TRAJECTORY CONTROL OF A DELTA ROBOT FOR TELESCOPIC MAST SYSTEMS ASSEMBLY

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TRAJECTORY CONTROL OF A DELTA ROBOT FOR TELESCOPIC MAST SYSTEMS ASSEMBLY

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ABSTRACT

TRAJECTORY CONTROL OF A DELTA ROBOT FOR TELESCOPIC MAST SYSTEMS ASSEMBLY

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In this study, trajectory control of a Delta Robot with three degrees of freedom was carried out. The design of Delta Robot has been examined. The images of the components of the robot are shared with the components. The Telescopic Mast System has been examined and the contribution of Delta Robot on this system has been demonstrated. Delta Robot's Workspace Analysis has been done by" Trajectory Control" and how to follow the path is described. The most efficient path was selected and a trajectory control was done on a determined path. A simulation was created in the MATLAB Simulink Multibody Environment, inverse kinematic codes were placed in the system and a PID control system was added. PID optimization was performed by using MATLAB Optimization Toolbox. This assembly system is simulated with the MATLAB Simulink program and the results are shared.

Keywords: Parallel Manipulator, Trajectory, Delta Robot.

ÖZ

BİR DELTA ROBOT'UN TELESKOPİK MAST SİSTEMLERİ İÇİN YÖRÜNGE KONTROLÜ

GÜL, Özgün

Yüksek Lisans, Makine Mühendisliği Anabilim Dalı

Tez Yöneticisi: Yrd.Doç.Dr. Özgün Selvi (Çankaya Üniversitesi)

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Bu çalışmada, üç derece serbestlik derecesine sahip bir Delta Robotun yörünge kontrolü gerçekleştirilmiştir. Delta Robot tasarımı incelenmiştir. Robotu oluşturan bileşenlerin tanımlanmış ve görevleri anlatılmıştır. Teleskopik Mast Sistemi incelenmiş ve Delta Robot'un bu sisteme katkısı analiz edilmiştir. Delta Robot'un "Çalışma Alanı Analizi" yapılmıştır. Yörünge kontrolü ve bu yörüngenin kontrolünün nasıl yapılacağı anlatılmıştır. En verimli yol seçilmiş ve belirlenen bir yolda bir yörünge kontrolü yapılmıştır.MATLAB Simulink Multibody ortamında bir simülasyon oluşturulmuş, ters kinematik kodları sisteme yerleştirilmiş ve bir PID kontrol sistemi eklenmiştir. PID optimizasyonu, MATLAB Optimization Toolbox kullanılarak yapılmıştır. Bu montaj sistemi MATLAB Simulink programı ile simüle edilmiş ve sonuçlar paylaşılmıştır.

Anahtar Kelimeler: Paralel Manipülator, Yörünge, Delta Robot.

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It has been a great pleasuret express my special thanks to my lovely family and my friends for their unrequited supports .

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LIST OF ABBREVIATIONS

CTC	Computed Torque Control
MDDS	The Manifold Deformation Design Scheme
ANFIS	Adaptive Neuro-Fuzzy Inference System
DMOC	Discrete Mechanics and Optimal Control

CHAPTER 1

INTRODUCTION

Over the past 20 years, technology has changed the infrastructure of the production and installation methods. Conventionally, manpower has been used extensively for manufacturing and assembly purposes. With the introduction of computers and technology in the industry, automation has become a must. Automation allowed companies to mass-produce products at high speed and high capacity, with exceptional speeds and repeatability and quality.
Today, robotic solutions are widely used by companies for automation.

1.1 Motivation

This paper provides information about how to increase accuracy, and performance with Delta Robot and to make mass production and assembly more efficient. In this project, it is aimed to make assembly proceedures more efficient by introducing Delta Robots to the assembly line of MILMAST products. The MILMAST Telescopic Mast Systems product family can be used on any land or offshore platform for civil or military purposes. MILMAST has 3, 4 and 8-meter mast towers when fully extended. The application areas of these products range from search and surveillance, electronic communication and war, target collection devices, weapon turrets, sensor and radar systems, fire fighting applications.

1.2 Background

The Telescopic Mast System requires robot manipulators which benefit from automation advantages. There are basically two types of robotic manipulators: serial and parallel.

The serial robots are consist of several components that are connected in serial, such as the rotary and prismatic connection types. Base plate of the robot is fixed with the joints used, while travelling plate is free to move in space.

A parallel robotic manipulator comprise a kinematic array in which the end effector is connected to a traveling platform and the traveling platform is connected to the fixed platform with at least two arms to the fixed base platform. Advantages:

Light: In parallel manipulators, the motors, which are the heaviest components in the system, are integrated into the fixed platform. Parallel manipulators are light because the legs are light.

Fast: When the same amount of power is used, a parallel robot moves faster than the serial robot.

Strong: In the form of a closed robot against external force, the end effector supported by the kinematic legs is more rigid than the serial robots. If the legs are long and heavy, they will be weak.

Accurate: Parallel robots are more sensitive than serial robots. The reason for this is that the assembly of parallel robots can provide this.

Parallel manipulators are intended to be used in installations of the Telescopic Mast System to make assembly more precise, safer and more economical. Trajectory planning is required for this selection and placement of the Telescopic Mast System.

1.2.1 Trajectory Planning for Pick and Placement

The number of joints defines the movement of the robot and can also use. Although unpredictable movements may occur during the start and end path, the robot reaches the desired position by these methods.

A three-dimensional parallel manipulator was selected for this project. The delta robot has many advantages such as precision, robustness and handling of large loads. For this reason, this robot can be used in the assembly of the Telescopic Mast System.

1.2.2 Delta Robot's History

Today, delta robots are well established in the automation industry. Delta robots are preferred by many manufacturers as stock item.

- The history of parallel robots goes back to 1938 when Pollard filed his patent application about a "Position Controlling Apparatus" for car painting. [1]
- The foundation for parallel robot was laid down in 1947 by Gough. He established the kinematic structure that allows positioning and orientating a moving platform. He built a prototype of this machine in 1955. [2]
- During the 1960s, Gough and Stewart designed a hexapod incorporating six prismatic actuators.[3]
- In the 1980s, Clavel invented a parallel robot at the École Polytechnique Fédérale de Lausanne (EPFL) known as Delta robot with three translational dof dedicated to high-speed application. [4]
- The industrial development started 1987, when the Swiss company Demaurex purchased a license from the EPFL to commercialize the Delta robot. [5]
- ABB Flexible Automation bought another license and launched its first Delta robot (i.e. IRB 340 FlexPicker) in 1999. [5]
- A three translational dof parallel cube-manipulator , was proposed based on the concept of DELTA robot (Liu et al., 2003). [6]

1.3 Literature Review

In this section, delta robot and its applications in the literature are shown.

Motion Control and Planning

The structure and kinematic analysis of Jian and Lou [7], in this study, Delta Parallel Robot which has been examined the design and assembly of this system is explained. An elliptical trajectory experiment of the Delta Parallel Robot was performed. The kinematic model of Delta Robot, the control structure of the servo system and the motion planning method were analyzed. Using elliptical experiments, they have approved the application and performance of the motion control system. This represents the data about the accuracy and stability of the Delta Parallel Robot system. Zhang et al. arc[8], works the optimal trajectory motion was performed using sine.Hsu et al. arc[9], motion planning and control using drawing robot system.

Pick and Place

Chen et al. arc. [10] described the lame curves used to smooth the motion trajectory. The trajectory receives the position, velocity and acceleration information of the interpolation points and the trajectory parameters are optimized with the minimum output energy function of the motor. In this study, the motion trajectory of the robot is sensitized by the curves and the position, velocity and acceleration of the trajectory points are calculated. Chen et al. arc. [11] define 3-freedom Delta Robot trajectory in the space for the pick and placement study was done.

Robust Control

Rachedi et al. arc. [12], in this study, dynamic model of parallel manipulator is nonlinear. The nonlinearity should be checked by using robust model. It is aimed to implement two model based control devices on a direct drive Delta robot. These controllers are H∞ and the CTC. Simulation results show us, the H∞ the linear dynamic model of the robot was used to visualised both the sensivity and complementary sensitivity matrices of the closed loop system. These controllers are more robust compared to the CTC controller. Lin et al. arc. [13], designed a smoothing robust control mechanism for Delta Robot. they used MDDS control method to tested the motion of delta robot. The related tests were performed and the MDDS control method was observed to have better control performance than PID. Lin et al. arc. [14] , works robust control for smooth control.

Dynamic Modelling and Control Simulation

Hao et al. arc. [15], in this study, examined the inverse dynamic modeling and control simulation of cable-modified delta robot. This examine based on virtual work principle. The trajectory tracking utilising a Pd torque control scheme has been referanced and the performance of this control unit simulated with MATLAB and ADAMS programs.

Path Following

Bishof et al. arc. [16], shows that rotary drive in 3D space by using examples of moving rigid body. For the Delta Robot FESTO EXPT – 45 has the kinematics and dynamics equations are very similar. The project identifies any appropriate path that can be parameterized to the PFC strategy, and the compatibility check is defined accordingly. The experimental verification, a proposed Delta Robot is used.

Workspace Analysis

Cha et al. arc. [17], Delta Robot's workspace of study has done. In this study in the study areas is necessary to determine the robot parameters were studied on the simulations.

Trajectory Planning

Haberfeld et al. arc. [18], present air manipulation design. The combined the ability of aerial movement and precision of trajectory points by using both Delta Robot and quadcopter. Simulation results support the theory behind the coupled system. In order to balance a quadcopter successfully, the mechanism and related equations have been developed, and then the most appropriate trajectory providing flexible task constraints has been followed.

In this study by Asgari and Ardestani [19], it was tried to draw attention to the fact that parallel manipulators moved very precisely to monitor the desired trajectory in engineering applications. This project presents an alternative methodology toward the common method for investigating this problem depend on the Adaptive Neuro-

Fuzzy Inference System (ANFIS) controller for low mobility parallel kinematic manipulators. Inverse kinematics model of the parallel robot was performed. For the inverse kinematics problem, the solutions generally show two possible poses for each limb. Since the dynamics of the robot is strongly influenced by non-linearity and disturbances, the neuro-fuzzy approach and accuracy of the Computed Torque Control C - T method have been described. Thus, the applicability of the ANFIS control method for this new mechanism has been proven and demonstrated by simulation. The best parameters for the fuzzy controller were determined using ANFIS.

In this study by Shareef and Trachtler [20], DMOC is a newly developed tech. for robotic man. which proposes a solution for the problem of trajectory optimization. The formulation of the trajectory optimization problem was determined and the DMOC method was applied to optimize the orbit on a specific geometric path. By taking into consideration of cost, DMOC method is more preferable than other methods that demonstrate the effectiveness and applicability.

Cheng et al. arc. [21] shows kinematics analysis of 3P-Delta parallel mechanism through the velocity and acceleration expressions, the singularity of the mechanism justified by Jacobian matrix. Boundaries of the workspace of the mechanism, was determined with the help of Jacobian matrix and inverse kinematics solution, which were optimized by genetic algorithm to define minimum global Jacobian conditions number. Trapezoidal velocity curve helps to construct the platform of mechanism and the trajectory of the mechanism. During the trajectory, the platform can follow the desired path.

Castañeda et al. arc. [22], in this study, it was aimed to solve the problem of trajectory monitoring for Delta Robot proposed adaptive control design in this Project. Thanks to the controller, it is also tested in results of real-time experiments converge on numerical simulations at many levels. Adaptive control is design for using a variation of the active decay frame. Speed measurements on the robot's ports are not used to improve the control action. The controller was simulated when applied in real time and the experimental result was obtained. Chen et al. arc. [23], worked trajectory planning using lame curve for 3 dof Delta Robot.Wang R. and Wang X. [24], is also study trajectory planning for Delta Robot.

General problems of path and trajectory planning

A robot must perform the functional movements in the work area. For this, the best trajectory should be found the object should be moved away from the trajectory area. For this purpose, the planning of the movement must be calculated correctly. It is possible to make efficient and functional movements by selecting the best from hundreds of alternatives. There are two critical situations that need to be considered in order to be able to plan the route correctly.

Singularities

There are critical points in the working area of a robot, robots can reach countless variations at these points. These points are called singularity. Generally, there are two types of singularities. These are arm and wrist singularities.

1.4 Thesis Overview

First of all, the robot was chosen for Telescopic Mast system. It was decided that this robot would be a delta robot. In Section 1.3, information about robots will be given. In this section, we will explain why parallel robots are selected and Delta Robot is suitable in our system.

In Chapter 2.1 there is the configuration of the delta Robot. The images of the components forming the robot will be shared with the components. The definition of the degree of freedom in Chapter 2.2, and the robot we will use in our system, will be given the mathematical calculation of this degree of freedom. In Chapter 2.4 the Telescopic Mast System will be examined. The purpose and system requirements of this system will be given in this section. In Chapter 2.5, Inverse Kinematics equations and how to apply them to the system will be explained. In Section 2.6, the Delta Robot Workspace Analysis will be analyzed. In Chapter 3 Trajectory Planning will be examined. Path Description and Path Generation will be discussed in this section. Cartesian Space Schemes and Joint Space Schemes will be examined in this section, as well. And applied graphics will be exhibited in this section. Then, applications were done in MATLAB program. Delta Robot's trajectory calculations were made. Later, a simulation was created in MATLAB Simulink Multibody environment and inverse kinematic codes were placed and a PID control system was added in Chapter 4. PID optimization was performed using the MATLAB optimization toolbox. The system was then simulated in MATLAB environment using predetermined trajectory models. There is conclusion of thesis in Chapter 5.

CHAPTER 2

DELTA ROBOT CONFIGURATIONS

2.1 Introduction

In industry, robotics and automation eliminate errors, improve quality and reduce production costs. Today's automation systems aim to increase efficiency and become a necessity for mass production and assembly.

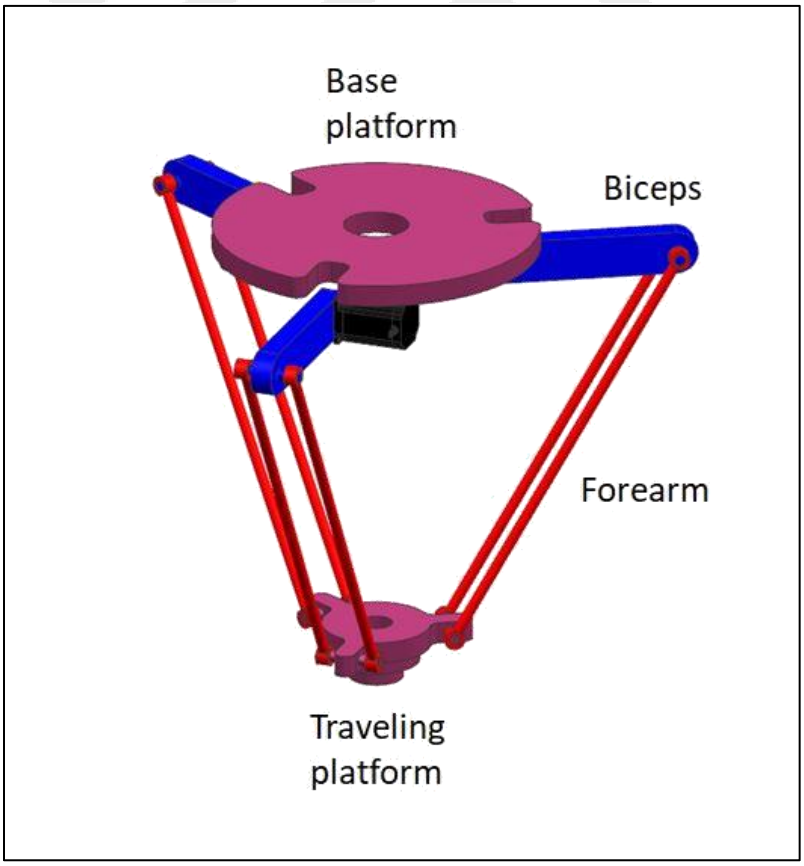


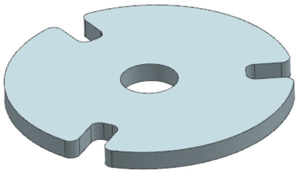
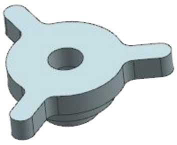
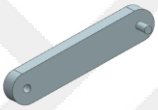
Figure 1. Delta Robot Assembly

High torque motors are integrated on the fixed platform. A motor is mounted perpendicular to the shaft axis of each motor. These biceps arms are connected with the forearm to limit the twisting movement. These arms are positioned. The connections in the forearm collar move freely through the ball joints and are connected to the movable platform. The desired operations can be carried out by the end effectors on the moving platform.

The basic structure of the delta robot consists of the following:

- **Base plate:** Base plate is fixed and it holds the motor.
- **Biceps arm:** Biceps arm transfers the motion from the motor to biceps through the joints.
- **Forearm:** Forearm holds the traveling plate and positions it at the desired position.
- **Traveling plate:** It holds the end-effector.

Table 1. Delta Robot Components

	Base plate
	Traveling plate
	Biceps arm
	Forearm

2.2 Degrees of Freedom

Determining the degree of freedom in robot applications is crucial. If a manipulator has 6 degrees of freedom, it can be as desired in space. The degree of freedom can be 3 or 4 according to the function of the robots. The number of movements of the robot can move is explained by the following figures.

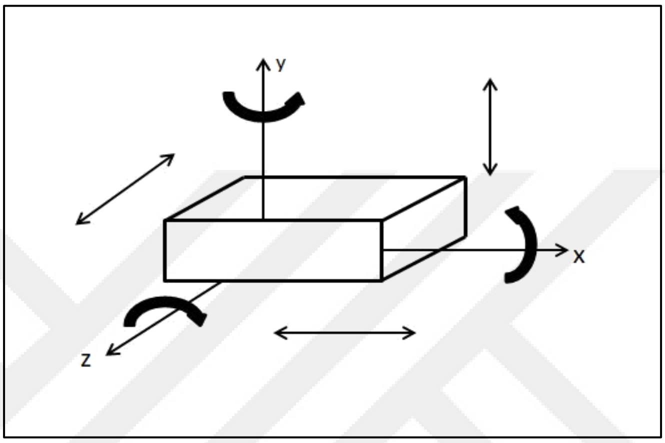


Figure 2. Degree of Freedom

The end effector can be positioned in the robot to increase the degree of freedom in the parallel robot. The end effector provides extra degree of freedom.

Using the spatial Kutzbach mobility equation for the Figure 1 Delta Robot figure:

$$M = 6\,(N-1) - 5J_1 - 4J_2 - 3J_3 \qquad (2.1)$$

$$M = 6\,(14-1) – 5(15) – 4(0) – 3(0)$$

$$M = 3 \text{ dof}$$

where:

M is the mobility, or number of degrees-of-freedom

N is the total number of links, including ground

J_1 is the number of one-dof joints

J_2 is the number of two-dof joints

J_3 is the number of three-dof joints

J_1 – one-dof joints: revolute and prismatic joints

J_2 – two-dof joints: universal joint

J_3 – three-dof joints: spherical joint

2.3 Telescopic Mast Systems

Telescopic Mast System has a wide range area of usage such as communication, military applications, lighting systems, surveillance thanks to its light, durable and reliable structure. The products provide high load capacity, speed, performance and efficiency together.

Figure 3. MILMAST Telescopic Mast Types

Assembling Telescopic Mast's bracket's fasteners by using Delta Robot is our main focus in order to increase efficency, for this reason, our system should be pricise.

Telescopic mast systems' overhead accessories are assorted such as antennas, routers, rotators, tilters, double rotators/tilters, extension tubes which are customable according to customer needs and desires.

Delta Robots are available for assembling these various accesories into interfaces which are between customer accessories to Telescopic Mast System because of desired precision between interface to accessories.

Pick and place, and correct placement features will be examined while assembling customers' accessories into Telescopic Mast's interface.

Working area of Delta Robots should be predetermined, the robot takes the fasteners from their position and will mount the fasteners to the Telescopic Mast Interface at the stated position and the installation will take a place.

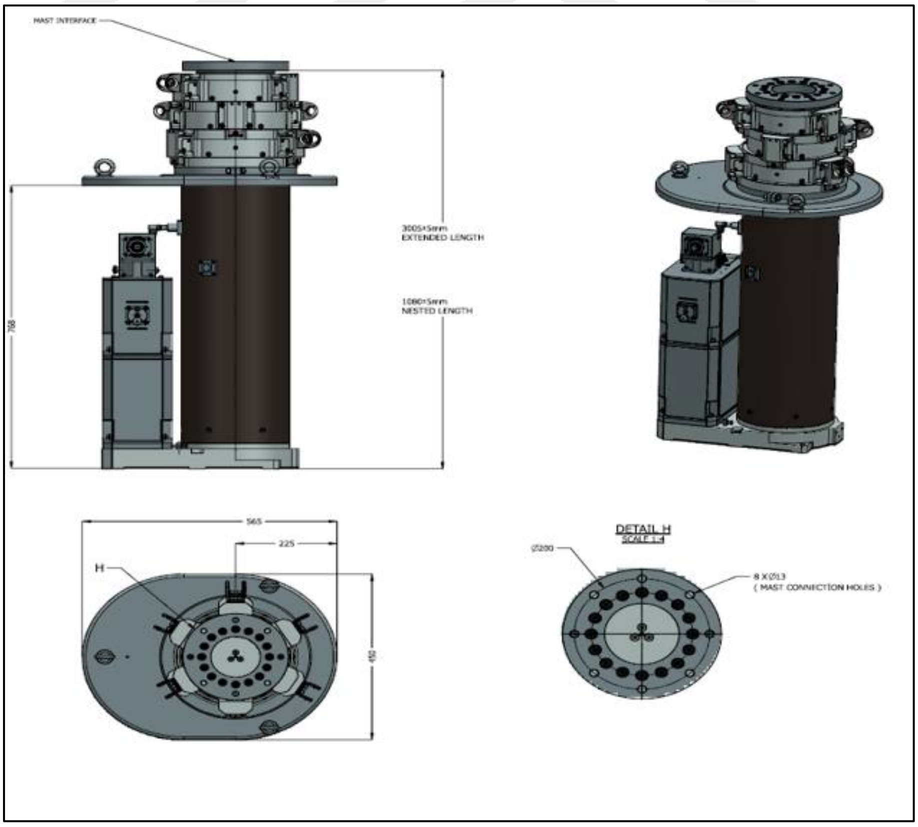


Figure 4. System Technical Drawing 1

The technical measurements of Telescopic Mast, Telescopic Mast Interface and Delta Robot are as follows:

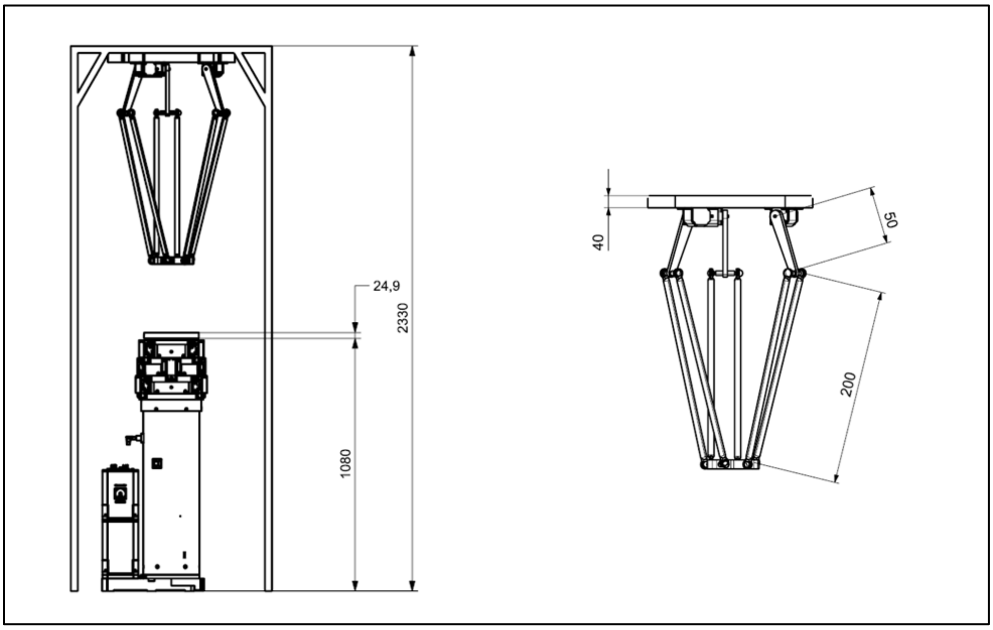


Figure 5. System Technical Drawing 2

2.4 Inverse Kinematics

Delta Robot inverse position kinematics is examined below:

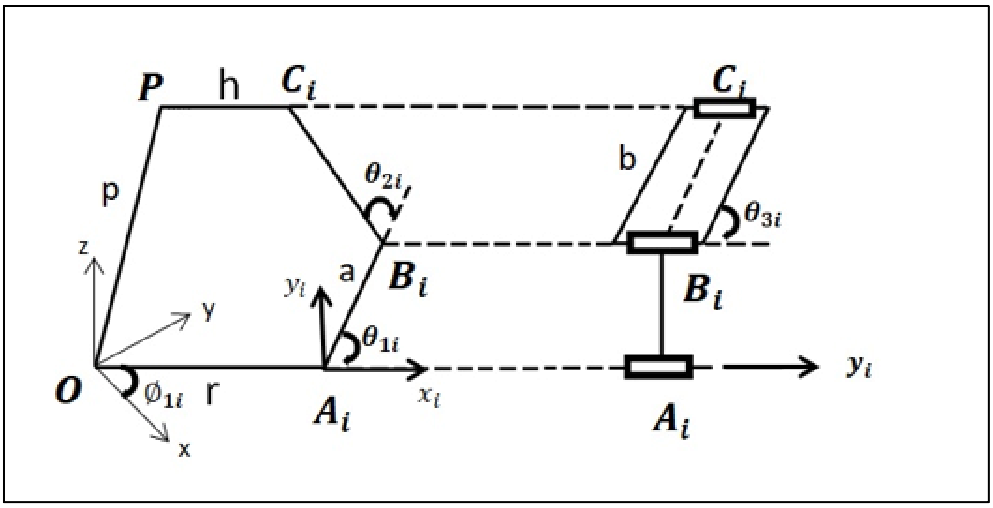


Figure 6. System Position Kinematics

The Jacobian matrix is obtained as follows.

$$J_\theta \begin{bmatrix} \dot{\theta}_{11} \\ \dot{\theta}_{12} \\ \dot{\theta}_{13} \end{bmatrix} = J_p \begin{bmatrix} \dot{p}_x = V_x \\ \dot{p}_y = V_y \\ \dot{p}_z = V_z \end{bmatrix} \tag{2.2}$$

$$\overrightarrow{OP} + \overrightarrow{PC_i} = \overrightarrow{OA_i} + \overrightarrow{A_iB_i} + \overrightarrow{B_iC_i} \tag{2.3}$$

In the matrix form we can write it as

$$\begin{bmatrix} ac\theta_{1i} + bs\theta_{1i}c(\theta_{1i} + \theta_{2i}) \\ bc\theta_{3i} \\ as\theta_{1i} + bs\theta_{3i}s(\theta_{1i} + \theta_{2i}) \end{bmatrix} = \begin{bmatrix} C_{xi} \\ C_{yi} \\ C_{zi} \end{bmatrix} \tag{2.4}$$

where

$$\begin{bmatrix} C_{xi} \\ C_{yi} \\ C_{zi} \end{bmatrix} = \begin{bmatrix} c\phi_i & s\phi_i & 0 \\ -s\phi_i & c\phi_i & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} + \begin{bmatrix} h - r \\ 0 \\ 0 \end{bmatrix} \tag{2.5}$$

For inverse kinematics, travelling platform's position vector is obtained and the moving platform can find the desired position by locating the angles θ_{11}, θ_{12}, θ_{13}.

θ_{3i} and θ_{2i} are solved from the following equations and θ_{1i} is found.

$$\boldsymbol{\theta_{3i}} = \cos^{-1} \frac{\mathrm{Cyi}}{b} \tag{2.6}$$

$$\boldsymbol{\theta_{2i}} = \cos^{-1} \kappa \tag{2.7}$$

$$\boldsymbol{\theta_{1i}} = \text{atan2}((ci(3,1) * L + l * (ci(3,1) * \cos\theta_{2i} ci(1,1) * \sin\theta_{2i} * \sin\theta_{3i} / (L\text{^}2) + l * \sin\theta_{3i} * (2 * L * \cos\theta_{2i} + l * \sin\theta_{3i})) , (\csc(theta\_3i) * (ci(1,1) * l * \cos\theta_{2i} + ci(1,1) * L * \csc\theta_{3i} + ci(3,1) * l * \sin\theta_{2i}) / (l\text{^}2) + (L\text{^}2) * \csc\theta_{3i} * (2 * l * \cos\theta_{2i} + L * \csc\theta_{3i}))) \quad (2.8)$$

for other two arms, the same process is required.

2.5 Delta Robot Workspace Analysis

The working area of the robots is directly proportional to the robot parameters. It is the operation of the robot in a wide range of operations which is desirable in robotic operations, but this will affect the robot dimensions at the same rate. For this reason, it is critical determining the robot parameters appropriately. Determining the parameters is the most significant part for workspace analysis.This paper analyzed the working area of delta robots which are the most used parallel manipulators. The delta robot has three arms and each arm consists of three rotating joints. One of these joints is a revolute joint, one is a connection and the other is a spherical joint. The spherical one has a limited rotation range and may affect the size of the work area. For this reason, a working area according to the dimensions of the robot will be removed. The following image shows the operating range of the robot to be used in the system. It was created by simulating in MATLAB environment.

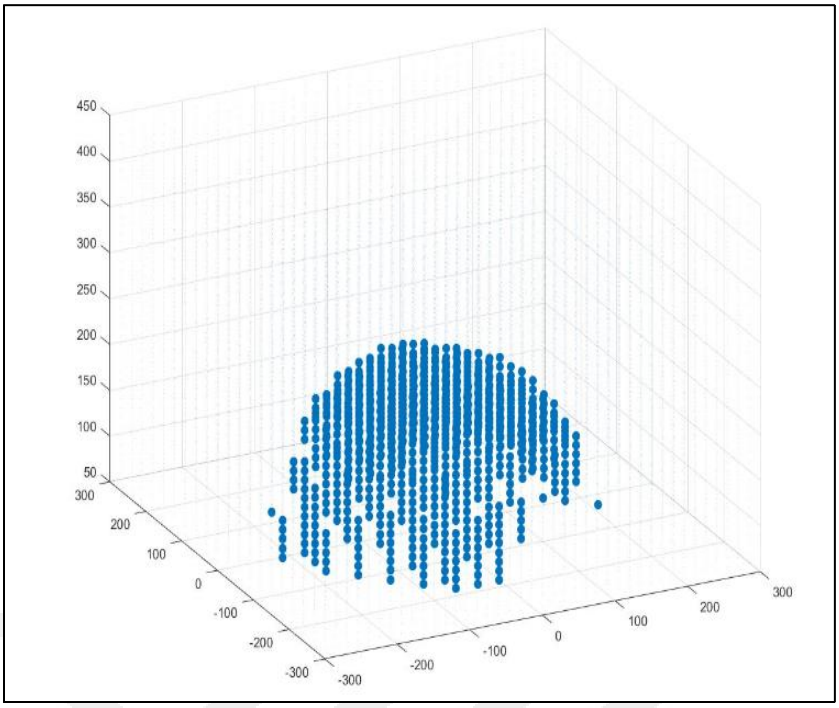


Figure 7. Delta Robot Workspace Analysis

CHAPTER 3

TRAJECTORY PLANNING

3.1 Introduction

The workspace area of a manipulator must be defined. It is a critical and important issue to define a suitable route according to the work to be done when designing the system. Generally, it is desirable that the motion of the parallel manipulator is smooth. To achieve this, an appropriate function must be defined.To provide smooth paths, restrictions must be made according to the characteristics of the path between the crossing points .

3.1.1 CartesianSpaceSchemes

The motion definition of the robot we used can be made and it can use Cartesian Space Schemes to define the trajectory position.The Cartesian-based path can be defined using the functions of time representing the variables. When the path is created in Cartesian space, the angles of the joint are calculated by inverse kinematic equations.

3.1.2 Joint Space Schemes

Each point of path is usually determined by a desired position and orientation of the robot. The joint passing through the transition points and going to the target point must be smooth. In the Cartesian method, the desired position is determined at each point. In this way, joint space schemes reach the desired position at certain points. At these points, the shape of the route is simpler than the Cartesian method.

3.1.2.1 Cubic Polynomials

The time between the first position and the desired position of the parallel manipulators is critical. Using the inverse kinematics equations, the joint angles between the target position and the starting position are computed. The initial position of the parallel manipulators is given, so that the angle of the joints is determined.

For a more smooth motion, the values at the start and end position of the path can be used.

$$\theta(0)= \theta_0 \tag{3.1}$$

$$\theta(t_f)= \theta_f \tag{3.2}$$

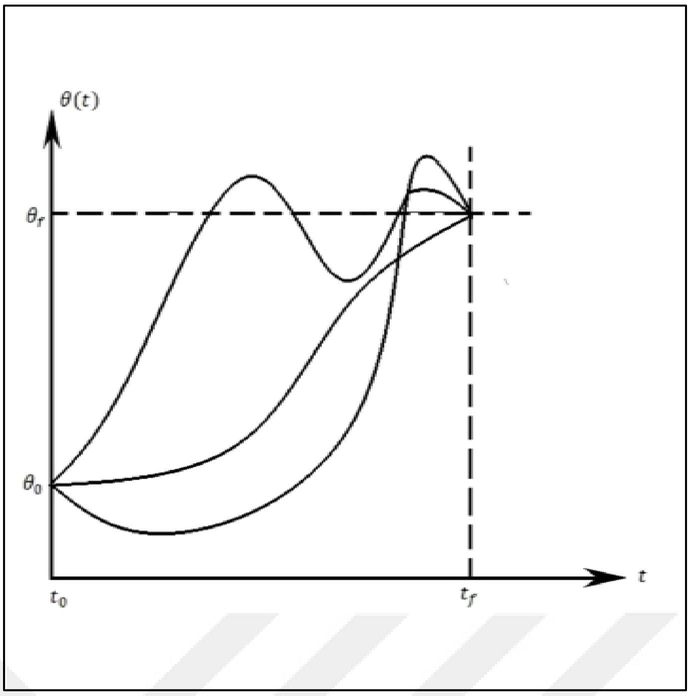


Figure 8. Cubic Polynomials of Trajectory Planning

The function must be continuous. The continuous velocity indicates that the initial and last velocity should be zero. The related derivatives are taken:

$$\dot{\theta}(0) = 0 \quad (3.3)$$

$$\dot{\theta}(t_f) = 0 \quad (3.4)$$

Since a cubic polynomial has four coefficients, a polynomial of at least third order is used.

$$\theta(t) = a_0 + a_1t + a_2t^2 + a_3t^3 \quad (3.5)$$

Thus, velocity and acceleration are found in the following form.

$$\dot{\theta}(t) = a_1 + 2a_2t + 3a_3t^2 \quad (3.6)$$

$$\ddot{\theta}(t) = 2a_2 + 6a_3t \quad (3.7)$$

There are four equations with four unknowns:

$$\theta_0 = a_0 \quad (3.8)$$

$$\theta_f = a_0 + a_1t_f + a_2t^2_f + a_3t^3_f \quad (3.9)$$

$$0 = a_1 \quad (3.10)$$

$$0 = a_1 + 2a_2t_f + 3a_3t^2_f \quad (3.11)$$

Solving these equations for the a_i we provide,

$$a_0 = \theta_0 \quad (3.12)$$

$$a_1 = 0 \quad (3.13)$$

$$a_2 = \frac{3}{t2f}(\theta_f - \theta_0) \quad (3.14)$$

$$a_3 = \frac{-2}{t3f}(\theta_f - \theta_0) \quad (3.15)$$

This solution is valid in the zero state of the speed at the start and end position.

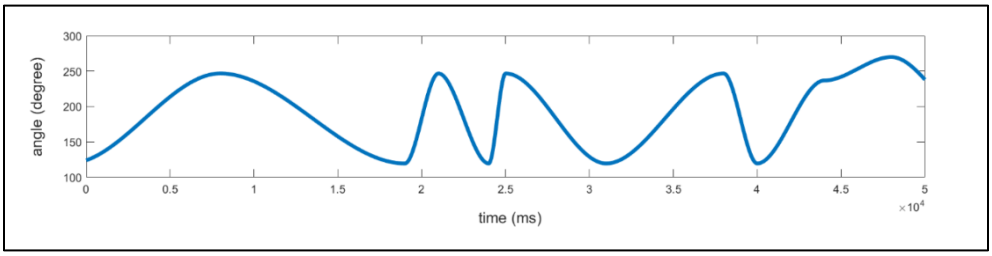


Figure 9. Cubic Polynomial for Motor 1

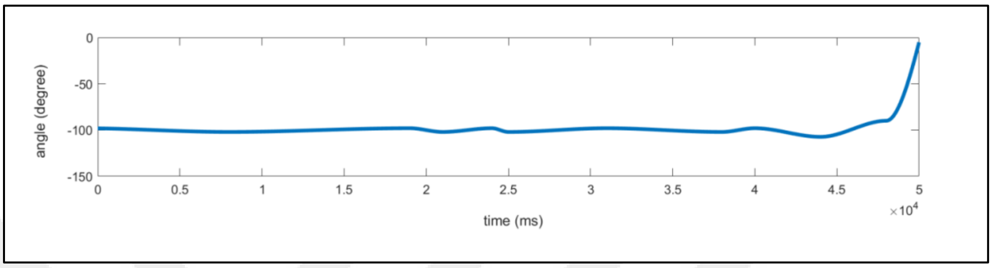


Figure 10. Cubic Polynomial for Motor 2

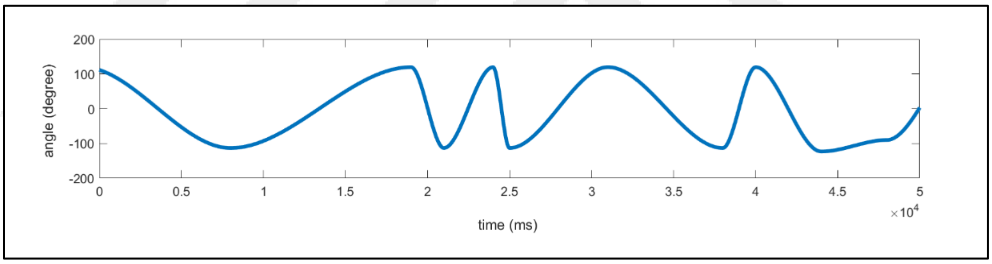


Figure 11. Cubic Polynomial for Motor 3

3.1.2.2 Linear Function with Parabolic Blends

The other path shape selection is linear. In this method, making interpolation between the current joint position and the final position by passing a straight line in space.

However, forward linear interpolation alone is not sufficient. To create a smooth path, parabolic blends are used on some parts of the point of path.

$$\ddot{\theta}(t_b)=\frac{\theta_h-\theta_b}{t_h-t_b} \quad (3.16)$$

$$\theta_b= \theta_0+ \frac{1}{2}\,\ddot{\theta}t_b^{2} \quad (3.17)$$

where $t = 2t_h$

$$\ddot{\theta}\,(t^2_b) - \ddot{\theta}\,t\,t_b + (\theta_f - \theta_0) = 0 \quad (3.18)$$

The movement time t is the desired period of time. θ_f, θ_0, and t are given. Typically, an acceleration is selected, and corresponding. The adequate acceleration must be high enough to achieve correct results. To provide acceleration and others:

$$t_b - \frac{1}{2} + \frac{\sqrt{\ddot{\theta}^2 t^2 \;-\; 4\ddot{\theta}\;\;(\theta_f-\theta_0)}}{2\ddot{\theta}} \quad (3.19)$$

$$\ddot{\theta} \geq \frac{4(\theta_f-\theta_0)}{t^2} \quad (3.20)$$

The Joint Space Schemes method is simulated using Linear function using Cubic Polynomials and Linear function with parabolic blends equations in MATLAB media and is shown in the graphs below.

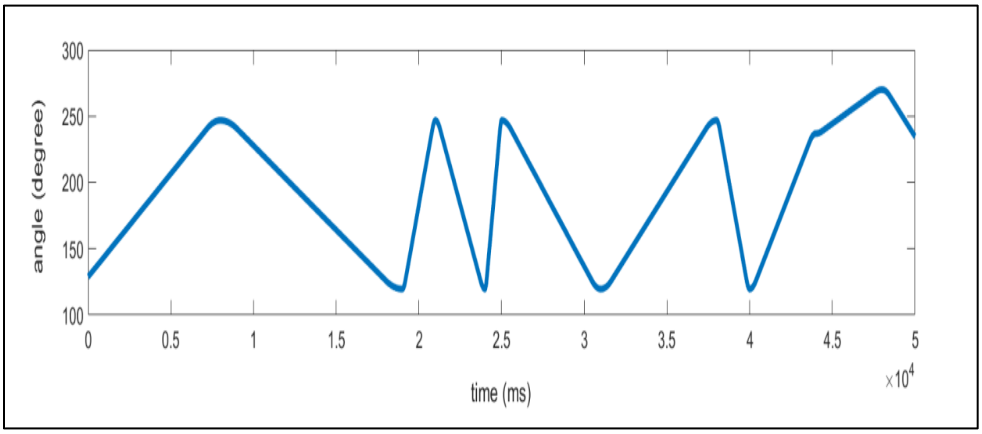


Figure 12. Parabolic Blend for Motor 1

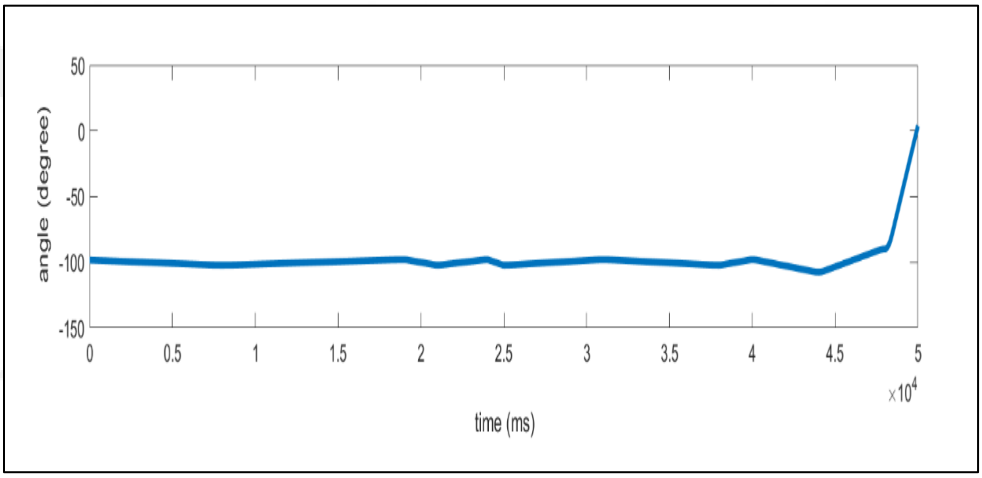


Figure 13. Parabolic Blend for Motor 2

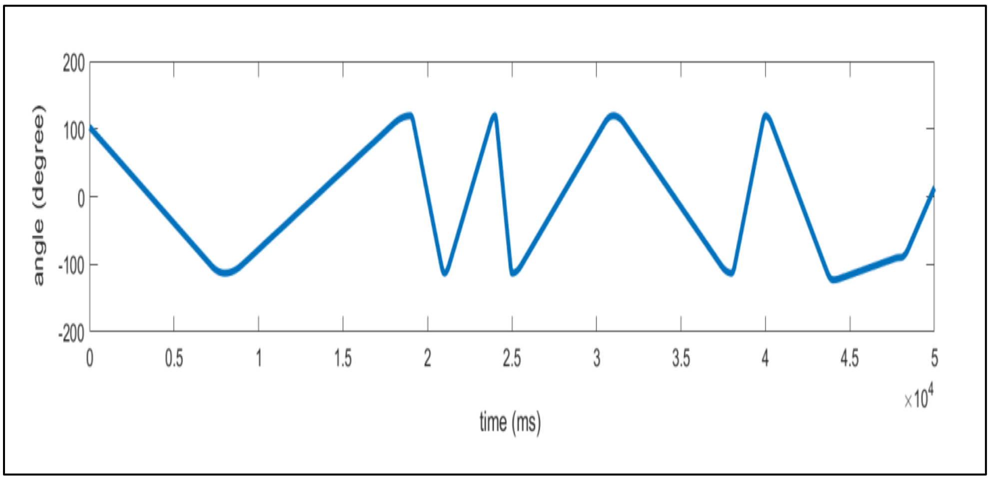


Figure 14. Parabolic Blend for Motor 3

CHAPTER 4

SIMULATION MODEL

4.1Simulation Methodology

The Telescopic Mast and Delta Robot were modeled in three dimensions in the Autodesk Inventor program. Then, this model is opened in simulink environment by using the tool in Autodesk Inventor program in xml format. Using the Inverse Kinematics equations given in previous chapters, the values of the inverse kinematic equations are determined for the determined path. The results of the elements used in the Matlab Simulink environment and the required entries of these elements will be shared.

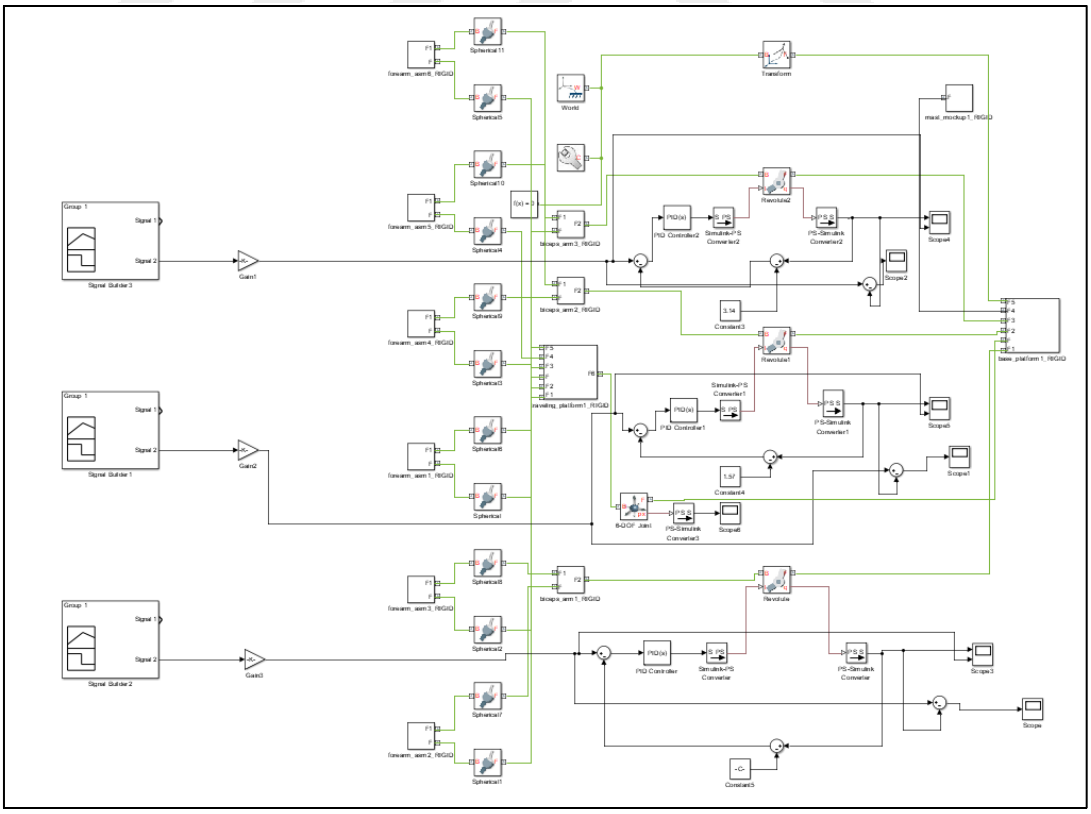


Figure 15. Telescopic Mast System MATLAB Simulink Model

The PID Controller is integrated into the system from the "Optimization Toolbox" section of the MATLAB Simulink program. The purpose of this is that each motor reaches the target angle in the specified time. Therefore, PID Controller is added to the system

4.2 Simulink Components

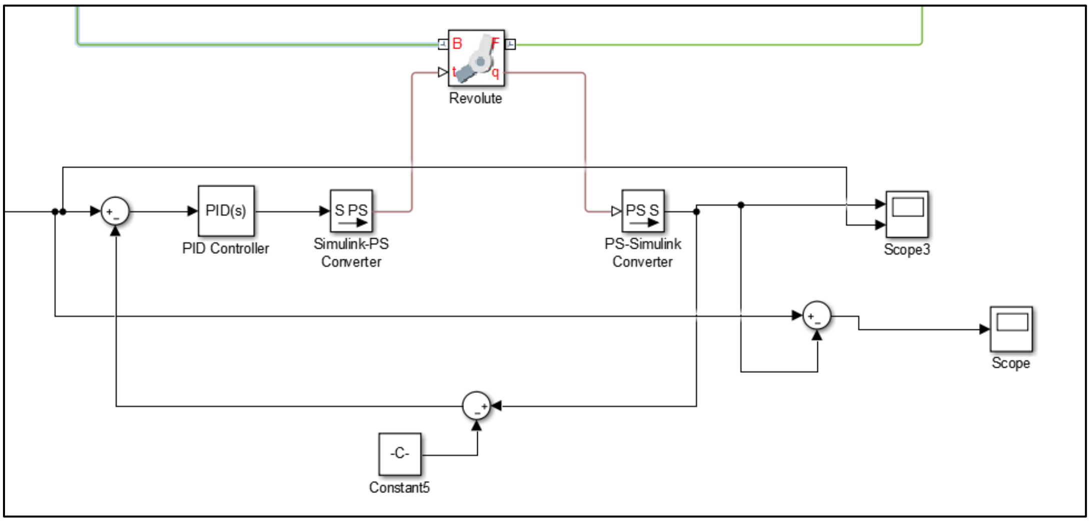
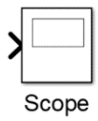
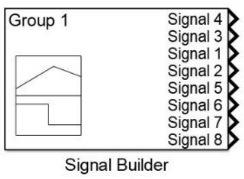
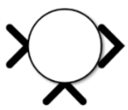
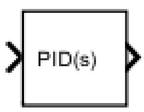


Figure 16. Simulink Model Detail

The system shows that there are three engines for three arms, three biceps arm, six forearm and one fixed platform and one movable platform.Components such as Simulink – PS Converter , PS – Simulink Converter , PID Controller , Matlab function , Scope and Sum were used to create simulations in Simulink.

Table 2. MATLAB Simulink Components

Symbol	Component name	Function
	Simulink – PS Converter	The Simulink-PS converter block is used to convert the input data on the Simulink to the physical signal.
	PS – Simulink Converter	The PS-Simulink Converter block is used to convert physical signals to the Simulink output signal.
	Scope	The data generated during a simulation can be viewed with this component.
	Signal Builder	Uses inserted function for input and output data.
	Sum	Adds matrix inputs and outputs to the system, executes related operations.
	PID Controller	The PID controler is used for each arm to reach the targeted angle in the targeted time.

4.3 Simulations Graphics

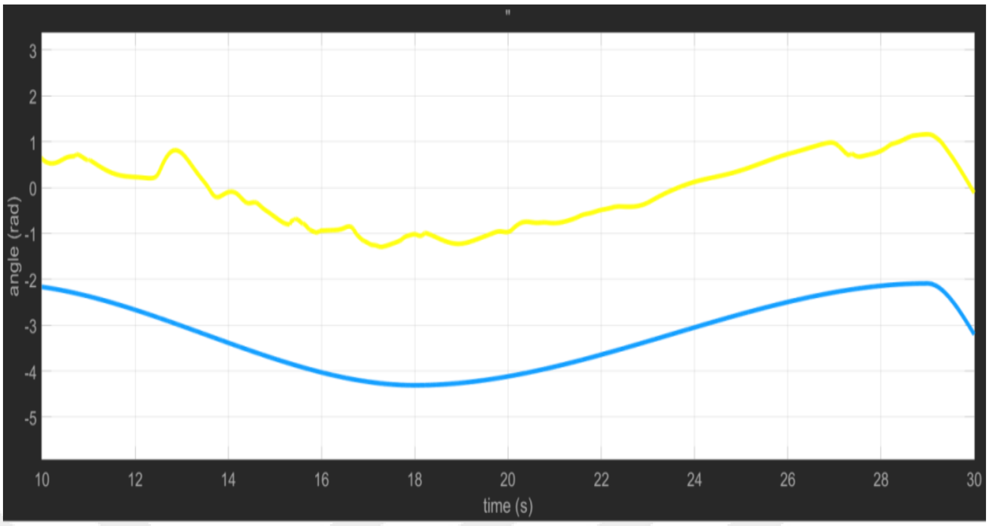


Figure 17. Motor 1 Objective and Cubic Path

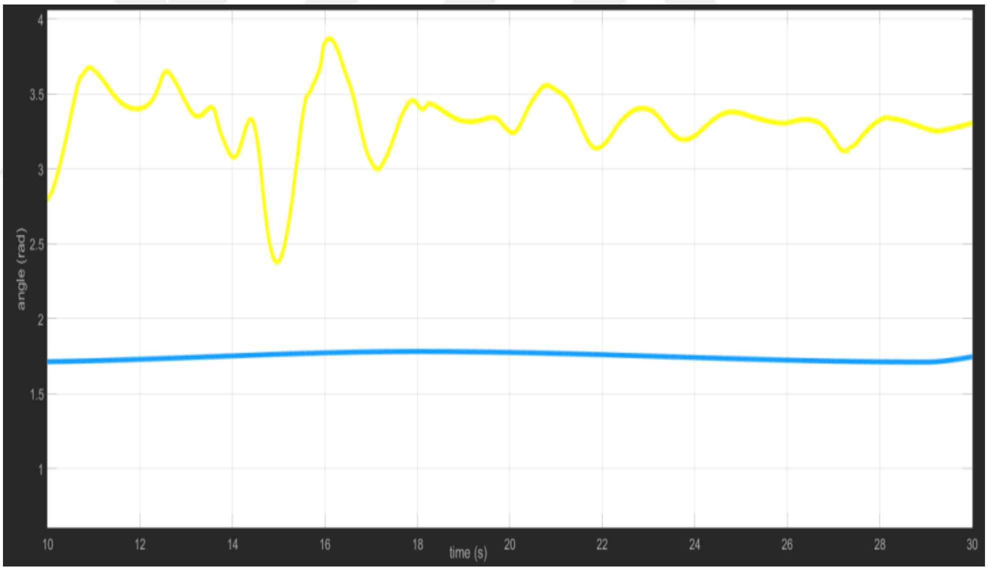


Figure 18. Motor 1 Error for Cubic

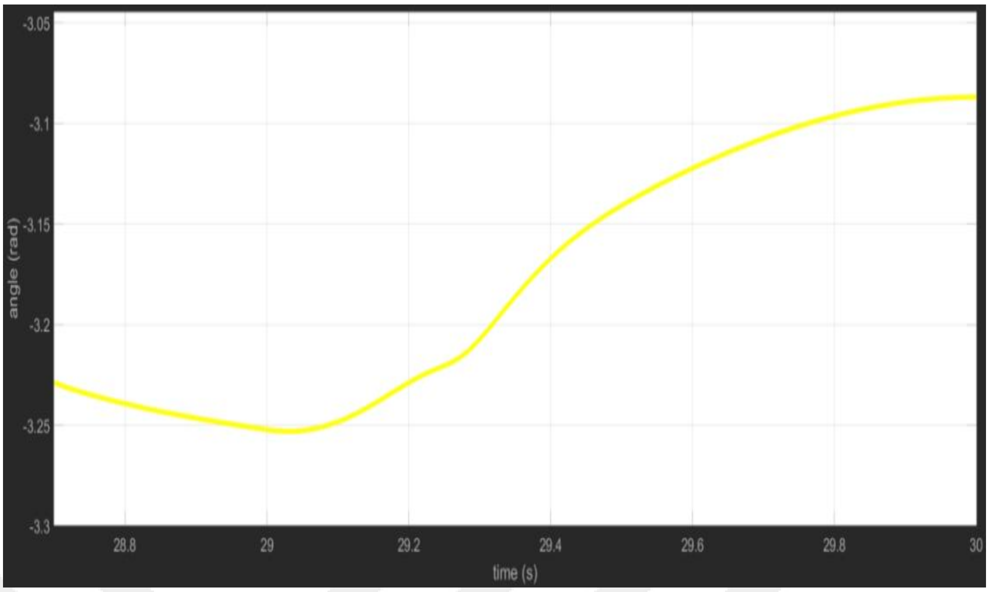


Figure 19. Motor 2 Objective and Cubic Path

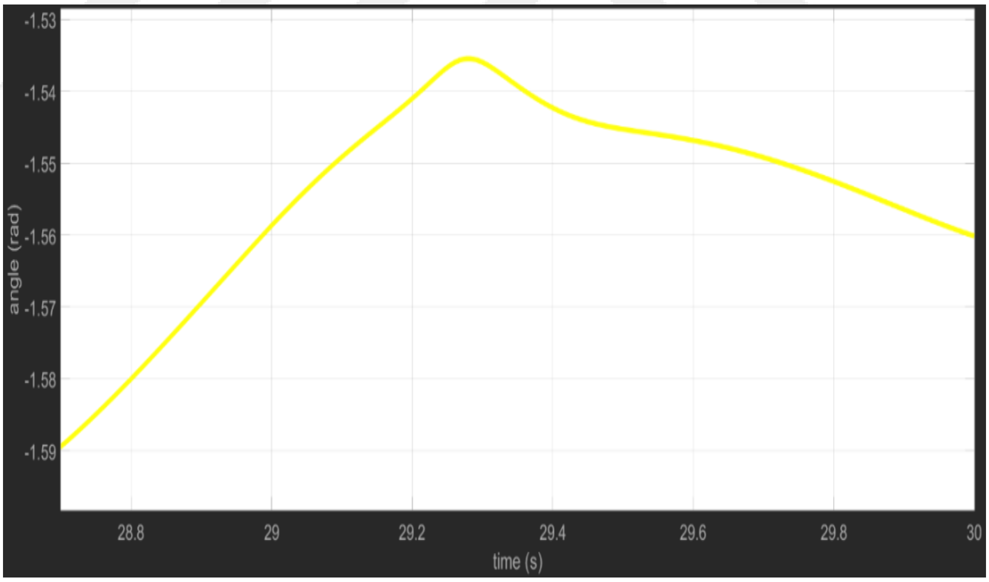


Figure 20. Motor 2 Error for Cubic

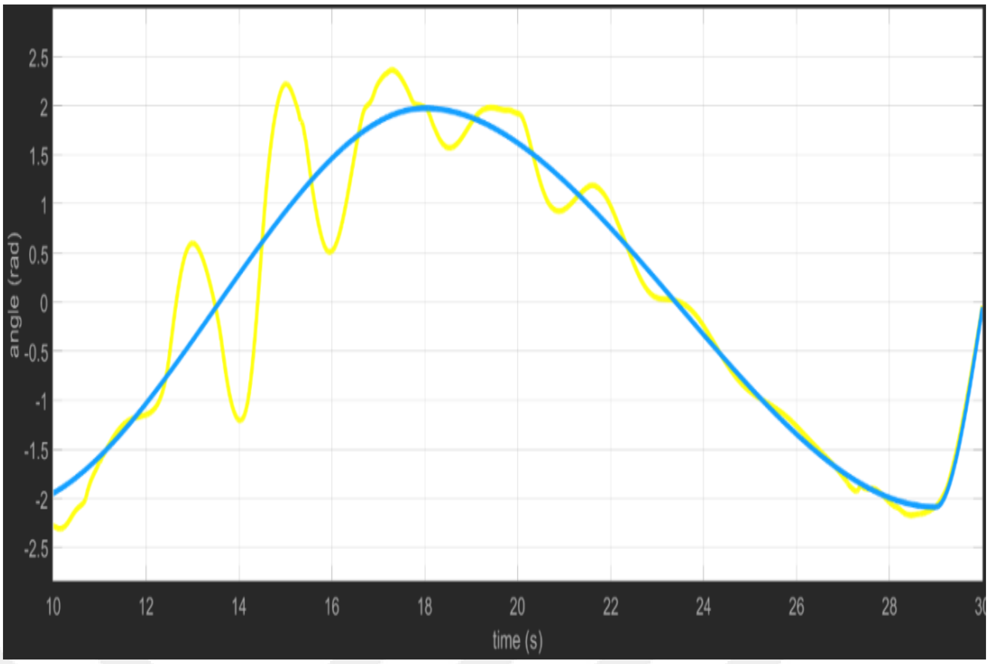


Figure 21. Motor 3 Objective and Cubic Path

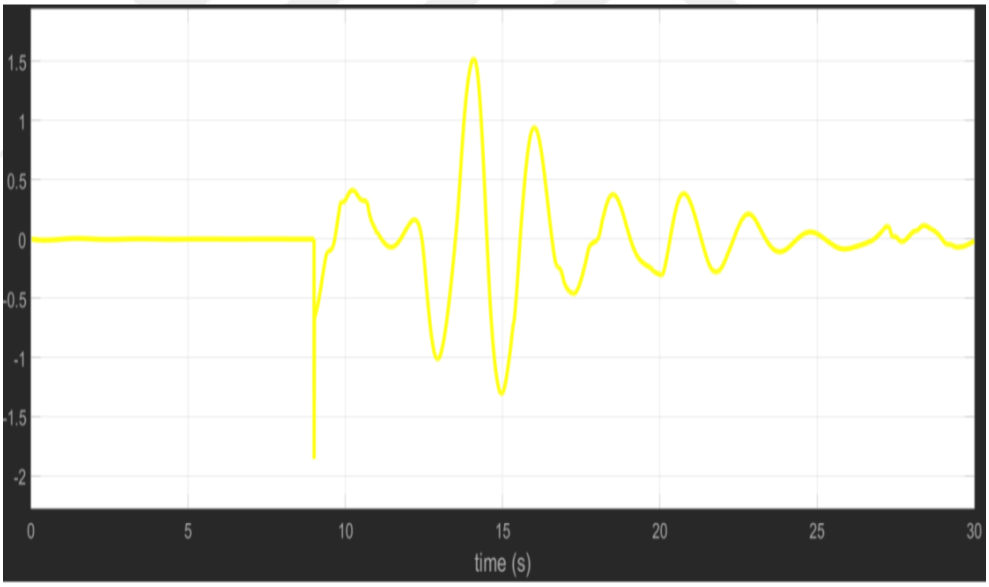


Figure 22. Motor 3 Error for Cubic

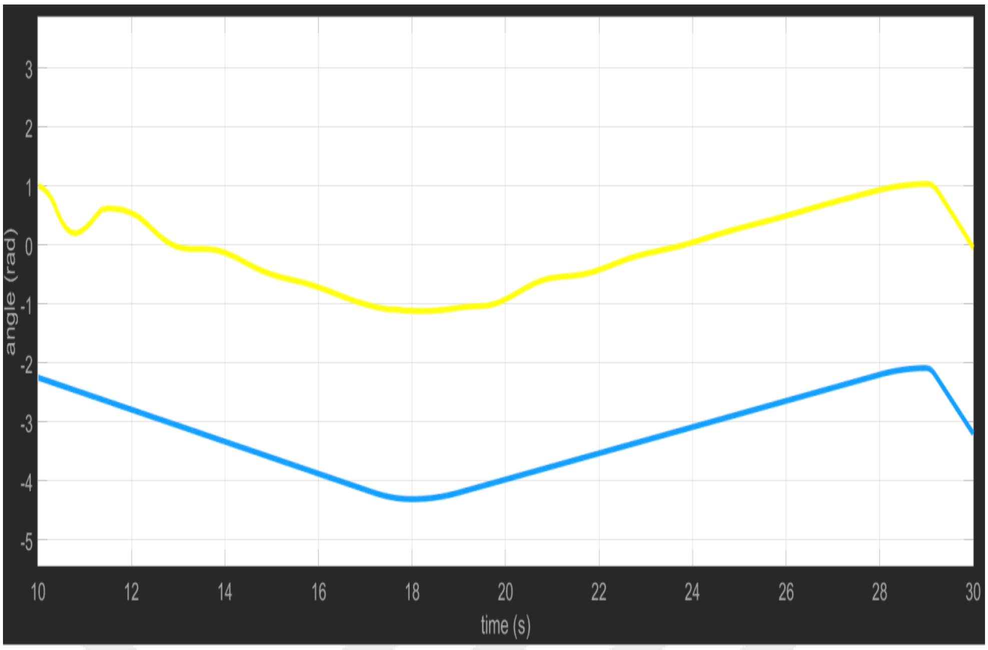


Figure 23. Motor 1 Objective and Parabolic Path

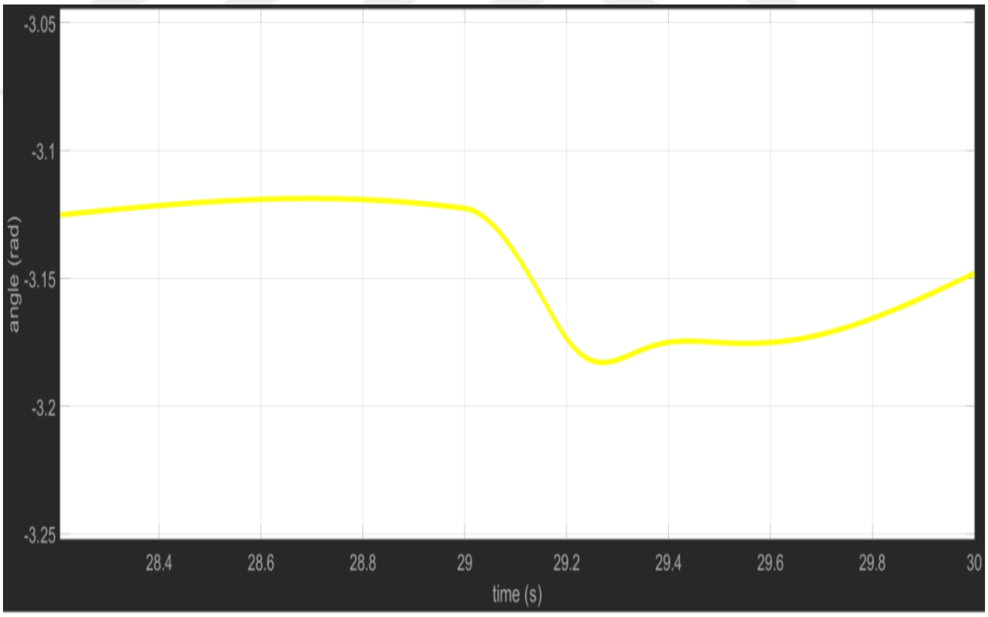


Figure 24. Motor 1 Error for Parabolic

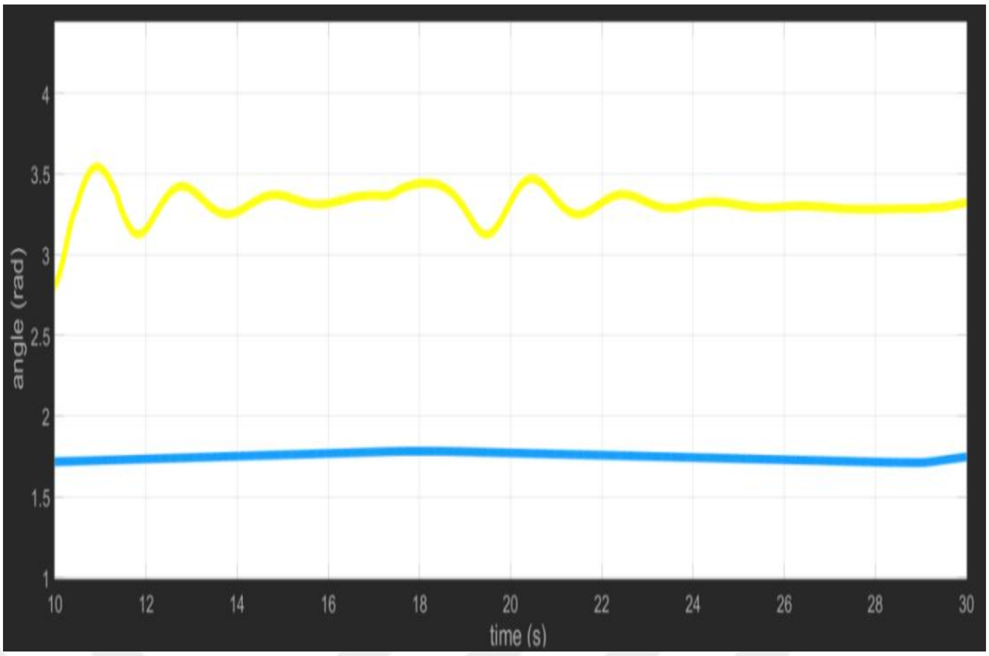


Figure 25. Motor 2 objective and parabolic path

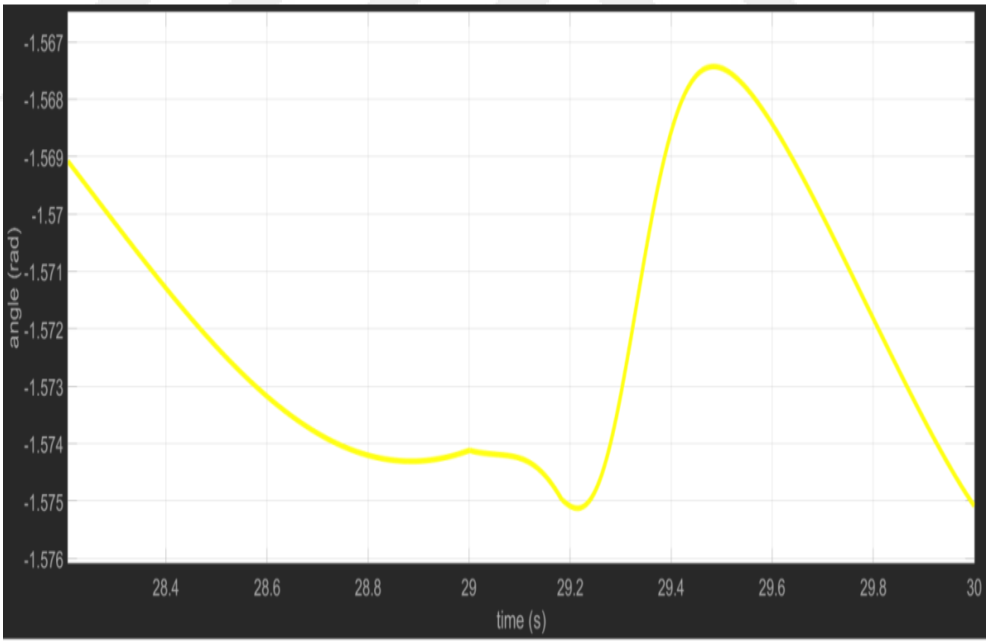


Figure 26. Motor 2 Error for Parabolic

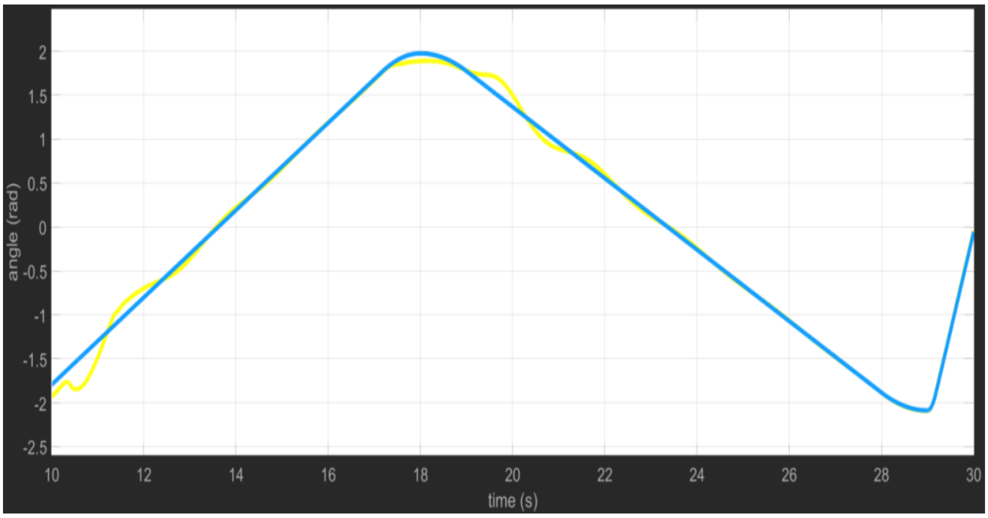


Figure 27. Motor 3 Objective and Parabolic Path

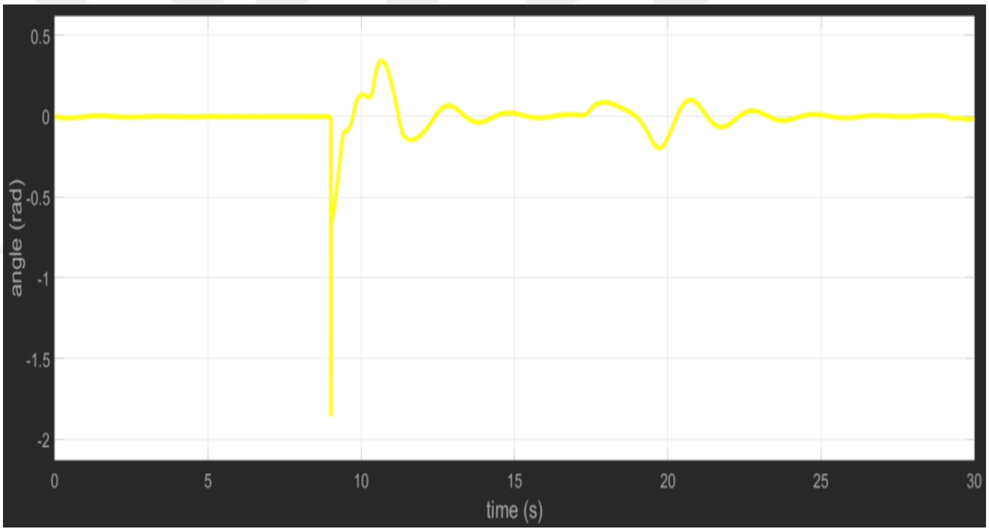


Figure 28. Motor 3 Error for Parabolic

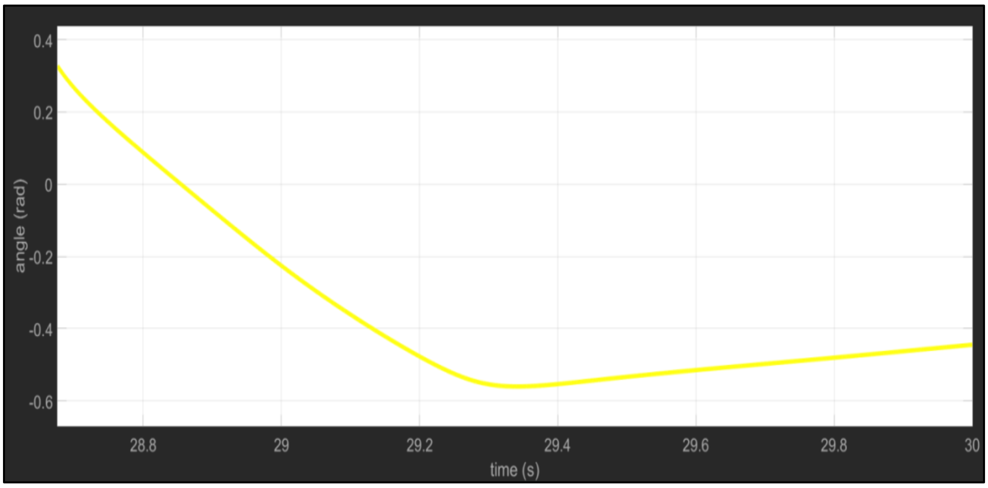


Figure 219. Objective and Cubic for x Direction

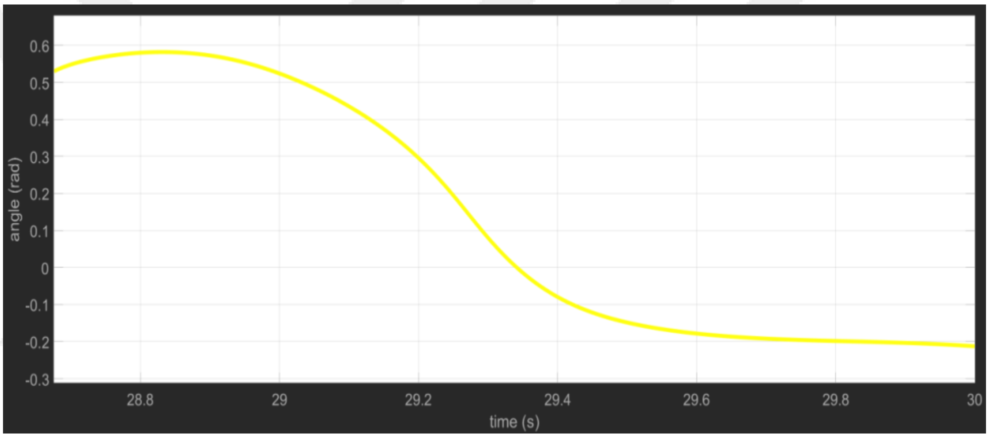


Figure 30. Objective and Cubic for y Direction

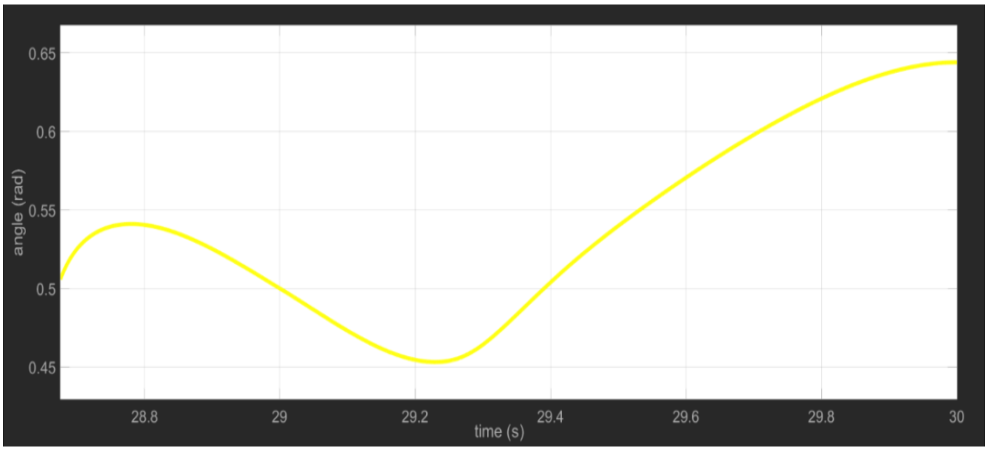


Figure 31. Objective and Cubic for z Direction

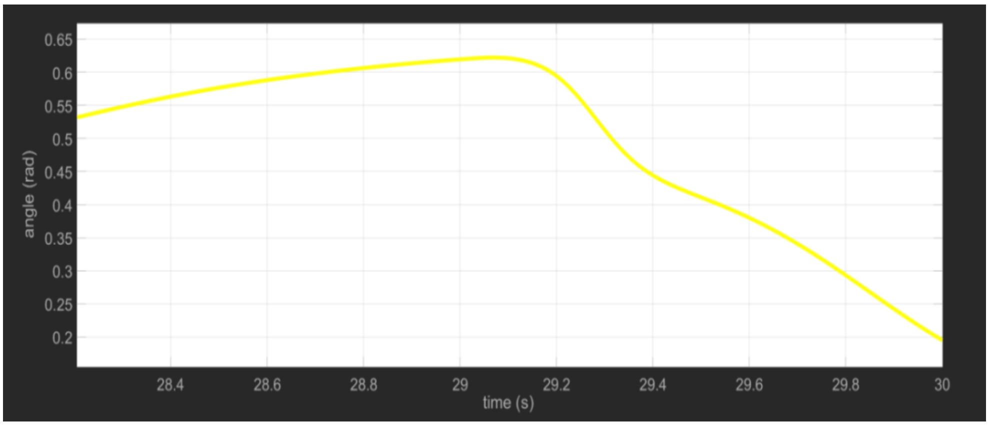


Figure 32. Objective and Parabolic Blend for x Direction

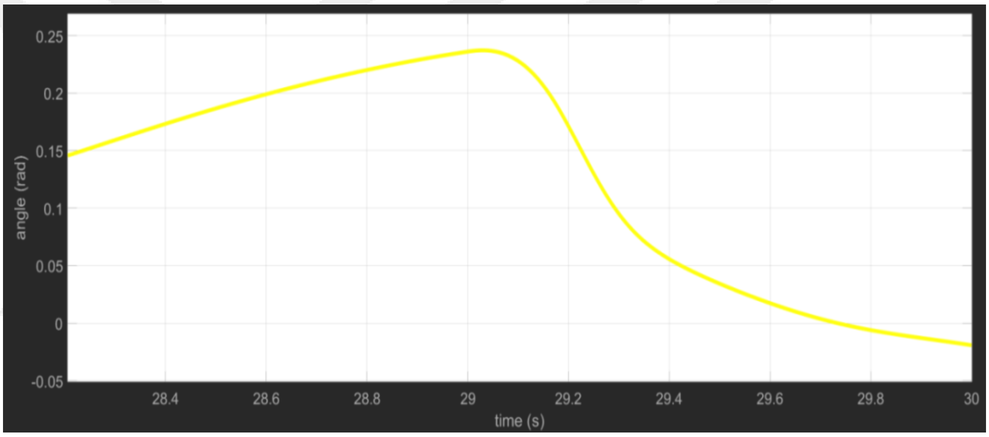


Figure 33. Objective and Parabolic Blend for y Direction

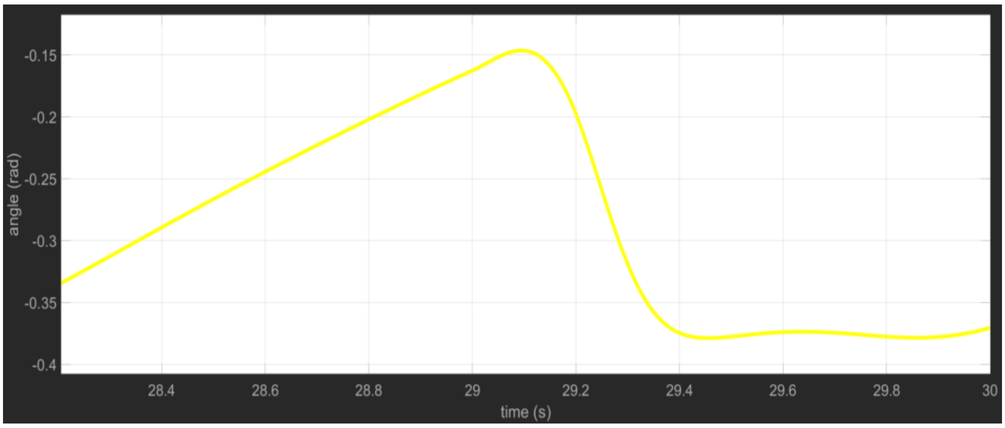


Figure 34. Objective and Parabolic Blend for z Direction

CHAPTER 5

CONCLUSION

In this study, a Delta Robot with three degrees of freedom for industrial use and installation of this robot on Telescopic Mast Systems were examined. Information about the Delta Robot and the parts of this robot has been given. The Telescopic Mast System has been examined and the mates are mentioned. Delta Robot's Workspace Analysis was made. Then "Trajectory Control" was made in the direction of a trajectory determined for Delta Robot. This process was simulated in the MATLAB Simulink environment and the results were expressed in graphs and discussed. The efficiency of Delta Robot with Trajectory Control in the assembly process for this system has been observed.

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