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Simulation and Kinematic Modeling of 3 Axis Robot Arm for Random Weld Joint and Welding Operation

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Abstract: *Robot welding is a fast and accurate welding to obtain a good joint strength. In this thesis, a 3-axis robotic arm has been modeled using CAD tool for performing welding operations. For the developed robotic arm, forward & inverse kinematic analyses have been performed to move the weld torch in the desired trajectory. A new seam tracking methodology, named sewing technique has been introduced for the welded joints available in Computer Aided Design (CAD) environment. This methodology, gives the seam path by drawing a line through the adjacent centroids of curve fitted in the weld joint volume. Obtained geometric path and kinematic constraints are given as input to the modeled robot for performing welding operation followed by desired trajectory. Validation of the developed methodology has been done through simulation results while performing welding operations for different weld profiles.*

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1. INTRODUCTION

With an unremitting requirement for better productivity and the provision of end products having uniform quality, manufacturing industries are turnoff more and more toward the computer-based automation. Now a days, industries are having automated machines are used to perform variety of prearranged tasks in manufacturing process. Nevertheless automated machines are generally expensive as well as inflexible in performing variety of tasks. Due to these limitations, the development of robots having capable of performing a variety of manufacturing functions in a more flexible working environment at lower production costs.

Robotics is the branch of electrical engineering, mechanical engineering, control engineering and softwareengineering that deals with the design, development, operation, and utilization of robots using computer systems for their control, bidirectional communication and information -processing. Motion planning of the robot that is kinematics and dynamics part is taken care by control and mechanical aspect of robotics whileelectrical aspect of robotics deals with powering the on board sensors and actuators module. Use of artificial intelligence technique through programming and implementation of suitable algorithm makes the robot intelligent andautonomous.

2. OBJECTIVES

The aim of the research work is to introduce the new methodology for robot welding in CAD environment to increase productivity in manufacturing industries. The objective of the current study is to design and perform the robot welding in CAD environment as well as validation of simulation results.

The following objectives were consequently stated for this research work:

- To perform forward and inverse kinematic analysis of a 3-axisrobot.
- To extract the coordinate data from theCAD geometry of existed weldedjoints.
- To obtain weld seam from sewingtechnique.
- To simulate the robot to follow the weld seam path obtained from seamtracker.

To validate simulation results of robot with help of CATIA.

1. MECHANICAL DESIGN ARCHI-TECTURE OF ROBOTWELDING

Manipulator kinematics pacts with the motion of robot arm with respect to the fixed frameof reference without considering the forces or moments which cause the motion of the robot arm. Manipulator kinematics includes forward kinematic analysis as well as inverse kinematic analysis. In forward kinematic analysis for given link lengths and joint angles we haveto find out the position and orientation of theend effector with respect to fixed reference frame. Where as in the inverse kinematic analysis for a given position and orientation of end effector wehaveto obtain jointparameters.

3. ROTATION KINEMATICS

A robotic system consists of links and they are modelled likerigid bodies. Therefore, rigid body features areno displacement in the body and take a vital rolein robotics. As the robot links may rotate / translate with respect to each other, it is required to find their relative

configurations with respect to world reference frame. The relative position between link B and link A is well-defined by a coordinate transformation ATBbetween attached link referenceframes.

Consider a rigid body B and a global coordinate frame OXYZ with a local coordinate frame oxyz as shown in Fig.3.1(a). Primarily the body B is fixed to the ground G and their reference frames are coinciding at Point O as represented in Fig. 3.1(b).

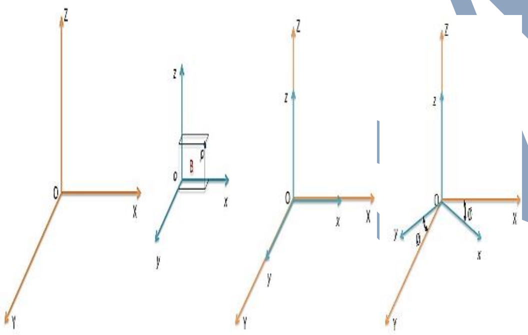


Fig.1 a) Global & Local Coordinateframes,

b) Initial frames position and

c) Local frame rotation with respect to global frame

In the global coordinate frame the rigid body B rotates about the Z-axis and making an angle of □ degrees as shown in Fig. 3.1(c), then body point P coordinates in the global and local coordinate frames are given by theEq. (3.1).

$$G(p) = R(Z, \emptyset)B(p)(3.1)$$

Here$R(Z, \emptyset)$is rotational mapping matrix

$$G(p) = \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix} \text{and} B(p) = \begin{Bmatrix} x \\ y \\ z \end{Bmatrix}$$

Let *(i_X, j_Y, k_Z)* and *(i_x, j_y, k_z)* be the unit vectors along the coordinate axes of the OXYZ global coordinate system and oxyz local coordinate systems respectively.

$$p_{XYZ} = Xi_X + Yj_Y + Zk_Z = xi_x + yj_y + zk_z = p_{xyz}$$

The point *p* can be defined by using the definition of scalar product as the components of a vector as represented in Eq. (3.2).

$$\left.\begin{aligned} X = i_x.p = i_X.i_x x + i_X.j_y y + i_X.k_z Z \\ Y = j_Y.p = j_Y.i_x x + j_Y.j_y y + j_Y.k_z Z \\ Z = k_W.p = k_W.i_x x + k_W.j_y y + k_W.k_z Z \end{aligned}\right\} \quad (3.2)$$

$$\begin{Bmatrix} p_X \\ p_Y \\ p_Z \end{Bmatrix} = \begin{bmatrix} i_X . i_x & i_X . j_y & i_X . k_z \\ j_Y . i_x & j_Y . j_y & j_Y . k_z \\ k_W . i_x & k_W . j_y & k_W . k_z \end{bmatrix} \begin{Bmatrix} p_x \\ p_y \\ p_z \end{Bmatrix}$$

$$= \begin{bmatrix} \cos(\emptyset) & \cos(90+\emptyset) & \cos(90) \\ \cos(90-\emptyset) & \cos(\emptyset) & \cos(90) \\ \cos(90) & \cos(90) & \cos(0) \end{bmatrix} \begin{Bmatrix} p_x \\ p_y \\ p_z \end{Bmatrix}$$

$$= \begin{bmatrix} \cos(\emptyset) & -\sin(\emptyset) & 0 \\ \sin(\emptyset) & \cos(\emptyset) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} p_x \\ p_y \\ p_z \end{Bmatrix}$$

From the above mapping matrix can be written as,

$$R(Z,\emptyset) = \begin{bmatrix} \cos(\emptyset) & -\sin(\emptyset) & 0 \\ \sin(\emptyset) & \cos(\emptyset) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Accordingly the global coordinates of the point p can be obtained by rotation angle with respect to X- axis and Y- axis in local coordinate frames and the transformations are represented by Eqs. (3.3) & (3.4).

$$R(X,\emptyset) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\emptyset) & -\sin(\emptyset) \\ 0 & \sin(\emptyset) & \cos(\emptyset) \end{bmatrix} \qquad (3.3)$$

$$R(X,\emptyset) = \begin{bmatrix} \cos(\emptyset) & 0 & \sin(\emptyset) \\ 0 & 1 & 0 \\ -\sin(\emptyset) & 0 & \cos(\emptyset) \end{bmatrix} \qquad (3.4)$$

To denote rotations about the principal axes of OXYZ coordinate system the basic rotation matrices should be sequentially multiplied. Since matrix multiplications are not commute, the order of performing rotations is important.

a. FORWARD KINEMATICANALYSIS

Forward kinematics or direct kinematics of the manipulator is used to find out the position and orientation of theend-effector for a known joint angles and link parameters. Manipulator consists of so many parts the positions can becalculated with respect to the different reference frames. An analysis of the links at different position is methodically calculated. Schematic diagram for the direct kinematics of a manipulator is represented in Fig.3.2.

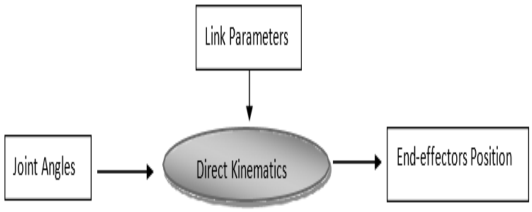


Fig.2 Schematic diagram of direct kinematics of a manipulator

Coordinate frames for the manipulator are assigned as shown in the Fig.3.3. Table 3.1 shows the values of links and joints.

Table 1Values of links and joints specification

Specification	**Value**	**Units**
Number of axes	3	
No of Links	3	
Lengths of Link1, Link 2 and Link 3	70,100,70	mm
Work Envelope	Body Rotation : 360 Elbow Rotation :180,-180 Wrist Rotation : 90,270	degrees

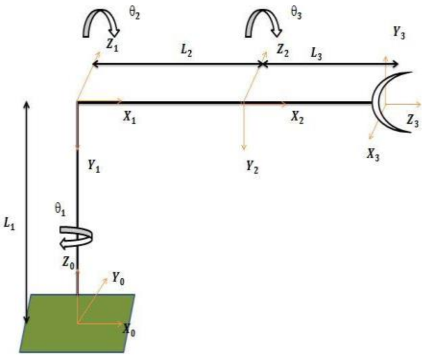


Fig.3 Link coordinate frame of the manipulator

The kinematic information includes: position, velocity, acceleration, and jerk. However, forward kinematics generally refers to position analysis. So the forward kinematic analysis is equivalent to a determination of a combined transformation matrix and it is represented in Eq. (3.5) &Eq. (3.6).

$$T_i = Rot\ (z, \theta_i) * Rot\ (x, \theta_i) * Rot\ (y, \theta_i) \qquad (3.5)$$

$$T_3^0 = T_0^1 * T_1^2 * T_2^3 \qquad (3.6)$$

Where the first transformation matrix is represented in Eq. (3.7)

$$T_0^1 = \begin{bmatrix} cos\theta_1 & -sin\theta_1 & 0 & l_1 cos\theta_1 \\ sin\theta_1 & cos\theta_1 & 0 & l_1 sin\theta_1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} (3.7)$$

The second transformation matrix to relate the first frame to second frame is represented in Eq. (3.8)

$$T_0^2 = \begin{bmatrix} cos\theta_2 & -sin\theta_2 & 0 & l_2 cos\theta_2 \\ sin\theta_2 & cos\theta_2 & 0 & l_2 sin\theta_2 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} (3.8)$$

The third transformation matrix which relates thesecond frame and end-effector frame which can be represented by Eq. (3.9),

$$T_0^3 = \begin{bmatrix} cos\theta_3 & -sin\theta_3 & 0 & l_3 cos\theta_3 \\ sin\theta_3 & cos\theta_3 & 0 & l_3 sin\theta_3 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} (3.9)$$

Therefore, the transformation matrix to relate theend-effector frame to the base frame is represented by Eq. (3.10)

$$T_0^1 = \begin{bmatrix} cos(\theta_1+\theta_2+\theta_3) & -sin(\theta_1+\theta_2+\theta_3) & 0 & r_{14} \\ sin(\theta_1+\theta_2+\theta_3) & cos(\theta_1+\theta_2+\theta_3) & 0 & r_{24} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(3.10)

Where, and are represented by Eq. (3.11) &Eq. (3.12)

$$r_{14} = l_1 cos\theta_1 * (l_2 \cos(\theta_1+\theta_2) + l_3 \cos(\theta_1+\theta_2+\theta_3)) \quad (3.11)$$

$$r_{24} = l_1 sin\theta_1 * (l_2 \sin(\theta_1+\theta_2) + l_3 \sin(\theta_1+\theta_2+\theta_3)) \quad (3.12)$$

We can find the coordinate of the tip point in the base Cartesian coordinate frame if we have the geometry of the robot and all joint variables.

$$X = l_1 cos\theta_1 * (l_2 \cos(\theta_1+\theta_2) + l_3 \cos(\theta_1+\theta_2+\theta_3))$$

$$Y = l_1 sin\theta_1 * (l_2 \sin(\theta_1+\theta_2) + l_3 \sin(\theta_1+\theta_2+\theta_3))$$

4. METHDOLOGY FOR CAD ASSISTED ROBOTWELDING

At present, robots areextensively used for performing welding operation for increasing the quality of the weld as well as for better production rate. In the current section, robot has to perform welding operation in CAD environment/ virtual environment. Extraction of the coordinate data from theexisted geometry can be possible by writing program in CATIA.

4.1. MANIPULATOR DESIGN INCATIA

This robot is a 3 axis robot which consists of three links as well as three joints. Three links of manipulator namely base link, shoulder link, and wrist link. Link 1 is fixed on the base and it will rotate about Z- axis. Link 1 and link 2 are connected by revolute joint and link 2 will rotate about X-axis. Link 2 and link 3 are connected by revolute joint and link 3 will rotate about X- axis. Connections between the links are represented in the Fig.4.1. On a robot end- effector link welding gun has to be attached to perform the welding operation for specified seam position.

The forward and inverse kinematic analysis has been performed. Forward kinematic analysis is used for finding the position of anend effector by knowing the joint angles. Inverse kinematics is used for finding the joint angles from the given position of anend effector.

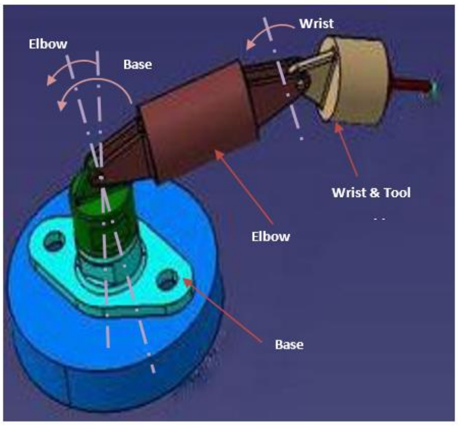
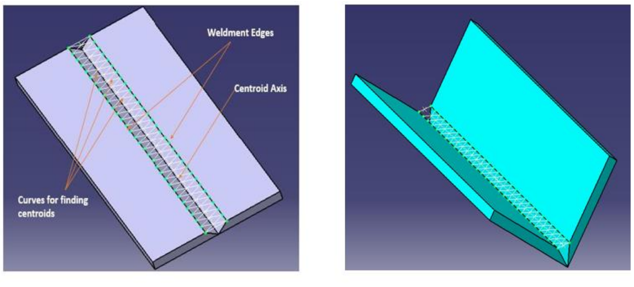


Fig. 4 CATIA model of 3-axis robot arm

4.2. EXTRACTING COORDINATE DATA FROM CAD GEOMETRY OF WELDEDJOINTS

From theexisted CAD model, it is very easy to know the geometry where to bewelded. In this approach, control points are considered along the length/ periphery of the welding joint. The control points of oppositeedges are connected by a curve and along theentire length we haveto draw the curves. These curves representation is shownin Fig.4.2. By joining the centroids of each curve we will get a path that path is nothing but weld seam path. This techniqueis known as sewing technique and it can bemodelled by generative shape design modulein CATIA. By knowing weld seam coordinatesit is very easy to obtain thejoint angles of a robot. Finally along the weld seam path and it will perform the weldingoperation.



(a) (b)

Fig.5 Sewing diagram in CATIA for butt and l shape weld joint

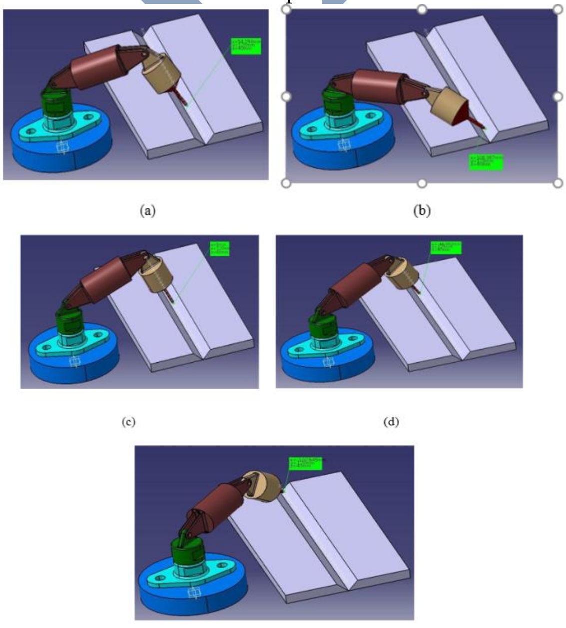
From the diagram, we can observe that weld seam path can be obtained by using the centroids of theeach curve. The procedure for the butt joint as well as L-shape joint is same. By knowing the weld seam it is very easy to weld the any profile. After extracting the coordinate data, we can import the data into Excel and after we can find the inverse kinematic solution for particular weld seam path.

4.3. INVERSE KINEMATICSOLUTION

Ininversekinematicsolution,fortheknownlink lengthsandpositionofend-effectoritis veryeasytoobtainjointangles.Byusingtheequationswewillfindthebaseangle(θ_1)and afterthat3Rproblemcanbeconvertedinto2Rproblem.AnExcelsheethasbeenprepared tofindouttheallthejointangles.Twocombinationsofelbowangle(θ_2),andwristangle(θ_3)canbeobtainedfromtheinversekinematicmodelequations.

4.4 ROBOT SIMULATION AND ITSVALIDATION

From the kinematics, the base angle and the other two sets of elbow and wrist angles are known. For those two sets, the robot simulation has been performed. In simulation, the robot will move along the seam path given from sewing technique. Different point coordinate representations are shown in Fig. 5.1. Fig. 5.1 (a) - (d) presents coordinate representation for one set of feasible combination and Fig. 5.1 (e) – (h) shows representation of second set of unfeasible combination.Table.1. shows the point coordinate data of weld seam path.



(a) (b) (c) (d) (e)

Fig 6 Point co-ordinate representation of robot for butt joint

Table.2. Point coordinate data of weld seam path.

S. No.	X	Y	Z	S. No.	X	Y	Z
1	120	90	80	16	1.034483	105.5172	61.89655
2	112.069	91.03448	78.7931	17	-6.89655	106.5517	60.68966
3	104.1379	92.06897	77.58621	18	-14.8276	107.5862	59.48276
4	96.2069	93.10345	76.37931	19	-22.7586	108.6207	58.27586
5	88.27586	94.13793	75.17241	20	-30.6897	109.6552	57.06897
6	80.34483	95.17241	73.96552	21	-38.6207	110.6897	55.86207
7	72.41379	96.2069	72.75862	22	-46.5517	111.7241	54.65517
8	64.48276	97.24138	71.55172	23	-54.4828	112.7586	53.44828
9	56.55172	98.27586	70.34483	24	-62.4138	113.7931	52.24138
10	48.62069	99.31034	69.13793	25	-70.3448	114.8276	51.03448
11	40.68966	100.3448	67.93103	26	-78.2759	115.8621	49.82759
12	32.75862	101.3793	66.72414	27	-86.2069	116.8966	48.62069
13	24.82759	102.4138	65.51724	28	-94.1379	117.931	47.41379
14	16.89655	103.4483	64.31034	29	-102.069	118.9655	46.2069
15	8.965517	104.4828	63.10345	30	-110	120	45

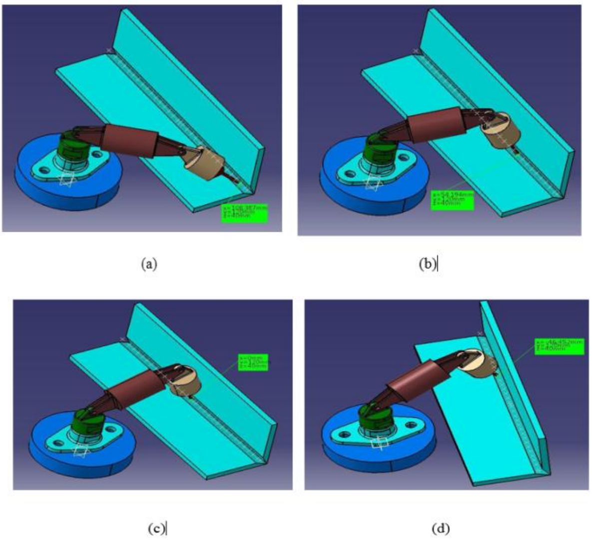

(a) (b)
(c) (d)

Fig 7 Point co-ordinate representation of robot for L joint

Trajectory planning for weld seam path is given by

- The obtained geometric path (seam path) and kinematic constraints will begiven as input to the developed robotic arm for performing weldingoperation.
- In this analysis thetrajectory planning is performed according to the3rd order cubic splineinterpolation.

For the cubic spline trajectory

$$H(t) = a1 * t^3 + a2 * t^2 + a3 * t + a4$$

The constant values can be obtained while subjected to following boundary conditions:

- At$t=0$, $a4 = \theta_0(given)\ and\ v_0 = a3/t$

At$t=1$, a1+a2+a3+$\theta_0 = \theta_f$

$$v_f = (3a1 * t^2 + 2a2 * t + a3)/t$$

$$a_f = (6a1 * t^2 + 2a2)/t^2$$

5. CONCLUSION AND FUTURESCOPE

This paper investigation has been carried out to simulate the weld seam path using the robotic arm in CAD environment. Robot arm consists of three links and three joints. The joints areall rotary in nature. First 3D CAD model has been created after that kinematic analysis has been performed. Inverse kinematic solution has been developed by using anExcel sheet and that data is given to CAD model as input file program.

The conclusions drawn from the current investigation are depicted as 3-axis robotic arm has been modelled using CAD tool for performing welding operations. For the developed robotic arm, forward & inverse kinematic analyses have been performed to movethe weld torch in the desiredtrajectory. A new seam tracking methodology, named sewing technique has been introduced for the welded joints availablein Computer Aided Design (CAD)environment. This methodology, gives the seam path by drawing a linethrough the adjacent centroids of curve fitted in the weld joint volume. Obtained geometric path and kinematic constraints are given as input to the modelled robot for performing welding operation followed by desiredtrajectory. Validation of the developed methodology has been done through simulation results while performing welding operations for different weldprofiles.

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