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Modelling and Control Two-Link Robot Arm Based On Fuzzy Logic

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Abstract:
This paper presents a Modeling, Simulation and Control of a Two-Link robot arm.This Workis taken from the FinalYear capstone project. First The Robot specifications, Robot Kinematics, Forward kinematics and InverseKinematics of Two-Link robot arm were presented. Then The dynamics ofthe Two-Link robot arm was studied toderive the equations of motion based on Euler-Lagrange Equation of motion. And then the modeling of the Two-Link robot arm using Simscape Multibody andRobotics system toolbox,A Control Design was performed using Fuzzy Logic controller for the modeling and control Technique. The models have been done based onMATLAB2020Rb/Simulink software.

Key Word*:Modeling, Two-Link robot arm, Fuzzy Logic Control, Simscape Multibody Toolbox, Robotic System Toolbox,MATLAB2020Rb/Simulink.*

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I. Introduction

The need for robots is rising quickly in our technology driven economy, and they are used in a wide range ofindustries. In the manufacturing industry, military, education,biomechanics, welding, automotive industry, pipeline monitoring, space exploration, and online trading, the study of robotarm control has become very popular[1].The aim of the research in [2] was on analyzing, modeling,and simulating a humanoid robot hand from a biologicalperspective, with a particular emphasis on bones and joints.With the help of Matlab/Simmechanics, a dynamic modelof a humanoid hand is created using model-based design,and a new approach to the inverse kinematic model is presented. Their research has led them to the conclusion thatthey have created a MATLAB model that can be utilized toregulate finger mobility.

Over the past few decades, modeling, simulation, and robotarm control have attracted a lot of attention in the field ofmechatronics, and the search for improved robot arm controlstill goes on. Both the Denavit-Hartenberg (DH) method andthe product of exponential formula are used in literature [3] toaddress the kinematics model of a 4-DOF robot arm, and thestudy's findings reveal that both methods produced the sameanswer.

This isbecause robots can operate in hostile, unpredictable environments where humans cannot.Recently, the use of robot arms todispense medications to patients and assist in the rehabilitationof the elderly and disabled has grown in popularity in thehealthcare industry. High accuracy and precision with zerotolerance for error are essential for effective use of thesedevices[4]. According to [5], a robot arm is a type of mechanical toolthat can be programmed to perform a variety of tasks andwas created with the goal of interacting with the environmentsafely. It is a mechanical device in that it has joints and linksfor stability and durability, yet they are unnecessary from akinematic standpoint because the forces driving the motionare not taken into account.

A robotic arm is a type of mechanical tool that can beprogrammed and controlled to perform a variety of tasksand interact with the environment safely. From a kinematicsperspective, the issues with significant non-linearity in thecoupling response forces between joints, which are causedby coupling effect and inertia loading [6], are not adequatelyrepresented. However, to address the regulating factors, a thorough understanding of dynamic modeling difficulty involvingthe robotic arm.

By using the Lagrange method toextract the kinematic and dynamic equations, the author of[7] modeled, simulated, and controlled a 3-DOF articulatedrobot manipulator. They then compared the resulting analyticalmodel with a simulated model created using the Simmechanicstoolbox.To track a reference trajectory, a PID controller is usedto further linearize the model with feedback. According to theresearch, a robot manipulator is challenging to manage becauseof the complexity and nonlinearity of the dynamic model.provided a linearized mathematical model and control of atwo-DOF robotic manipulator. They also developed a mathematical model based on kinematic and dynamic equations bycombining the Denavit Hartenberg and Lagrange approaches. In his research, two distinct control algorithms were usedto compare how well the robot manipulator performed[8].

In the [9] the mathematical modeling, control and simulationof a 2-DOF robot arm were presented.According to the resultsanalysis,the robot arm was controlled to reach and stay withina desired joint angle position throughimplementation andsimulation of PID controllers using MATLAB/Simulink.Also,the result revealed that changes in initial joint angle positionsof the robot arm resulted in different desired joint anglepositions and this necessitated that the gains of the PIDcontrollers need to be adjusted and turned at every instantin order to prevent overshoot and oscillation that associatedwith the change in parameters values.

In the [10] test the effect of disturbance in control the firstDOF of PUMA 560 using non model based FO-Fuzzy-PID controller and compared its results with two model-basedcontrollers (CTC, ANN). Also, we study the effect of change of inertias parameters in the two cases Model based control andnon- Model based control and then discus which controllergive the best results.The main objective of this paper is thatthe non-Model based FO-Fuzzy-PID is able to emulate themanipulator dynamic behavior without the need tohave acomplex nonlinear mathematical model for the robot.In the [11] modelling and control of two degrees of freedom(2-DOF) robotic arm were carried out. Lagrange-Euler methodwas used to obtain the dynamic equations of the robot.Thesystem was controlled in the simulationenvironment. SlidingMode Control (SMC) and Proportional-Integral-Derivative(PID) control methods were proposed to control the 2 DOFrobotic arm. The saturation function is used for the chatteringproblem of the sliding mode control method.

Lagrange-Euler method was used to obtain the dynamic equations of the robot. The system was controlled in the simulationenvironment. Sliding-Mode Control (SMC) and ProportionalIntegral-Derivative (PID) control methods were proposed tocontrol the 2 DOF robotic arm. The saturation function is usedfor the chattering problem of the sliding mode control method.The dynamics of the 2-DOF robot arm was studied to derivethe equations of motion based on Euler-Lagrange Equationof motion as in [12]. A Control Design was performedusing PID controller for the modeling and control Technique.The models have been done based on MATLAB/Simulink software.the result showed that a slight changes in initial joint anglepositions of the robot arm resulted in different desired jointanglepositions and this necessitated that the gains of the PIDcontrollers need to be adjusted and turned at every instant in order to prevent overshoot and oscillation that associated withthe change in parameters values.

In the [13] Fuzzy controllers are designed for the eightlegs walking robot and the optimal parameters of the fuzzycontrollers are adjusted using the PSO algorithm. The studiedwalking robot has twenty-four joints therefore, twenty-fourfuzzy controllers are designed on for each joint. The Simscapetoolbox is used to implement the walking robot and the simulation toolbox is used to construct the proposed controllerswith the optimization algorithm.

In the [14] where the problems of the forward and inversekinematics have been addressed and find solutions to it usingthe artificial intelligence algorithm fuzzy Neural Petri net. TheMATLAB program was used to simulate the forward and reversekinematics equations and then use the simulation results asdata (inputs, outputs) for the proposed algorithm and runthe program to update weights and give the required resultsdepending on the ratio meansquare error given.In the [15] introduced a numerical tool for the simulation ofrobotic grasping using Simulink and Simscape Multibody. Thetool is based on SynGrasp, a previously developed MATLABtoolbox allowing purely kinematics or quasi-static analyses.The library of functions and blocks developed in this workadds a fundamental module enabling dynamics simulations.The Simscape Multibody model of a robotic hand can bedefined in a straightforward way from SynGrasp modelsthanks to a series of functions based on programmatic modelediting. In this way, even users with limited experience withthe Simscape Multibody environment can build robotic handmodels and run dynamics simulations.

II. Methodology.

The basic knowledge about robot manipulators and presentsRobot Kinematics and dynamics of the Two-Link robot arm andthen the modelling of the two-link robot arm usingSimscape Multibody and Robotics system toolbox based onMATLAB2020Rb/Simulink, and the last idea of the fuzzylogic control.

III. Systems Kinematics.

The science of motion that treats motion without regardto the forces which cause it, that it is called Kinematics. Within the science of kinematics, one studies position,velocity,acceleration, and all higher order derivatives of theposition variables (with respect to time or any other variable(s)). Hence, the study of the kinematics of manipulators refers to all the geometrical and time-based properties ofthe motion as in [16][17]. Studying the robotic manipulators Kinematics and dynamics of the Two-Link robotic arm,then mathematically modeling a two-link robotic arm usingSimscape Multibody and Robotics system toolbox based onMATLAB2020Rb/Simulink. Apply Fuzzy Logic Control foroptimum tracking performance. In robot simulation, systemanalysis needs to be done, such as the kinematics analysis,its purpose is to carry through the study of the movements ofeach part of the robot mechanism and its relations betweenitself. The kinematics analysis is divided into forward andinverse analysis.

The **forward kinematics** consists of findingthe position of the end-effector in the space knowing themovements of its joints as $\boldsymbol{F}(\boldsymbol{\theta}_1, \boldsymbol{\theta}_2, \dots, \boldsymbol{\theta}_n) = [\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}, \boldsymbol{R}_d]$, andthe **inverse kinematics** consists of the determination of the jointvariables corresponding to a given end-effector position andorientation as$\boldsymbol{F}(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}, \boldsymbol{R}_d) = [\boldsymbol{\theta}_1, \boldsymbol{\theta}_2, \dots, \boldsymbol{\theta}_n]$.Fig.1 shows asimplified block diagram of forward and inverse kinematicsmodelling.

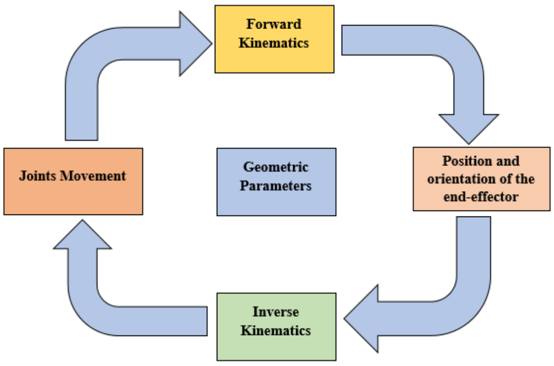

Fig. 1. Forward and Inverse Kinematics Block Diagram.

IV. Systems Dynamic.

The fundamental approaches to write equation of motionof a quadrupedal robot mechanism are generallyrepresentedin two methods: The Newton-Euler formulation and Langrageformulation [17]. Fig.2 shows the visualdisplay of the two-link robotic arm in the Mechanics Explorer platform. For arigid body, the spatial equation of motion is used for Newtonand Euler's equation. The most common conical form ofdynamic motion of robot is the joint space formulation iswritten in (1).

$$M(\theta)\ddot{\theta} + C(\theta, \dot{\theta})\dot{\theta} + G_g(\theta) = \tau \quad \cdots \quad (1)$$

$M(\theta)\ddot{\theta}, C(\theta, \dot{\theta})\dot{\theta}, G_g(\theta)$and τ are inertial matrix, Coriolisand centrifugal, gravitational vector and torque output vectorrespectively. In this thesis, Lagrange equation is used due tomore favorable in complex robotic manipulator configuration.

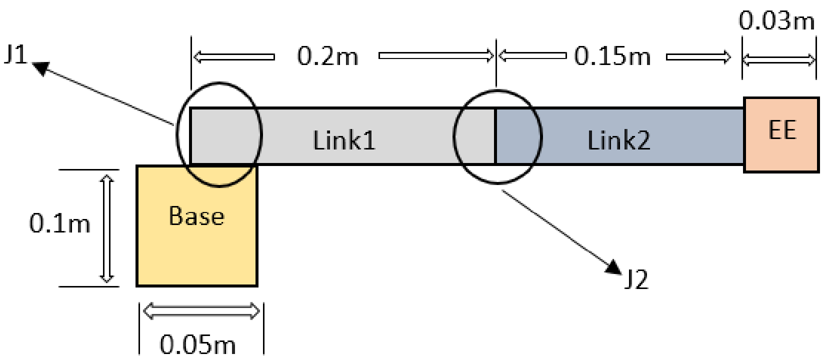

Fig.2. general Frame of two-link robotic arm.

V. Simscape Multibody Toolbox.

To examine the effectiveness of the control system to drivethe robot under any disturbances,the simulation of therobotsystem with a controller is a crucial issue. Therefore, numerousresearchers performed this issue using various simulationprograms [13]. The majority of those studies need the authorsto employ two programs: one to simulate the controlled systemand the other to show the robots movements in various settings.In this study, the Simscape Multibody toolbox is used tovisualize the motion of the controlled robots under variousapplied disturbances and build the controller system for thetwo-degree of freedom robot.The Simscape Multibody toolboxcontains many libraries and Simulink blocks by which anyarchitecture of the robot can build such as mobile robots,roboticmanipulators with the different numbers of joints,and walking robots. It also contains simulation and controlinterfaces to help users to obtain required simulation resultsand display feasible the motion of a simulated robot[14].

Multibody simulation is used to analyze the behavior ofcomplicated mechanical and robotic systems, such as grippers and manipulators, and tries to solve the kinematic and dynamicdifficulties of mechanical systems [18]. A localreferenceframe with its origin in the center of mass of the body, itsmass, its tensor of inertia in the local reference frame, andother auxiliary references to define the constraints that arerepresented by relationships between the motion parametersare the primary parameters used to describe bodies in themultibody simulator. Both stiff and flexible bodies are represented using a single block or a combination of several thatcan explain their mechanical behavior. All bodies are attachedto one another using joints or the appropriate constrains, andeverything is put together to form an articulated mechanism.The degree of freedom in this mechanism is a result of thekinematic relationships that theconstraint blocks give.Simscape Multibody can import 3D models acquired through3D scanning [19] and use data from external 3D CAD programs like SolidWorks (Dassault Systmes,Vlizy-Villacoublay,France) to parametrizebodies, constraints, actions, and joints.The bodies' shape and ensuing inertial characteristics definethem, and the user can change these characteristics dependingon the physical system being researched. Bodies can besubjected to forces and moments, and contact limitationscan be established. By linking blocks that represent variousmechanical components, Simscape enables the modeling ofphysical systems.By linking blocks that represent variousmechanical components, Simscape enables the modeling ofphysical systems. Blocks from Simscape and Simulink canbe combined in a model and connected using the properconnectors. The basic structure to build a two-joint roboticarm is shown in Fig.3.and the Fig.4 representdepicts the visual display of the two-link robot arm in theMechanics Explorer platform.

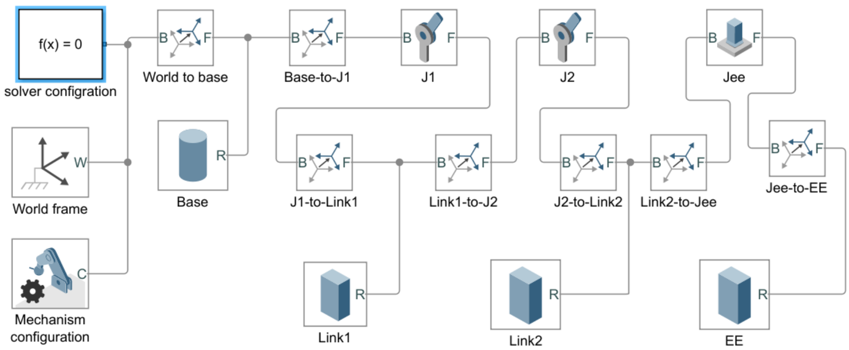

Fig.3Simscape Multibody Model of Two-Link Robot Arm.

To understand the used Simulink blocks that are shown inFig.3 their functions are described as follow:

1. **Solver Configuration:** Defines the configuration values for the simulation.
2. **World Frame:** Provides access to the world or groundframe, a unique motionless, orthogonal, right-handedcoordinate frame predefined in any mechanical model.World frame is the ground of all frame networks in amechanical model.A model can have multiple World Frame blocks, but allrepresent the same frame.Port **W** is a frame port identified with the world frame.Any frame port directly connected to **W** is also identifiedwith the world frame.
3. **Mechanism Configuration:** Sets mechanical and simulation parameters that apply to an entire machine, thetarget machine to which the block is connected. In theProperties section below, you can specify uniform gravityfor the entire mechanism and also set the linearizationdelta. The linearization delta specifies the perturbationvalue that is used to compute numerical partial derivativesfor linearization.Port **C** is frame node that you connect to the target machine by a connection line at any frame node of the machine.

4. **Rotational Joint:** Represents a revolute joint (**J1** and **J2**) acting between two frames. This joint has one rotational degree offreedom represented by one revolute primitive. The jointconstrains the origins of the two frames to be coincidentand the z-axes of the base and follower frames to becoincident, while the follower x-axis and y-axis can rotatearound the z-axis.In the expandable nodes under Properties, specify thestate, actuation method, sensing capabilities, and internalmechanics of the primitives of this joint. After youapply these settings, the block displays the correspondingphysical signal ports.Ports **B** and **F** are frame ports that represent the baseand follower frames, respectively. The joint direction isdefined by motion of the follower frame relative to thebase frame.
5. **Weld Joint:** Represents a weld joint (**Jee**) between two frames.This joint has zero degrees of freedom. The follower andbase frames are always coincident.Ports B and F are frame ports that represent the base andfollower frames, respectively.

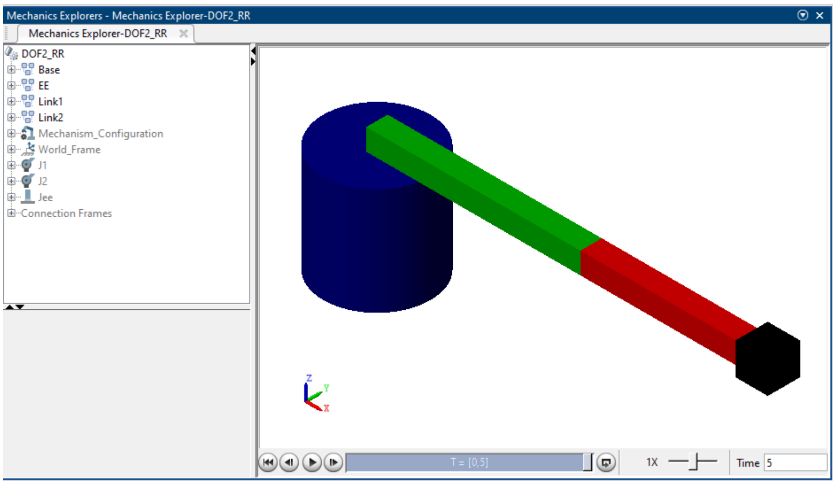

Fig.4 depicts the visual display of the two-link robot arm in the Mechanics Explorer platform.

VI. The Robotics System Toolbox.

The Robotics Toolbox handles topics including kinematics,dynamics, and trajectory creation and offers many of thefunctions needed in robotics. It can be a potent educationaltool and is effective for modelling as well as foranalyzingthe outcomes of research with actual robots. The kinematicsand dynamics of serial-link manipulators aregenerally represented using description matrices in Robotics Toolbox. Therecursive Newton-Euler formulation is used to determine theinverse dynamics. Although Simulink can also be used withit, MATLAB was the original intended platform[18][19][20]. In this paper the polynomialtrajectory,CoordinateTransformationConversion, InverseKinematics, ForwardKinematicswere represented as follow:

• **Trajectory generation:**Itisrepresentingthereferenceinputofrobot.Generatepolynomialtrajectoriesthroughmultiplewaypoints. Specifyan[NxP]matrixofPwaypoints.SettheWaypointsourceparametertoexternalto specify theseparametersasblockinputs. Inthis paper thepolynomialtrajectorywaspresentedwiththreesignals(XYZ).[X]=[0.35,0.25,0.25,0.15,0.15,0.25],[Y]=[0,0.01,0.11,0.11,0.01,0.01],[Z]=[0.110.110.110.110.110.11],andtimepoint=[0,0.5,1.5,2.5,3.5,4.5].

• **Coordinate Transformation Conversion:**Convertto aspecifiedcoordinatetransformationrepresentation.

• **Inverse Kinematics:**Computejointconfigurationstoachieveanendeffector(gripper) position.

• **Forward Kinematics:**Computetheendeffector(gripper) position toachievejointconfigurations.

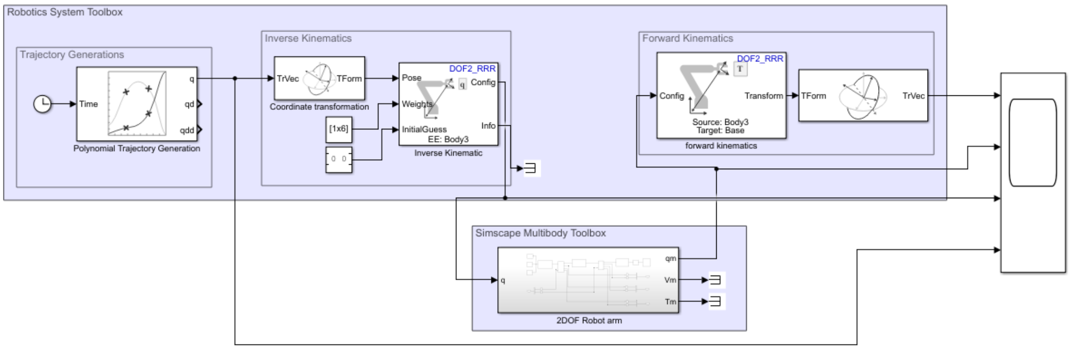

Fig.5Block scheme of two-link robot arm based on Simscape MultibodyToolbox and Robotics Toolbox.

VII.Fuzzy Logic Control

As previously stated, a Two-Link robot arm has intrinsiccomplexity and nonlinearity, making the construction of areliable controller for this system rather difficult. The majority of researchers employ the robust fuzzy controller whencreating a controller for a nonlinear system. As a result of afuzzy logic controller's reasonable performance for controllingnonlinear and uncertain systems, researchers discovered that,in the majority of cases, its performance can outperform thatof a traditional PID controller[21][22][23].There are mainadvantages of using fuzzy logic systems such as it can beapplied to plants that are difficult to model mathematicallyand the controller can be designed to apply heuristic rulesthat reflect the experience of human experts. On the otherhand, a fuzzy logic system has several parameters that shouldbe properly adjusted.Numerous algorithms, including neuralnetworks, genetic algorithms, ant colony optimization, andparticle swarm optimization, are used to choose the best valuesfor the fuzzy system[24]. This research suggests using afuzzy controller to regulate the Two-Link robot arm's gait.Thefuzzy controlleris builtusingthe centroidandMamdaniinference methods.Fivetriangularmembershipfunctionsaredefinedforeachinput. TheLinguistictermsofeachinputareassignedas:NegativeBig(NB),NegativeSmall(NS),Zero(Z),PositiveSmall

(PS)andPositiveBig(PB).Theparametersofinputmembershipfunctionsareassumedfix(nottunedbyPSOalgorithm).Fivetriangularmembershipfunctionsareassumedfortheoutputofthefuzzycontrollerassignedas NegativeBig(NB),NegativeSmall(NS),Zero(Z),PositiveSmall(PS),PositiveBig(PB). The connection between the fuzzy controller and the Two-Link robot arm is shown in Fig.6. and Fig.7 show the FuzzyLogic Controller Type (PD+PI).

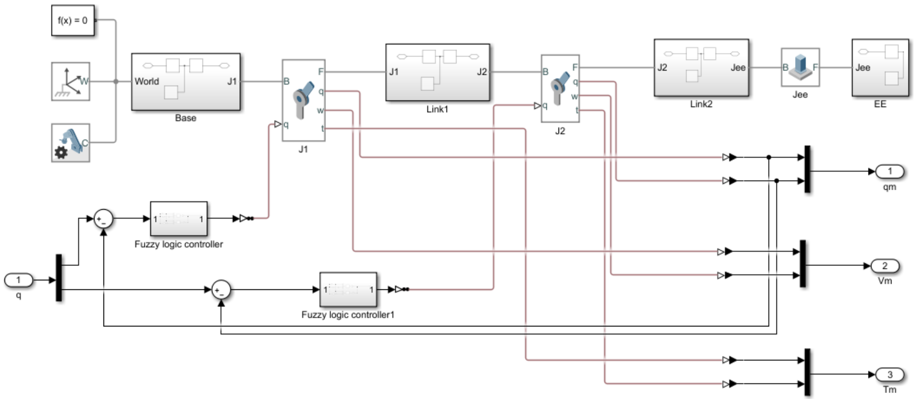

Fig. 6. Fuzzy Controller with theTwo-Link Robot Arm.

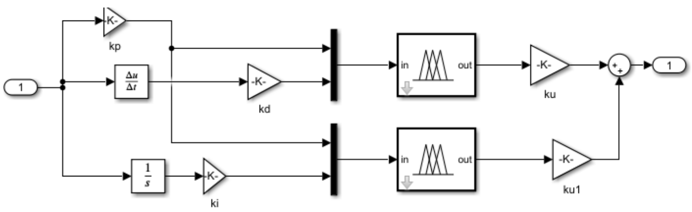

Fig.7 Fuzzy Logic Controller Type (PD+PI).

VIII. Simulation Results and Discussion.

In this paper, the SimScape Multibody toolbox is used todesign and simulate the Two-Link robot arm as shown inFig.4given previously. It has two revaluate joints, A different fuzzycontroller is designed for each joint. Theparameter valuesfor two-linkrobot arm presented inTable I are used for the simulation. This model is further splitinto sub-systems to reduce system complexity and size andlatter combined as one model as depicted in Fig.6 In Simulinktoolbox Fuzzy is available which is implemented to controlthe joint angle. Fuzzy Logic controller parameter values arepresented in Table II.

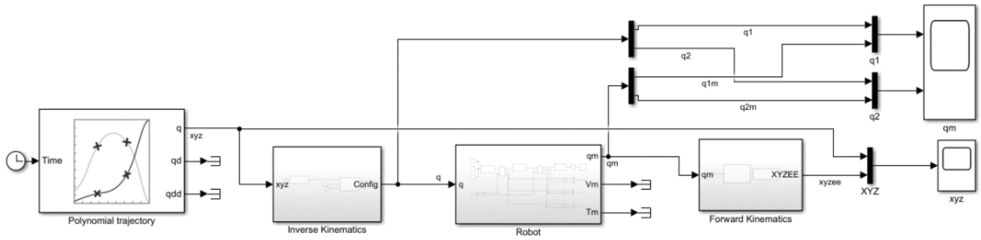

Fig. 8. Simulation model for two-link robot arm.

Tableno 1: Parameters of The Two-Link Robot Arm.

Parameters	Base	Link one	Link two	End-effector (gripper)	Units
Mass(m)	1	1	1	1	Kg
Length(l)	0.1	0.2	0.15	0.03	m
Gravity(g)	9.81	9.81	9.81	9.81	ms^{-2}
Radius(R)	0.05	-	-	-	m

Table no 2: Fuzzy Logic Controller Parameter of Two-Link Robot Arm.

parameters	Link one	Link two
K_p	10	10
K_d	0.25	0.26
K_I	0.1	0.1
K_u	0.15	0.15
K_{u1}	0.16	0.16

The results for open loop and closed loop as shown below:

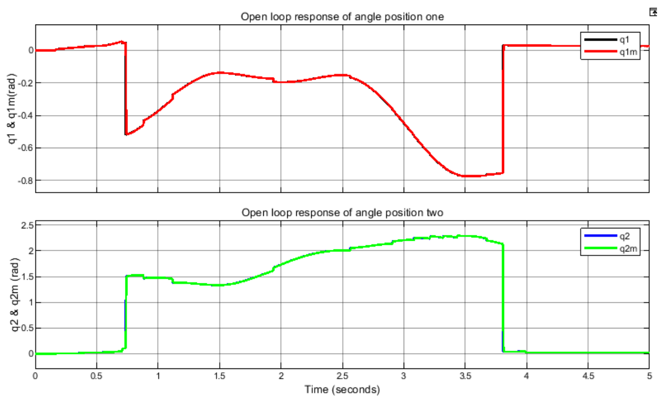

Fig. 9. Open loop response of angle position.

From Fig.9We notice that the response isnot following the desired trajectory with relatively some error of q1 and q2.

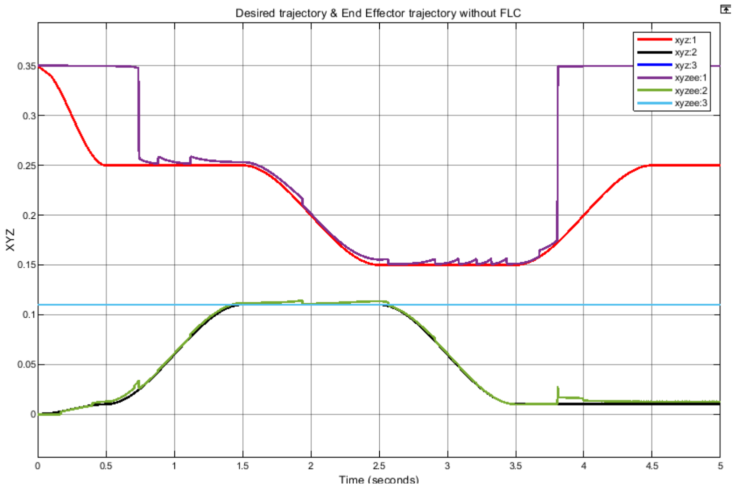

Fig.10Comparison between desired trajectory and Open loop response ofend effector trajectory.

From Fig.10We notice that the response is not following the desiredtrajectory with relatively some error. where(xyz:1) desired trajectory inthe x-axis is not equal to (xyzee:1) end effector trajectory in the x-axis,and (xyz:2) desired trajectory in the y-axis is not equal to (xyzee:2)end effector trajectory in the y-axis, and (xyz:3) desired trajectory in thez-axis is equal to (xyzee:3) end effector trajectory in the z-axis.

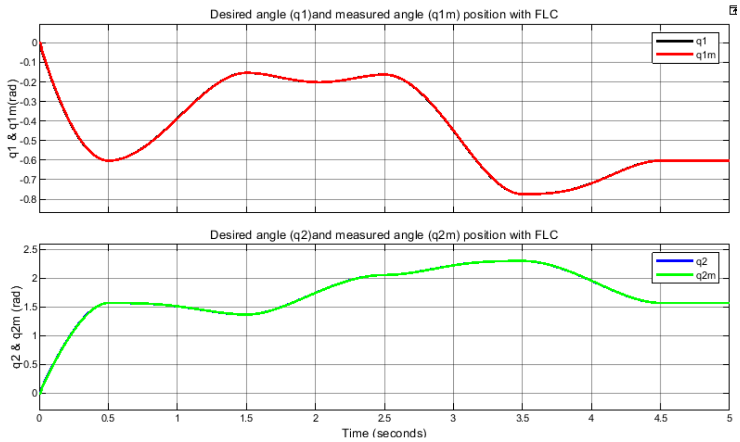

Fig.11 Output response of angle position(q1, q2) with Fuzzy logic controller.

From fig.11We notice that the response is following the desired angle position withrelatively good manner.Where q1(desired angle of joint one) it is equal to q1m(measuredangle of joint one),and q2(desired angle of joint two) it is equal toq2m(measured angleof joint two).

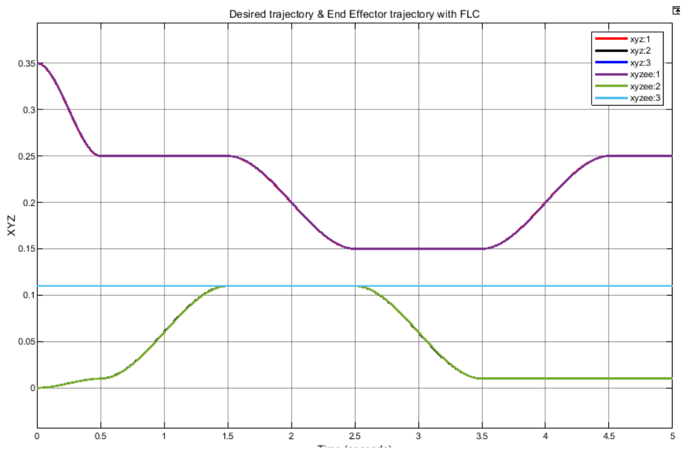

Fig.12 Output response of end effector position with Fuzzy logiccontroller.

From fig.12We notice that the response of the end effector trajectory(xyzee)is following the desired trajectory(xyz) with relatively zero error.

IX. Conclusion

In this paper, a simulation tool for motion analysis and assessing the dynamics of the suggested model was used tomodel the two-link robot arm using simpscape Multibody and Robotics system toolbox. The process for designing organigram procedures consisted of four sequential steps:Mathematical Model; Simscape Model;Controller Design; Robotic Arm Motion Modeling.

The enhanced FLC, which reduces tracking error and optimizes trajectory for the efficient torque at joints. Threetrajectory signals are used to operate the system and comparethe suggested controller's response time characteristics withthose of the uncontrolled in order to regulate the motion of thejoint angle combinations via a range of angles and coordinates.According to a survey of recent literature, classical controlis ineffective and unreliable formanipulating robots under avariety of uncertainties, including model uncertainty, changingpayloads, and parameter change. The literature suggests thatcombining FLC with traditional control methods enhances thesystem's robustness and effectiveness.

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