Kinematic Modelling and Simulation of Manipulator for Executing Welding Operations with Arbitrary Weld Joint Profiles

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Abstract: Current investigation deals with the development of an automated seam tracking methodology for the weld joints accessible in pc motor-assisted style setting. To perform welding operations, an industrial robot has been modelled in the CAD platform with three degrees of freedom. Later, kinematic models have been developed in order to navigate the end-effector through the obtained weld seam path. Simulation results for different weld joints shows the robustness of the developed methodology**.**

Key words: seam tracking, CAD, industrial robot, forward and inverse kinematic, weld seam path

1. Introduction

Now a days, manufacturing industries require more and more automated machines to compete and fulfill the globalrequirements within given time limit. Proper motion planning algorithms are necessary for robotic systems may be of manipulator or mobile platforms, in order to execute their specific tasks [1-2]. Motion planning of industrial robots is a critical issue because of its end effectors path constraints [3-4]. Whereas, the motion control of mobile robots or the mechanical behavior of the robot depends upon the wheel geometric constraints while the robot is in motion [5-6]. Bae et al. [7] used image processing algorithm to get the weld pool center and also investigated that how fuzzy logic approach can be used to monitor the manipulator and welding torch. Motion planning of mobile robot deals with generation of safest and shortest pats while reaching its target position [9-11]. There are several motion planning techniques have been developed based on to artificial intelligence algorithms [12-15]. But these techniques are not suitable for performing welding operation.

Thiswork describes about CAD based robot modelling as well as simulation. The new method is based on sewing technique and simulation in CAD environment. The development of CAD assisted robot welding covers mechanical design, Extraction of coordinate data, importing the coordinate data to MATLAB, inverse kinematic solution, and simulation.

2. Kinematic Model of 3-Axis robot

In robotics, manipulator kinematic analysis means forward and inverse kinematic analysis, it refers to calculate the relations between end-effectors and joint angles. So for forward kinematics, the joint angles are the inputs and the outputs would be the coordinates of the end-effectors. On the other hand for inverse kinematics, the given inputs are the coordinates of the end effector and the output to calculate would be joint angles.

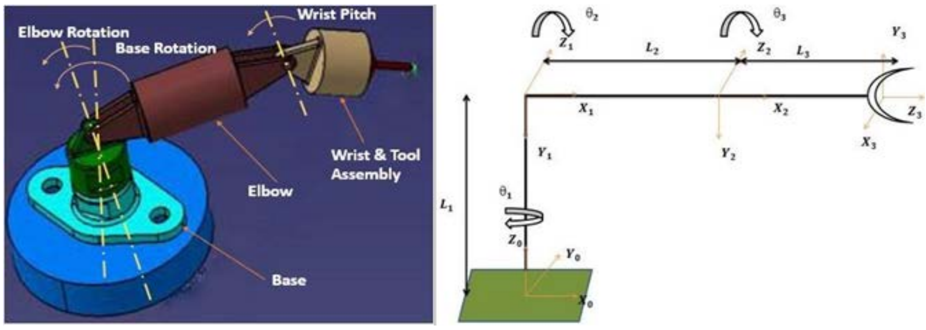


Fig.1.3-axis manipulator in CAD environment and its coordinate reference frame

Table 1: Considered robotic arm stipulations

Element specification	Quantity	Measurement
DOF corresponds to each axis	Three	Rotational motion
Number of rigid elements/links	Three (Base, Elbow & wrist)	
Link length of the above	70,100 & 70	mm
Work-volume	Link-1 turn : 360 Link-2 turn:180,-180 Link-3 turn: up to 270^0	Rotation in degrees

2.1. Arm Matrix Determination

Direct kinematics for the most part alludes to position examination of the tool. Therefore, forward kinematic examination is equal to finding of manipulator network with joining change frameworks as described in Eq. (1).

$$T_3{}^0 = T_0{}^1 * T_1{}^2 * T_2{}^3 \quad (1)$$

Therefore, the arm equation of the developed manipulator is:

$$T_3{}^0 = \begin{bmatrix} \cos(\theta_1+\theta_2+\theta_3) & -sin(\theta_1+\theta_2+\theta_3) & 0 & r_{14} \\ \sin(\theta_1+\theta_2+\theta_3) & \cos(\theta_1+\theta_2+\theta_3) & 0 & r_{24} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

Where, $r_{14} = l_1 cos\theta_1 + l_2 cos(\theta_1 + \theta_2) + l_3 cos(\theta_1 + \theta_2 + \theta_3)$;
$r_{24} = l_1 sin\theta_1 + l_2 sin(\theta_1 + \theta_2) + l_3 sin(\theta_1 + \theta_2 + \theta_3)$
Represent the Cartesian coordinates of the end effector position.

2.2. End-Effector Position Estimation

A basic mathematical methodology is actualized to take care of the backward kinematic issue. Fig.2 represents the line diagram of the modelled manipulator. From the time when the point (θ3) relies on upon elbow edge (θ2), so there will be "2 wrist edges comparing to every connection development (left and right or upward and descending).

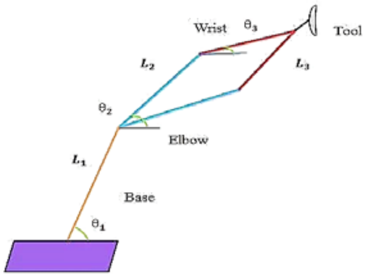


Fig.2 Line diagram for performing kinematic analysis

The base point can be controlled by Eq. (3)
Base point $\theta_1 = arctan\ (r_{14}/r_{24})$ (3)

Subsequent to finding θ_1, a three revolute issue can be changed over to two revolute planar issue. Therefore, '2' joint points ($\pm\theta_3$) be obtained for the same instrument point as takes after:
The controller end point worldwide location is given as per Eqs. (4) & (5)

$$Y = l_2 cos\theta_2 + l_3 \cos(\theta_2 + \theta_3) \quad (4)$$
$$Z = l_2 sin\theta_2 + l_3 \sin(\theta_2 + \theta_3) \quad (5)$$

Therefore

$$\theta_3 = cos^{-1}\left(\frac{Y^2 + Z^2 - l_2^2 - l_3^2}{2 l_2 l_3}\right) \quad (6)$$

To calculate θ_2, arc tan function can be used as per Eq. (7)

$$\theta_2 = \pm atan2\sqrt{\frac{(l_2 + l_3)^2 - (Y^2 + Z^2)}{(Y^2 + Z^2) - (l_2 - l_3)^2}} \quad (7)$$

These two arrangements are rung as elbow up & down positions and corresponding joint angle θ_2 are given by:

$$\theta_2 = atan2\frac{Z}{Y} + atan2\left(\frac{l_3 sin\theta_3}{l_2 + l_3 \cos\theta_3}\right) \quad \theta_2 = atan2\frac{Z}{Y} - atan2\left(\frac{l_3 sin\theta_3}{l_2 + l_3 \cos\theta_3}\right)$$

3. Seam Tracking Approach

For the available 3D model, it is anything but difficult to know the geometry of the weld crease shape. Current methodology, control positions are reflected alongside the length/outskirts of the weld job. These points of inverse edges are associated through a bend further these bends are drawn along the whole length. By joining the center points of every bend, we would get a way and that way is only weld seam as appeared in Fig.3. This systematic approach is called as sewing strategy and it can be displayed in CATIA which is appeared in Fig .4.

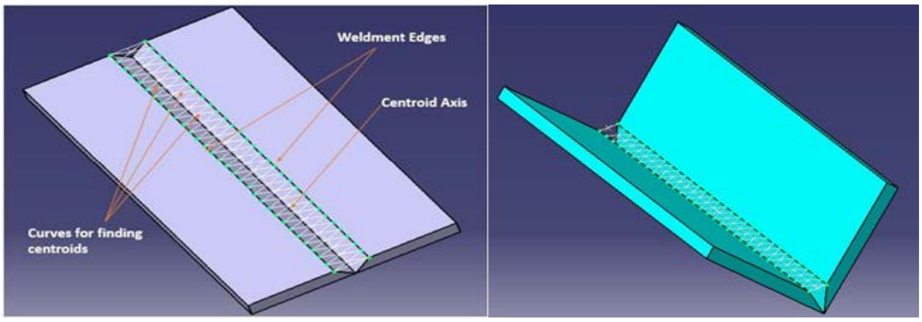
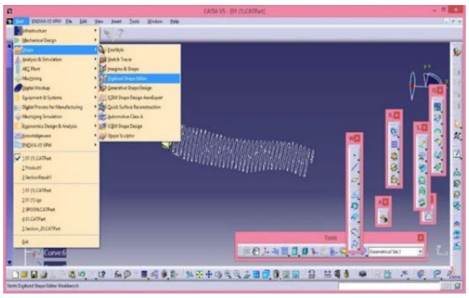


Fig.3 Sewing Technique for butt and L shape joints

3.1 Extracting Coordinate Data from CAD Geometry of Weld Joints and importing same to MATLAB

The crease coordinate information from sewing procedure can extricate effortlessly. The project has been produced in CATIA to separate the point coordinate information into Excel. By opening CATIA window with seam path and by clicking on the program directly we can get the point coordinates in Excel sheet and then imported the same data to MATLAB. The 3D plot has been generated there for the weld seam coordinate data and it is shown in Fig.5. With the known weld crease arranges it is anything but difficult to get the parameters of a robot controller. At long last, the robot would operate the welding task.



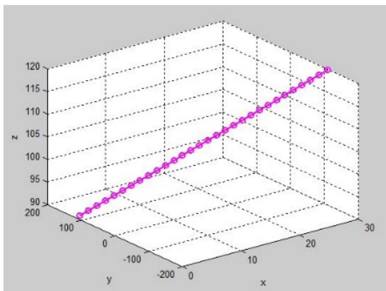


Fig.4. Sewing diagram in CATIA

Fig.5. Weld seam to be followed by robot

4. Welding Task in Virtual Environment

The got geometric way (crease way) and motion requirements will be input information to the modelled automated robot to execute welding operation. This manipulator is referred to the info parameters prior to execute welding. Present study deals with the examination the path planning is performed by third order cubic spline introduction.
Eq. (8) represents the cubic spline trajectory representation with necessary boundary constraints:

$$S(t) = \mathrm{b1} * t^3 + \mathrm{b2} * t^2 + \mathrm{b3} * t + \mathrm{b4} \quad (8)$$

At t=0, b4 $= S_0$ $(given)$ and $v_0 =$ b3 ; At t=1, $\mathrm{b1} + \mathrm{b2} + \mathrm{b3} + S_0 = S_f$

$v_f = (3\mathrm{b1} * t^2 + 2\mathrm{b2} * t + \mathrm{b3})$; $a_f = (6\mathrm{b1} * t + 2\mathrm{b2})$

The developed method is implemented to perform welding operation in the virtual environment. A typical operation for butt welded joint is represented Fig.6.

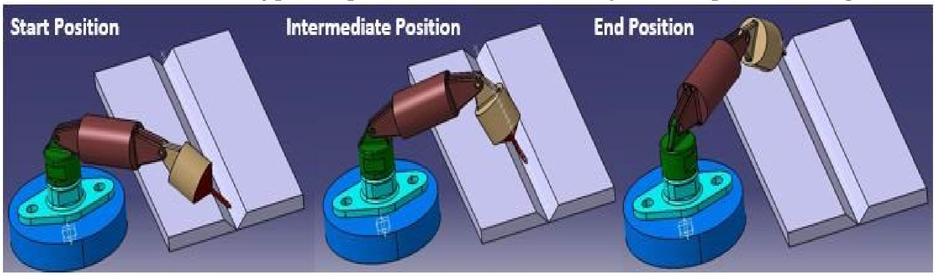


Fig. 6. Welding task for butt joint in virtual environment

5. Assessment with Earlier Research

A percentage of the previous exploration showed speaks to the different philosophies for performing seam tracking and welding task. An itemized correlation is illustrated in Table 2.

Table 2 Evaluation with earlier techniques

Past work	Technique for seam Tracking	Recognition of Seam start & end points	Trajectory with respect to Kinematics
[7]	Perception with optic sensor	Yes	No
[8]	Perception with laser sensor	No	Yes
[13]	Computer modelling	No	Yes
Current study	CAD assisted	Yes	Yes

6. Conclusion

The current research work meted to mimic the 3-pivoted automated manipulator in computer aided atmosphere for executing welding task despite the fact taking after the weld crease way and its posture analysis requirements. Another crease following philosophy, named sewing procedure has presented for the welded joints accessible in virtual work-space. Acceptance of the created technique performed through reenactment outcomes while carrying out welding processes with various weld contours.

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