FACULTY OF ELECTRICAL ENGINEERING

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

THE INVESTIGATION OF THE POSITION CONTROL FINGER FOR REHABILITATION ROBOT USING 5DOF ROBOTIC ARM MANIPULATOR

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Bachelor of Mechatronics Engineering

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"I hereby declare that I have read through this report entitle "The investigation of the position control finger for rehabilitation robot using 5DOF robotic arm manipulator" and found that it has comply the partial fulfilment for awarding the degree of bachelor of Electrical Engineering (Mechatronics)"

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A report submitted in partial fulfilment of the requirement for the degree of Mechatronics Engineering

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STUDENT'S DECLARATION

I Declare that this report entitle "The investigation of the position control finger for rehabilitation robot using 5DOF robotic arm manipulator" 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 : ....

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Date : 2 Jun 2016

To my beloved Mother (Faridah Bt Samakon) and Father (Allayarham Marikon Bin Marjo).

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ABSTRACT

Robotic rehabilitation is widely use especially in application of finger rehabilitation. Every year, 15 million people worldwide suffer a stroke. Patient with stroke disease need long time and lot of rehabilitation training. Modern method nowadays, the robot rehabilitation method is use to give repetitive task and focus to targeted rehabilitation technique. This method will give the patient ability to do the rehabilitation training by their own even at their home. In this investigation is to position control of finger rehabilitation robot using 5 DOF robotic arm. The problem of control finger for rehabilitation is how to generate the trajectory generation in terms of angular position from initial and final of the robot during rehabilitation session. Moreover, the problem in term of different size and length of the human finger need to be consider as well as the movement of the robot need to same with actual human finger motion. The objective for this investigation is to investigate, design and evaluate the position control of finger rehabilitation robot using 5 DOF robotic arm using KUKA Youbot and VREP simulation software.This investigation focus on the simulation in VREP by using the KUKA Youbot robot. The finger that have been evaluate for this investigation is only for index finger. Based on the Cartesian space scheme method, this method able to determine the position of the end effector by using the quarter circular formula and parabolic equation. The methodology of this investigation is the quarter circular formula will determine the total path point to generate the smooth motion of the robot using MATLAB software. To determine the trajectory path of end effector for different length of human finger, the parabolic circular motion has been used in the VREP simulation software to observe and analysis the position, velocity and acceleration of the robot and it effect to the finger joints. This investigation able to control the movement of the finger rehabilitation robot with the different length of the patient's finger with the absolute error 0.067m for x-axis and 0.044m for y-axis. The accuracy for the 15 path point that use in this simulation is 97.2 percent. To reduce the force acting to the finger joints, the simulation need to use the joint velocity below 10 deg/sec and the acceleration 0.3 deg/sec^2. The simulation able to control the position of the index finger during rehabilitation session.

ABSTRAK

Robot pemulihan semakin luas digunakan terutamanya dalam aktiviti pemulihan jari. Setiap tahun, lima belas juta orang diseluruh dunia menghidap penyakit strok. Pesakit dengan berpenyakit strok memerlukan jangka masa pemulihan yang lama dan latihan pemulihan yang banyak. Meggunakan kaedah moden zaman sekarang, kaedah robot pemulihan diperlukan untuk memberi tugas yang berulang – ulang kepada jari dan memfokuskan kepada teknik yang diperlukan sahaja. Melalui kaedah ini akan memberi pesakit keupayaan untuk melakukan latihan pemulihan dengan sendiri walaupun mereka berada di rumah sendiri. Dalam penyiasatan pada posisi pengawalan jari untuk robot pemulihan dengan menggunakan 5 sudut pada kebebasan robot tangan. Penyataan masalah untuk pengawalan jari adalah bagaimana untuk menjana trajektori untuk robot dalam keadaan kedudukan sudut dari kedudukan awal dan kedudukan akhir untuk robot bergerak pada sesi latihan pemulihan. Seterusnya, pemasalahan dari segi perbezaan saiz dan panjang jari manusia perlu diberi perhatian serta pergerakan robot hendaklah sama dengan pergerakan sebenar jari manusia. Objektif penyiasatan ini adalah untuk menyiasat, mereka dan mengesahkan untuk mengontrol kedudukan jari untuk proses rehabilitasi menggunakan 5DOF robot tangan dengan mengunakan robot jenis KUKA Youbot dan simulasi VREP. Penyiasatan ini berfokuskan pada simulasi di dalam VREP dengan mengunakan KUKA Youbot. Jari yang telah dikaji dalam kajian ini adalah jari telunjuk sahaja. Berdasarkan kaedah ruang kartesian, kaedah ini membolehkan untuk mendapatkan posisi pada hujung robot dengan mengunakan formula suku bulatan dan formua parabolic. Untuk metodologi pada penyiasatan ini adalah formula suku bulatan akan menentukan jumlah titik laluan untuk menjadikan pergerakan robot semakin lancar dengan menggunakan MATLAB. Untuk menentukan laluan trajektori pada hujung robot dengan pelbagai panjang jari, kaedah formula parabolic akan digunakan di dalam simulasi VREP untuk di perhatikan pergerakanya dan dianalisa data untuk posisi terbabit. Penyiasatan ini membolehkan untuk mengawal posisi pergerakan pada jari semasa sesi rehabilitasi dengan panjang jari berlainan dan kesalaha yang sbenarnya hanya 0.067m untuk paksi x dan 0.044m untuk paksi y.

ketepatan untuk lima belas titik laluan yang dipilih adalah 97.2 peratus. Untuk mengurangkan daya tolakan pada sendi jari, simulasi ini perlu untuk mengunakan kadar halaju dibawah 10 darjah/ s dan kadar pecutan sebanyak 0.3 darjah/s^2. Simulasi ini Berjaya mengawal posisi untuk jari telunjuk semasa proses rehabilitasi.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Every year, 15 million people worldwide suffer a stroke. Of these, 5 million die and another five million are left permanently disabled [5]. Stroke in Malaysia is the third largest cause of death and estimated over 40,000 people are suffered in Malaysia. [6]. Loss ability by post stroke patient during movement their thumb and finger is critically issues observes by clinical and frequently reported by patient. The limited ability to activate the movement of finger and thumb extensor muscle is the main problem for the patient [1]. In order to increase the improvement finger and thumb movement, the targeted rehabilitation technique need to implement during rehabilitation session [2]. The targeted rehabilitation technique will make the recovery period faster.

The ability to identify and detect the actual position for the finger and thumb motion is beneficially tool in improve the finger and thumb movement. Robot based on the controlling human finger for post stroke patient can be used to control frequently the actual movement of the finger. Nowadays, due to shortage time during therapist session for rehabilitation, it is not possible for patient to receive long term rehabilitation. In order to improve the recovery for finger motion in short time, the rehabilitation for patient using robot allow them to independently carry out rehabilitation exercise [3]. The actual motion with the control finger motion during rehabilitation using repeatable motion generated by robot will able the patient recover in proper technique in future.

Furthermore, using robot application in Malaysia will solve the problem for the rehabilitation instructor to monitor the patients frequently, it will give patient an advantaged to create the ability to do repetitive practice task during rehabilitation session in order to give repetitive practice for physical therapy to patient without the present of instructor [4]. In addition, motion of robot can be controllable and able to quantify the recovery progress performance make them suitable to calibrate the rehabilitation motion with the recovery progress [5]. Using this advantage, the rehabilitation session will goes smoothly with no human error by physiotherapists. Robot based rehabilitation will improve rehabilitation session more efficient because the no of finger rehabilitation robot can use more than three in a time. Make the more patient able to receive physical treatment in a period of treatment without need extra energy of physiotherapist. The robot will increase the effeteness of finger rehabilitation in future.

1.2 Problem statement

The complex problem of control finger for rehabilitation is how to control the trajectory generation for initial angular position (x_i), final angular position (x_f), initial angular velocity (v_i), final angular velocity (v_f), initial angular acceleration (a_i), and final angular acceleration (a_f) for the 5 DOF robot to move during rehabilitation of index finger. If the initial angular acceleration is increase, the jerk of the 5DOF robot will increase. Moreover, when the decreasing of the initial angular acceleration (a_i), the jerk for robot will decrease, but the time taken to complete one cycle of the robot finger movement will increase. Therefore, how to compare the acceleration and jerk based on the human joint finger force limit.

Every people have different size of finger either long or short on their length and bigger or smaller on their size. The problem of to control the finger rehabilitation robot trajectory movement is different size and length of human finger. Furthermore, how to use the mathematical equation for the circular motion, parabolic circular motion and Cartesian space scheme to generate the movement of robot for the different finger length. How to produce the movement from that equation so the movement of the finger will be the same as the movement of actual human finger motion.

The problem of control the accuracy of the robot is when the manipulator need to move the finger from initial position to the final position without produce much error and keep the finger joints will not getting hurt. The path description and generation for the trajectory of the robot need to synchronous with the of actual normal finger trajectory. This is because in motion of the patient finger during rehabilitation activity, the muscle need to generate like normal movement of the actual finger and the motion of path need to be specify during this investigation. The motion of path need to move the manipulator from the initial position to the final desired position.

1.3 Objective of the project

The objective of this project are:

1. To investigate the finger control for rehabilitation using 5 DOF robotic arm.
2. To Design the Angular position (x_i, x_f), angular velocity (v_i, v_f) and angular acceleration (a_i, a_f) of the Finger rehabilitation robot using KUKA Youbot robot.
3. To evaluate the control of finger using 5 degree of freedom robot during the finger rehabilitation using V-REP software.

1.4 Project scope

This project will investigate the how to control the finger motion by using the fundamental of the trajectory generation subject. The 5 DOF robot used in the simulation is only KUKA Youbot and not using other type of 5 DOF robotic arm.

The focus to generated movement of the 5 degree of freedom robot can be simulate by using virtual robot experimentation platform software (VREP). The experimental tool to show the output for this investigation is by using V-REP software. Moreover, this investigation is able to control the finger motion during rehabilitation with the different size and length finger of the human. This investigation only focus trajectory of human index finger in the V-REP simulation software.

The boundary of research by using VREP simulation software is the gravitational force acting on the KUKA Youbot might be different compare to the actual KUKA Youbot in real world. The different value of gravitational force might affecting the velocity and acceleration in the VREP might be different compare to the actual KUKA Youbot. Therefore, in this investigation, the velocity and acceleration just focus for the VREP simulation software.

In other to investigate the analysis of finger rehabilitation robot, the analysis for accuracy, percentage of error and absolute error is analyse based on the angular position of different finger length, angular velocity and angular acceleration joints for the trajectory of the 5 DOF robot and the force acting to the finger.

CHAPTER 2

LITERATURE REVIEW

2.1 Theoretical Background

2.1.1 Robotic Rehabilitation

Nowadays, the development of robotic rehabilitation in other to help the patient in rehabilitation activity has increase in the biomedical engineering across the world. The robotic rehabilitation works in very complete task trajectory. This is because the robotic rehabilitation works in unpredictable environment and need to communicate with human ability to do some movement task in rehabilitation training. Robotic rehabilitation is more complex compare to industrial robotic manipulator.

In the biomedical engineering, there are many type of robot use in various task to rehab the patient like 3 DOF robotic arm use to move the movement of finger, the 7 DOF robot use for nursing robot [17] and pneumatic cylinder to generate the movement of finger. For those robotic manipulator, the trajectory movement is mostly generated by using trajectory planning. In the trajectory planning, there are two method basically used to generated the end effector trajectory. The method is joint space scheme and Cartesian space scheme.

There are several rehabilitation task involve to enhance the patient ability by the robot. The task training such as teaching with active assistance robot, training with passive assistance and training with no assistance robot. The modern technology was implement at the rehabilitation robot with the combination of the feedback sensor to analyse the ability and performance of the patient during rehabilitation training session. The visual based movement also make the robot able to learn the behaviour of the patient ability make the robot to decide either down scale or up scale the movement of the rehabilitation training.

2.1.2 Background of finger rehabilitation robot Model

The anatomy of the human hand as shown in figure 2.1.1.1. The anatomy for human hand skeleton is consist of 27 bones. In this investigation, the focused is for index finger. For index finger, there have 3 joint and 4 bones for this finger skeleton. The joint consist of Distal Interphalangeal (DIP), proximal interphalangeal (PIP) and methacarpophalangeal (MCP) [14]. For the bones of index finger, there have distal phalanges, Middle phalanges, proximal phalanges and metacarpals. The related for this purposed into this investigation is, the MCP, DIP and PIP joint is need to consider on control of finger rehabilitation by using 5 DOF robotic arm.

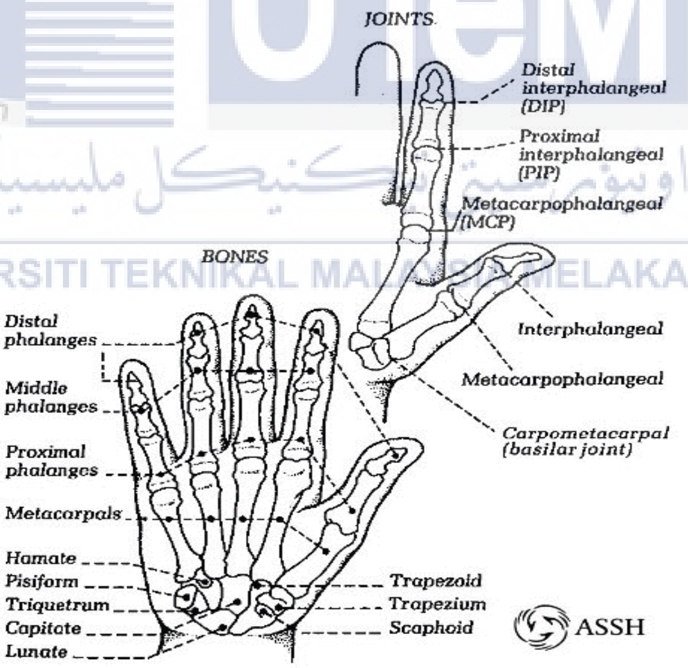

Figure 2.1.2.1: show the basic finger anatomy.

The rehabilitation for thumb finger, 5DOF robot is used to generate the movement of thumb finger. Furthermore, the motion is not focus on passive rehabilitation technique only, they also improve the rehabilitation technique by implement the finger motion with hand wrist movement in other to improve the effectiveness for patient rehabilitation. The wrist movement is generated by using 2DOF robot [15].

To generate the finger movement, the actual data from human finger movement is implement in this investigation. The actual finger movement from the research [16] is likely movement in parabolic circular shape perimeter. The figure is shown in figure 2.1.2.2 below.

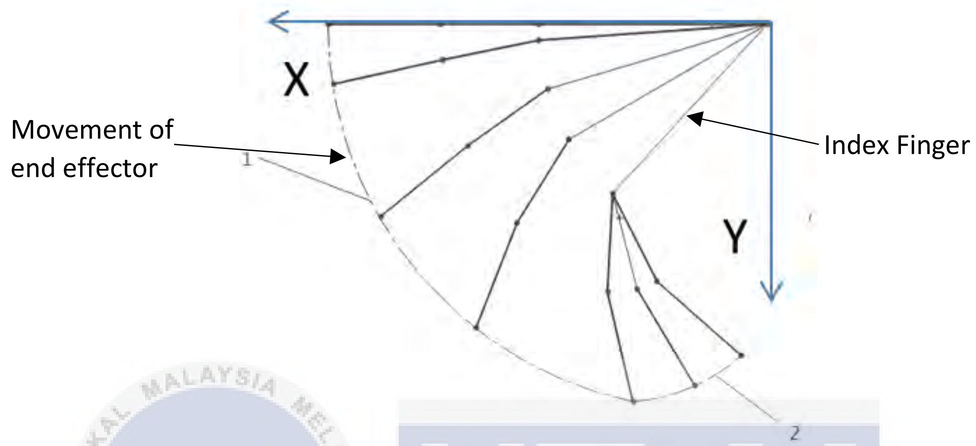

Figure 2.1.2.2: The finger trajectory movement

Finger rehabilitation investigation need several method to gain analysis from the finger motion, to compare and analyse the result from this investigation. Form previous study, the method that apply in rehabilitation activity is vital in terms of accuracy of the position, acceleration, velocity, and angle of each finger joint. This is because every parameter need to synchronise with the normal finger motion of human.

The method use in [9] is the method to generate the finger motion using the combination multi ginger haptic interface robot controlled by surface electromyogram (EMG). The movement of the finger is generated by robot using exoskeleton actuator and the electrical activity of muscle respond is monitor and recorded trough the detection of EMG. This will able to monitor and control every muscle activity by controlling the movement of robot. The EMG is used to measure the bioelectrical signal come from the voluntary contraction of muscle. This signal will give lot of information about a person's intent. It is useful method in other to find the actual normal finger motion in terms of contraction of muscle to be analysis and come out with the control system method [8].

During the rehabilitation for patients, the EMG system will estimate the joint angle of the patient finger. Joint angle is applicable to the robotic system. This is because to generate the finger motion, the angle for each joint in finger need to be estimated in actual position. The angle of joint will affect the muscle contraction. In addition, when the angle was determined, the calculation for different type of exercise can be calculate. This is helpful method in order to produce various exercise for the finger including flexion and extension. [9]. the finger motion for this system can be generated more than 3-directional motion

Furthermore, the hand rehabilitation support system based on self-motion control was developed [10]. The system was developed with the exoskeleton device that support using symmetric master-slave motion system that applicable for virtual reality environment. This is applicable for the patient that have one side hand or finger problem only. The motion is drive by healthy patient hand itself to control other hand that have problem to move.

The other application for robot rehabilitation for finger stroke is by using cable actuated rehabilitation system [11]. The system was developed to train each finger to move using cable loop linear displacement movement. The force from the movement will generated the movement of finger. This system have deferential sensing system and clutch system which allows every each finger movement independently using one actuator.

2.2 Trajectory Generation

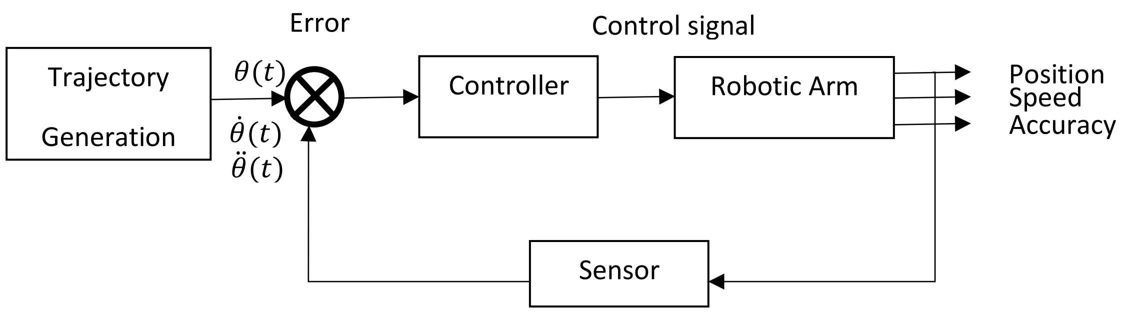

Figure 2.2.1: The Trajectory Generation Block Diagram.

Trajectory generation is the terms to describe the desired motion of a manipulator in multi-dimensional space. The terms trajectory is refer to the time, acceleration and velocity for every single degree of freedom for the manipulator. In investigation of control finger for rehabilitation, we using the trajectory generation to specify the trajectory or path point in desired position to move the robot in the form of parabolic circular motion.

Using trajectory, the motion of every manipulator can easily generated through the specifying trajectory description for the desired motion. User can easily specify the desired goal position for the end effector to move the finger and let the system to determine the exact shape and path for the manipulator to move to the desired goal position. [11]. The movement for the finger rehabilitation robot depend on the initial position and final position that will define by the user. The trajectory motion for the parabolic motion of the robot will generated by the computer through the define point. Trajectory is computing on the digital computer. The trajectory point is computed at certain rate call path update rate. The rate is typically range between 60 and 2000Hz.

2.2.1 Joint-Space Scheme

The joint-space scheme method is to related the path and time and describe it in terms of function of joint angles. The path is commonly describe in terms of position and orientation for the tool frame {T} and station frame {S}. By using inverse kinematic method, each of this parameter is converted to the set of desired joint angle. When the n function pass through via point and end goal point, the smooth function will be determine. The time required for all the joint to move and reach through via point is need to be same resulting the in the Cartesian position of {T} at each of via point. [11]. The purpose for this method in this investigation of the finger control for rehabilitation is when the end effector move the finger, the trajectory parameter for the joints robot need to be control. This is because the synchronisation of the angular position, angular velocity and angular acceleration to the movement of the finger will give the best result for the finger control during this simulation.

2.2.2 Cartesian Space scheme

Cartesian space scheme is a one of the method from path generation method that describe the function of the Cartesian position and orientation in terms of time function. This is because, during the spatial shape path during the end-effector, the motion is sometimes not in straight line through space. The shape depend on the particular kinematic that been used by the manipulator. Sometimes the shape is quite complicated either straight line, sinusoidal, circular and many more. Through Cartesian space scheme, the spatial shape path can be specify between path points.

Each point at this schemes is refer to the orientation and position based on tool frame and station frame. To transform the function into time that represent Cartesian variable, the function need to splined together to form trajectory function first. Without using inverse kinematic at the beginning of this process, the user is easy to organize the definition path point using the {T} as specification relative to {S}.

Therefore, by using the parabolic equation in the control system of the robot movement, the Cartesian space scheme for the robot can be generated based on this equation. The position from one path point to another path point will for the robot movement can be calculated when the initial position and final position of the robot is define from the user. The inverse kinematic for this simulation regarding the Cartesian space scheme will automatically calculated by the controller robot in the computer algorithm.

2.2.3 Cartesian straight line motion (CSLT)

Cartesian straight line motion is the function for the general Cartesian motion in condition for straight line. The Cartesian motion that implement this function such as sinusoids or ellipses. To define this function more detail, the CSLT is useful to defining the motion for straight line condition when the general capability for Cartesian motion can be variable as function of time when specify the motion path.

To planning the CSTL, the angle of axis representation can be implement to this function to determine the orientation for three number. This orientation then combine with the 3 x 1 Cartesian position representation. Consider the terms of ${}^S_A T$ is via point for relative to station frame. The position for end effector is given $s_{P_{A\,ORG}}$ and orientation for end effector is${}^S_A R$. The rotation matrix is define as s_{K_A}. The six values of X represent 6×1 vector for Cartesian position and orientation. Thus the equation:

$$^{S}\chi_A = \begin{bmatrix} ^{S}P_{AORG} \\ ^{S}K_A \end{bmatrix}$$

The example for this purpose of the equation above is when determine the best minimum rotation for the given initial position to rotate to the end effector position.

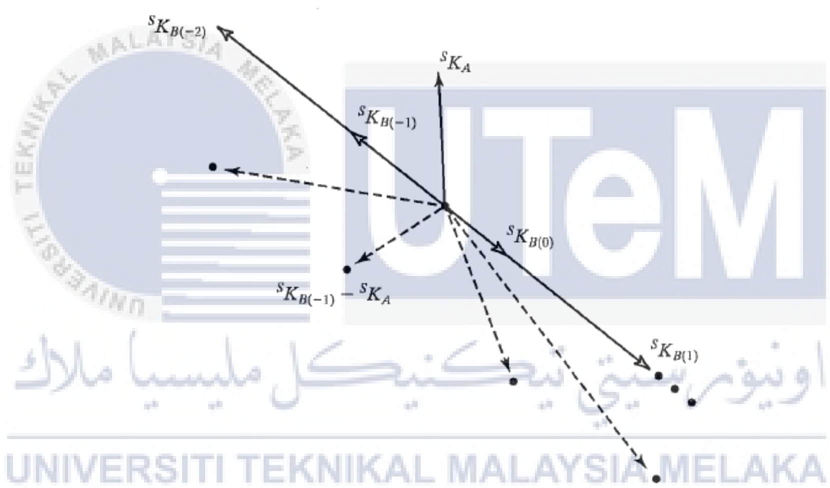

Figure 2.3.1.1: show the 4 different minimum rotation position to be choose.

s_{K_A} Is the initial position and s_{K_B} is the final end effector position. In other to rotate at the specific position, one position from four different rotation position (Broken Lines) will choose wisely to determined minimum rotation. This case the minimum rotation will be $s_{K_{B\,(-1)}}$. Addition for one more constraint is needed to calculate splines parabolic and linear section. This is because the blend time for every degree of freedom for the joint need to be same. To do that, the acceleration every degree of freedom must be differ from each other [11]

2.3 The technique to generate the robot movement

2.3.1 The quarter circular motion equation for the robot movement.

To generated the movement of the robot to lift the index finger of the patients, the equation of the circular trajectory motion able to implement into the algorithm. This is because, from the research [20], the circular trajectory motion training will provide many positive advantage for the upper arm rehabilitation for the movement training in the circular manner. This is because, the research shown that circular motion will give positive impact in recovery of the upper limb by improving muscle performance and train the brain to adapt with this motion[20].

To implement the circular motion into the index finger movement during rehabilitation session, the quarter circular motion is the best method to generate the motion trajectory of the robot in circular motion. This is because, the movement from the extension of the index finger to flexion of the index finger is likely the motion of the circular motion. Therefore, this method will be considered as the one method to generate the trajectory of the robot.

2.3.2 The parabolic circular motion equation for the robot movement.

The method to move the robot arm along the Cartesian space scheme by using the parabolic equation will give the full motion for the robot to move the finger during rehabilitation session. By using the symmetrical parabolic curves with length of the finger and the curvature is already define and store into the algorithm will make the end effector move to the desired motion [21]. This method will generated the smooth path of the robot motion during the movement of the robot when move the index finger.

Moreover, the parabolic equation is able to set into the algorithm in order to generated the parabolic circular motion when the desired position is define at the beginning of the simulation by user. Therefore, this method will be potential to use in this simulation due to its shape likely same with the real human finger motion.

2.3.3 Comparison among Different Trajectory Generation Method

In the trajectory generation method by using Cartesian space scheme, there are two method available which is quarter circular motion and the parabolic circular motion.

Table 2.1.1: the comparison between two methods in trajectory generation.

Technique	**Explanation**	**Comment**
Quarter circular motion	Move the initial path point to the desired goal position for the robot in circular motion	Easy to compare the different path point for the movement of the end effector.
Parabolic circular motion	Move the end effector to parabolic circular motion during rehabilitation session.	The equation is more complex but it will generate the full finger motion in rehabilitation session like real human finger motion.

By referring the table 2.4.1, the circular motion is easy to use when comparing the different path point number by using MATLAB software. The smoothness of the circular curve make the analysis will be more accurate compare to parabolic circular motion. The determination of the path point is vital in other to produce the smooth curve during the movement of the finger rehabilitation robot. The quarter circular motion also easy to plot the path point when coordinate of the path point able to calculate manually using the formula of the trigonometry equation. Apart from that, the quarter circular motion will be use to prove the different number of the path point will affect the accuracy smoothness of the movement end effector.

The parabolic circular equation is able to generated the motion trajectory for the robot to move the index finger nearly same with the real human finger. This equation is more complex compare to the quarter circular motion. Apart from that, this equation is easy to use when it was set to the algorithm for the calculation of the Cartesian space scheme position during the finger rehabilitation robot.

For this investigation, the Cartesian space scheme method which is the parabolic circular motion will be used to generate the movement of robot in parabolic circular motion from initial to final position. Furthermore, the quarter circular motion of the robot is use to find the suitable path point for the robot to move smoothly in the Cartesian space scheme. Therefore, by combining this two method, the investigation for finger control for rehabilitation will achieve their objective to move the finger using 5 DOF robotic arm.

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CHAPTER 3

METHODOLOGY

This chapter, the methodology for this project will be discuss. This project is use software simulation in order to produce outcome and result from this investigation. To generate the trajectory for 5 degree of freedom robotic arm, the trajectory generation for joint and Cartesian space scheme will be implement as the method to determine the motion for the robot. The quarter circumference formula and cubic polynomials equation need to write as a code to generate the trajectory in the simulation software through this method. Furthermore, the trajectory parameter to generate the motion for the robotic arm is include it position, angular velocity and angular acceleration. In this chapter, the section is include theoretical description for proposed idea, objective for this methodology, material and equipment, the data type, procedure of implementation, simulation and method to analyse the data

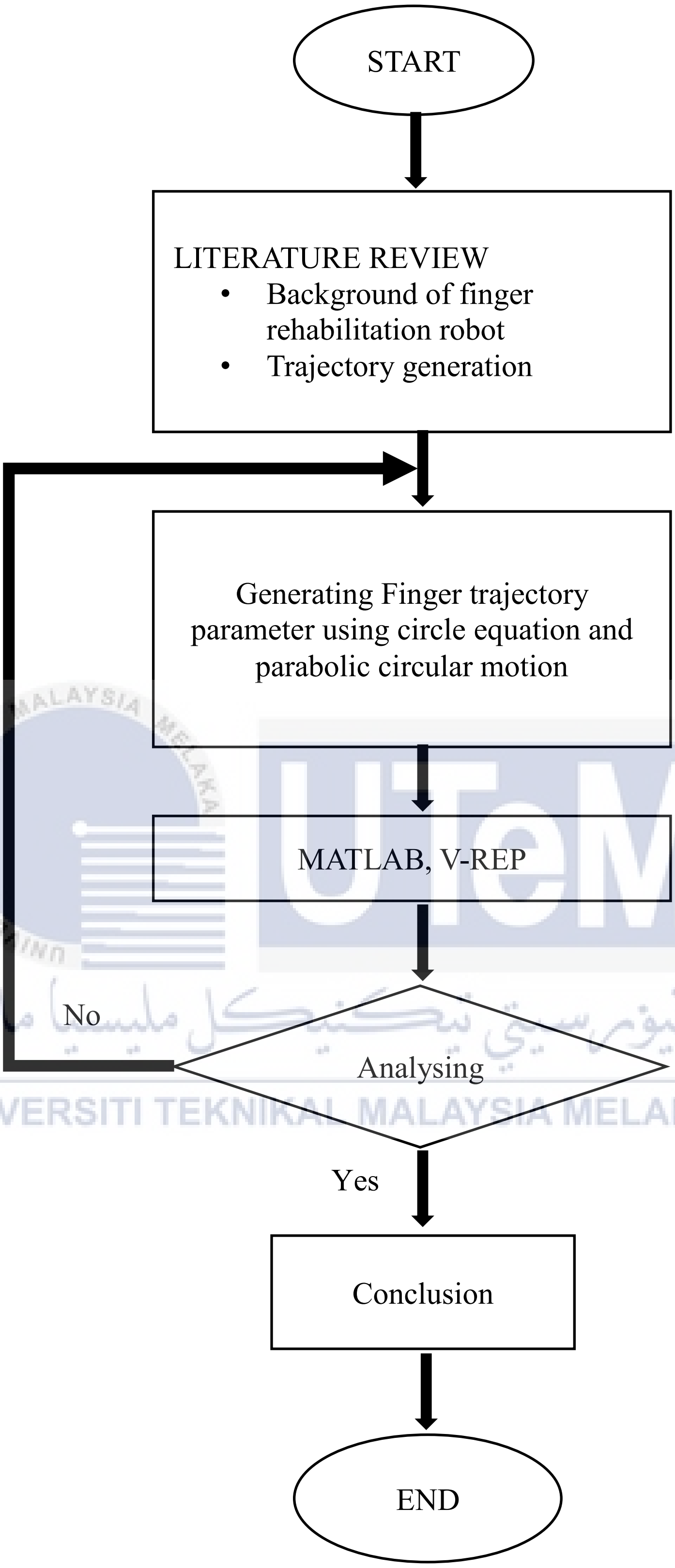

Figure 3.1: the overall methodology process

3.1 Theoretical description for proposed idea.

This investigation is only focus to index finger. To generate the trajectory for finger rehabilitation using 5 DOF robot arm closer to human finger motion, the principle of Cartesian space scheme in trajectory generation will be used.

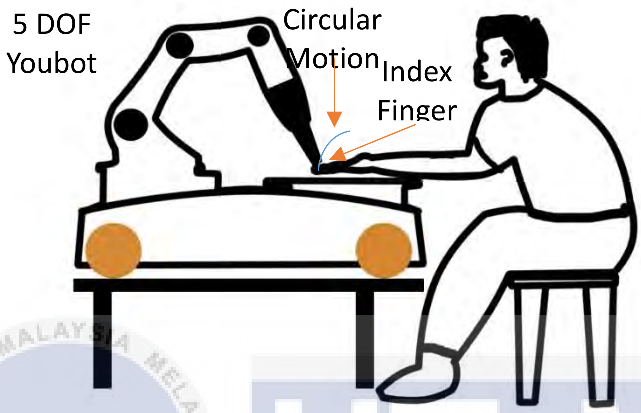

Figure 3.1.1: Scenario for Finger Rehabilitation robot work

The figure 5.3.1 show the scenario for the human index finger rehabilitation process using 5 DOF Youbot robotic arm. The patients will seat in front of the robot. The index finger will placed at the surface platform of the Youbot robotic arm. The end effector of the robot will move the end of index finger in parabolic circular motion. Moreover, to generate the trajectory path point of the end effector, the quarter circumference will be used to calculate the path for different index finger length.

The length of index finger patient is represent by r.

$$Length\ of\ finger\ = r \qquad (3.1)$$

To find the quarter circular motion trajectory for the robot, the circumference for the quarter of circle:

$$C = 2\pi r/4 \qquad (3.2)$$

Thus, to determine the position for path point based on the quarter circular motion of the robot:

$$p = (x, y) \quad (3.3)$$

$$x = r\cos\theta \quad (3.4)$$

$$y = r\sin\theta \quad (3.5)$$

$$p = (r\cos\theta, r\sin\theta) \quad (3.6)$$

To find theθ, the trigonometry equation for the circle will be used.

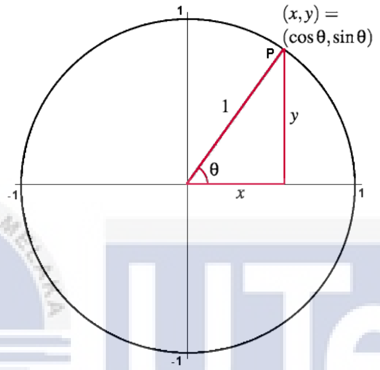

Figure 3.1.2: the trigonometry circle to find θ.

In addition, to generate the smooth motion for the robot to move from initial angular position to the final angular position, the different number for the path point will be compared in the MATLAB simulation. The comparison will be determine by the analysis of percentage of error and accuracy for the different number of path point with the actual circular motion for the index finger.

The parabolic equation will be used to generate the full motion for the robot to move the finger. Previously, the quarter circular motion used to prove the different length and path point will affect the smoothness of the motion for the robot. The parabolic equation is use in VREP to generate the motion to be same with the human finger motion.

The movement end effector equation:

$$z = z_0 + a(y - y_s)\,(y - y_e) \quad (3.7)$$

Where the value of a:

$$a = \frac{z_{max} - z_0}{(y_{max} - y_s)\,(y_{max} - y_e)} \quad (3.8)$$

To generate the next path point:

$$y = y + shift \tag{3.9}$$

Shift = the distance from one path point to the next path point.

z_0 Is the initial z-axis position for the position target of the end effector.

z_{max}= Z-axis maximum position

y_s = Y-axis start position

y_e=Y-axis end position

y_{max}=Y-axis maximum position

3.2 Flow chart for KUKA Youbot motion's code.

Figure 3.2.1 shown the process of the KUKA Youbot motion in movement of the finger for rehabilitation. In this code, at the beginning of the process the user need to set the length of the patient finger. This is because the parabolic motion will depend on the length of the patient's finger. After that, when the simulation is start, the end effector of the robot will move to the initial position to grip the attachment of the patient's finger. The algorithm for the parabolic equation will calculate the next path point for the end effector to move. The algorithm will always recalculated from one path point to the next using their loop for 15 path point. After 15 path point, the movement of end effector will reverse back to the initial position. After reach the initial position, the one cycle of the finger rehabilitation movement is finish. The counter will calculated until the desired repeated cycle for the robot to move. in the flow chart at figure 3.2.1 there are 30 cycle for the finger rehabilitation robot need to move.

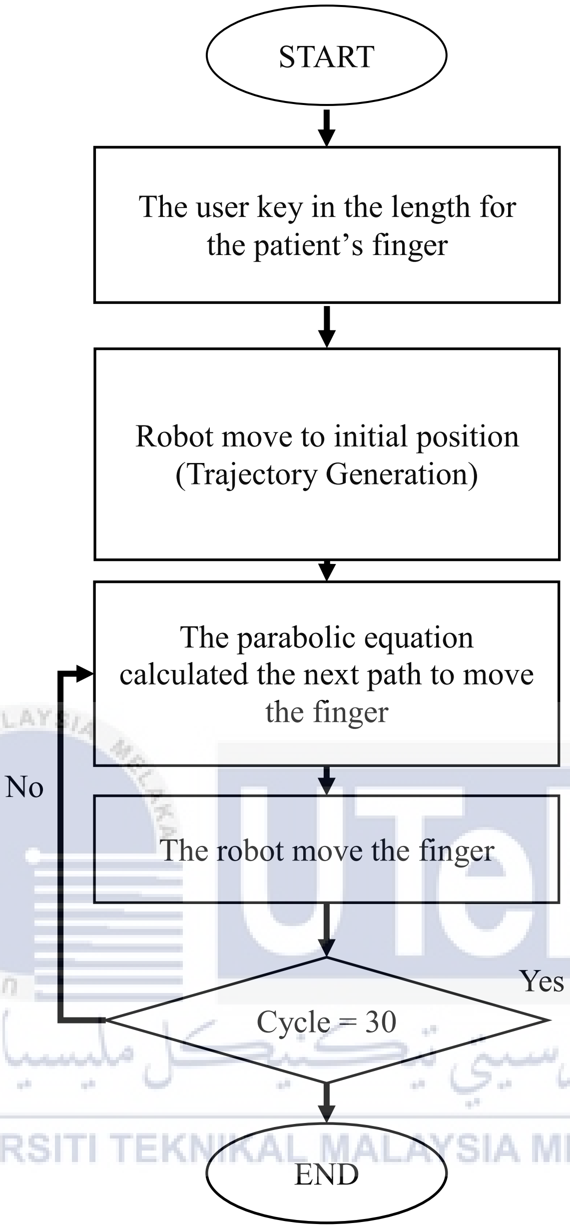

Figure 3.2.1:flow chart for the algorithm of the finger rehabilitaion robot

3.3 KUKA Youbot workspace for finger rehabilitation simulation

The KUKA Youbot arm is a serial of chain consisting of five revolute joint called degree of freedom. This robot is 5 degree of freedom. The KUKA Youbot consist two finger gripper which 70mm opening limit [19]. For the simulation of the finger rehabilitation robot, the workspace for the robot just only use the y-axis and the z-axis only. The figure 3.3.2 and figure 3.3.3 shown the robot work space during the simulation of the finger rehabilitation robot.

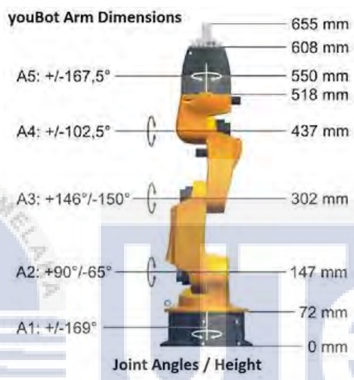

Figure 3.3.1: the rotation limit and the length detail for the KUKA Youbot

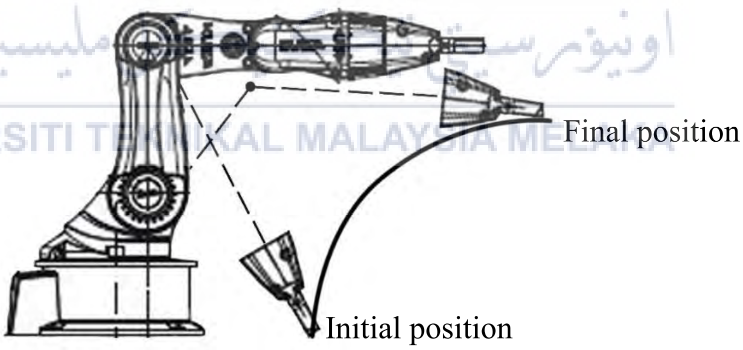

Figure 3.3.2: The side view of workspace for the end effector during finger rehabilitation simulation

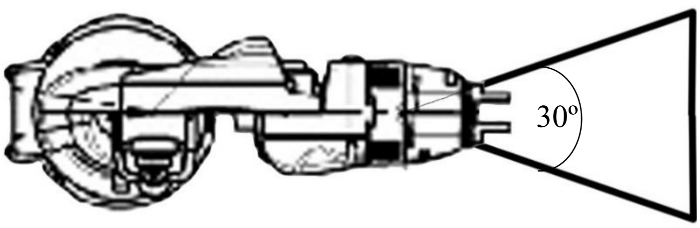

Figure 3.3.3: The top view for the workspace of the robot during rehabilitation simulation.

3.4 Consideration on the validity of the simulation.

To investigate the finger position during the rehabilitation using the robot, the finger model in the simulation need to same with the actual human finger behaviour. I believe if the joints finger behaviour is same with the human finger, the result data will be same with the actual finger rehabilitation. Furthermore, the human finger joints have the rotation limit. The limit of each joint is need to concern in order to produce the simulation nearly same with the actual finger motion during rehabilitation. Therefore, when the finger model in the VREP simulation is set to be same. As the result, the robot able to be control during the simulation and the effect of the movement of robot finger rehabilitation to finer joints able to evaluate. Therefore, there are the detail every finger joint rotation range limit [18]:

I. MCP 0^{o} to 90^{o}
II. DIP 0^{o} to 45^{o}
III. PIP 0^{o} to 45^{o}

The main factor to control the robot movement by evaluating the finger joints force. For the human finger joints, there are rotation range limit for the force able to acting to the finger joints. The force range limit is at the table 3.2.1. Based on the figure 3.2.1, the finger is at the final position of the motion before it is back to the initial position. Due to rotation range limit of the finger joint, the simulation will produce the graph show the force and torque exerted to finger by the robot when the joint finger reached to their joint rotation limit. Therefore, by implementing this real finger joint rotation limit, the result that obtain from this investigation will affect the safety precaution method that will be implement when controlling the robot finger rehabilitation movement.

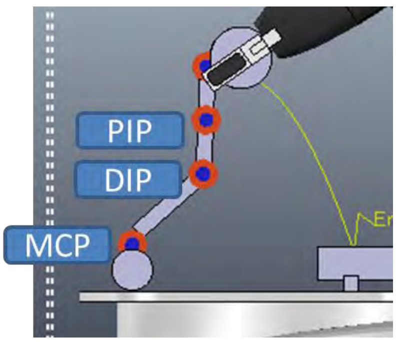

Figure 3.4.1: The index finger rotation limit

Table 3.2.1: The index finger force range limit

Finger joints	Force (Nm)
MCP	0 to 0.16
DIP	0 to 0.29
PIP	0 to 0.29

3.5 Reliability of the data

The reliability of the data for this simulation in terms of the measurement is vital to be consider. The measurement data for the simulation in term of the measuring the force acting on the finger joint might be different compared to the actual measurement force acting to the real human finger. This is because the force acting to the finger joints by the real KUKA robot is influence by the weight of the robot and the gravitational force acting to the robot. This may affect the investigation result because the measurement of this cannot be control.

Furthermore, the uncertainties for robot position cannot be control. This is because the overall of the KUKA Youbot movement in VREP is calculate by the computer. When the exact point is define to the robot as the target position, there are still have an error for the robot when move to the target position. Therefore, the repeated simulation in order to produce the exact accuracy for the robot is vital to avoid the robot move exceed to target position.

3.6 Objective for simulation

In this investigation, there are two simulation. The first is using MATLAB the and second is using VREP simulation software with LUA programming language. Therefore, there are the different objective for each simulation.

1. Objective simulation using MATLAB:
   I. To validate the circular equation of circle will generated different length of the finger movement.
   II. To compare and analysis the different no of path point will produce the smooth motion for the end effector.
2. Objective simulation using VREP:
   I. To generated the actual movement of the robot to move the finger using parabolic equation in VREP using LUA language.
   II. To determine the effect of each trajectory position, velocity and acceleration of each joint of the robot to the finger during rehabilitation session.
   III. To analyse the finger joint effect from the movement of the robot during simulation.

3.7 Material and equipment

This investigation of control finger for rehabilitation using 5 DOF robotic arm is conducted by using software programme. The software programme is MATLAB, V-REP simulation. This two combination of software program is needed to produce outcome for this investigation. The MATLAB software is high language programme that use to compute technical aspect and integrate with combination of visual, computation and programming. This software environment is easy to use because this software use the familiar mathematical notation to calculate the solution and problem. The other typical uses is also for simulation, mathematical solution, and algorithm development and data analysis.

Virtual robot experimentation platform or V-REP is the robot simulator that integrate with development environment. The V-REP is based on control each of the object part via scrip embedded and remote API client. To control the simulation for robot, others controller can be used such as C/C++, Lua, Java and Phyton software. This simulation use LUA programming that already inside the VREP software to set the algorithm for the parabolic equation and robot movement.

3.8 Setup experiment and simulation

To simulate the equation from the theoretical description for proposed idea, the simulation to produced output based on the graph result is needed. The graph result based on the trajectory for the index finger rehabilitation robot will is include position, angular velocity and angular acceleration graph.

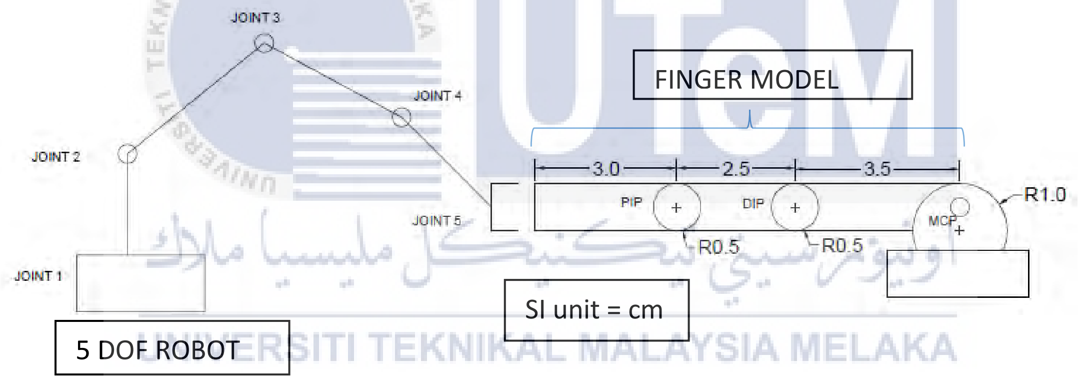

Figure 3.5.3: the V-REP simulation drawing setup to simulate the finger trajectory motion.

To implement the trajectory of the index finger in the simulation form, the V-REP software is used. The setup for the simulation if in figure 3.5.2. The rectangular shape attach to the circle of joint is represent the index finger. The index finger joint is PIP, DIP and MCP. The 5 DOF robot arm that used in this experiment in V-REP is you bot from Kuka robot. After the setup was done, the coding to control the trajectory of the robot motion to move the index finger is by using LUA programming. To calculate the absolute error from the movement of the robot trajectory, the V-REP need to show the graph for angular position, angular velocity and angular acceleration. The Vrep simulation setup based on the simulation drawing setup is in the figure 3.5.4.

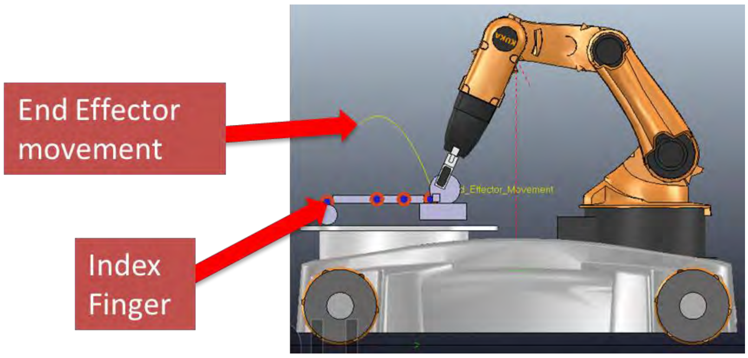

Figure 3.5.4: The experimental setup in V-rep

3.9 Procedure of simulation

1. The simulation is need to set up as shown in figure 3.5.4 in the VREP simulation software.
2. The algorithm need to create by using the parabolic equation in the LUA programming language in the VREP.
3. The range limit of the joint finger was set in order to match with the actual human finger.
4. The simulation is begin with the key in of the finger length for 7cm to the algorithm.
5. Run the simulation and observe the motion of the robot.
6. Analyse the robot motion, position, velocity, acceleration of the joint robot and the joint finger force and torque graph.
7. The simulation is repeated from the step number 4 until step number 6 for different finger length for 8cm, 9cm, 10cm and 11cm.

3.10 Accuracy analysis

To approach the objective for this methodology, the result that obtain from the Matlab simulation, V-REP simulation software was compare with the actual human index finger trajectory motion. The result obtained need to undergo analysis by calculated the mean, percentage of error and root mean square error for the finger trajectory motion using high order polynomials.

Absolute error to find the position error for the end effector of the robot during move the finger.

$$\Delta x = x_{o-}x \qquad (3.5.1)$$

Percentage error is to calculate the error occur for the different path point for the end effector of the robot to move the finger during rehabilitation session.

$$=\%\text{error} = \left|\frac{Theoritical - Experimental}{Theoritical}\right| \times 100\% \qquad (3.5.2)$$

The accuracy of the different path point need to be calculate in order to determine the best path point.

Accuracy=

$$= 1 - \left|\frac{Theoritical - Experimental}{Theoritical}\right| \qquad (3.5.3)$$

CHAPTER 4

RESULT AND DISCUSSION

In this part, the result for the simulation will be discussed. In other to generate the trajectory path for the finger rehabilitation robot, the quarter circular path need to be used to prove how many path point will be used to produce smooth circular motion for the end effector of the robot. Furthermore, this investigation is focused on Cartesian space scheme method. Moreover, in other to simulate this trajectory path, the simulation using MATLAB simulation will be done. This preliminary simulation is to find the variable parameter for different length of patient finger and different path point in the quarter circle motion finger robot trajectory. The next simulation is in V-REP software. The parabolic circular equation was used to generate the trajectory planning for the robot to move in Cartesian space scheme. The analysis is be done after the result was obtain. The analysis for the parameter such as angular position, angular velocity and angular acceleration need to be compare with the effect on the controlling finger position in order to minimize the negative effect that may cause the finger getting hurt during rehabilitation session.

4.1 Simulation for different length of patient's finger

By using MATLAB, the simulation was conduct to determine whether using the quarter circumference equation will determine the trajectory path using different length of patient index finger. Based on the figure 4.1.1, the graph show the trajectory based on the quarter circumference equation. The length of index finger used in this simulation is from 7, 8, 9, 10, and 11. By using the total number of path point is fifteen, the trajectory path for the end effector for the robot move is smooth path motion. The equation for the quarter circumference are able to generate the quarter circular trajectory with the different number of index finger length.

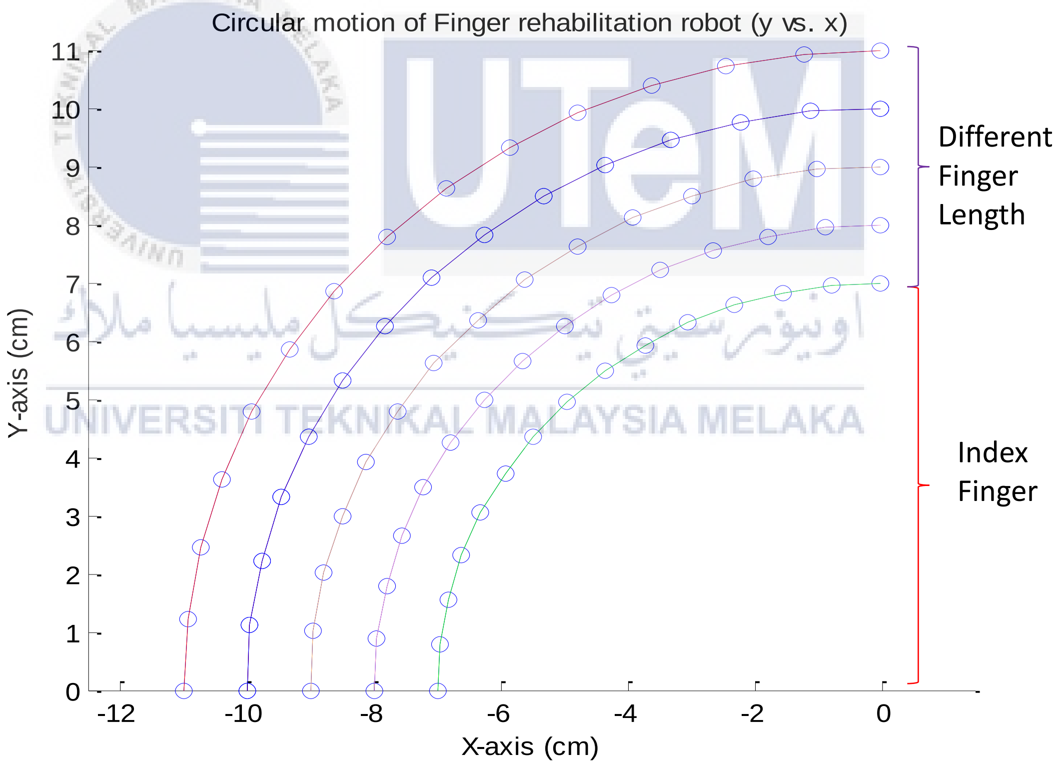

Figure 4.1.1: The angular position of different length of finger

4.2 Simulation to determine the smooth trajectory for end effector of robot.

In other to determine the trajectory for the end effector to move, the path point for the trajectory need to be consider. Based on the figure 4.2.1, the different path point show the different trajectory smoothness. When we are using five and ten path point, the trajectory smoothness is leaser compare to fifteen path point and above.

Table 4.2.1: The variable data for the path point simulation

Radius (Finger length) (cm)	No of path point	Initial position (x-axis) (cm)	Final position (y-axis) (cm)
7	5	-7	7
8	10	-8	8
9	15	-9	9
10	20	-10	10
11	25	-11	11

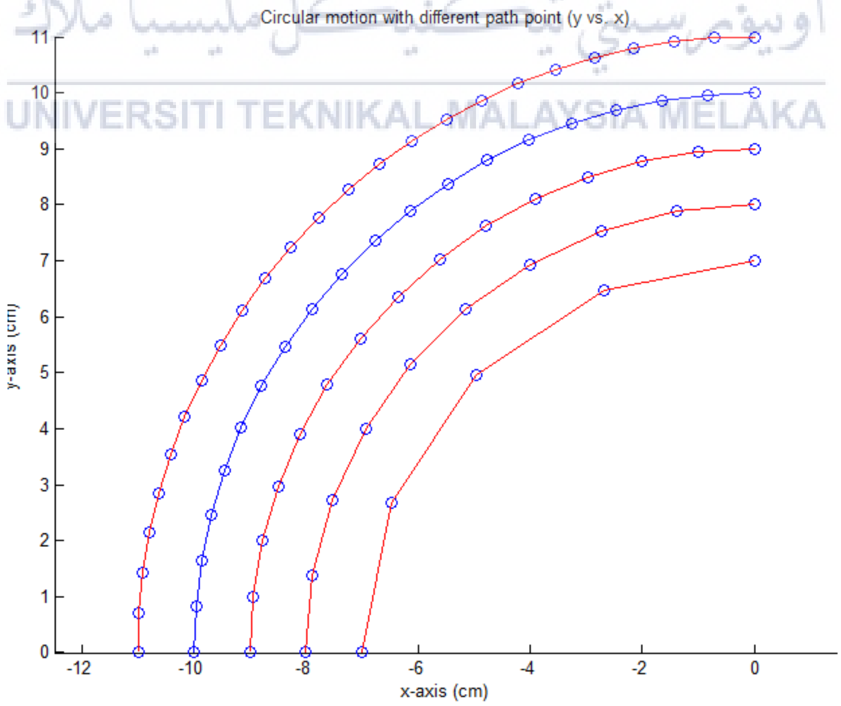

Figure 4.2.1: The end effector trajectory with different no of path point

From the analysis that have been made, the graph in figure 4.2.2 show the accuracy for the different path point number. The time take for the robot to move the finger in one cycle of movement is depend on the number of the path point.in order to minimize the time for the one cycle movement, and maintain the smoothness of the gripper movement, the fifteen path point is chosen due to the accuracy for 97.5 percent and it is able to minimize the time. Compare to the five and ten path point, the accuracy is least accurate compare to fifteen path point. For twenty and twenty five is more accurate, but the time taken to complete one cycle for rehabilitation is take too long.

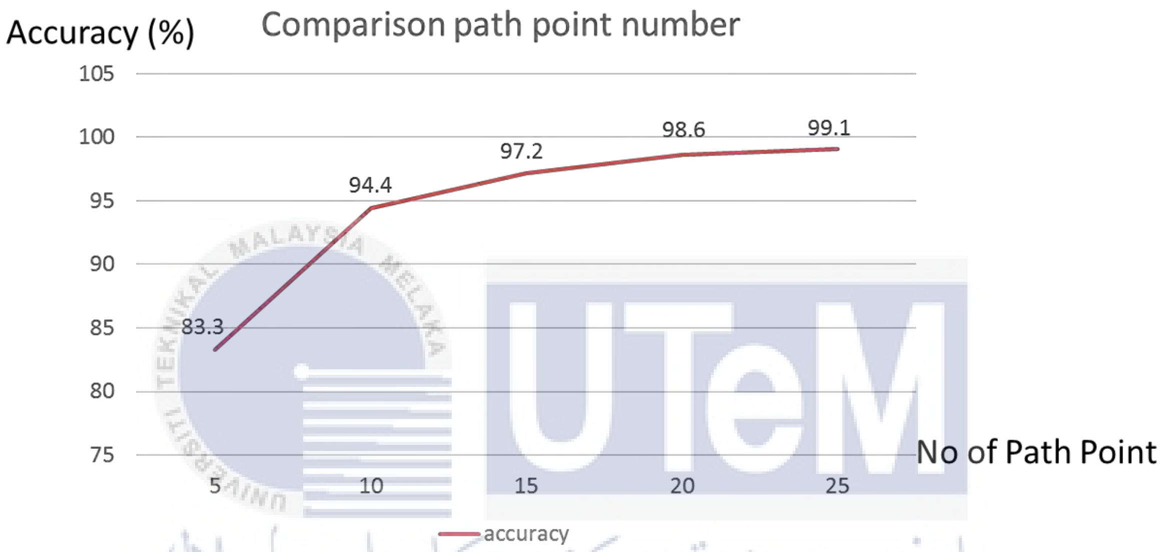

Figure 4.2.2: The accuracy of different number of path point.

4.3 Simulation to in V-REP using LUA to determine the parabolic circular motion for end effector of robot.

4.3.1 The robot end effector position for different length of patient's finger.

For this section, since the VREP already using LUA language programming, so in this project the LUA was used to build the algorithm for the parabolic equation to generated the parabolic circular motion for the gripper to move the finger. Since the movement of the finger is same with the parabolic circular motion, the equation was use as the algorithm to calculate the motion is various patients' finger length. The length was key in to the algorithm and the algorithm calculated the position for the gripper robot to move the finger in Cartesian space scheme.

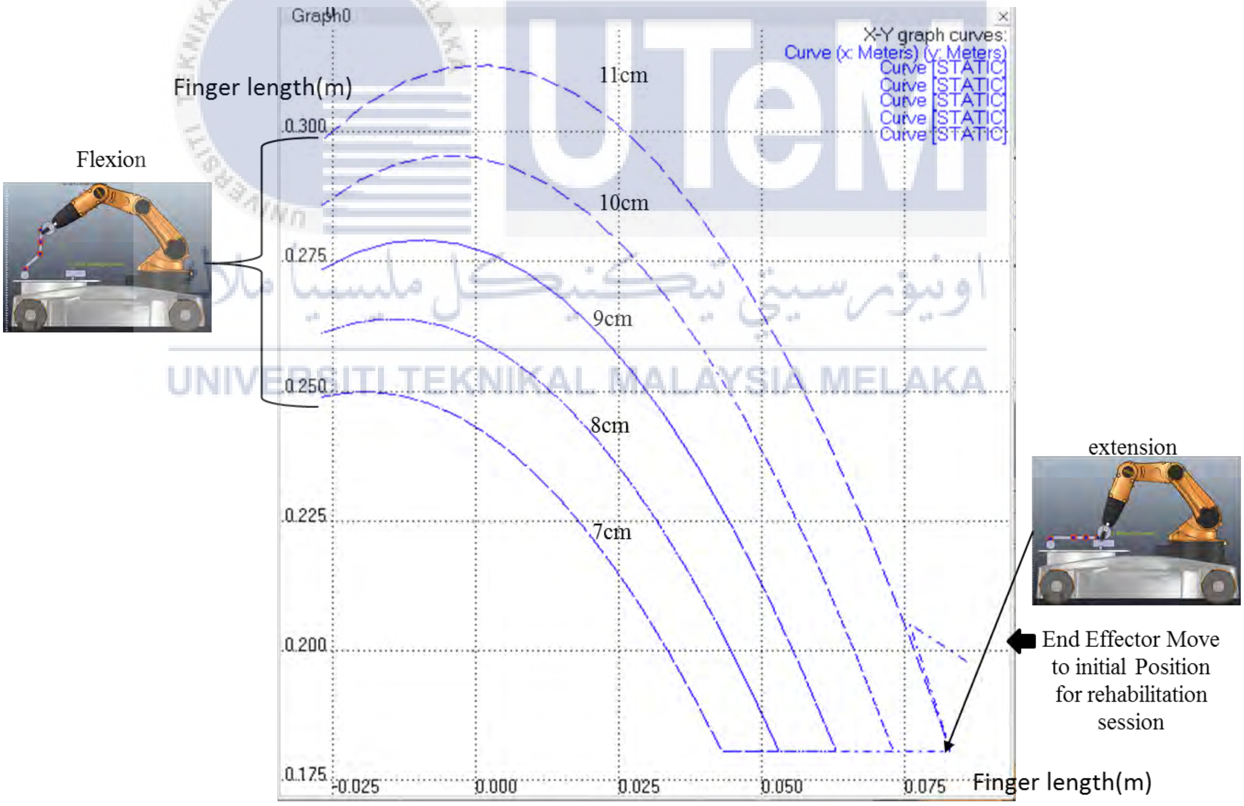

Figure 4.3.1.: The different finger length position for the robot movement in VREP.

From the figure 4.3.1, the parabolic equation that already programed in the LUA programming language will generated the motion of the robot to move the finger to extend and flexes like the normal finger movement. The different length of the finger's length can be generated during the simulation. In real rehabilitation session, the user able to key in the patient's finger length and the movement of the robot will produce depend on the length of the finger.

Based on the result, the error occur at the final position of the robot during flexion of the finger. The error is calculated using the equation of absolute error at equation 3.3.1. The average absolute error of the end effector in x-axis is 0.0067m and for y-axis is 0.044m unreachable to the final position. This error is occur due to the systemic error in the robot controller system. Apart from that, this error can be reduce by controlling the control system for the robot in order to make the end effector move to the accurate target position. Although there was error occur, this error is not critical because the end effector does not exceed the more than final position. The patient's finger is safe because it is not exceed the rotation limit in figure 3.2.1 of the finger.

4.3.2 The robot joint position during movement of finger rehabilitation.

Figure 4.3.2 show the joint position for the robot during movement of finger for rehabilitation simulation in VREP. The Finger rehabilitation robot only use three joint. Joint 1, joint 2 and joint 3. This is because the movement is only in y-axis and z-axis.

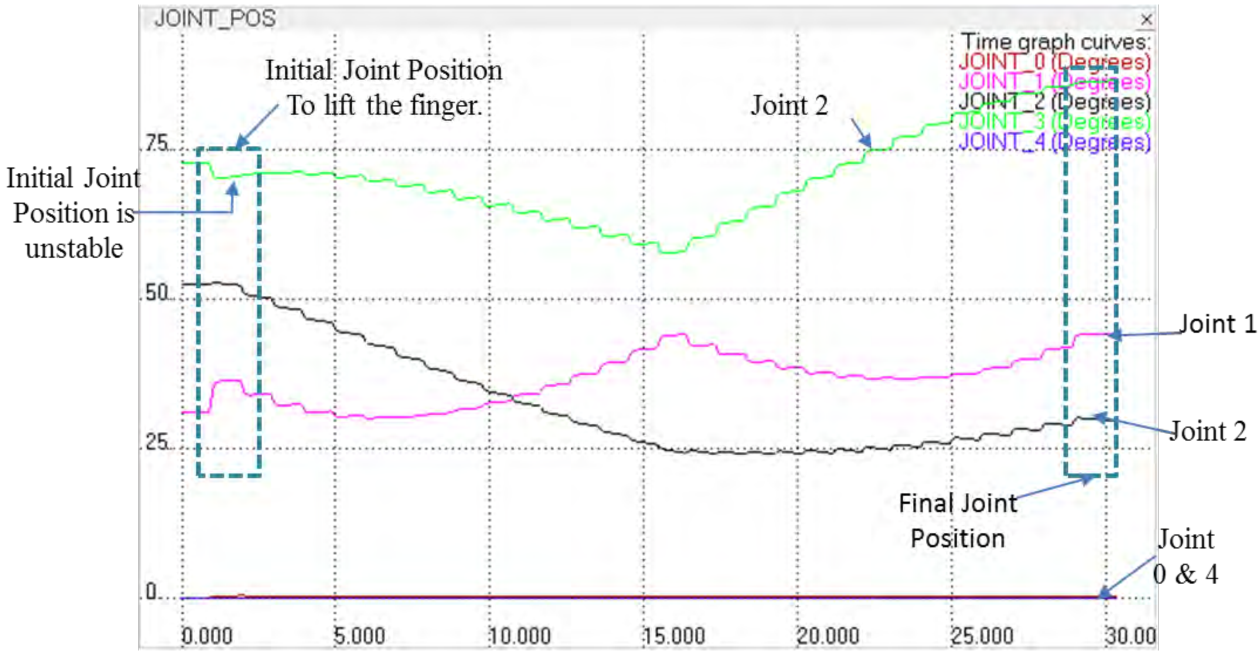

Figure 4.3.2: The joints position for the robot movement in VREP.

Based on the graph in the Figure 4.3.2, the joint position is not very smooth over the time. This is because the end effector of the robot need to accelerate from one path point and decelerate to the next path point. This is due to the delay time for the algorithm to calculate the next path point. The delay time for the algorithm is 0.005s. Furthermore, to make the joint position always continues change over the time, the new controller for linear function with parabolic blend need to be added in the algorithm for the next project. This is because for this investigation is focus for the position of robot during rehabilitation.

4.3.3 The robot joint velocity during movement of finger rehabilitation.

The finger rehabilitation robot is grip the attachment at the end of the finger. Apart from that, the robot movement need to be control by controlling their velocity during the robot movement. This is because, the safety of the finger is vital. The robot cannot move exceed the finger rotation limit especially during high speed of the end effector. Based on the joint velocity graph shown in figure 4.3.3, the velocity always decrease when the end effector of the robot reached to the next path point.

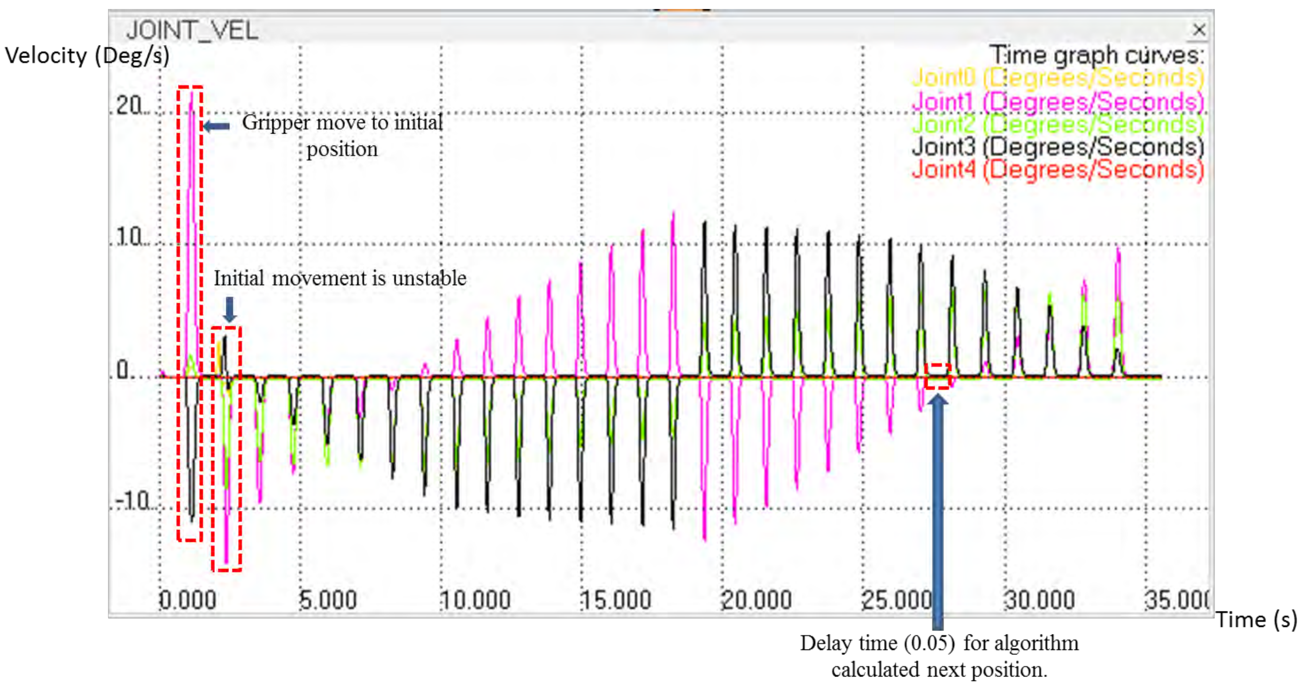

Figure 4.3.3**:** The angular velocity of the robot in V-REP

Based on the analysis from the joint velocity graph in figure 4.3.3.1, at the beginning velocity at the initial position, the movement is unstable. This is due to the joint velocity for the joint 1 is too high exceed the 13 degree per second compared to the other joint. The unstable movement at the initial position is due to the jerk occur at the end effector of the robot. The jerk at the beginning of the movement might be influence the motion of the finger suddenly fast. This problem might cause finger joint especially for the MCP getting hurt every time the robot move the finger at the initial position. To overcome the problem, the limit for the maximum velocity for the robot need to be consider. The maximum velocity for the robot must be below the 10 degree/second. This is to make sure the finger joint still adapt to the movement during rehabilitation.

4.3.4 The robot joint acceleration during movement of finger rehabilitation.

The derivative of the joint velocity for the movement of the robot during rehabilitation is the joint acceleration. The figure 4.3.4.1 show the point to point acceleration over the time.

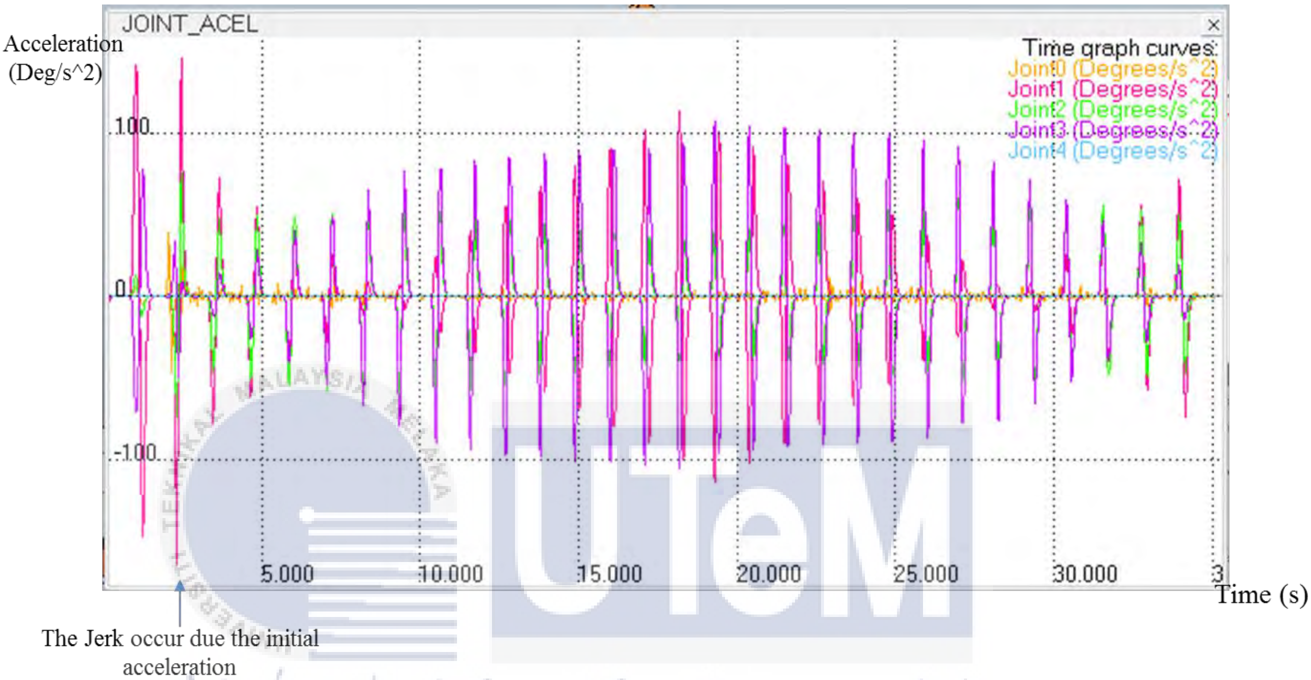

Figure 4.3.4.1: The angular acceleration of the robot in V-REP

The analysis for the graph shows there are unstable acceleration due to the jerk occur at the initial acceleration. The situation is same with 4.3.3 that the jerk will affect the initial velocity unstable. For the initial acceleration, the robot suddenly accelerate more than $150deg/sec^2$. Apart from that, the acceleration need to be decrease in order to minimize the jerk at the initial acceleration. The tradeoff for this problem is by reducing the acceleration at the controller from $1deg/sec^2$ to 0.3 deg/sec^2 and reduce the jerk but the time take for the robot to move the finger for one cycle will increase.

4.3.5 The finger joint force and torque during movement of finger rehabilitation.

To make sure the safety of the finger during the simulation, the forces and torque is measured during the robot movement to lift the finger. This is because this analysis is crucial in order to find the effect of the robot movement to the finger. The data from the robot jerk at the initial acceleration caused the forces exerted on the MCP Joints is higher compare to other finger joint. After that, the next movement show there are several time the DIP will receive the force from the robot movement. The figure 4.3.5.1 and show the graph for the joint force with angular acceleration for $1 deg/sec^2$.

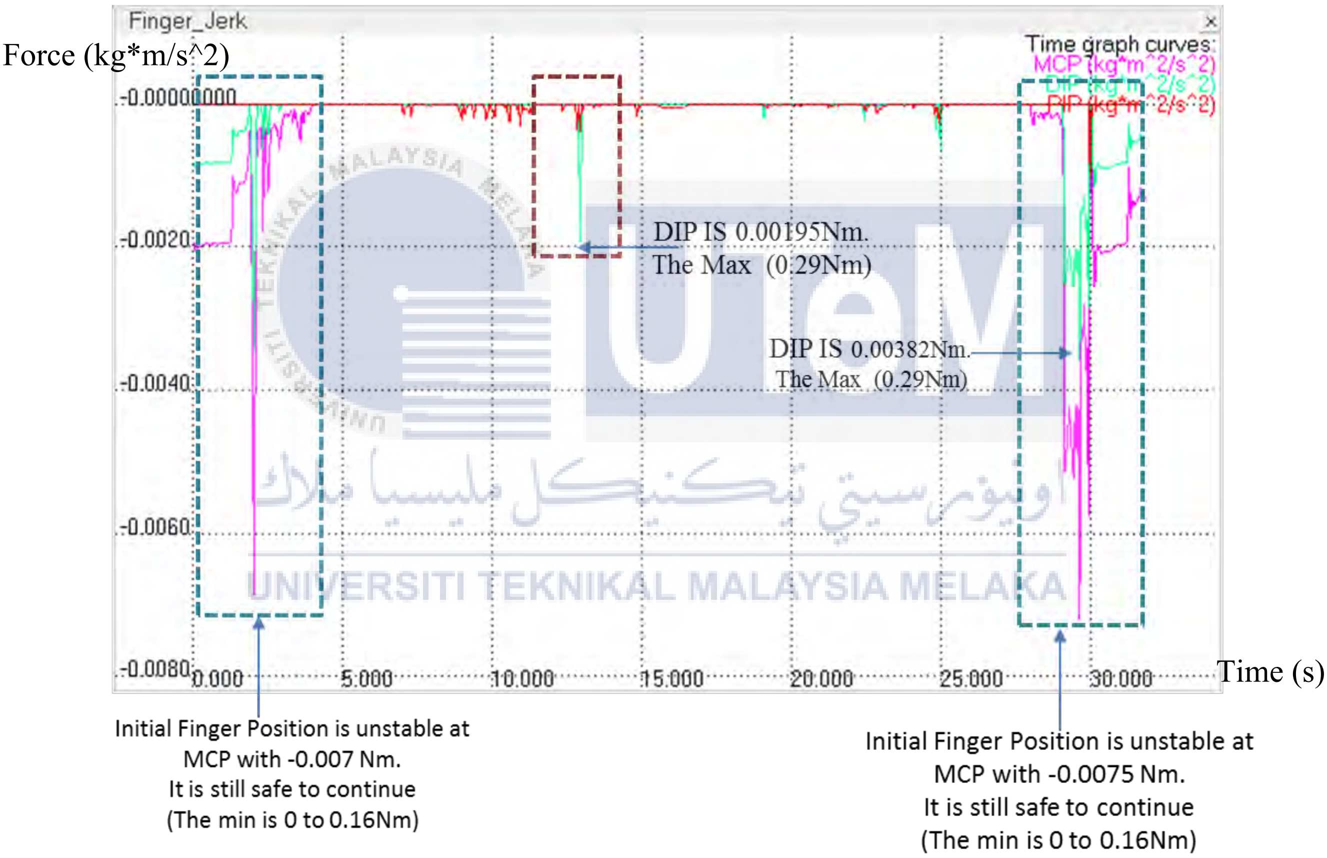

Figure 4.3.5.1: The force for the joint at acceleration1 deg/s^2

The trend show that when the velocity at the $1deg/sec^2$ the initial force acting to the MCP joint is-0.007Nm. Although there are force acting to the MCP finger, the -0.007Nm is still consider in the safe range because the finger joint can afford to withstand from the range of 0Nm to 0.16Nm.For the DIP joint for the finger, during the movement is at the maximum position of the parabolic circular motion, the force acting to the DIP is 0.00195 Nm. The force exerted to the DIP joint is -0.00195Nm and it is not exceed the maximum value of force that can be exerted to the DIP joint 0.29Nm. Therefore, to reduce the force exerted to the finger from finger rehabilitation robot, the limit position 1cm from initial point and 1cm from final point need to reserve. This is to make the safety precaution to the finger rehabilitation robot when there have the jerk during the movement of end effector. This also will avoid the unwanted accident from the robot motion during the rehabilitation that may cause the serious injury to the patient's finger.

The figure 4.3.5.2 show the different between the MCP joint forces with the different number of the acceleration of the joints robot. This comparison is made to show the analysis for the suitable acceleration of the joints robot that produce least jerk at the MCP joints. Based on the analysis, the trend show the increasing number of jerk at the robot if because the increasing number of the acceleration of the joints robot. Moreover, from the analysis, the suitable robot joints acceleration is 0.3 deg/sec^2.This acceleration is suitable to minimize the jerk in the robot finger rehabilitation with the maximum time taken to complete one cycle of the rehabilitation movement. Therefore, by reducing the acceleration to 0.3deg/sec^2, the posture of the finger joints will be more comfortable and the injury able to reduce.

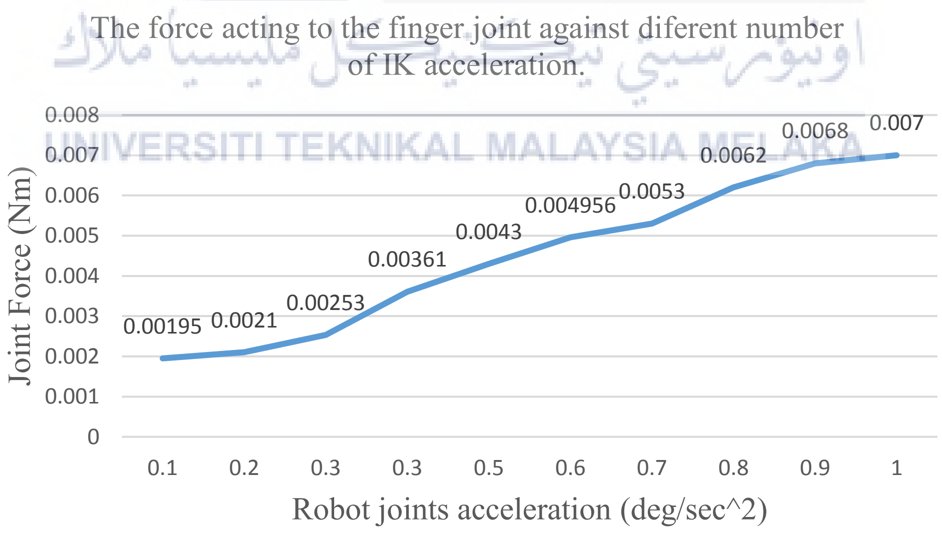

Figure 4.3.5.2: The MCP joint force vs different robot joints acceleration.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

The result show that to generate the trajectory motion for the end effector of finger rehabilitation robot to move in the parabolic of circular motion, the fifteen path point is used in order to generate the smooth trajectory motion for the end effector. The percentage accuracy for the fifteen path point in this motion is 97.2 percent compare to 100 percent and the percentage of error is 2.8 percent. Furthermore, one of the problem in this investigation in terms of different length for index finger have been solve. By using the parabolic equation, the trajectory for different length of finger can be determine. The movement also is same with the normal human finger motion. The finding support the objective to investigate the finger for rehabilitation using 5DOF robotic arm is success. The parabolic equation can give full motion for robot to control and move the finger during rehabilitation session with absolute error 0.067m for x-axis and 0.044m for y-axis. The motion is close the real finger motion. The design for the velocity and acceleration limit for the end effector need to below the $10m/s$ and $0.3m/s^2$ respectively in order to minimize the jerks and reduce the finger muscle from getting hurt. Therefore, with that result, the objective design the Angular position (x_i, x_f), angular velocity (v_i, v_f) and angular acceleration (a_i, a_f) of the finger rehabilitation robot using KUKA Youbot robot is able to achieve. This will conclude that the evaluation the control of finger using 5 degree of freedom robot during the finger rehabilitation using V-REP software can be done by using all the method in this investigation. Therefore, the finger rehabilitation robot using 5 degree of freedom is reliable to provide the rehabilitation for the patient finger and the simulation able to provide the valid result to be implement in the real human robot finger rehabilitation due to this simulation follow the most characteristic of the real human finger.

5.2 Future work

For future work in, the movement of end effector will using Linear Function with parabolic blend to make need to implement in this project in order to make the movement in smooth motion. This control finger for rehabilitation will be implement in hardware robot. The variation for the movement of the end effector during the rehabilitation session will be done to find the most accurate technique.

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APPENDIX A

The programming code for the KUKA Youbot for finger rehabilitation robot using LUA language.

```
setIkMode=function(withOrientation)
  -- simSetThreadAutomaticSwitch(false) -- Don't get interrupted for this function
   if (ikMode==false) then
      simSetObjectPosition(gripperTarget,-1,simGetObjectPosition(gripperTip,-1)) --
gripperTip
   end
   if (withOrientation) then
      simSetExplicitHandling(ikWithOrientation1,0)
      simSetExplicitHandling(ikWithOrientation2,0)
   else
      simSetExplicitHandling(ik1,0)
      simSetExplicitHandling(ik2,0)
   end
   for i=1,5,1 do
      simSetJointMode(armJoints[i],sim_jointmode_ik,1)
   end
   ikMode=true
   simSetThreadAutomaticSwitch(true)
end
setFkMode=function()
   simSetThreadAutomaticSwitch(false) -- Don't get interrupted for this function
   simSetExplicitHandling(ik1,1)
   simSetExplicitHandling(ik2,1)
   simSetExplicitHandling(ikWithOrientation1,1)
   simSetExplicitHandling(ikWithOrientation2,1)
```

```
  for i=1,5,1 do
    simSetJointMode(armJoints[i],sim_jointmode_force,0)
  end
  ikMode=false
  simSetThreadAutomaticSwitch(true)
end

openGripper=function()
  simTubeWrite(gripperCommunicationTube,simPackInts({1}))
  simWait(0.8)
end

closeGripper=function()
  simTubeWrite(gripperCommunicationTube,simPackInts({0}))
  simWait(0.8)
end

setGripperTargetMovingWithVehicle=function()
  simSetObjectParent(gripperTarget,vehicleReference,true)
end

setGripperTargetFixedToWorld=function()
  simSetObjectParent(gripperTarget,-1,true)
end

gripperTarget=simGetObjectHandle('youBot_gripperPositionTarget')

gripperTip=simGetObjectHandle('youBot_gripperPositionTip')

vehicleReference=simGetObjectHandle('youBot_vehicleReference')

vehicleTarget=simGetObjectHandle('youBot_vehicleTargetPosition'
```

```
--youBotArmJoint4=simGetObjectHandle("youBotArmJoint4")


armJoints={-1,-1,-1,-1,-1}
for i=0,4,1 do
   armJoints[i+1]=simGetObjectHandle('youBotArmJoint'..i)
end
ik1=simGetIkGroupHandle('youBotUndamped_group')
ik2=simGetIkGroupHandle('youBotDamped_group')
ikWithOrientation1=simGetIkGroupHandle('youBotPosAndOrientUndamped_group')
ikWithOrientation2=simGetIkGroupHandle('youBotPosAndOrientDamped_group')
gripperCommunicationTube=simTubeOpen(0,'youBotGripperState'..simGetNameSuffix(ni
l),1)
--ikSpeed={50,50,50,50} --0.2
ikSpeed={0.2,0.2,0.2,0.2} --0.2
ikAccel={0.3,0.3,0.3,0.3} --0.1
ikJerk={0.9,0.9,0.9,0.9}  --0.1
--fkSpeed={0.1,0.1,0.1,0.1,0.1}
fkSpeed={10,10,10,10,10}
fkAccel={0.6,0.6,0.6,0.6,0.6}
fkJerk={10,10,10,10,10}


setGripperTargetMovingWithVehicle()
setFkMode()
openGripper()
setIkMode(true)
-----User initialization------------
Ystart=0.07300
Zstart=0.18003
Ymax=0.029375
Zmax=0.27302
Yend=-0.082
```

```
Zend=0.35
-------Parabolic Equation-----------
a = (Zmax-Zstart)/((Ymax-Ystart)*(Ymax-Yend))-- to find (a)
shift = 0.006666667 --shift for next path point
k= {0,Ystart,Zstart}
for h=1,1,1 do --repitition for the rehabilitation cycle
for i=1,15,1 do --enter how many path point
if (k[3]<Zend)then
simRMLMoveToPosition(gripperTarget,-1,-1,nil,nil,ikSpeed,ikAccel,ikJerk,k,nil,nil) --
move the kuka end effector
closeGripper()
k[1]=0
k[2]=k[2]-shift
k[3]=(Zstart)+ a*((k[2]-Ystart)*(k[2]-Yend))  --parabolic equation
print(k[1],k[2],k[3]) --print to the vrep console
end
end
--end effector reverse back to initial position--
for i=1,15,1 do
if (k[3]<Zend+0.1)then
simRMLMoveToPosition(gripperTarget,-1,-1,nil,nil,ikSpeed,ikAccel,ikJerk,k,nil,nil)
closeGripper()
k[1]=0
k[2]=k[2]+shift
k[3]=(Zstart)+ a*((k[2]-Ystart)*(k[2]-Yend))
print(k[1],k[2],k[3])
end
end
end
openGripper()
```