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Position Control of 3R Manipulator using the PI Controller

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Abstract:- The purpose of this paper is to study the performance of the 3R manipulator arm using the PI controller. The robotic arm is intended with 3 joints, 2 links, and 3 DC motors. PI controller is employed to get the specified position of the robotic joints. In this analysis, the link length of the robotic arm is calculated to modifycarrying the will object weight. The position of the robotic arms end effector is calculated with a kinematic modeling technique that embraces forward and inverses kinematic. The robotic toolbox is employed to find the position of the robotic arm through forward and inverse kinematics. The PI control technique is employed for the correct position of the tip effector, during this analysis, the gain of the PI controller is tuned by the Autotuning technique. In this analysis, the output position of the robotic arm is shown in MATLAB simulation. Forward and the inverse kinematic result are also shown in MATLAB graphical user interface.

Keywords:- *PI Controller, Kinematic Modeling, DC Motors, GUI, 3R Manipulator.*

I. INTRODUCTION

Any mechanical arm that is operational under a PC management system can be called an industrial manipulatoror it can be coined as the robotic arm. These robotic arms generally consist of two parts that are namely links and joints. These joints can be manipulated to either produce a rotary or linear motion. These links and joints form up kinematic chains that create the fundamental structure of the robotic arm. This mechanism is used in several product lines such as assembly, packaging, injection molding, and even in some intricate machining operations like grinding cuttingand attachments where a continuous path of robot trajectoryis put into use.

The science in which motion of the body is purely described using mathematics is termed kinematics. This branch has its absolute restriction to a purely geometrical description of motion employing position, orientation, and their time derivatives. The Denavit Hartenberg notation provides a typical methodology when it comes to writing the kinematic equation of the manipulator. The kinematic analysis of a robot is mainly branched into two is Forward Kinematics and Inverse Kinematics. In forward kinematics, a kinematic equation is used and the position of the end effector is computed by feeding the values of the joint parameters whereas when it comes to inverse kinematics the kinematic equation is used along with the already known position of the end effector to find the joint parameters of the robotic arm.

Robotic arm controller has quite the demand and its challenging when it is put to test in the industrial field as well as the military. Robots are commonly used to do highly repetitive, unsafe, and dangerous tasks which have various functions such as assembly, material welding, resistance welding, arc welding, machines tool unload and load functions, spraying, painting, etc. A robotic arm could be a robot manipulator, usually programmable with analogous functions to a human's arm. These robots are generally set for tasks that follow the teach and repeat technique. A robotic arm could be a Robotic Arm controller that is designed to perform difficult and exacting activities in the industrial field furthermore it could be widely used in military and alternative applications.

The Proportional and Integral controller is widely used in control systems to rectify any potential error between the setpoint and the absolute value concerning the feedback received. Thus, these PI controllers come in handy for industry applications and are regarded as the core when it comes to the working of the KEB drives. When PI control is used in PLCs it provides a feedback path to the encoder and creates an SLC that is sensorless closed-loop control.

This paper is divided into covering three main contributions. First off we have the mechanical aspect of designing the robot arm which is considered to pick up the desired object. Next, the inverse and forward kinematic are elaborated with the help of the robotic toolbox in MATLAB. Ultimately PI gain is designed to be used by the system with the help of auto-tuning implemented under the principle of Auto tuning.

This paper has been organized as follows, the second section describes the mechanical style of the 3_DOF (Degree of freedom) Articulated mechanism Arm. The third section calculates the kinematic modeling, the fourth section expresses calibration of the PI gain for DC motor, and finally, section five shows simulation results for the 3R manipulator mechanism arm with MATLAB/Simulink.

When a control system that is to be designed has to be stable and faster in response time, the PI controller is the way to go as it is an excellent technique when applied to the system is comparatively more robust than another kind of controller. There are several other advantages of PI controllers it can be used to achieve zero steady-state error and guarantees maximum peak overshoot when compared with the integrative-only controller thus providing overall better stability.

When PI control is used in a system it eliminates the unnecessarily forced oscillations which could otherwise induce a negative effect in the speed of responseadditionally posing a problem since in PI controllers one cannot determine what a potential error can affect the system but alternatively PI serves right when a system exposed to large noise and disturbances, in times of transport delays and when faster response time is required in the system.

II. FLOW CHART OF ROBOT ARM CONTROL

In this analysis, the look parameters of the robotic arm are thought of. And then, the position of the tip effector is calculated with kinematic modeling methodology in laptop,to induce the particular position of the robotic joint angle, an inflammatory disease controller is employed. During this paper, Kinematic modeling is an important role in the style and robotic arm management. robotic arm mechanics deals with the analytical study of pure mathematics motion of robotic arm from the mounted reference of an organization as a operate of your time while not reference to movements that cause the motion.

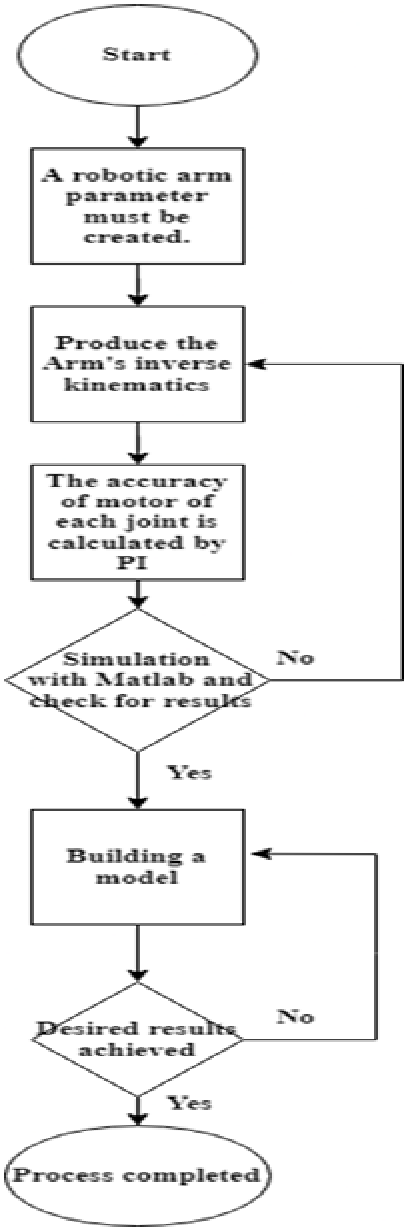

Fig 1 Shows the Flow Chart of Robot Arm Control

III. KINEMATIC ANALYSIS

The analysis of the behavior of multi-degree of freedom kinematic chains which make up the structure of robotic systems is called robot kinematics. The robot's connections are treated as rigid bodies, and its joints are supposed to give pure rotation or translation, due to the focus on geometry.

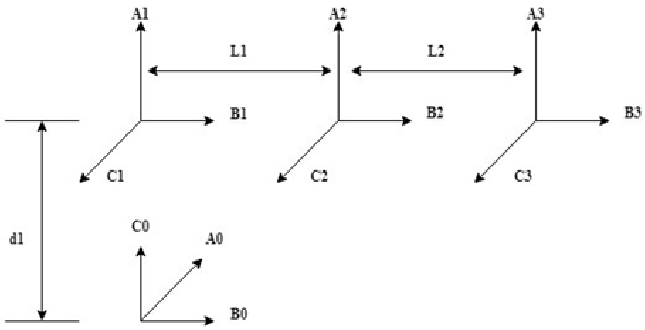

Fig 2 Shows the Kinematic Frame of 3 DOF Robot

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Table 1 D-H Parameters for Robot Arm

I	a_i	d_i	α_i	θ_i
1	0	5	90	θ_1
2	13	0	0	θ_2
3	9	0	0	θ_3

The transformation matrix of the robotic arm is

$$ {}^{i-1}T_i = \begin{bmatrix} c\alpha_i & -c\alpha_i s\theta_i & s\alpha_i s\theta_i & a_i c\theta_i \\ s\theta_i & c\alpha_i c\theta_i & -s\alpha_i s\theta_i & a_i s\theta_i \\ 0 & c\alpha_i & c\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

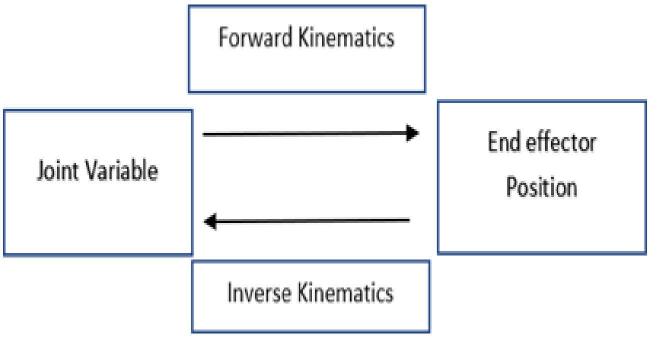

Fig 3 Kinematics of Robotic Arm

A. Forward Kinematics

Forward kinematics is the utilization of a robot's kinematic equations to calculate the location of the end-effector givena set of joint variables once the actuators' values are known.

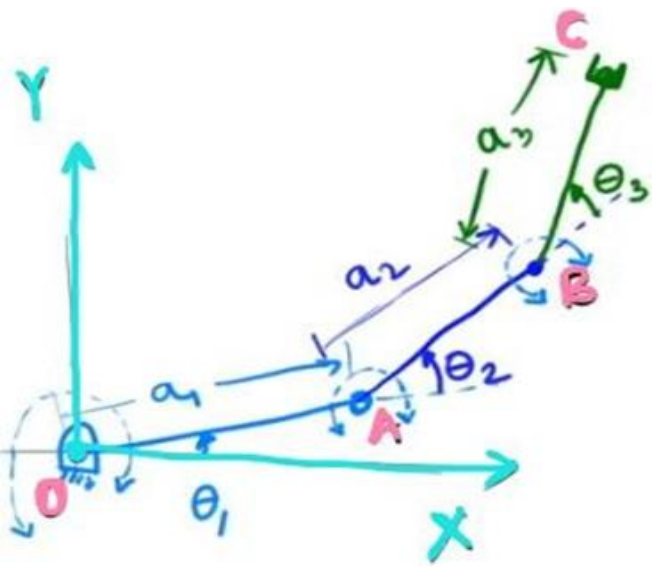

Fig 4 Forward Kinematics of the Robotic Arm

By considering the lines OA AB, BC as vectors the sum ofthese vectors will be equal to the straight-line vector OC.

$$\vec{OC} = \vec{OA} + \vec{AB} + \vec{BC}$$

All these vectors can be represented in the form of a matrix. Here $a_1 a_3$ represents the link length

$$\begin{bmatrix} a_1 & \cos & \theta_1 \\ a_1 & \sin & \theta_1 \end{bmatrix} + \begin{bmatrix} a_2\cos(\theta_1+\theta_2) \\ a_2\sin(\theta_1+\theta_2) \end{bmatrix} + \begin{bmatrix} a_3 & \cos & (\theta_1+\theta_2+\theta_3) \\ a_3 & \sin & (\theta_1+\theta_2+\theta_3) \end{bmatrix} = \begin{bmatrix} c_x \\ c_y \end{bmatrix}$$

Theta represents the joint angles

$$\emptyset = \theta_1 + \theta_2 + \theta_3$$

$$\text{Position} = C_x, C_y$$

$$\text{Orientation} = \emptyset$$

Final positions can be obtained from these equations.

$$P_x = a_1 C\theta_1 + a_2 C(\theta_1 + \theta_2) + a_3 C(\theta_1 + \theta_2 + \theta_3$$
$$P_y = a_1 S\theta_1 + a_2 S(\theta_1 + \theta_2) + a_3 S(\theta_1 + \theta_2 + \theta_3$$

The manipulator's final position is made up of two parts: position and orientation. About the location of Point C, the End Effector position may be described as the Inclination angle concerning the X-axis.

B. Inverse Kinematics

Inverse mechanics typically refers to the position and orientation of finish effectors. It helps to seek out joint variables to attain the correct position of supply location half. The orientation will be calculated with the given position into one homogenous transformation matrix (T) that describes the orientation and position of the top effector, and so the inverse mechanics is applied to work out every joint angle. There will be several solutions in inverse kinematics. These inverse kinematics was solved with the help of the DH method.

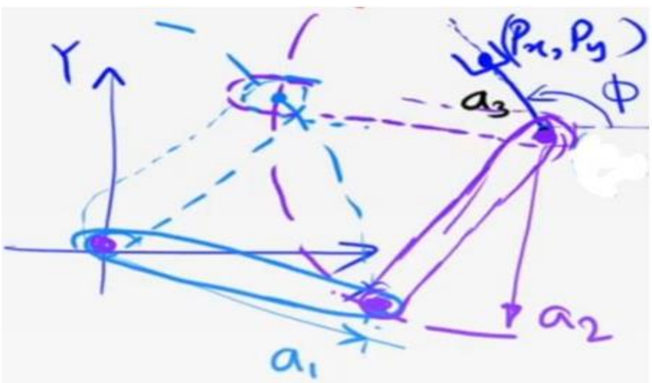

Fig 5 Inverse Kinematics of the Robotic Arm

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From the Forward kinematics, we have achieved these equations

$$P_x = a_1C\theta_1 + a_2C(\theta_1+\theta_2) + a_3C(\theta_1+\theta_2+\theta_3)$$
$$P_y = a_1S\theta_1 + a_2S(\theta_1+\theta_2) + a_3S(\theta_1+\theta_2+\theta_3)$$
$$\emptyset = \theta_1+\theta_2+\theta_3$$

The end positions can be denoted as Px, Py. For the given Px, Py &set values we will be obtaining the two different combinations.

$$P_x = \omega_x + a_3\cos(\emptyset)$$
$$P_y = \omega_y + a_3\sin(\emptyset)$$

To find $\omega_x$and ω_y we modify the equations as

$$\omega_x = P_x - a_3\cos\emptyset$$
$$\omega_y = P_y - a_3\sin\emptyset$$

By utilizing the given a1,a2,Wx,Wy we need to find θ_1&θ_2

$$c_2 = \cos\theta_2 = \frac{\omega_x^2+\omega_y^2-a_1^2-a_2^2}{2a_1a_2}$$

And check if $c_2 \leq 1$ and then compute for sin values, itwill have two solutions

$$S_2 = \sin\theta_2 = \sqrt{1-c_2^2}$$

$$S_2 = \sin\theta_2 = -\sqrt{1-c_2^2}$$

And finally, theta values can be obtained from

$$\theta_2 = a\tan 2(S_2, C_2)$$

Similarly, the Theta 1 values can be obtained and manipulated

IV. MODELLING OF DC MOTOR

Since DC motors are crucial in control systems, it is necessary to develop and assess a mathematical model for motors. A layout of an armature-controlled DC motor with such a constant field circuit is shown in the picture. It's shown as a series circuit with resistance and inductance. The voltage supplied by the amplifier to drive the motor isknown as the input voltage. The spinning of the armature windings under the fixed magnetic field induces the back EMF voltage. The system is separated into three key equation components to obtain the transfer function of the DC motor: electrical equation, mechanical equation, and electro-mechanical equation.

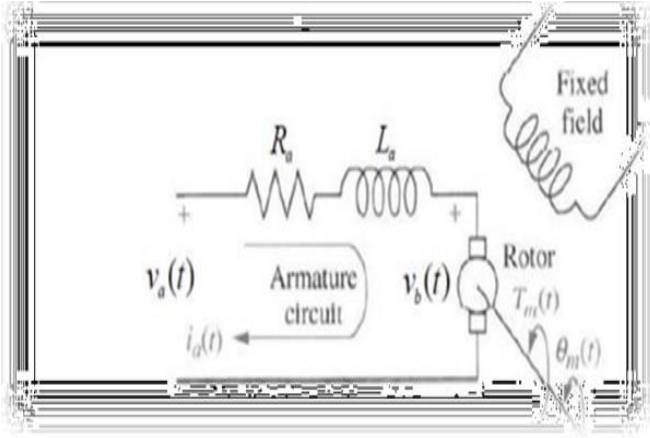

Fig 6 Schematic of DC Motor

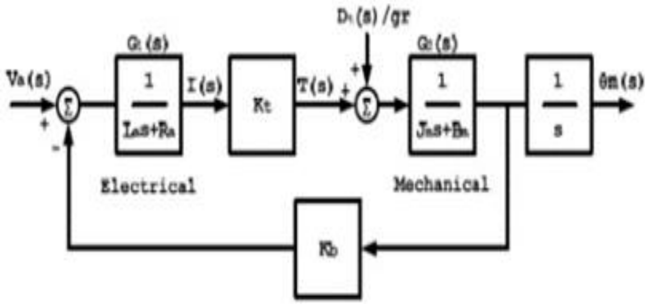

Fig 7 Block Diagram of DC Motor

The transfer function of the dc motor can be obtained from the block diagram

$$G_{position}(s) = \frac{\theta(s)}{V(s)} = \frac{K_t}{s[J_mL_as^2+(L_aB_m+R_aJ_a)s+K_tK_b]}$$

Fig 8 obtained from the block diagram

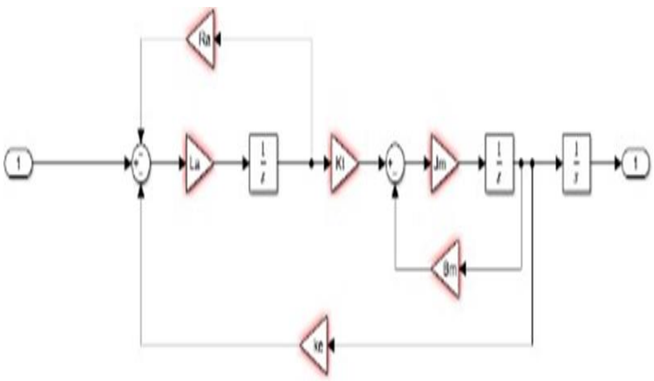

Fig 9 Simulink Model of DC motor

Table 2 Parameters of the DC motor

Parameters	Value
Moment of Inertia	J_m= 0.000052 kg.m^2
Friction Coefficient	B_m = 0.01 N.ms
Back EMF Constant	K_b = 0.235 V/ms^{-1}
Torque Constant	K_t = 0.235 Nm/A
Electrical Resistance	R_a = 2 ohm
Electrical Inductance	L_a = 0.23 H
Load Torque	τ_L (t)

V. TUNING THE PI GAIN FOR DC MOTOR

In the given system the robot control arm's power supply is used as a 12V DC supply for all Arduino microcontrollers and DC motors.

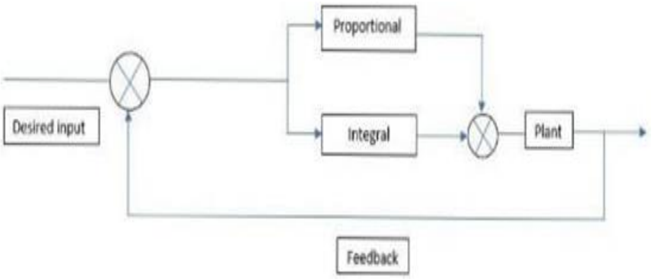

Fig 10 Block Diagram of PI Controller

In this system, DC Motors have six wires. The red color is motor power (connect to at least one motor terminal). Black color is additionally motor power (connects to the opposite motor terminal). The green color is encoder GND. The blue color is encoder Vcc (3.5- 20V). Yellow color is encoder A output and White color is encoder B output. Most DC motors run at the very best rev (revolutions per minute) once the specified power is equipped. The speed of DC motors is controlled by exploitation pulse dimension modulation (PWM), a method of speedily pulsing the ability on and off. the share of your time spent sport the on/off quantitative relation determines the speed of the motor. every pulse is thus fast hence the motor seems like it's spinning continuously without any shuttering.

Since PI controller is more commonly used adjusting certain parameters to maintain the standard is advised. If the process variable surpassingly changes quicker with a control variable, the user will start to get a low gain which could range as low as 0.1, this tends to happen when the reset is being adjusted in the time interval that has the rangefrom one to ten repeats per minute.

In another scenario, let's say the process variable, PV changes slowly then we will have to start with the higher gains and resort to comparatively lower resets which could be between 1.95 and 8 and 0.495 and 0.5 respectively. It would more efficient to proceed if only one of these parameters is adjusted at a time and the results are observed rather than inspecting multiple parameters at the same time, this has to be continued until or unless a stable process is achieved. If we were to start with a more measured approach resorting to a low gain with derivative and integral inactiveis the way to go. When this process takes place begin manipulating the gain y incrementally doubling the value until the oscillation occurs.

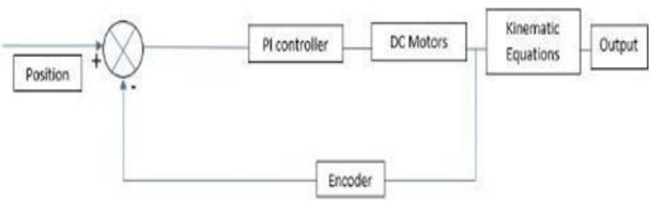

Fig 11 The control block of Robotic Arm control

P determines the reaction to current error, I determine the reaction to the total of recently appeared errors The total of all 2 elements contributes to the management mechanism like speed management of a motor within which P worth depends upon current error, Iconjointly depend on the build-up of the previous error.

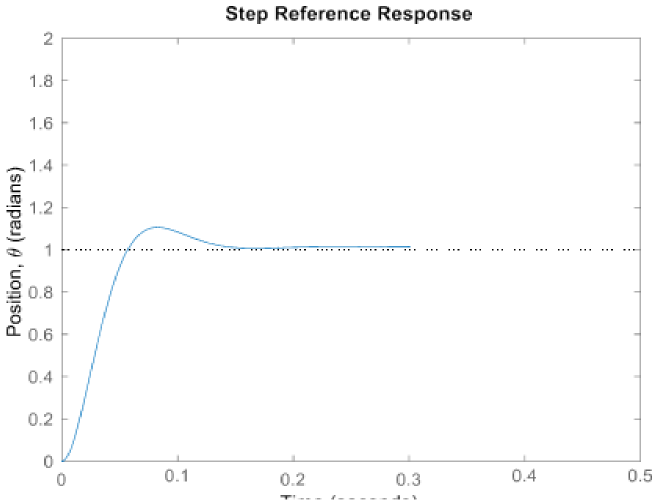

Fig 12 PI control response of DC motor

VI. GRAPHICAL USER INTERFACE

GUIs are created in response to command-line interfaces perceived steep learning curve, which requires instructions to be entered on a computer keyboard. They greatly facilitate the operation of coming up with and building GUIs. A user interface example has been ready for three DOF robotics for the forward mechanics as well as the Inverse Kinematics. Push buttons, sliders, axes, etc. will be another on that. Addition's area unit being visible on them. file at the same time as a operate. The robotics chest is embedded into the user interface. The results area unit compared with the expressions obtained within theanalytical answer. it's tried that very same results area unitobtained by the robotic chest and therefore the analytical

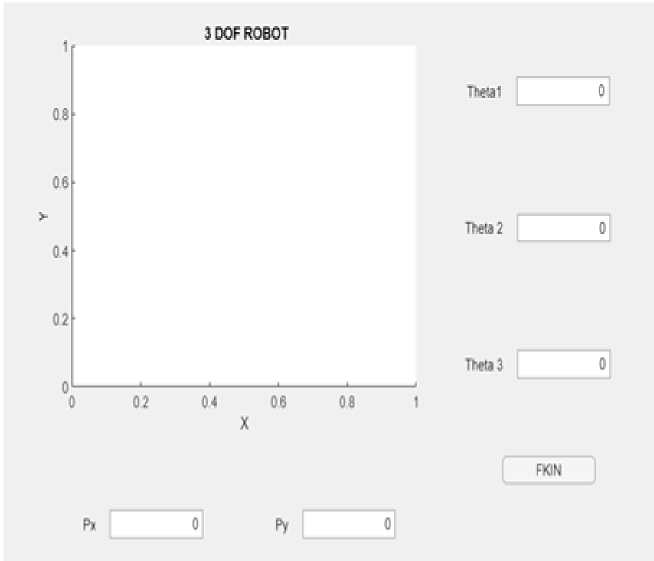

Fig 13 GUI model for Forwarding kinematics

VII. EXECUTION

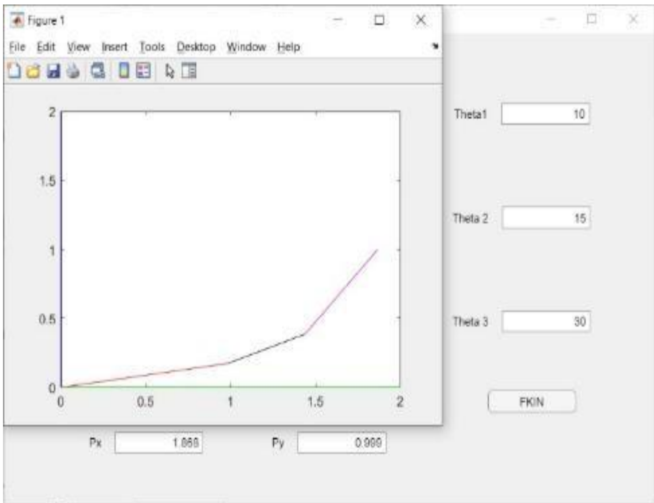

Fig 14 GUI Simulation for Forwarding Kinematics

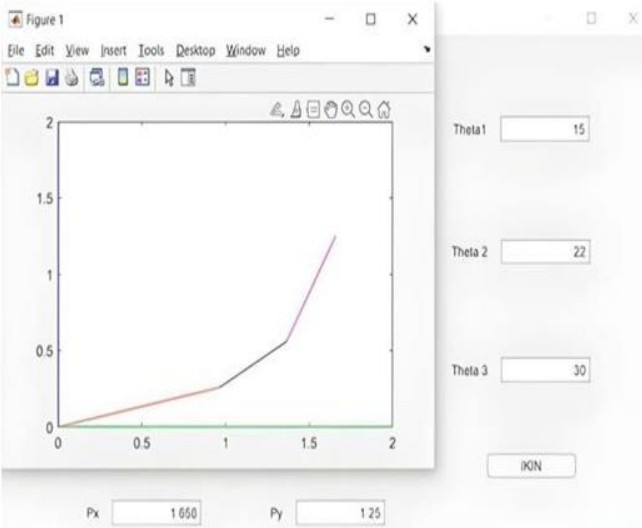

Fig 15 GUI simulation for Forward kinematics

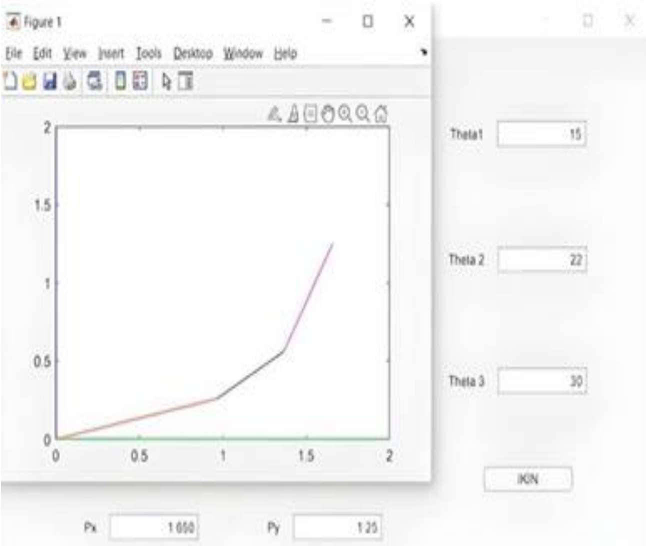

Fig 16 GUI simulation for Inverse kinematics

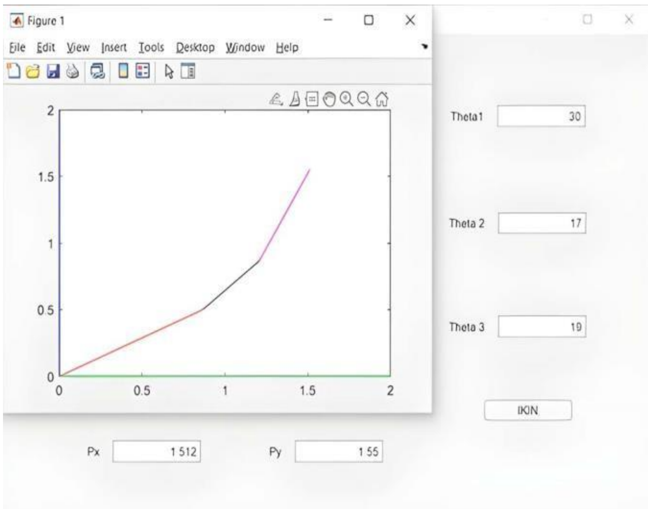

Fig 17 GUI simulation for Inverse kinematics

VIII. RESULTS AND DISCUSSIONS

This paper has been researched the position management for three DOF Robotic arms. The link length and weight of the mechanical arm are thought about by mistreatment of needed parameters. The forward and inverse kinematic are calculated with the help of D-H parameters and analytical methodology. And then, the PI controller is employed to urge the particular position of the mechanical arm. PI gains are tuned by Auto Tuning methodology. Finally, the results are shown in the MATLAB Simulink package.

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