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**AND EDUCATION**

**FALCUTY OF MECHANICAL ENGINEERING**

**DEPARTMENT OF MECHATRONICS**

**Optimization Algorithms for Inverse Kinematics of**

**Robot** **Fanuc m2000iA 900L**

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# INTRODUCTION.

Industrial robots have long been used to replace the necessity of the human operator in repetitive tasks or dangerous environments. From the early stages, with respect to the specificity of the application, each specific IR model may be efficiently integrated into flexible manufacturing cells by considering its maximum reach ability and payload. Both major functional features are basically depending on the length of each IR's link, the available limits for each IR's joint orientation as well as some specific constructive features of each IR's subassemblies

The Fanuc M2000iA 900L is a heavy payload industrial robot designed for applications requiring substantial lifting capacity and high precision. It operates with closed-chain kinematics and is capable of handling complex tasks in manufacturing environments. The robot’s large reach and payload make it suitable for heavy-duty operations, such as palletizing, assembly, and material handling in large-scale industrial applications.

Its workspace and motion are determined by the number of degrees of freedom (DOF) and the specific configuration of its joints, which include both rotational and translational movements. The robot's kinematics are described using the Denavit-Hartenberg (D-H) convention, with a 4×4 homogeneous transformation matrix used to compute both forward and inverse kinematics. This allows the robot to calculate the necessary joint angles to reach a target position or orientation.

# TECHNICAL SPECCIFICATION

Fanuc m2000iA 900L is a heavy payload serial link robot with closed-chain kinematics and 6 DOF. The technical specifications and functional parameters of the Fanuc m2000iA robots are detailed.

|  |  |  |
| --- | --- | --- |
| **Manufacturer and model** | | **Fanuc m2000iA 900L** |
| Maximum payload (kg) | | 900 |
| Number of NC axis | | 6 |
| Repeatability (mm) | | 0.5 |
| Reach (mm) | | 4638 |
| Maximum speed | 1 | 45 °/s |
| 2 | 30°/s |
| 3 | 30°/s |
| 4 | 50°/s |
| 5 | 50°/s |
| 6 | 70°/s |
| Working range | 1 | +165° / ˗165° |
| 2 | +100° / ˗60° |
| 3 | +35° / -130° |
| 4 | +360° / ˗360° |
| 5 | +120° / ˗120° |
| 6 | +360° / ˗360° |
| Weight (kg) | | 9600 |
| Table 1: Technical specifications of Fanuc m2000iA 900L | | |

# CONSTRUCTIVE PARAMETERS AND D-H MODIFIED TABLE

D-H modified table is utilized for modeling chains of bodies connected by joints. Initially, the D-H convention was applied solely to single-loop chains, but it has now become almost universally applicable to most serial chain structures.

In this study, the modified D-H parameters will be used to represent the frames of the industrial robots being analyzed [17]. The following procedure has been followed to attach the link frames (Figs. 3 and 4) [4]:

## ROTATION MATRIX

We have rotation matrix and translation matrix:



and translation matrix.



Then we expand both to a 4x4 matrix:



## DH principle

* The (z)-axis aligns with the direction of the joint axis.
* The (x)-axis is parallel to the common normal (or directed away from . If there is no unique common normal (i.e., parallel (z) axes), then (d) (as described below) is a free parameter.
* The direction of is from to
* The (y)-axis is determined from the (x)- and (z)-axes to form a right-handed coordinate system***.***

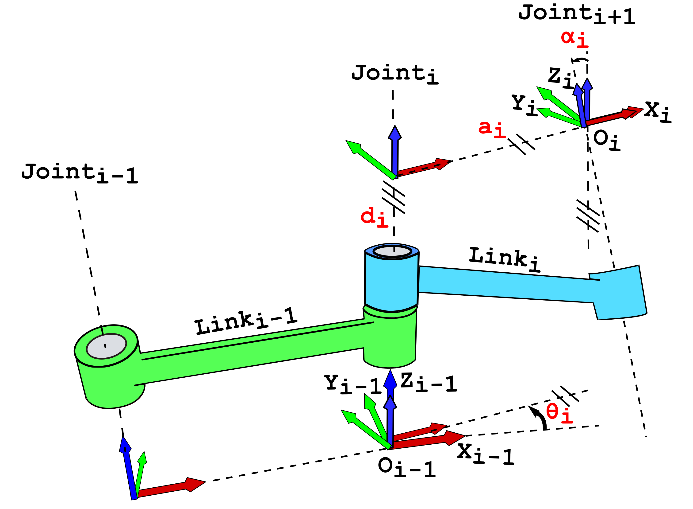
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Figure 1: D-H parameters

## DH modified rules

 is the rotational displacement around the axis  between and 

 is the translational displacement along the axis  from  to 

 is the rotational displacement around the axis  between  and 

 is the translational displacement along the axis  from  to 

*A diagram of a mechanical arm

Description automatically generated*

Figure 2: Dimensional specifications and joint numbering of the Fanuc m2000iA Industrial robot:

## Homogeneous Transformation Matrix

Transformation matrix between robot links:







where:



# LINK PARAMETERS

The link parameters define the dimensions of the robot arm, including joint offsets as per the Denavit-Hartenberg convention, and specify the position and orientation of each joint relative to the preceding one. The link parameters for the Fanuc m2000iA 900L robots are specified in the below Table. These parameters are used to determine the Homogeneous Transformation Matrix.

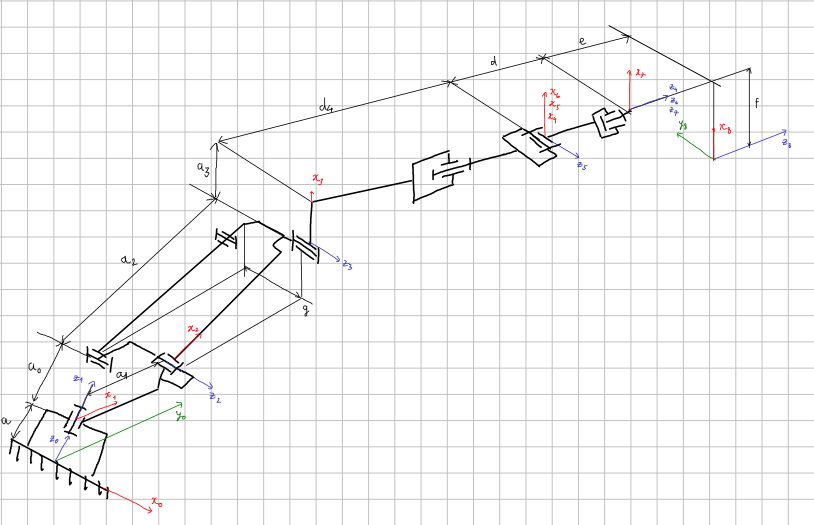


Figure 3: Assignment of link frames for Fanuc m2000iA 900L Robot

#### DH\_Table:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Link** | **(mm)** | **()** | **(mm)** | **(rad)** |
| 1 | 0 | 0 | 0 | θ1 |
| 2 | 500 | -90 | 0 | θ2 |
| 3 | 1700 | 0 | 0 | θ3 |
| 4 | 180 | -90 | 2850 | θ4 |
| 5 | 0 | 90 | 0 | θ5 |
| 6 | 0 | -90 | 0 | θ6 |

# FORWARD KINEMATICS

For an n-axis rigid-link manipulator, the process of solving the forward kinematics involves calculating the position and orientation of the robot's end effector based on its joint parameters. This calculation provides a precise description of the end effector's location and orientation with respect to the robot's base frame. This is essential for accurately predicting the robot's behavior and controlling its movements in a defined workspace.

From modified DH table’s values, we can deduce that:

* Link 1: 



* Link 2: 



* Link 3: 



* Link 4: 



* Link 5: 



* Link 6: 



Forward kinematics is employed to define the shape and boundaries of the working envelope. A uniform step value is established for the joint limits across all axes. Utilizing the position vector derived from the forward kinematics' homogeneous transformation matrix, a vector delineating the position vectors for Px and Pz is formulated. Each entry in this vector corresponds to a set of Cartesian coordinates representing a specific position. Using these coordinates, which map out the XOZ plane's working envelope shape, a three-dimensional model is created by revolving the traced spline around the θ1 rotational axis.

For the robot under study, this process is illustrated with resultant visualizations displayed in Figure 1, specifically for the Fanuc m2000iA 900L robot. The robot can only use a limited combination of joint limits. This limitation arises from the presence of a lever-type link that necessitates a specific geometric constraint:

|  |  |
| --- | --- |
|  |  |

This is why the working limit of the lever’s joint should not exceed the inferior limit of .

From these transformation matrices, we can conclude that the transformation matrix to convert position from the end working point to the global coordinate origin is:



























Note that: , , , is denote , , ,  respectively for minimalist purpose.

# INVERSE KINEMATIC

Inverse kinematics is used to compute the joint angles required to achieve a desired position and orientation of the end-effector relative to the base frame. The Fanuc m2000iA 900L robot, which has two joint offsets (on the X and Z axes), can achieve a total of 6 sets of joint angles for a given position, depending on the configuration of the robot.

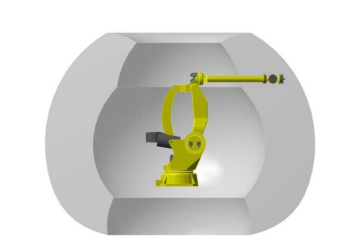


Figure 4: Working envelope of Fanuc m2000iA

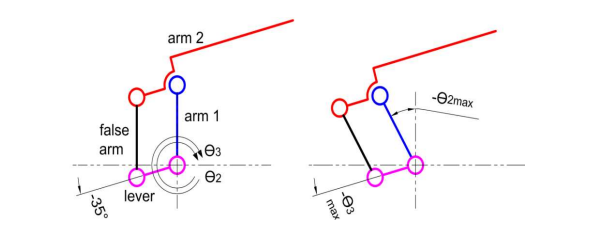


Figure 5: Geometrical constraint applied to the Fanuc m2000iA Robot.

Computation of , , and using the elements of the position vector from the T matrix:



To determine the optimal equations for each joint, a study of the motion plane is conducted. The solutions for each joint can be computed by simplifying the equations using the inverse kinematics identities proposed by John Craig. The resulting equations are presented below:

For :



For :

,

.

Let:   



For :



Rewriting:



Let:   



For , , and  equations are used:







Each solution uses the geometrical identity that transforms a specific position from Cartesian space to joint space:



For :







For :







For :







# SIMULATION BY MATLAB

## Parameter:

+ a1 = 500, a3 = 180, a2 = 1700, d4 = 2850.

|  |  |
| --- | --- |
| Theta i | Value |
| 1 | 0 |
| 2 | -90.030548 |
| 3 | -34.964052 |
| 4 | 0 |
| 5 | -35.9946 |
| 6 | 0 |
| Table 3: Parameters | |

Forward kinematic:



* Px = 2730, Py = 0, Pz = 3481.9
* Inverse kinematic:

A screenshot of a computer

Description automatically generated

|  |  |
| --- | --- |
| Theta 5 = | A number with numbers on it  Description automatically generated with medium confidence |
| Theta 6 = |  |

* **CONCLUSION**

In the present work, a forward and inverse kinematics parametric analytical model was discussed. Symbolic solutions for inverse kinematics are presented.