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DESIGN OF A PROTOTYPE OF A PICK AND PLACE ROBOTIC ARM

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***Abstract*— In the industry today, continuous attempts to realize optimal efficiency and increased productivity have spawned much progress in the use of intelligent automated devices and machines to perform various operations and tasks. In this accordance, we have designed a prototype of a 5 degree of freedom robotic arm, a SCARA configuration which will be implemented in an industry to pick and place multiple number of components (Taper roller bearings) from a horizontal stack into a loading crate. The following paper presents the development of kinematic model, development of inverse kinematic model and also validation of forward kinematics using MATLAB. The joint link parameters have been developed by using Denavit-Hartenberg Parameters, and a generalised algorithm.**

Index Terms— **Denavit-Hartenberg Parameters, Kinematics, Pick and place robotic arm, Taper roller bearings.**

I. INTRODUCTION

The word 'robot' was first used to denote a fictional humanoid in a 1921 play R.U.R. by the Czech writer, Karel Capek [1]-[2].The term robot is derived from word 'robota' which means forced labour. Automation has become an integral part of modern day industries. Also the use of robotic arms has grasped the minds of all to replace humans in time consuming and cumbersome activities. With this intention we were assigned an objective by an industry to design a prototype of a pick and place robotic arm to replace one of their human controlled activities at a work table. Our solution to this problem is a 5 degree of freedom robotic arm. We have implemented a SCARA (Selective Compliance Assembly Robot Arm) configuration for the robotic arm manipulator. This configuration consists of two revolute joints and one translational joint [1]. The main reason for using this configuration is that we have to map multiple positions in the loading crate, which represent the positions of the component. SCARA is the best suited configuration as it allows us to map the horizontal and vertical positions explicitly.

II. PROBLEM STATEMENT

The problem statement consists of that we have to design a robotic arm so that the outer races of super finished taper roller bearings which are automatically loaded in a horizontal stack and then placed in a loading crate manually be automated. The main consideration while gripping the component is that it is a super finished component and so it should not get tampered.

III. METHODOLOGY

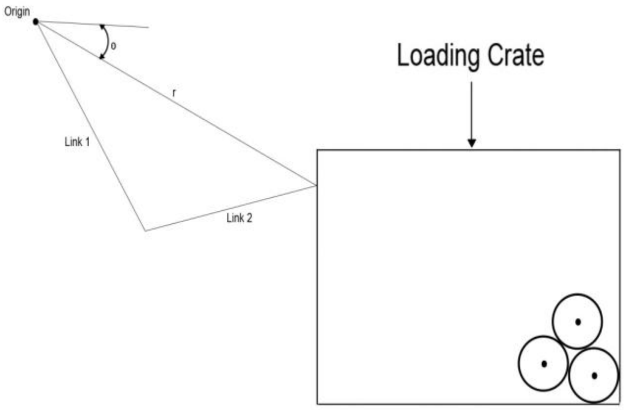


Fig. 1 Methodology of Robotic arm implementation

The method used to locate the positions of the component in the crate is as follows:
1. The column of the arm which is fixed represents the origin.
2. The horizontal plane will be mapped as a polar coordinate system, where r (radial distance) will represent the third side of the triangle formed by the two horizontal links, and angle θ will represent the angle formed by this third side with horizontal axis in Cartesian plane.
3. The linear actuator used will be used to map the vertical distance to locate the coordinate of the component.

IV. DENAVIT - HARTENBERG NOTATION [1]-[2]

The definition of a manipulator with four joint - link parameters for each link and a systematic procedure for assigning right - handed orthonormal coordinate frames, one to each link in an open kinematic chain, was proposed by Denavit and Hartenberg (1955) and is known as Denavit - Hartenberg notation [1].

With respect to frame {i-1} and frame {i}, the four DH parameters - two link parameters (a_i, α_i) and two joint parameters (d_i, θ_i) are defined as:

1. Link length (a_i) - Distance measured along x_i axis with z_{i-1} axis to the origin of frame {i}.
2. Link twist (α_i) - Angle between z_{i-1} and z_i axes measured about x_i axis in right hand sense.
3. Joint distance (d_i) - Distance measured along z_{i-1} axis from the origin of frame {i-1} to the intersection of x_i axis with z_{i-1} axis.
4. Joint angle (θ_i) - Angle between x_{i-1} and x_i axes measured about the z_{i-1} axis in right hand sense.

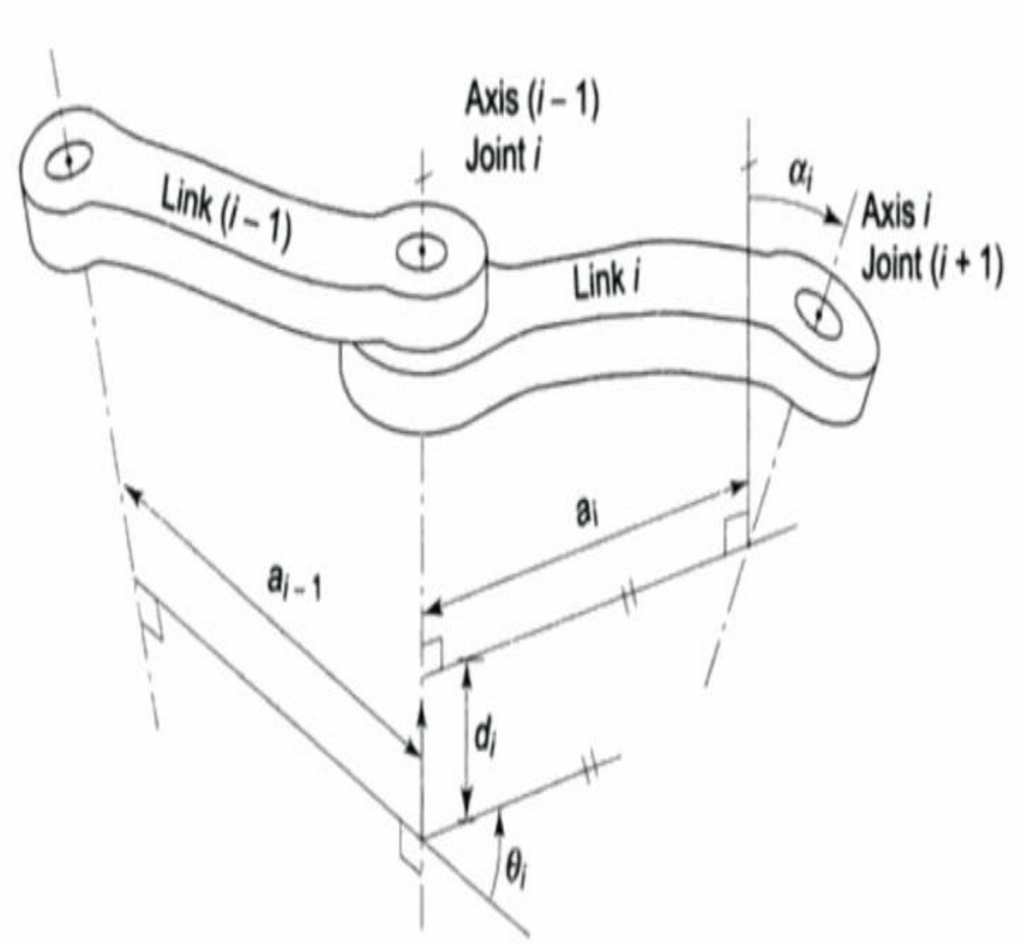


Fig. 2 DH convention for assigning frames to links and identifying joint link parameters [1]

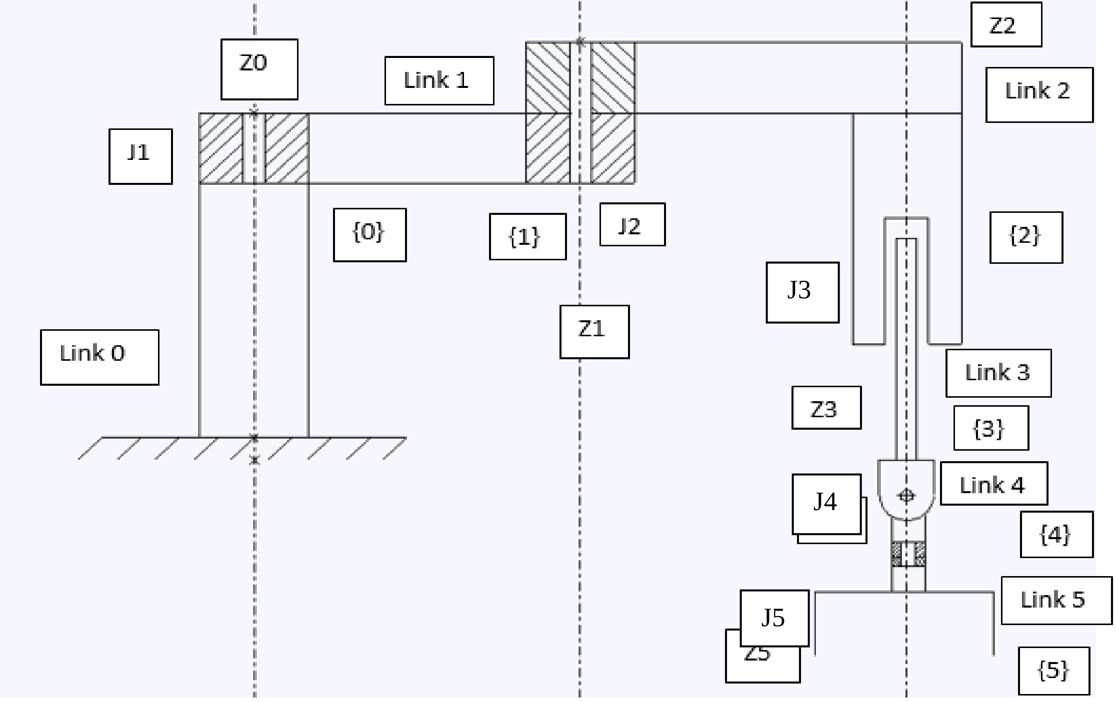


Fig. 3 Link Frame Assignment to the configuration

As shown in figure 2, the number of links and joints are identified.

Accordingly, Joint 1 (J1), Joint 2 (J2), Joint 4 (J4), Joint 5 (J5) are all revolute joints, whereas Joint 3 (J3) is a translational joint. Frame {5} represents the end effector whereas the rest of the configuration represents the manipulator.

Z1, Z2, Z3, Z4, Z5 represent the respective z_i axes of each link.

Following figure shows the frame assignment in which according to an algorithm, the frames for links 1 to link (n-1) ie. Link 4 are assigned first and then the frames of link 0 and link (n) ie. Link 5 are assigned.

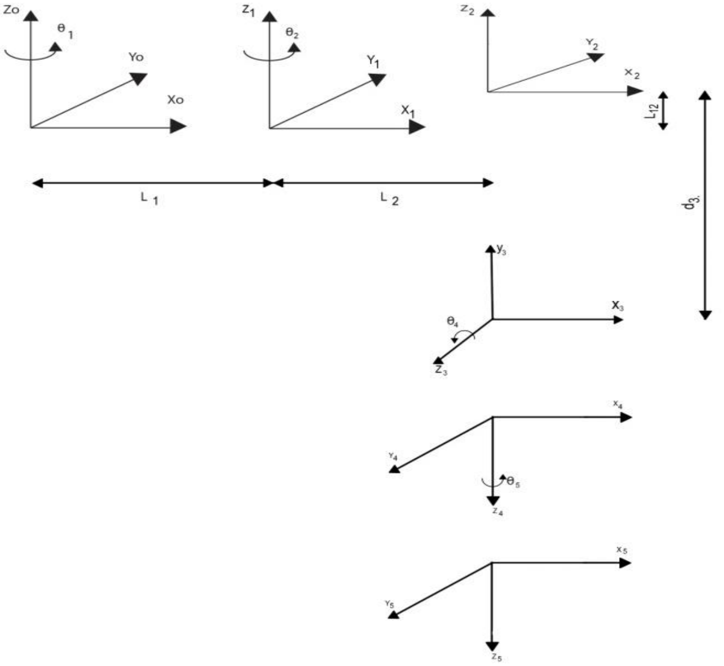


Fig. 4 Frame Assignment

From the assigned frames, and the nature of each joint, joint - Link parameters are assigned.

I. Joint - Link Parameters

Link	a_i	α_i	d_i	θ_i	q_i	$C\theta_i$	$S\theta_i$	$C\alpha_i$	$S\alpha_i$
1	L_1	0	0	θ_1	θ_1	C_1	S_1	1	0
2	L_2	0	L_{12}	θ_2	θ_2	C_2	S_2	1	0
3	0	90	d_3	0	d_3	1	0	0	1
4	0	90	0	θ_4	θ_4	C_4	S_4	0	1
5	0	0	0	θ_5	θ_5	C_5	S_5	1	0

Where,
$C\theta_i = \cos(\theta_i)$
$S\theta_i = \sin(\theta_i)$
$C\alpha_i = \cos(\alpha_i)$
$S\alpha_i = \sin(\alpha_i)$
L_1 = Length of Link 1 = 185 mm.
L_2 = Length of Link 2 = 185 mm.
L_{12} = Joint offset between links 1 and 2 = 0 mm.
d_3 = Length of Link 3 = 137 mm. + Actuated length of actuator rod of link 3

V. FORWARD KINEMATICS [1]-[2]-[5]

The robotic manipulator is designed to perform a prescribed task in the 3-D space. The end-effector, which has to follow a planned trajectory to carry out the prescribed task in the workspace, requires the control of the position of each link and the joints of the manipulator. To program and control the position and orientation of the end-effector, a mathematical model of the manipulator is required to refer to all geometrical and/or time based properties of the motion. This mathematical model is the kinematic model which describes the spatial position of joints and links, and position and orientation of the end-effector [1]. The transformation matrix is represented by ${}^{i}T_j$, where i represents the frame from which transformation takes place and j represents the frame to which transformation takes place. From the assigned frames and joint - link parameters, the following transformation matrices are obtained:

$$ {}^{0}T_{1} = \begin{bmatrix} C\theta_1 & -S\theta_1 & 0 & L_1C\theta_1 \\ S\theta_1 & C\theta_1 & 0 & L_1S\theta_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{1}T_{2} = \begin{bmatrix} C\theta_2 & -S\theta_2 & 0 & L_2C\theta_2 \\ S\theta_2 & C\theta_2 & 0 & L_2S\theta_2 \\ 0 & 0 & 1 & L_{12} \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{2}T_{3} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{3}T_4 = \begin{bmatrix} C\theta_4 & 0 & S\theta_4 & 0 \\ S\theta_4 & 0 & -C\theta_4 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{4}T_5 = \begin{bmatrix} C\theta_5 & -S\theta_5 & 0 & 0 \\ S\theta_5 & C\theta_5 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

The final Transformation Matrix is

$$ {}^{0}T_5 = {}^{0}T_1 * {}^{1}T_2 * {}^{2}T_3 * {}^{3}T_4 * {}^{4}T_5 \qquad (1) $$

VI. INVERSE KINEMATICS [1]-[2]-[4]

The Forward kinematics model developed gives the position vector of the coordinates of the point which is located by the manipulator. Inverse kinematics is used to evaluate the joint parameters when the position vector of end effector is known. In our case, we have the coordinates that is the position vector of the end effector available for different positions and hence want to evaluate the joint variables. The joint variables, θ_4, θ_5, d_3 are predefined by mere observation and the orientation of end effector required while pick and place operation. However, joint variables θ_1, θ_2 need to be evaluated and hence an inverse kinematic model for the respective joint variables was developed.

$$ \begin{bmatrix} C_{12} & -S_{12} & 0 & L_2 * C_{12} + L_1 * C_1 \\ S_{12} & C_{12} & 0 & L_2 * S_{12} + L_1 * S_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Where,
$C_{12} = \cos(\theta_1 + \theta_2)$
$S_{12} = \sin(\theta_1 + \theta_2)$
which represents the transformation matrix from frame {0} to frame {2}.
A matrix equation of the form

$$ A * O = B \qquad (2) $$

is solved and the joint variables are evaluated.
where,
A = Transformation matrix
O = Origin vector
B = Position vector
The origin vector is

$$ O = [\,0 \quad 0 \quad 465 \quad 1\,]^T $$

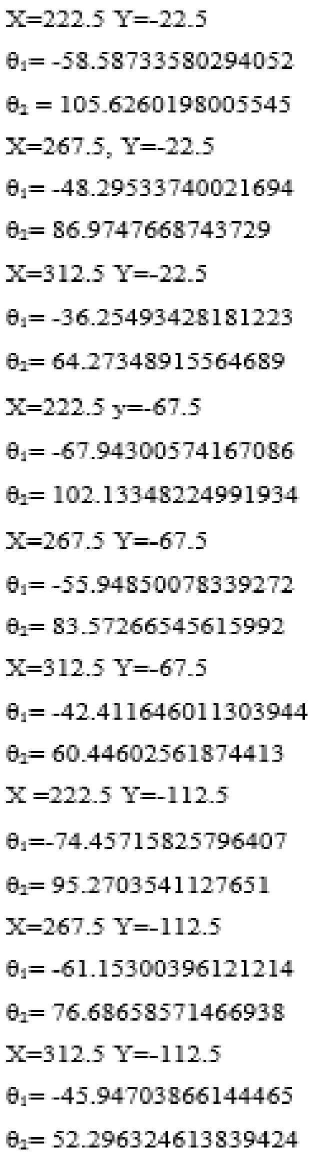
Where 465 is the length of column i.e. Link 0, which is fixed.

VII. VERIFICATION OF INVERSE KINEMATICS MODEL BY SUBSTITUTION IN FORWARD KINEMATICS MODEL

The inverse kinematic model was developed in JAVA and the forward kinematic model was developed in MATLAB. Following table verifies the horizontal plane coordinates of the end effector i.e. X and Y coordinates.

VIII. VERIFICATION OF INVERSE KINEMATICS MODEL BY SUBSTITUTION IN FORWARD KINEMATICS MODEL

Joint Angles		Actual position		Calculated position	
Θ_1	Θ_2	X	Y	X	Y
-58.58	105.62	222.5	-22.5	222.51	-22.48
-48.29	86.97	267.5	-22.5	267.51	-22.48
-36.25	64.27	312.5	-22.5	312.5	-22.48
-67.94	102.13	222.5	-67.5	222.32	-67.23
-55.94	83.57	267.5	-67.5	267.51	-67.46
-42.41	60.44	312.5	-67.5	312.5	-67.5
-74.45	95.27	222.5	-112.5	222.51	-112.47
-61.15	76.68	267.5	-112.5	267.51	-112.5
-45.94	52.29	312.5	-112.5	312.51	-112.48



```
X=222.5 Y=-22.5
θ1= -58.58733580294052
θ1 = 105.6260198005545
X=267.5, Y=-22.5
θ1= -48.29533740021694
θ1= 86.9747668743729
X=312.5 Y=-22.5
θ1= -36.25493428181223
θ1= 64.27348915564689
X=222.5 y=-67.5
θ1= -67.94300574167086
θ1= 102.13348224991934
X=267.5 Y=-67.5
θ1= -55.94850078339272
θ1= 83.57266545615992
X=312.5 Y=-67.5
θ1= -42.411646011303944
θ1= 60.44602561874413
X =222.5 Y=-112.5
θ1=-74.45715825796407
θ1= 95.2703541127651
X=267.5 Y=-112.5
θ1= -61.15300396121214
θ1= 76.68658571466938
X=312.5 Y=-112.5
θ1= -45.94703866144465
θ1= 52.296324613839424
```

Fig. 5 Data log file generated from software

In the Fig.5, X and Y represent the Cartesian coordinates and the values θ_1 and θ_2 represents joint variables

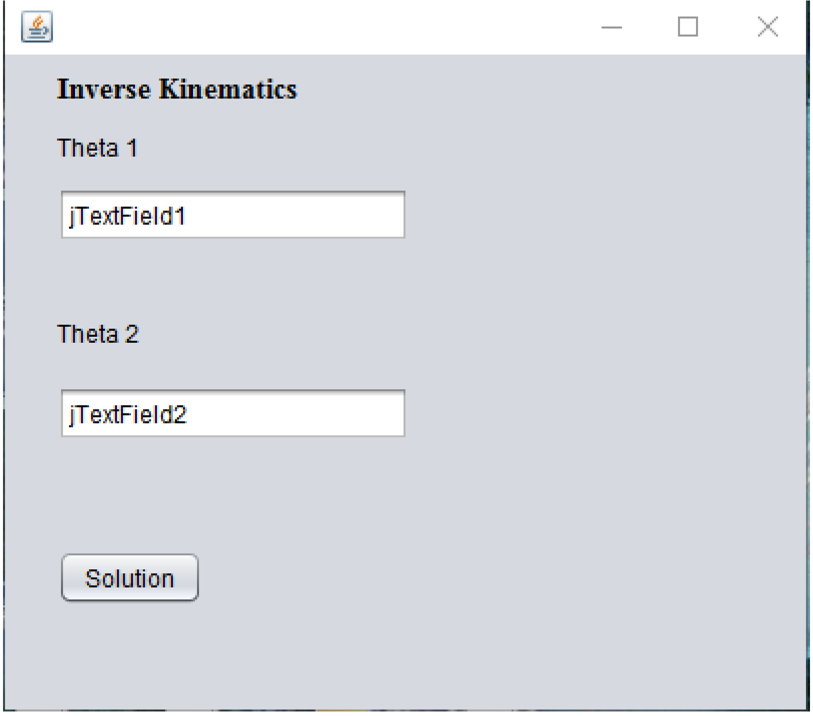


Fig. 6 GUI of Inverse Kinematic model output

In the Fig.7, the column represents link 0 and the parallel link plates represent link 1 and link 2 respectively, the linear actuator represents link 3, and the rest of sub-assembly represents link 4 and 5 collectively. The gripper module represents the end-effector

Fig. 7 Actual model designed in SOLIDWORKS

IX. CONCLUSIONS

As seen from Table II, the values of joint variables obtained by inverse kinematics are satisfactory. Also the forward kinematics model developed is perfect as the values closely approximate the real values with an error less than 1% which is very desirable for such an application.

REFERENCES

[1] R.K. Mittal and I. J. Nagnath, Robotics and Control, 2nd Edition, Tata McGraw-Hill Education, 2003.

[2] S. K. Saha, Introduction to Robotics, 2nd Edition, Tata McGraw-Hill Education, 2008.

[3] Ashraf Elfasakhany, Eduardo Yanez, Karen Baylon, Ricardo Salgado, Design and Development of a Competitive Low-Cost Robot Arm, November 15, 2011.

[4] Ravi Kumar Mourya, Amit Shelke, Sourabh Satpute, Sushant Kakade, Manoj Botre, Design and Implementation of Pick and Place Robotic Arm, International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME) Vol. 2, Issue 1, pp: (232-240), Month: April 2015 – September 2015 .

[5] Ayokunle A. Awelewa; Kenechukwu C. Mbanisi; Samuel O. Majekodunmi; Ishioma A. Odigwe; Ayoade F. Agbetuyi; Isaac A. Samuel, Development of a Prototype Robot Manipulator for Industrial Pick-and-Place Operations, 1,2,3,4,5Department of Electrical and Information Engineering, College of Science & Technology, Covenant University, Ota, Ogun State, Nigeria.