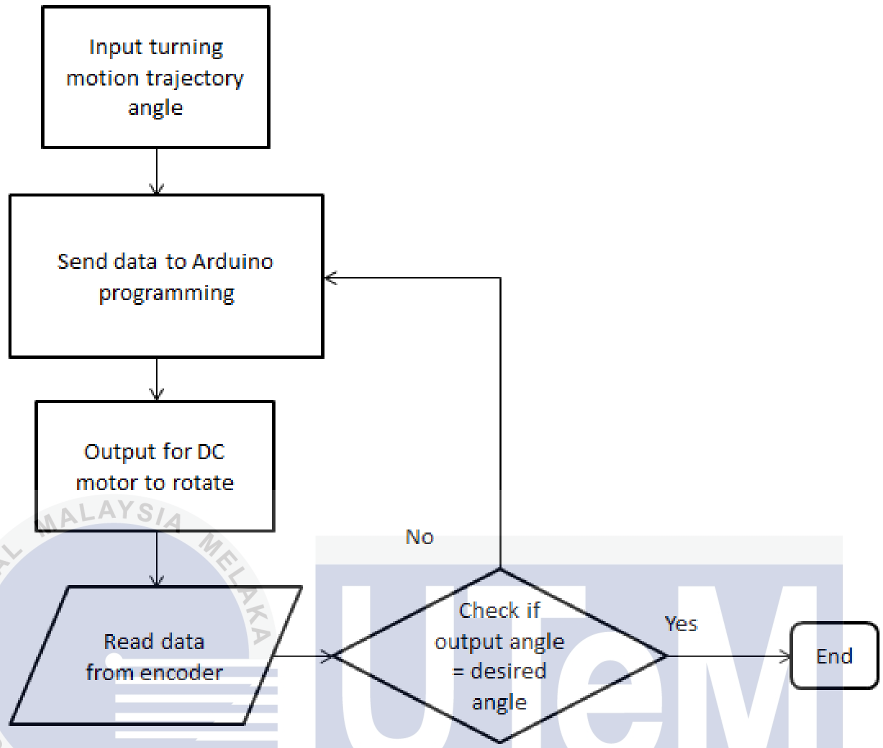

Figure 20: Flow chart of turning trajectory experiment

The figure above shows the generation of turning angle in the experiment. First, the desire angle of turning motion is inserted and sends to Arduino programming. It enables the DC motor to rotate according to the input angle. Then, the encoder feedback checks the desire data and the output data for the turning angle. If the output angle is deviate from the desired angle, it will send back to microcontroller and it will continue to rotate until reach the desire angle.

3.3 Experiment set up and procedure

There are two main parts to be focus in this section. The first one is the hardware that used to conduct the experiment. The second one is the design of the experiment according to different types of analysis.

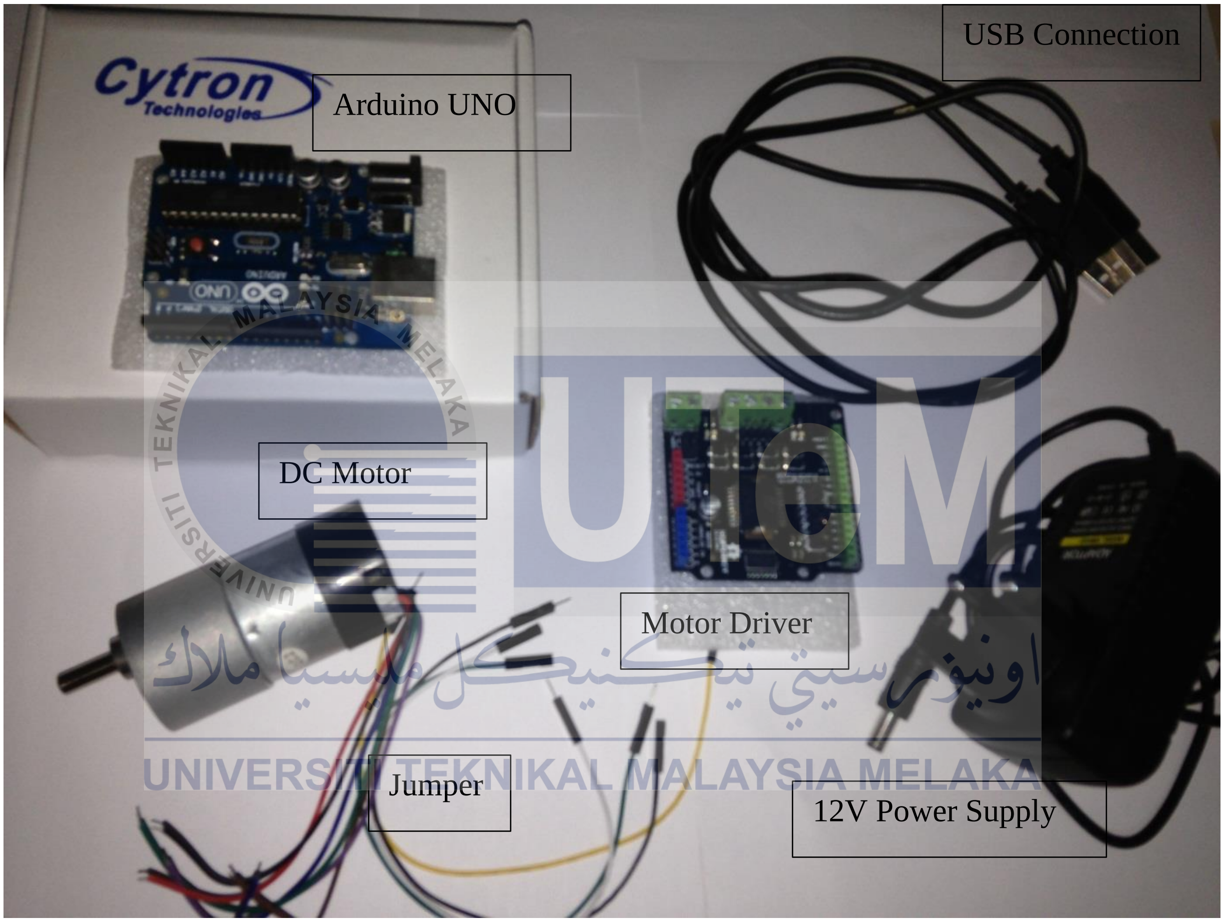

Figure 21: Component of the experiment

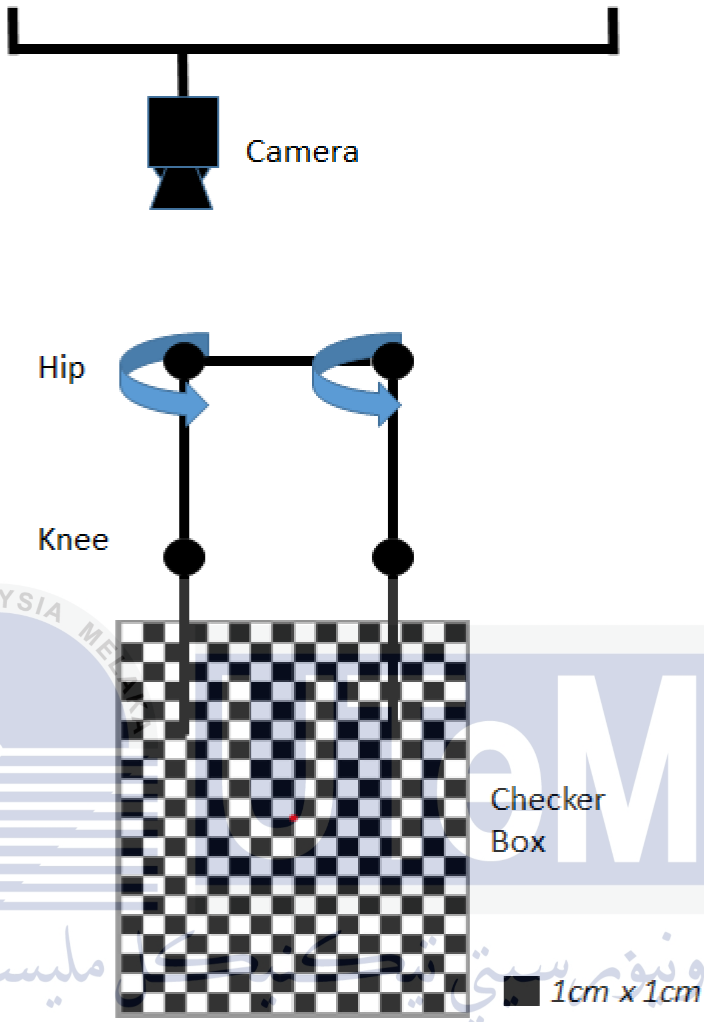

Figure 22: Experiment set up for experiment

The experiment is set up as the figure above. The set up as shown in the figure is to carry out 2 experiments for the limb assistive device prototype. The experiment is testing the accuracy and stability as it performs a turning motion. For accuracy test, the reading for the angle and time is important for the analysis. While for stability, the reading of the gyro is important for the test. (Procedure is attached in Appendix B)

3.3.1 **Design of the experiment**

A few methods are done to test the proposed design. The method of control the DC motor have to be analyze to get a better accuracy of turning angle, less overshoot and faster response time. The velocity of the DC motor has to be obeying the cubic polynomial. The turning trajectory generated has to be analyzing when it is integrated with other parts of the limb assistive devices. The turning motion has to be synchronizing with other motion in hip and knee.

i.) (a) Accuracy of tracking test (motor only)

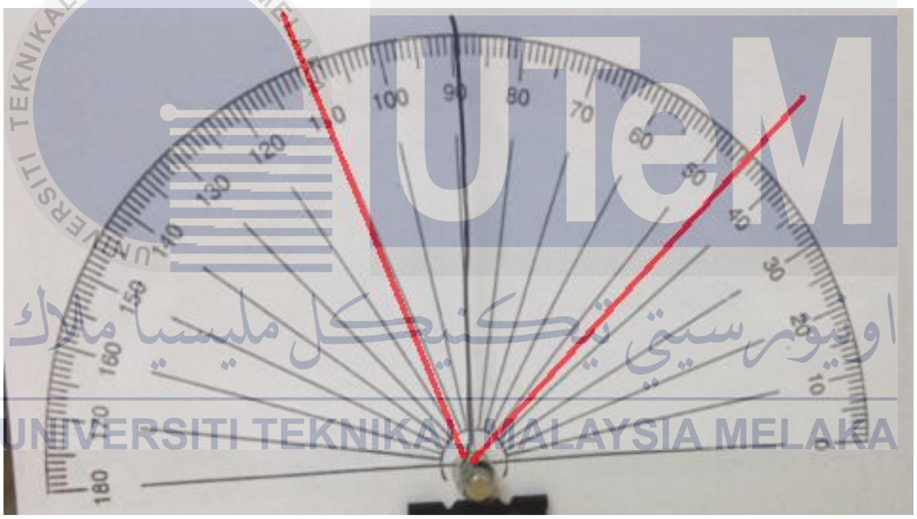

Figure 23: Accuracy of tracking for turning angle

After the research on desired angle for hip rotational, the value of angle is inserted into the trajectory generation block. The accuracy of rotational is very important in order to use the devise in long term. The device has to be good in accuracy and repeatability to avoid excessive turning that might hurt the user. The experiment of accuracy tracking can show the error make by the system and the different angle between desire and actual turning angle.

The condition is set in the programming in the Arduino controller. The PWM is generated by the command of the programming block. The motor will turn according to the PWM that is set and reach to the position of the desired angle.

Then, the encoder feedback plays an important role for the next step. The encoder feedback that attached to the motor shaft will sense the current position and give a feedback to the programming block. Next, it will check the difference angle between the desired and the actual angle in the programming block. The encoder feedback will keep check the current angle position with the desired angle position until it achieves the desired angle.

The experiment is repeated for 20 times, and each experiment data of the turning angle of the motor is recorded for analysis. Two angles are tested, which are 45 degrees for lateral rotational and 20 degrees for medial rotational. Then, it will be concern for 30 degree for hip and 45 degree for hip turning.

i.) **(b) Accuracy of tracking (Prototype)**

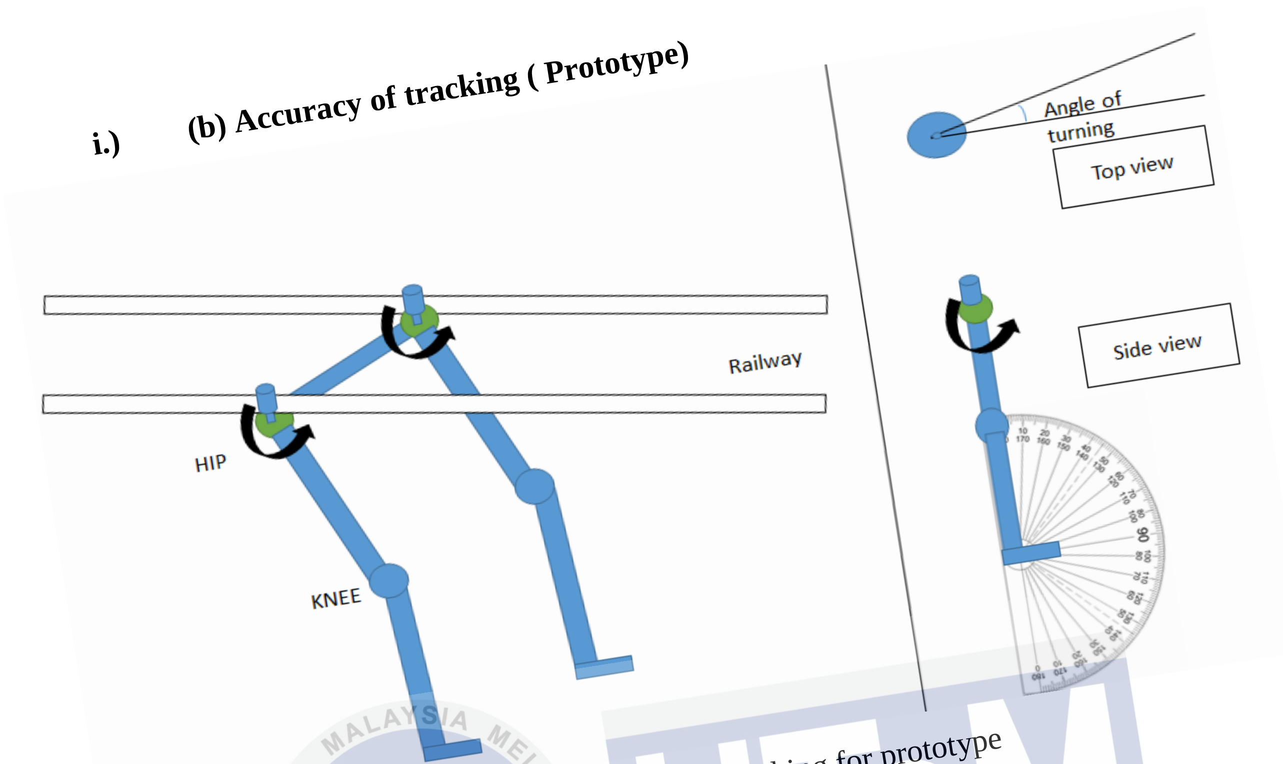

Figure 24: Accuracy of tracking for prototype

For prototype, the experiment is carried out in FYP2. After the testing in motor, the testing for prototype is conducted by using a video camera, stop watch, leg assistive device, checker box and a railway. The objective for the experiment is to test the accuracy of turning for the leg assistive prototype. The accuracy of tracking for the limb assistive device is tested with the cubic polynomial equation for turning motion trajectory.

For the validity of the experiment, a few factors are taking in the consideration when the experiment is conducted. The railway would not affect the experimental result as it is tested in a fixed position without moving. The experiment for the prototype is tested and it only focuses in y plan which is the turning part. Therefore, the guide of the railway would not have any effect on the result of the experiment. Therefore, the result of the experiment can be trusted.

A camera was use to record the accuracy of turning of the prototype. To ensure the result is accurate, a checker box is used under the leg assistive device. It was place perpendicular to the leg assistive device as the experiment purpose is to test the accuracy of turning. This can ensure that the angle can be tracked in a small resolution of angle.

Besides, as to ensure the reliability of the experiment result, a few precautions are considered to avoid the influence factors. By avoiding random error, the experiment is conducted for 20 times and average value for the experiment is taken. Then, a comparison result between desire and experimental is drawled. Next, the parallax error was also take into consideration as the reading is took by the eyes that places directly proportion to checker box.

ii.) Accuracy for turning trajectory

The purpose of the accuracy test for the turning trajectory is to analyze the turning pattern and the trajectory when the exoskeleton performs a turning. The turning angle and time is analyzed by using video record. The turning trajectory is analyzing using software Loger Pro and Matlab.

Each phase is being analyzed to fulfill the objective of the analysis. The turning trajectory should obey the cubic polynomial that proposes. The hip and the turning hip have the different turning trajectory as it required different velocity and turning angle.

3.3.2 **Experiment conduct**

Consideration when conducting experiment

In order to obtain reliable and valid data from the experiments, there are 4 considerations.

1. A water level is used to make sure the holder place horizontally so that the angles measured are not affected. Figure 25 shows the water level measuring the horizon of the holder.
2. The motor and encoder must be tested to ensure no position error.
3. The video camera view must place horizontally to the reference point so the angles measured from the prototype movement can easily observe from the video. Hence, parallax error can be reduced and the data obtain is more reliable.
4. In order to reduce data affected from random error and human error, the experiments must repeat 20 times to make the data reliable.

Figure 25: Water level ruler

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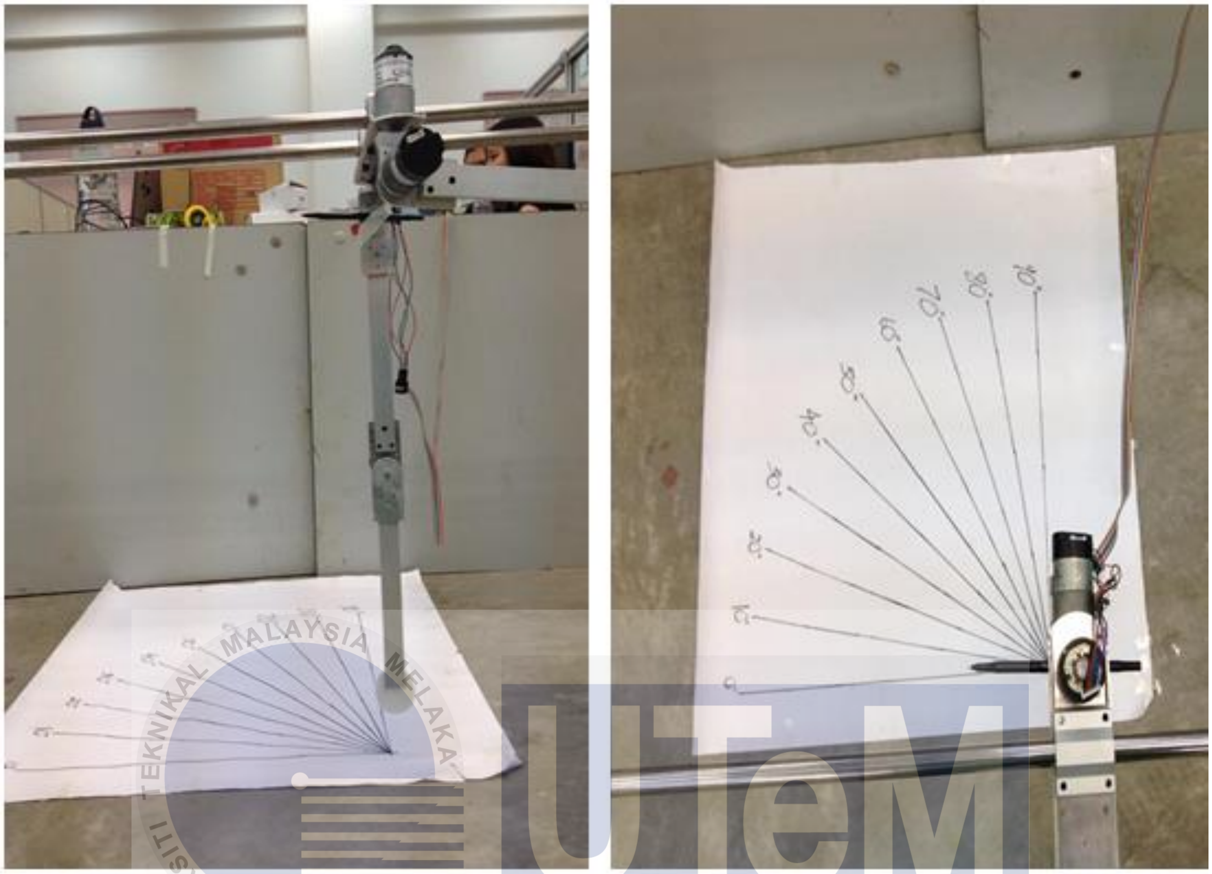


Figure 26: Experiment set up for accuracy test

Type of data gathered

The type of the data gathered is in interval form which is times taken to complete the turning trajectory. The angle is measure from top of the prototype.

3.3.3 **Safety Precaution**

1. The experiment is conducted using prototype instead of human being is to ensure the safety of the experiment. It can be danger if attach the prototype to human leg as the trajectory is a new study, unknown occurred. Hence, human leg will eventually get hurt.
2. To prevent the motor damage due to over-current cause by power surge, fuses are used to solve this problem.
3. To prevent motor damage due to over permitted angle's range, range of angle is set, where value of angle out of range will be prevented.

3.3.4 **Method of analysis**

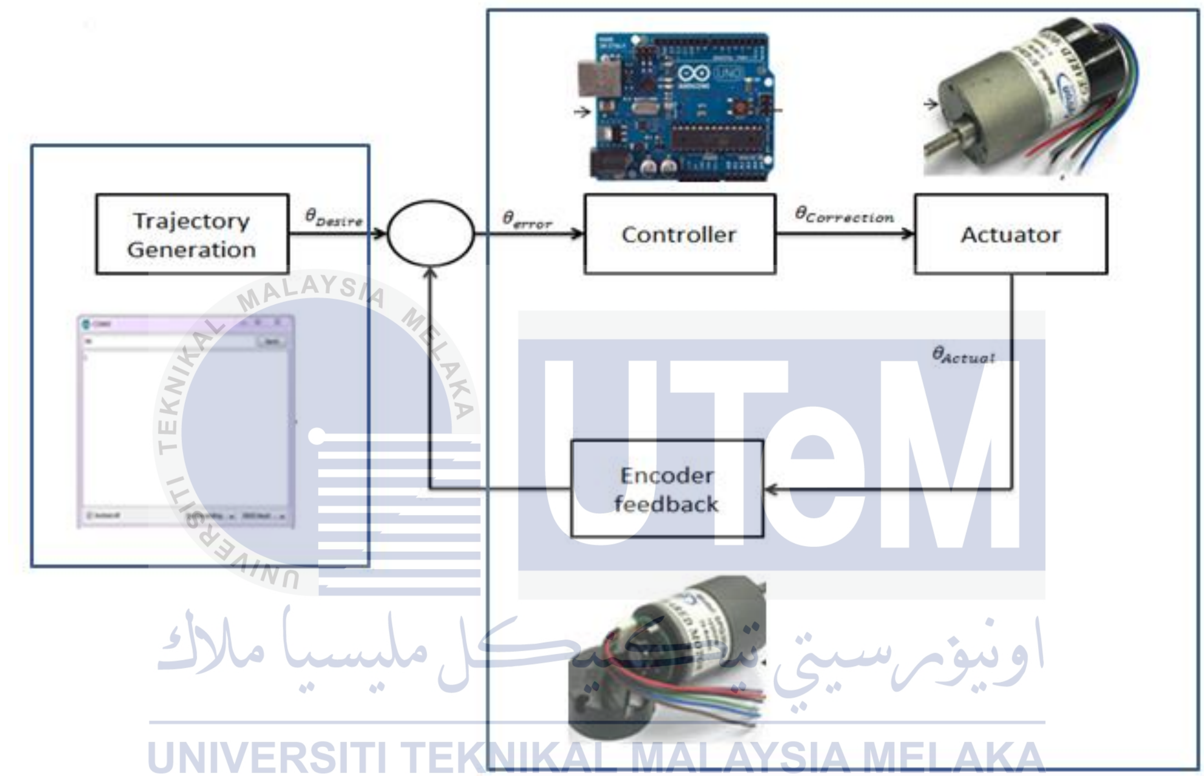
Analyze the data obtain through the experiments by using statistical method and graphical method. In statistical method, the average, standard deviation, percentage error and root mean square value is calculated from the data collected to see the variation from the proposed angles. In graphical method, variation of the results is compared using graph of the proposed angles and the measured angles. The time settling and percentage overshoot is calculated.

There are the steps to completing an accuracy test:

1. Repeat turning motion trajectory while walking using prototype for 20 times.
2. Use camera to record down every moment of the prototype testing.
3. Record down the location of pointer which is the angle.
4. Full in the data into comparison table and show the different between experimental result and theoretical result.
5. Calculate percentage of error according to the data collected

3.4 Development of prototype for validation of idea

The prototype is the part that is important to complete the thesis. The trajectory generation for turning angle is the main focus part for the project. While, the hardware part is used to conduct experiment and get the data of turning angle for further analysis.



3.4.1 Selection of actuator

The selection of actuator is one of the issues in the thesis. First, the size of the actuator has to be compact and wearable because it affects the dexterity of the hip exoskeleton rotational motion. Besides, the actuator carries significant weight for the whole mechanism.

The hip rotational motion exoskeleton is to assists the disable to have a better walking. So, the exoskeleton does not need a large power assistant that may harmful to the user.

Therefore, the safety issue is another important issue in the design process. Control of the motor is important as the efficiency of the motor is the key point of the design.

There are few factors that influent in choosing a most suitable actuator in the design. The factors are the angle position and angular velocity. Besides, the power to weight ratio and power consumption is also have to be considered.

Table 4: Type of motor

Motor Type	Function and advantages
Electric DC motors	It is the suitable option as DC motor is fairly simple to install, light in weight, portable, small in size, generally silent, and having a clean actuation system. It also has a wide range of control options for the specific motion profile. it provides greater accuracy and high precision.[16]
Hydraulic actuators	It is use fluid/liquid to transmit power to a joint. Hydraulic actuator has large in force and torque. However, it is very noisy and need complex apparatus to work on it. Example: compressor and cooling system.
Pneumatic actuators	It is use pressurized gas to produce an output force. It is lighter in weight. However, it needs higher maintenance and it has low accuracy and low sensitivity.
Magnetic brakes	It is a passive technology. It limits the motion by absorbing energy generated by the user. However, they are relatively heavy.

DC motor is choosing as the actuator for the leg assistive device. As to fulfill the turning motion of the exoskeleton device, the torque of the motor has to be sufficient for one leg. A calculation of torque is shown as below:

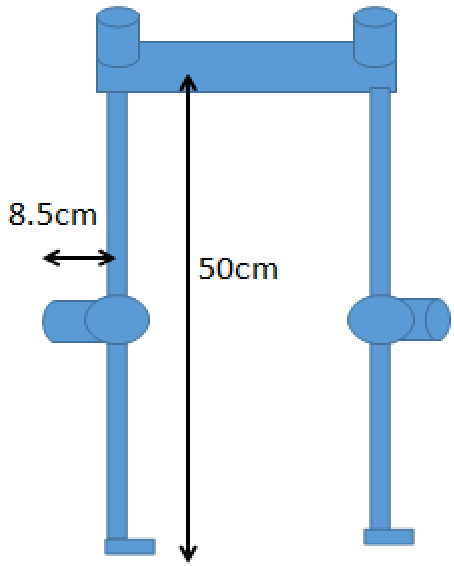


Figure 27: Prototype measurement

Table 5: Specification of prototype

Parts (prototype)	**Specification**
Weight on one side of leg	800g
Diameter of rotational	0.085m
Length of the legs	0.5m

The prototype is measured to calculate the torque required

$$\tau = Fd$$

$$= \text{mg. d}$$

$$= (0.8)\ (9.81)\ (0.085)$$

$$= 0.667\text{Nm}$$

After the calculation, the Dc motor is purchased. The motor use for turning motor are DC gear motor SPG30. The specification of the motor is attached in APENDIX A.

3.4.2 **Hardware of the experiment**

There are few hardware are used in order to get the data for the turning angle. The hardware is a supportive part that helps the thesis in doing analysis from the data collected. The hardware for the experiment has to choose wisely in order to get a more accurate result.

i.) Aduino control system

Figure 28: Arduino Uno Board

In the control system for the experiment, Arduino microcontroller is used. The Arduino Uno is programmed and acts as a control system in order to get the feedback data of the turning trajectory. It contain anything that needed to support the microcontroller which make it is easy to control and yet convenient for programming. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. The board is easy to use, simply put a USB and connect to a computer with AC- DC adapter. In programming, Arduino have many function like sending and receiving PWM signal, interrupt and switch between the input and output pins. The coding is shown in APPENDIX D.

ii.) Actuator- DC motor

This part is discussed about the actuator that use to for the turning trajectory for the lower assistive limb device. The DC motor is used and embedded with an encoder. DC motor has the torque that require and the encoder give the feedback of the derivatives angle of turning back to the microcontroller. After synchronize the DC motor with the microcontroller, the feedback data of the encoder have the trajectory angle and angular velocity.

Specification of the motor is shown as below:

MOTOR TORQUE/SPEED/CURRENT

Rated voltage	12VDC
No load speed	7000r/min
No load current	70mA
Rated torque	60gf • cm 5.88mN • m
Rated current	410mA
Rated speed	5200r/min
Stall torque	240gf • cm 23.5mN • m
Stall current	1 KA

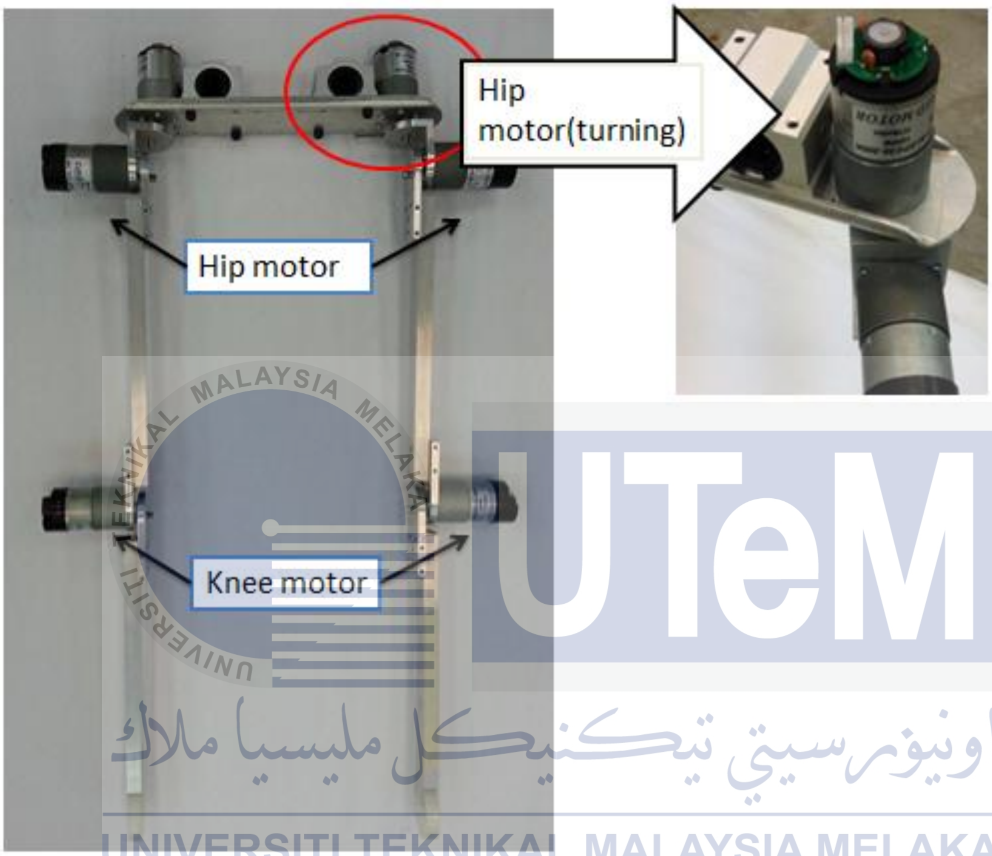
Figure 29: specification of the DC motor

Refer to Appendix A for more details

In order to control the DC motor to obey the trajectory motion, corresponding data needed to send back to DC motor. This data also known as PWM signal which function is to control the angular speed, α of the motor.

3.4.3 **Prototype assembly**

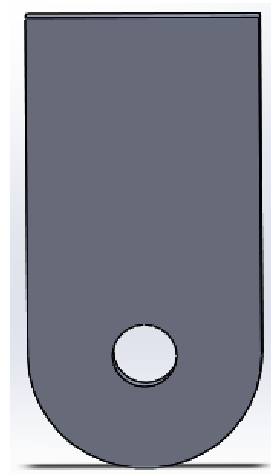
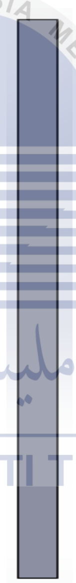
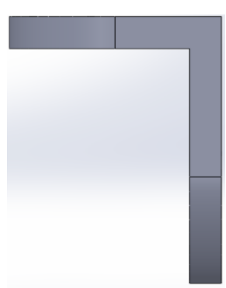
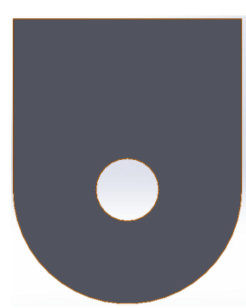
I.) Front view

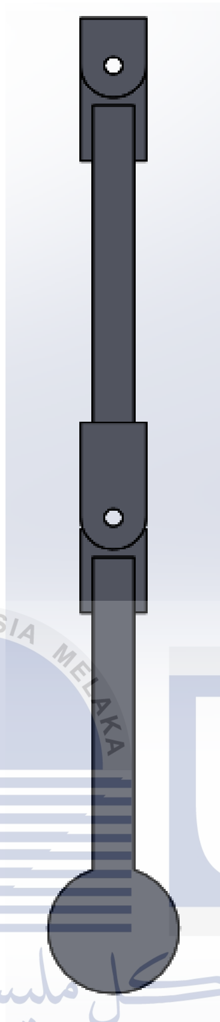
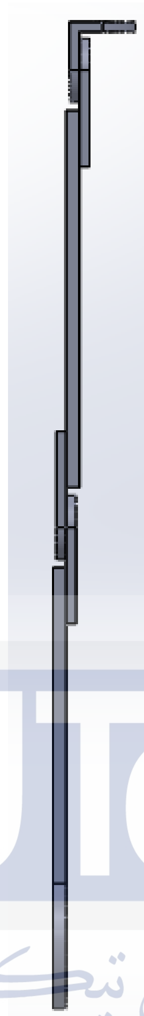
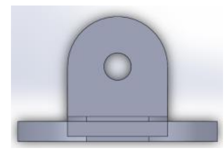


II.) Side view

Description: The prototype is developed for 3 degree of freedom which is for knee, hip and hip turning. The main focus of the thesis is to evaluate the performances of the prototype base on the turning part. The hips turning motor is installed on the top part of the leg assistive device and it is place horizontally to perform its turning motion. The detail drawing is show in APPENDIX E.

Table 6: Parts for the prototype

Description	Side View	Top View	Front View
3pieces of Motor Plates. Motor plate act as the motor holder. DC geared motor is attached to this plate and them assembled as the hip and knee joint.			
2pieces of Exoskeleton Links. Exoskeleton link act as the linkage between the hip joint and knee joint and the knee joint between the foot.			
1piece of Upper Hip Joints. 2 DC geared motor is attached for this mechanism. 1 is for turning trajectory and 1 is for stair climbing trajectory.			

Assembled Part (1 side) The 3 parts above are assembled to form the assembled part. The assembled part shown is 1 sided. The experiment prototype is 2 sided consist of left and right sided which similar to human lower limbs. 2 assembled parts is combined to form the experiment prototype.			

CHAPTER 4

RESULT

4.1 Experimental result

4.1.1 Tracking of accuracy test result (motor)

The performance is tested in term of the accuracy of the desire angle. The angle starts in the position of 90 degrees. Then, the desire output is tested for the medial and lateral rotation. The desire rotational of the lateral rotational is 30, 45, 60 and 90 degrees.

The red line is the original position which is 90 degrees before the input of trajectory generation. While, the black line show the output of the turning angle for the lateral rotational. The desire rotational of the lateral rotational is 45 degrees. The experiment is repeated for 3 trials for each 30, 45, 60 and 90 respectively.

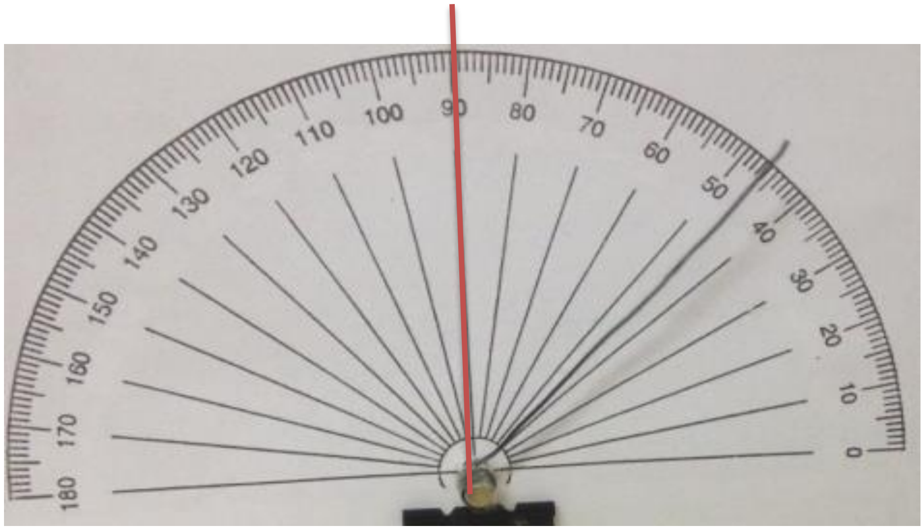


Figure 30: The rotational angle for 45 degree

The table below shows the accuracy for the turning angle for DC motor in term of percentage of error and standard deviation. The calculation is calculated according to the formula.

The formula percentage of error can be written as:

$$\%e = \frac{|B - A|}{A} * 100$$

Where A = Desire Angle (^{o})

B = Actual Response (^{o})

The formula for standard deviation or RMSE can be written as:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

Table 7: DC motor accuracy

DC motor accuracy								
Desire		**Measured (Actual)**					**Percentage of Error (%e)**	**Standard deviation, *σ***
Angle (°)	**Encoder value**	**Angle (°)**				**Accuracy (%)**		
		Trial 1	**Trial 2**	**Trial 3**	**Average**			
30 °	**85**	32	31	32	31.67	86.67	5.57	0.577
45 °	**128**	48	47	48	47.67	79.45	5.93	0.577
60 °	**170**	63	63	65	63.67	78.14	6.11	1.150
90 °	**255**	95	95	97	95.67	83.61	6.30	1.150
Average						Average % $= \frac{376.09}{4}$ = **94.02**	Average %e $= \frac{23.91}{4}$ = **5.98**	

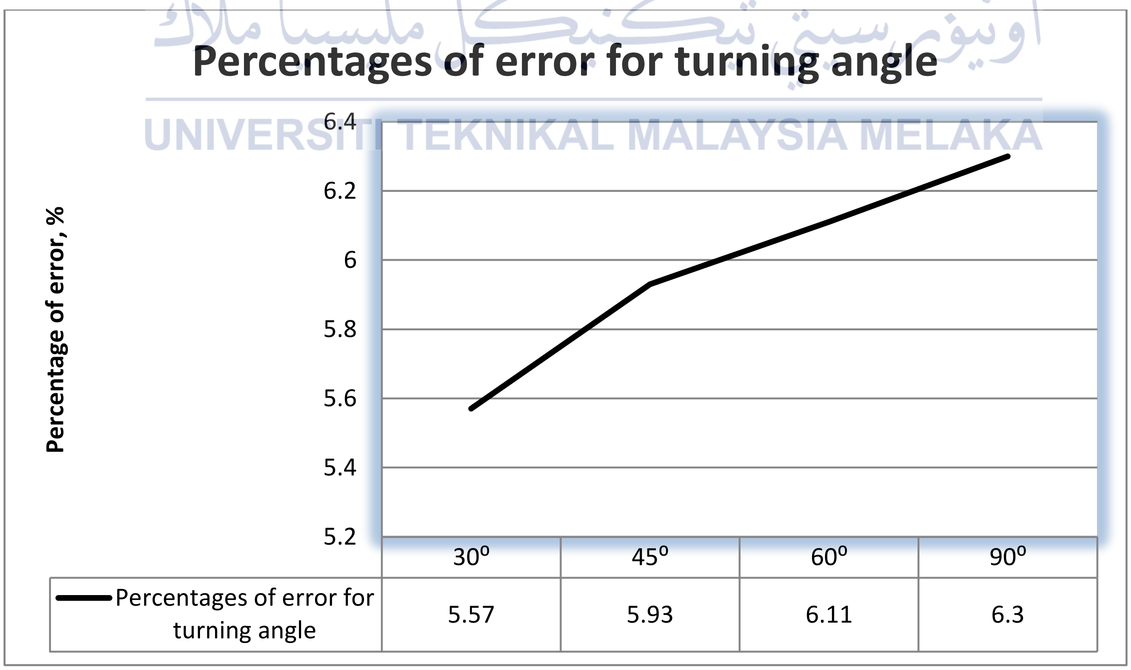


Figure 31: Percentage of error for DC motor

From the table, the percentage of error graph is plotted. The graph showed that the percentage error for each angle, which are 30, 45, 60 and 90 degrees. From the observation, the percentages of error are increasing as the turning angle increase. It can prove that the percentage of error is increasing as the turning angle for the motor is increasing. The error keep increasing is due to the duty cycle for the programming in the Arduino. The error can be reduce after using encoder to track the desire angle for DC motor.

Table 8: RMSE and mean error for DC motor

Times (s)	**Expected angles $\theta°$**	**Measured angles $\theta°$**	**Error angles $\theta°$**	**Percentage Error (%)**
0	0	0	0	0
0.1	0.57	1.55	0.98	170.57
0.2	2.19	3.19	1.00	45.86
0.3	4.68	4.87	0.19	3.96
0.4	7.89	6.90	0.99	12.60
0.5	11.67	9.51	2.15	18.47
0.6	15.84	12.83	3.01	19.00
0.7	20.25	16.88	3.37	16.63
0.8	24.74	21.60	3.14	12.70
0.9	29.16	26.82	2.33	8.01
1.0	33.33	32.28	1.05	3.14
1.1	37.10	37.62	0.52	1.40
1.2	40.31	42.38	2.07	5.13
1.3	42.81	46.01	3.21	7.49
1.4	44.42	47.87	3.45	7.76
1.5	44.99	47.19	2.20	4.89

Mean error	29.66/15 =**1.977**
RMSE/ Standard Deviation	**1.114**

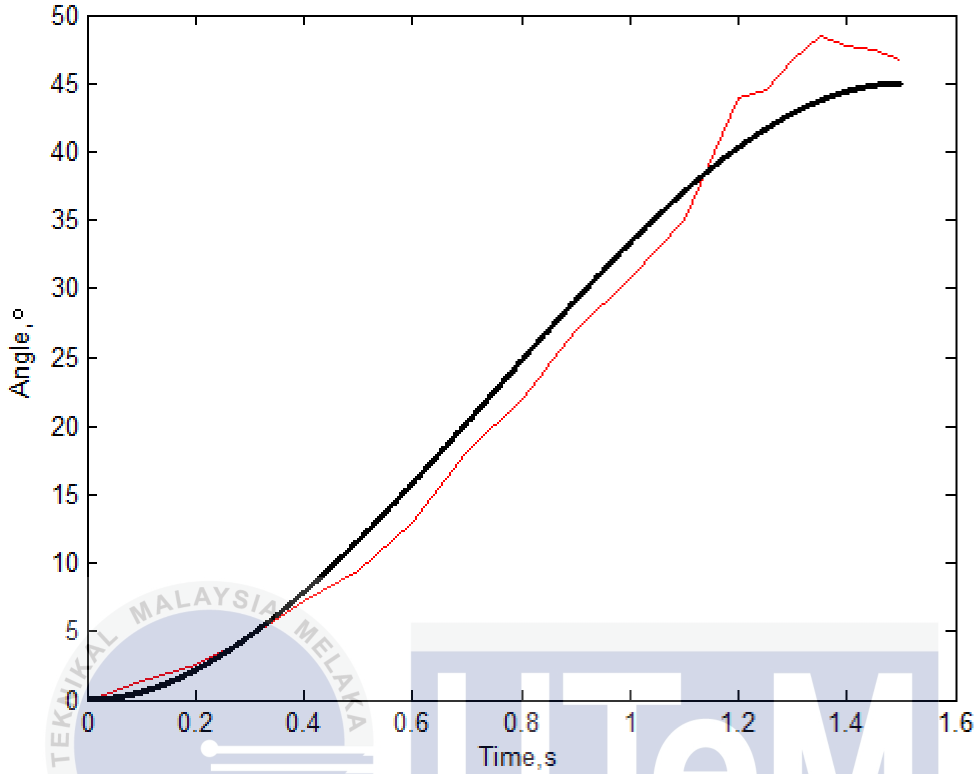


Figure 32: Tracking of accuracy graph (dc motor)

Graph shows the change in angle θ versus time s of motor turning trajectory. The red line is the experiment result while the black line is the desire result which obeys the rule of cubic polynomial. In the graph shown, the angle of rotational for the experiment result is deviate from the desire turning angle. The desire turning angle is 45 degrees for the lateral rotational, but the experiment result, the turning angle is about 48 degrees which have error of 2 degrees between them. The motor is fluctuating after 1.1 second and only reach 47 degrees at 1.5 seconds. To improve the smoothness of the turning angle, a PD controller is added to reduce the fluctuation for the motor in the next section.

4.1.1.1 Error of data

Base on the graph above, calculation has been made.

$$Percentage\ of\ error, e = \frac{Experimental - Theoritical}{Theoritical} \times 100\%$$

$$= \frac{48 - 45}{45} \times 100\%$$

$$= 6.67\%$$

$$Percent\ overshoot, \%OS = \frac{Overshoot - Steady\ State}{Steady\ State} \times 100\%$$

$$= \frac{49 - 45}{45} \times 100\%$$

$$= 8.88\%$$

4.1.2 Tracking of accuracy test result (prototype)

As discuss in chapter 3, there are 2 methods that conducted. The result shows the result for 2 methods of turning trajectory. For turning trajectory 1, it is a simpler trajectory for turning motion. It only need to turn one side of the leg in a stationary position while perform turning motion. After the desire angle is achieve in turning, then the other leg only have to follows and step to the same level.

For turning trajectory 2, it is a complex trajectory as compare to turning trajectory 1. It had 2 degree of freedom while perform the turning trajectory. The user needs to lift up the hip first in a stationary position. Then, it was turn to a desire angle that had been programmed. Then, the other leg also follows and step to the same level. Next, the person can continue the walking.

The formula for accuracy is as followed:

$$Accuracy = \frac{B}{A} * 100\%$$

Where A = Desire Angle (^{o})

B = Actual Response (^{o})

The formula for error percentage (% of error), %e can be written as:

$$\%e = \frac{|B - A|}{A} * 100$$

The formula for average accuracy can be written as:

$$Average\ accuracy = \frac{\sum \%}{20}$$

The formula for average error percentage can be written as:

$$Average\ \%e = \frac{\sum \%e}{20}$$

The formula for standard deviation can be written as:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

Table 9: Experimental result in turning accuracy for prototype (method 1)

No.	**Desire Angle (A)**	**Actual Response (B)**	**Accuracy (%)**	**Percentage of error (%e)**
1	45^o	44.0^o	97.78%	2.22%
	90^o	92.0^o	97.78%	2.22%
2	45^o	44.5^o	98.89%	1.11%
	90^o	91.0^o	98.89%	1.11%
3	45^o	45.0^o	100.00%	0%
	90^o	92.0^o	97.78%	2.22%
4	45^o	46.0^o	97.78%	2.22%
	90^o	88.0^o	97.78%	2.22%
5	45^o	45.5^o	98.89%	1.11%
	90^o	90.0^o	100.00%	0%
6	45^o	44.0^o	97.78%	2.22%
	90^o	92.0^o	97.78%	2.22%
7	45^o	45^o	100.00%	0%
	90^o	93.0^o	96.67%	3.33%
8	45^o	46^o	97.78%	2.22%
	90^o	92.0^o	97.78%	2.22%
9	45^o	45^o	100.00%	0%
	90^o	90^o	100.00%	0%
10	45^o	45.5^o	98.89%	1.11%
	90^o	90^o	96.67%	3.33%
11	45^o	44.5^o	98.89%	1.11%
	90^o	91.0^o	98.89%	1.11%
12	45^o	44.0^o	97.78%	2.22%
	90^o	92.0^o	97.78%	2.22%
13	45^o	45.5^o	98.89%	1.11%
	90^o	90^o	100.00%	0%

14	45^o	46^o	97.78%	2.22%
	90^o	92.0^o	97.78%	2.22%
15	45^o	43.5^o	96.67%	3.33%
	90^o	90^o	100.00%	0%
16	45^o	45^o	100.00%	0%
	90^o	90^o	100.00%	0%
17	45^o	44^o	97.78%	2.22%
	90^o	92.0^o	97.78%	2.22%
18	45^o	45.5^o	98.89%	1.11%
	90^o	93.0^o	96.67%	3.33%
19	45^o	44^o	97.78%	2.22%
	90^o	92.0^o	97.78%	2.22%
20	45^o	46^o	97.78%	2.22%
	90^o	88.0^o	97.78%	2.22%
DEGREE OF TEST (on turning hip)				
45^o			**Average accuracy** = $\frac{1970}{20} = \mathbf{98.50\%}$	**Average %e** = $\frac{29.97}{20} = \mathbf{1.50\%}$
90^o			**Average accuracy** = $\frac{1965.57}{20} = \mathbf{98.28\%}$	**Average %e**= $\frac{34.32}{20} = \mathbf{1.72\%}$

Table 10： Experimental result in turning accuracy for prototype (method 2)

No.	Desire Angle (A)	Actual Response (B)	Accuracy (%)	Percentage of error (%e)
1	45^o	44.0^o	97.78%	2.22%
	90^o	93.0^o	96.67%	3.33%
2	45	46.0^o	97.78%	2.22%
	90^o	91.0^o	98.89%	1.11%
3	45^o	45.0^o	100.00%	0%
	90^o	92.0^o	97.78%	2.22%
4	45^o	46.0^o	97.78%	2.22%
	90^o	92.0^o	97.78%	2.22%
5	45^o	45.5^o	98.89%	1.11%
	90^o	90.0^o	100.00%	0%
6	45^o	44.0^o	97.78%	2.22%
	90^o	92.0^o	97.78%	2.22%
7	45^o	45.0^o	100.00%	0%
	90^o	93.0^o	96.67%	3.33%
8	45^o	46.5^o	96.67%	3.33%
	90^o	88.0^o	97.78%	2.22%
9	45^o	45.0^o	100.00%	0%
	90^o	92.0^o	97.78%	2.22%
10	45^o	45.5^o	98.89%	1.11%
	90^o	93.0^o	96.67%	3.33%
11	45^o	45.0^o	100.00%	0%
	90^o	92.0^o	97.78%	2.22%
12	45^o	44^o	97.78%	2.22%
	90^o	91.5^o	98.33%	1.67%
13	45^o	45.5^o	98.89%	1.11%
	90^o	90.0^o	100.00%	0%

14	45^o	46.0^o	97.78%	2.22%
	90^o	92.0^o	97.78%	2.22%
15	45^o	43.5^o	96.67%	3.33%
	90^o	91.0	98.89%	1.11%
16	45^o	45.0^o	100.00%	0%
	90^o	90.0^o	100.00%	0%
17	45^o	41.0^o	97.78%	2.22%
	90^o	92.0^o	97.78%	2.22%
18	45^o	43.0^o	97.78%	2.22%
	90^o	93.0^o	96.67%	3.33%
19	45^o	44.0^o	97.78%	2.22%
	90^o	92.0^o	97.78%	2.22%
20	45^o	46.0^o	97.78%	2.22%
	90^o	88.0^o	97.78%	2.22%
DEGREE OF TEST (on turning hip)				
45^o			**Average accuracy** = $\frac{1967.8}{20} = \mathbf{98.39}$	**Average %e** = $\frac{32.19}{20} = \mathbf{1.61\%}$
90^o			**Average accuracy** = $\frac{1960.6}{20} = \mathbf{98.03\%}$	**Average %e**= $\frac{37.74}{20} = \mathbf{1.97\%}$

4.1.2.1 Summary of calculation

Table 11: Summary result for method 1 and method 2

	Method 1		**Method 2**	
	45^o	**90^o**	**45^o**	**90^o**
Accuracy (%)	98.5%	98.28%	98.39%	98.03%
Percentage of error (%e)	1.50%	1.72%	1.61%	1.97%
Mean error(^{o})	0.675	1.550	0.725	1.775
Standard deviation,σ	0.436	1.050	0.500	0.952

From the table above, the accuracy, percentage of error, mean error and standard deviation of the 2 method has been shown. The result only test for the motor for turning on hip as it was the main concern of the study of turning trajectory. The 45 degree is the desire angle of turning to perform a turning motion. So, the angle of 45^o and 90^o are conducted for the accuracy test on the prototype.

In test of 45^o, the accuracy for method one is higher which is 98.5% as compared to method 2 which has accuracy of 98.39%. The means error and the percentage of error are higher which are 1.61% and in method 2 as compared to method one which are 1.5% and 0.675^o. Obviously, it shows that the method 1 has a overall better performance as compared to method 2.

The result for the accuracy is accurate in method 1 because the turning trajectory is simpler and it has less phase of turning as compared of method 2. The method 2 required control the angle for the hip to 30^o, then only turn the hip turning motor for 45^o. The accuracy is affected as it perform up 30^o for the hip motor, then follow by turning 45^o away from the body for hip turning motor and finally perform down -30^o landed on the floor.

As to know the trajectory for the turning, 2 graphs are plotted for the turning trajectory of 45^{o} on the turning hip motor. The graph shows the experimental result and the desire result in term of trajectory. The trajectory for the turning angle should obey the cubic polynomial that shown in figure below.

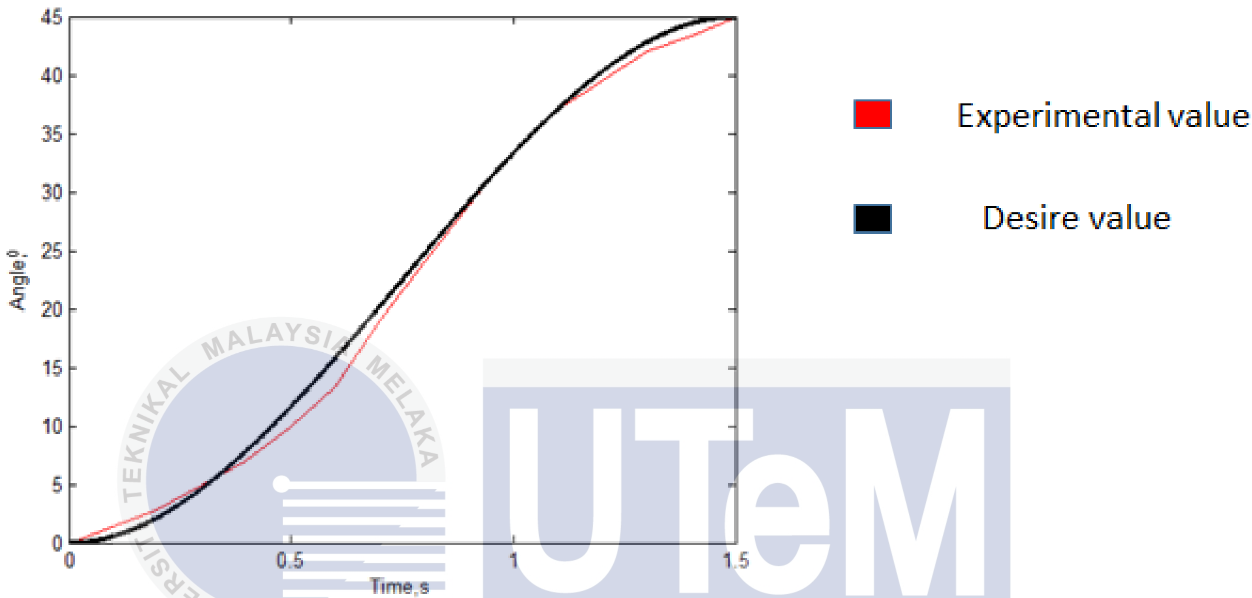


Figure 33: Turning trajectory for method 1

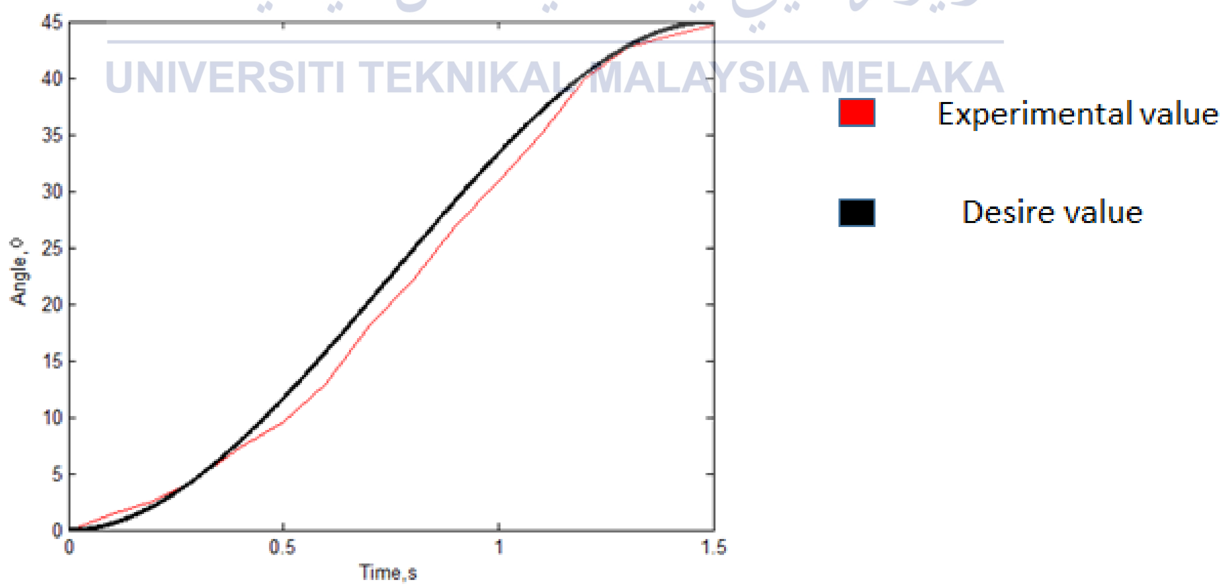


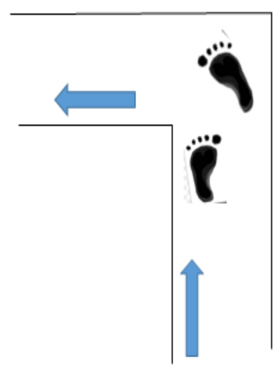
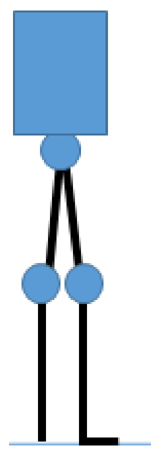
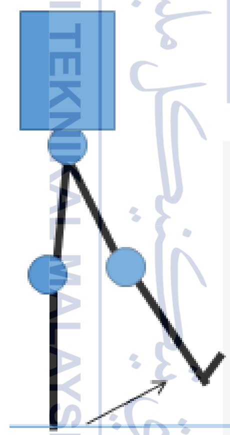
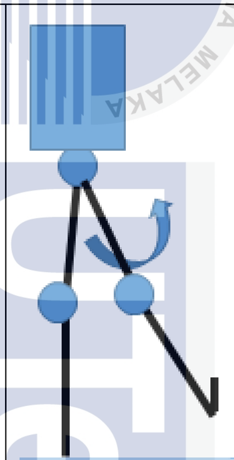
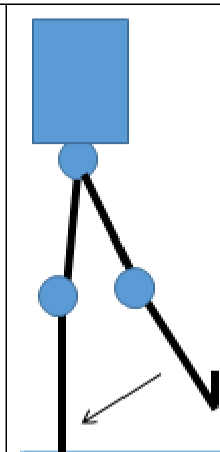
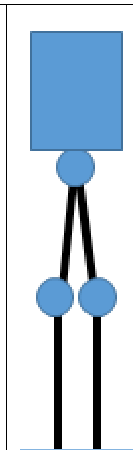
Figure 34: Turning trajectory for method 2

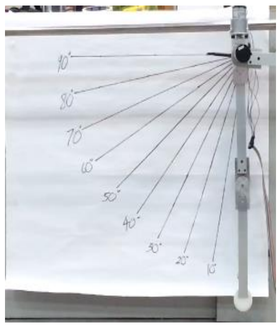
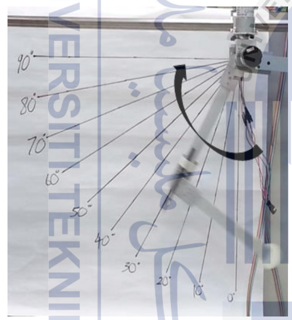
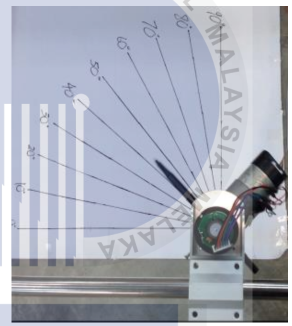
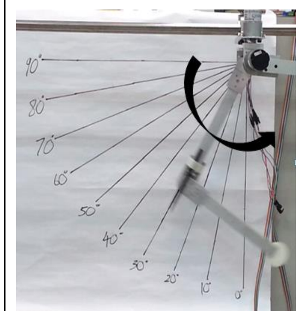
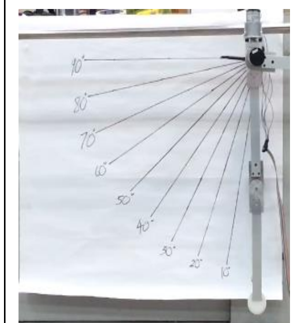
As the picture shown above, there are 2 graphs plotted and compared with the experimental and desire value for the turning trajectory. The black line shows the proposed or desire value of the turning trajectory which abbey the cubic polynomial. Next, the red lines show the experimental result for both methods. The value is get from software named loger pro. The graph is plotted after a video of turning motion is recorded. The results show that it was very accurate which it is turn according to the polynomial. The method 1 still has accurate result as compared to method 2.

4.1.3 **Phase of turning**

For this part of experiment, the comparison between the formula that proposed and the actual value that get from the experiment. The experiment is done by using video capture and interprets data by using Loger Pro and Matlab. The turning trajectory is being analyzed.

Table 12: Comparison of the phase of turning

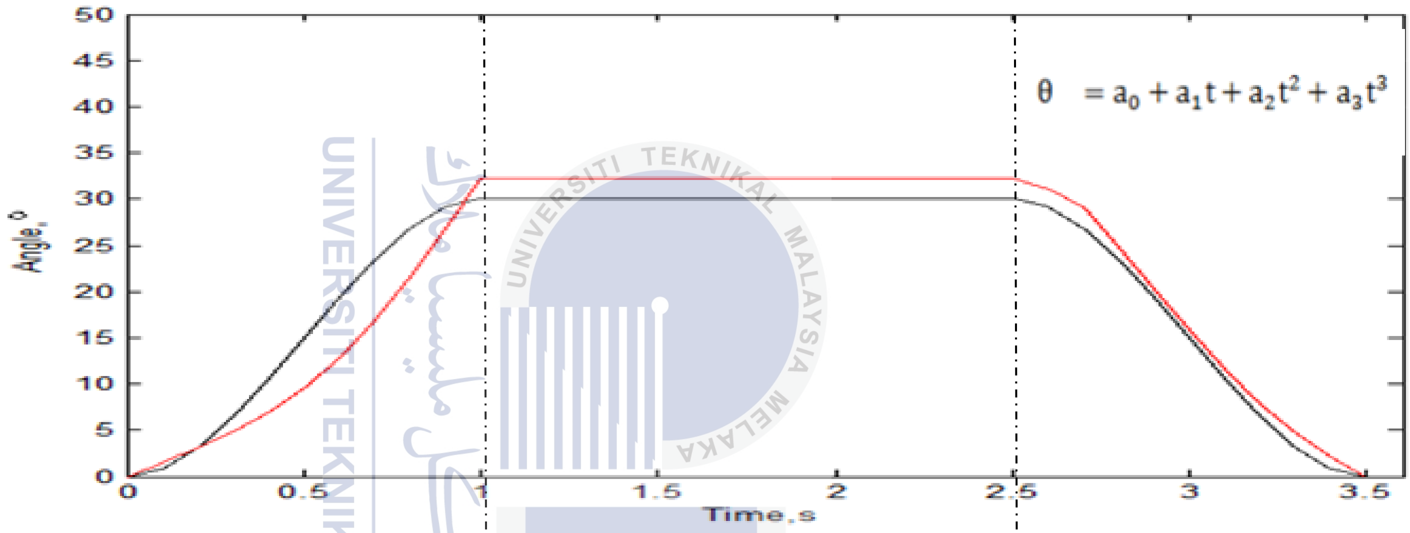
Turning motion 					
Phase	Stationary	Lift up right leg	Right leg turn 45^o	Right leg put downward	Left leg back to position
Description	The person is at stationary position before turning	When reach to a turning corner, the exoskeleton leg was lifted up to $+30^o$	The exoskeleton leg was turn to 45^o inside the body	The exoskeleton leg put downward, -30^o to landed on floor	Finally, the normal leg follow and back to original position which same level to

					the exoskeleton leg.
Motor	Motor stay in 0^o	The hip motor turn to $+30^o$	The Turning hip motor turn from 0^o to 45^o inside the body	The hip motor turn - 30^o	Normal leg move and back to the same level to exoskeleton
Prototype turning trajectory					
Time	0s	0-1.0s	1.0-2.5s	2.5-3.5s	3.5s
Experiment description	The experiment is conduction by using method 2. After recording the motion od the turning trajectory, the data is interprate by using software Loger Pro. Then, plot the graf with the data and compared with the equation that generated by using Matlab. The graf is seperated into 2 parts which are hip and hip turning parts. The trajectory is compared at the graphs below.				

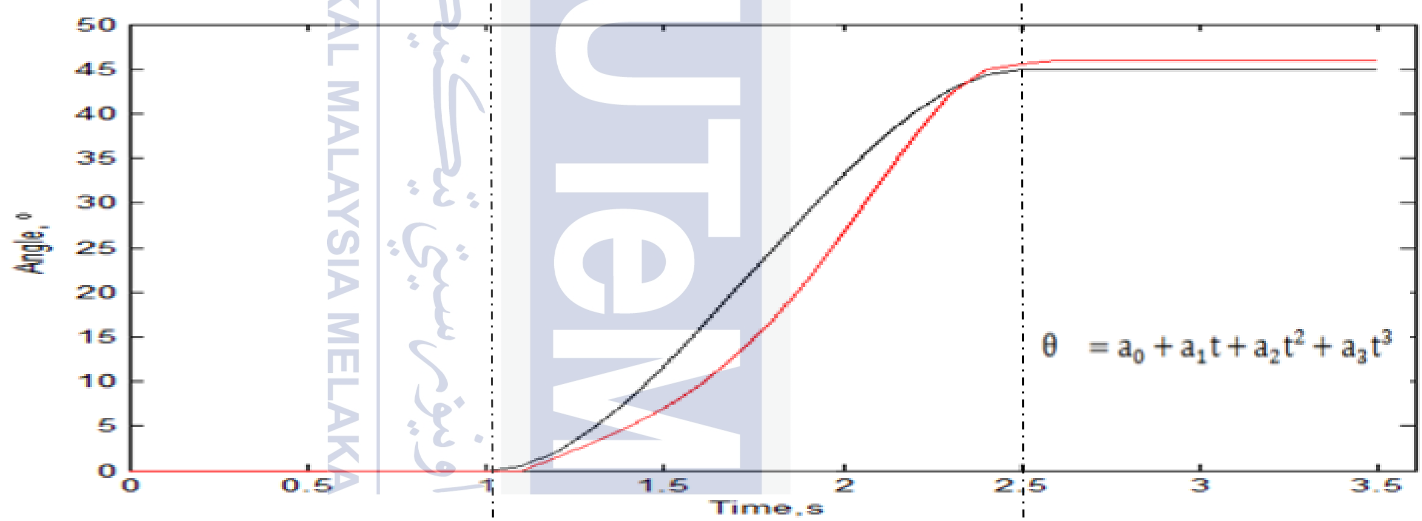
<table>
<tr>
<td>Matlab result:

Hip motor

Experimental value

Desire value</td>
<td colspan="5"></td>
</tr>
<tr>
<td>Hip turning motor

Experimental value

Desire value</td>
<td colspan="5"></td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td>0-1.0s</td>
<td>1.0-2.5s</td>
<td>2.5-3.5s</td>
<td></td>
</tr>
</table>

Hip	Description	For hip motor, it starts to lift up the leg from 0^o to $+30^o$. The motion follow the cubic polynomial equation	Then, it remain at $+30^o$ for 1.5s, when the turning hip motor perform 45^o of turning.	After turning motion for turning hip motor stop, the hip motor start to lower down the leg from $+30^o$ to 0^o which is on the floor	
Turning Hip		For the turning hip motor, it remains at 0^o at the 0-1s as it only require hip motor to move at starting.	The hip turning motion performs a turning trajectory from 0^o to 45^o towards the body.	The turning angle remain ar 45^o before it was fully landed on the ground.	

CHAPTER 5

DISCUSSION

For FYP2, the prototype is concern on one degree of freedom which is the turning motion of the hip for method 1. Besides, it includes 2 degree of freedom for method 2 of turning trajectory. By using Arduino microcontroller and DC motor, the output angle in produce by conducting the experiment. In the experiment, the angle of turning trajectory is inserted and the output is generated.

For the accuracy test, there are 2 methods to conduct the experiment. It is show that method 1 has higher accuracy as compared to method 2. The result for the accuracy is accurate in method 1 because the turning trajectory is simpler and it has less phase of turning as compared of method 2. The method 2 required control the angle for the hip to 30^o, then only turn the hip turning motor for 45^o. The accuracy is affected as it perform up 30^o for the hip motor, then follow by turning 45^o away from the body for hip turning motor and finally perform down -30^o landed on the floor.

In order to improve the result, some changes are needed to be done in future. The result can be improved by better resolution of output angle. Besides, the percentages of error should be improved by reduce the error of output angle. The experimental turning angle should be closer to the value of the desire turning angle. Meanwhile, the percent of overshoot should be reduce in order to avoid excessive turning angle when user using it. It might hurt the user if the motor is turn excessively.

CHAPTER 6

CONCLUSION AND FUTURE WORK

The idea of one side limb assistive device is work after the research and the experimental to test the performance of the prototype. The turning angle of the turning motion trajectory is tested after the research of position analysis. The most suitable turning angle on the hip turning is 45 degrees. In the experiment for tracking the trajectory of turning, it is prove that the solution and the formula using is obey the rule of cubic polynomial that proposed.

In order to test the performances of the device, experiment is carried out to test the design in term of accuracy, repeatability and stability. The desire angle for the turning motion has been tested in term of accuracy. The 2 different methods of turning trajectory are compared in term of the accuracy and the turning angle in different phase. It is prove that method 1 is easier to control and have a higher accuracy as compared to method 2. Besides, during the analysis of the phase of turning in method 2, there are a lot of improvements that can be done as to increase more degree of freedom in the ankle of the leg. By this, the performances for the turning can be improved by a better turning trajectory.

For the future work, the error of output turning angle should be reduce. The turning angle should be accurate as to improve the safety for the user. For the hardware part, the higher torque motor is needed for the next step. By this, the hardware can attach to a real human body and get a better analysis based on the performances. Besides, the stability test has to be carrying out in future to analyze more about the turning trajectory.

CHAPTER 7

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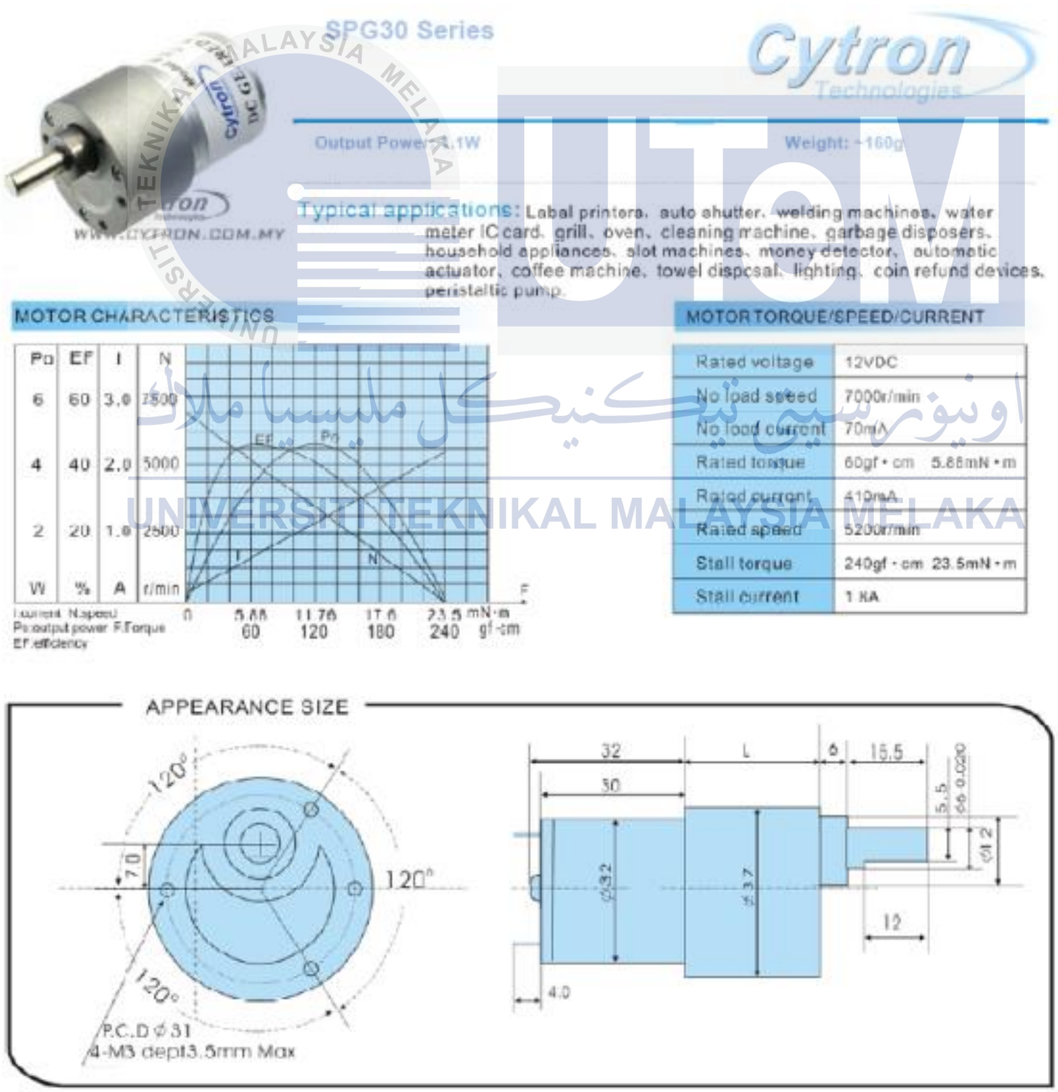
CHAPTER 8

APPENDICES

APPENDIX A



APPENDIX B

Procedure:

1. Connectors are linked from servo motor to Arduino-Mega 2560. Brown color wire is connected to the GROUND pin, Red color wire is connected to 5V supply pin and the orange wire is connected to Pin 8. The Arduino controller is connected to the PC using USB 2.0 to Printer Cable.
2. Coding is set and keyed into Arduino software. The angle of rotation to be tested is set at 10^o, 20^o and 30^o.
3. Measurement of the angle is done and recorded.
4. The accuracy of the servo motor rotation is then calculated.
5. The experiment in steps (b) to (d) is repeated for 15 times to get a better result.

APPENDIX C

Accuracy of tracking for turning motion (Prototype)

Research Objective

The objective of the experiment is to verify that the accuracy of tracking for the limb assistive device with the cubic polynomial equation for turning motion trajectory.

Hypothesis

The device is able of perform turning which obey the cubic polynomial equation to maintain it accuracy of turning.

Materials and equipment required.

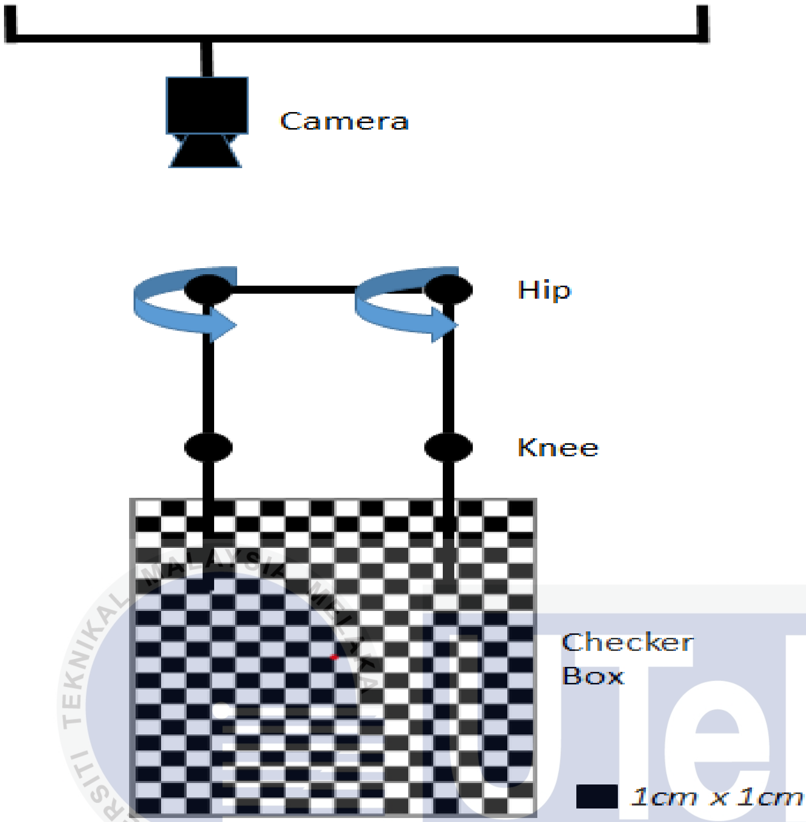
Leg Assistive device (prototype)

Video camera

Stop watch

Checker Box

Experimental set up



The experiment is set up as shown in figure1. The purpose for the experiment is to test the accuracy of turning for the leg assistive prototype. A railway is use as a support to complete the experiment. As to ensure the validity of the experiment, a few factors is taking in the consideration when the experiment is conducted. The railway would not affect the experimental result as it is tested in a fixed position without moving. The experiment for the prototype only focuses in y-axis which is the turning part. Therefore, the guide of the railway would not have any effect on the result of the experiment.

A camera was use to record the accuracy of turning of the prototype. To ensure the result is accurate, a checker box is used under the leg assistive device. It was place perpendicular to the leg assistive device as the experiment purpose is to test the accuracy of turning.

Besides, as to ensure the reliability of the experiment result, a few precautions are considered to avoid the influence factors. By avoiding random error, the experiment is conducted for 20 times and average value for the experiment is taken. Then, a comparison result between desire and experimental is drawled. Then, the parallax error was also take into consideration as student taking the reading directly proportion to checker box.

Procedure

Task 1

1.) The leg assistive device is set up as shown in figure 1.
2.) The leg assistive device is attached to a railway as guidance for the leg assistive device.
3.) The leg assistive device is turned a desire turning angle by a dc motor which is programmed by using Arduino. The position of the motor is control by using an encoder.
4.) The turning angle of the prototype is recorded according to the time. It is analyze by using Loger Pro software.

Table 13: The turning angle in prototype

Time (s)	Angle of turning (degree)
0 – 0.5	
0.5 – 1.0	
1.0 – 1.5	
1.5 – 2.0	

Method of analysis

Analyse the experimental result by using statistical method. Calculate the mean and standard deviation for the turning motion. Besides, the time to perform a turning motion is compared with the theoretical equation.

APPENDIX D

Coding of the microcontroller

```
int encA = 3;
int encB = 4;
int encPos = 0;
int encALast = LOW;
int n = LOW;
float val;
int x;
float STOP=0;



int pwm2 = 6;
int dir2 = 7;

void setup()
{
  pinMode(encA, INPUT);
  digitalWrite(encA,HIGH);
  pinMode(encB, INPUT);
  digitalWrite(encB,HIGH);
  pinMode(dir2,OUTPUT);
  Serial.begin(9600);
}
```

```
void loop()
{
  n = digitalRead(encA);

  if((encALast == LOW) && (n == HIGH))
  {
    if(digitalRead(encB) == LOW)
    {
      encPos--;
    }
    else
    {
      encPos++;
    }

    Serial.print(encPos);
    Serial.print(",");
    //Serial.println(" ");
  }
  if (Serial.available())
  {
    val = Serial.parseInt();



   x = val*780/360;
```

```
 //delay(50);
Serial.println(" ");
Serial.print(" x --->");
Serial.println(x);
Serial.print(" val --->");
Serial.println(val);

}

if(encPos < x-30)
{
  motor(255,true);
}

else if(encPos < x)
{
  motor(130,true);
}

else if(encPos == x )
{
  motor(0,false);
}

else if(encPos > x+2)
{
  motor(150,false);
```

```
    }

  encALast = n;
}

void motor(int pwm, boolean reverse)
{

   analogWrite(pwm2,pwm);
   if(reverse)
   {
     digitalWrite(dir2,LOW);
   }
   else
   {
     digitalWrite(dir2,HIGH);
   }
```

APPENDIX E