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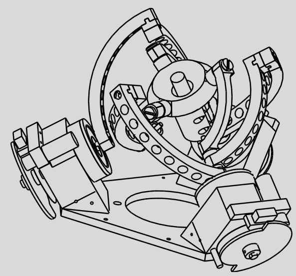


Advanced Robotics
Analytical Approaches
for the IKP of Serial Manipulators
By: M. Tale Masouleh
Deadline: 1392/02/10
Responsable TA: Amir-Hossein Karimi

Problem 1 (To be Solved by TA)

An experimental six-revolute robot is shown in an arbitrary posture in Fig 3.1.

- Produce the table with the Denavit-Hartenberge parameters of the manipulator;
- Find all arm inverse kinematic solutions for the positioning of point C, the center of the spherical wrist;

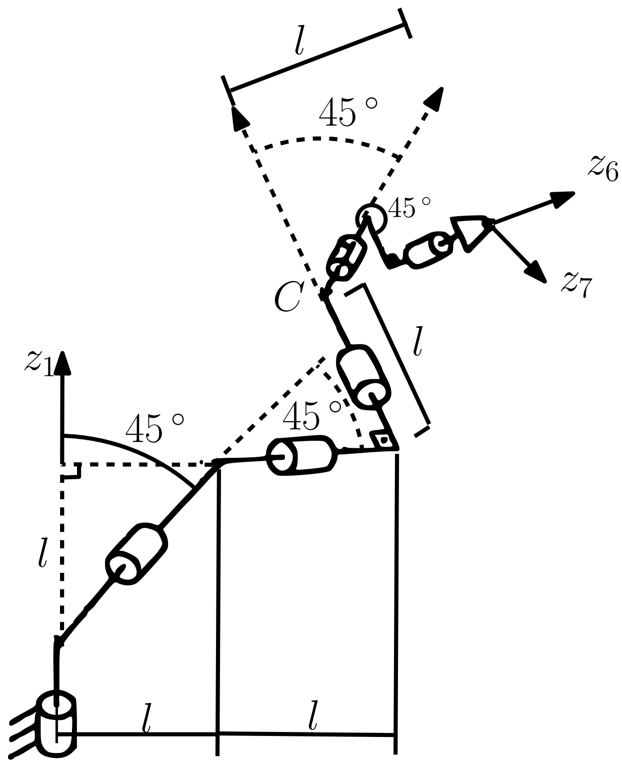


Figure 3.1: Arbitrary posture of an experimental six-revolute manipulator.

- Find all wrist inverse kinematic solutions for the orientations of the EE. In how many postures can this manipulator produce the same EE pose?

Problem 2

For the manipulator with the Denavit-Hartenberge parameters represented in Table 3.1:

- Find all the inverse kinematic solutions for the positioning of point C, the operation point;
- Solve the forward kinematic problem of this manipulator for an arbitrary configuration;

Table 3.1: Denavit-Hartenberge parameters of the manipulator in problem 2.

i	a_i	b_i	α_i	θ_i
1	0	b_1	$\frac{\pi}{2}$	$\frac{\pi}{2}$
2	0	1	$\frac{\pi}{2}$	θ_2
3	1	1	0	θ_3

- Find the Jacobian matrix of the manipulator at any configuration;
- Using the Robotic Toolbox for an arbirary operation point trajectories, solve the inverse kinematic problem to obtain some solution for the joint trajectories. Verify the results via computing the forward kinematic solutions and comparing them with each other;
- Compare the trajectories obtained by the Robotic Toolbox with the results of the second item in this problem.

Problem 3

An experimental six-revolute robot is depicted in an arbitrary posture in Table 3.2.

- For the defined tarjectory find the joint space trajectories by solving the IKP, using Robotic Toolbox.

$$x = 0.5 \sin t + 0.5,\ y = 0.5 \cos t + 0.5,\ z = t, \quad \text{for } t \in [0, \frac{\pi}{4}] \tag{3.1}$$

- Based on the above solutions, solve the FKP using the D-H parameters and compared the solution by the one obtained using the Robotic Toolbox.

Problem 4

Attached to this HW is the data sheet of the Motoman UP50N robot. Based on this sheet, produce a table of Denavit-Hartenberg parameters that describe the geometry of the robot. In the figures, all dimensions are indicated

Table 3.2: Denavit-Hartenberge parameters of an experimental six-revolute manipulator.

i	a_i	b_i	α_i	θ_i
1	1	1	$\frac{\pi}{4}$	θ_1
2	0	1	$\frac{\pi}{2}$	θ_2
3	1	0	0	θ_3
4	0	0	$-\frac{\pi}{2}$	θ_4
5	0	0	$\frac{\pi}{2}$	θ_5
6	0	1	0	θ_6

in mm. In order to speed up the marking, use the - and + signs associated with the joints to define the Z_i-axes unambiguously.

- For the defined tarjectory find the joint space trajectories by solving the IKP, using Robotic Toolbox.

$$x = 50\sin t + 800,\ y = 50\cos t,\ z = 1000, \quad \text{for } t \in [0, \frac{\pi}{2}] \tag{3.2}$$

- Based on the above solutions, solve the FKP using the D-H parameters and compared the solution by the one obtained using the Robotic Toolbox.

Problem 5

The reasoning applied in Section 4.4.2 of the book in order to solve the orientation problem of the IKP is based on the following sequence:

$$\theta_4 \longrightarrow \theta_5 \longrightarrow \theta_6 \tag{3.3}$$

In this question, you should solve the same problem as above but for the following sequence:

$$\theta_4 \longrightarrow \theta_6 \longrightarrow \theta_5 \tag{3.4}$$

More specifically, you should find the following:

- First you should start from the fact that:

$$\mathbf{R} = \mathbf{Q}_4\mathbf{Q}_5\mathbf{Q}_6 = \mathbf{Q}_3^T\mathbf{Q}_2^T\mathbf{Q}_1^T\mathbf{Q} \tag{3.5}$$

- Show that the $[\mathbf{e}_5]_4$ can be made equivalent to the last column of $\mathbf{Q}_4$ and $[\mathbf{e}_6]_4$ is the last column of $\mathbf{R}\mathbf{Q}_6^T$;

- Find a univariate expression wit respect to θ_4, using the fact that the projection of $\mathbf{e}_5$ into $\mathbf{e}_6$ is a constant value;

- For θ_4, you should find W, X, Y with respect to the known values

$$W\,c_4 + X\,s_4 = \tag{3.6}$$

  where $c_4 = \cos\theta_4$ and $s_4 = \sin\theta_4$;

- For θ_6:

$$\cos\theta_6 = \frac{r_{12}\sin\alpha_4\sin\theta_4 - \ldots}{\sin\alpha_5\cos\alpha_6} \tag{3.7}$$

$$\sin\theta_6 = \frac{r_{11}\sin\alpha_4\sin\theta_4 - \ldots}{\sin\alpha_5} \tag{3.8}$$

  From the above, it can be inferred that when $\cos\alpha_6 = 0$ the above fails to provide a solution for θ_6. Find an alternative to ciruvment the latter problem;

- For θ_5:

$$\cos\theta_5 = \frac{r_{31}\cos\theta_6 - \ldots}{\sin\alpha_5\cos\alpha_6} \tag{3.9}$$

$$\sin\theta_5 = \frac{\cos\alpha_4\cos\alpha_5\ldots}{\sin\alpha_5} \tag{3.10}$$

To have a more consistent answer, consider:

$$\mathbf{R} = \mathbf{Q}_4\mathbf{Q}_5\mathbf{Q}_6 = \mathbf{Q}_3^T\mathbf{Q}_2^T\mathbf{Q}_1^T\mathbf{Q} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \tag{3.11}$$

$$\mathbf{Q}_5\mathbf{Q}_6 = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix} \tag{3.12}$$

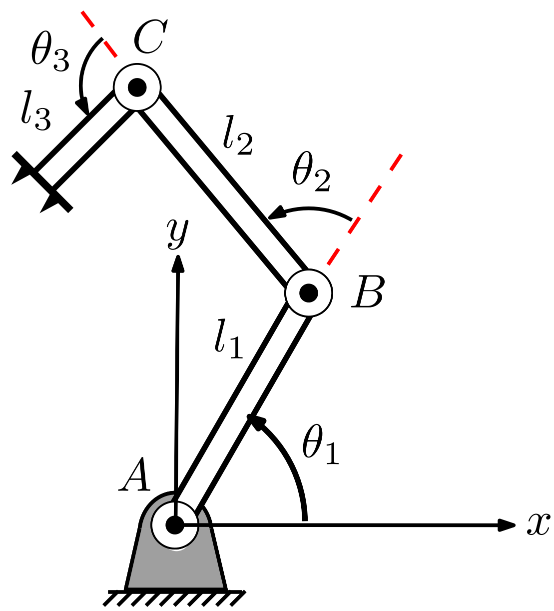


Figure 3.2: 3-DOF serial robot.

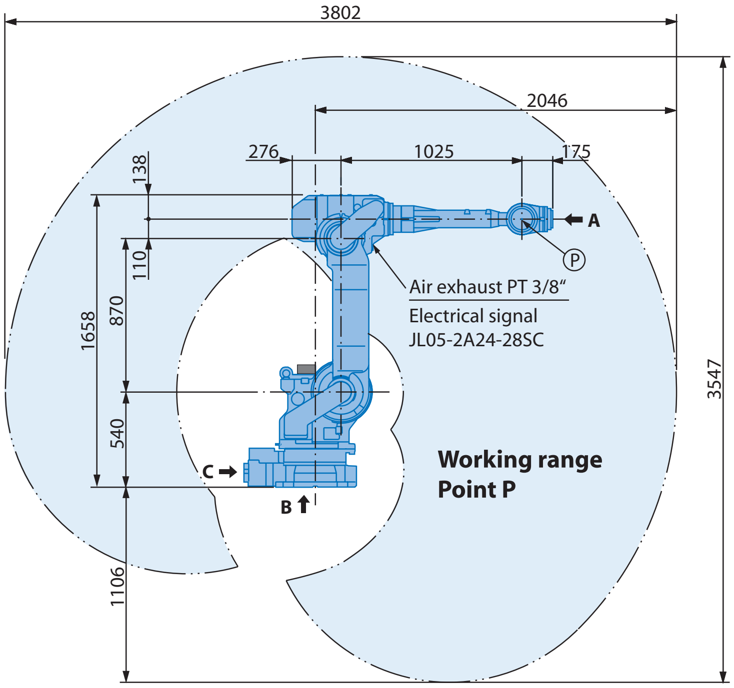
Problem 6

Obtain the dexterity of a 3-DOF planar serial manipulator, depicted in Fig. 3.2, by:

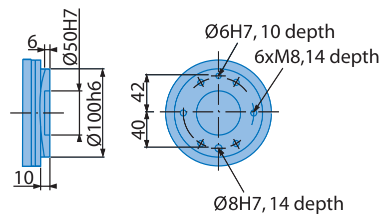
1. Derive the Jacobian;
2. Derive the dexterity of the mechanism;
3. For $\theta_2 = \frac{3\pi}{4}$, $l_1 = 1$ and $l_2 = \frac{\sqrt{2}}{2}$ for $l_3 = [\frac{1}{8}, \frac{1}{4}, \frac{1}{2}, 1]$ plot (2D) the dexterity with respect to θ_3;
4. For $l_1 = 1$, $l_2 = 1$ and $l_3 = 1$ plot (3D) the dexterity with respect to θ_2 and θ_3;
5. Plot the global dexterity with respect to θ_2 and θ_3.

Problem 7

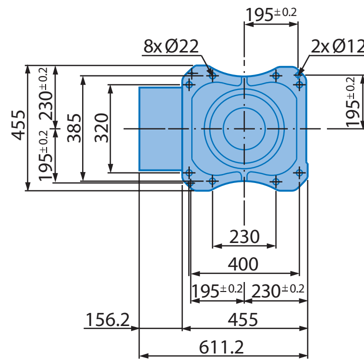
Fig. 3.2 represents schematically a RRR serial manipulator. Provide an optimal set of design parameters, i.e., l_1, l_2 and l_3, for this serial manipulator, which compromises the best possible global dexterity, obtained in item 5 of Problem 6, according to the guidelines of the Differential Evolution (DE) optimization algorithm. The required optimization software codes for DE, developed by Mohammad Hossein Saadatzi, are availabe here. In case of any question, do not hesitate to contact Morteza Daneshmand: mzdaneshmand@ieee.org.

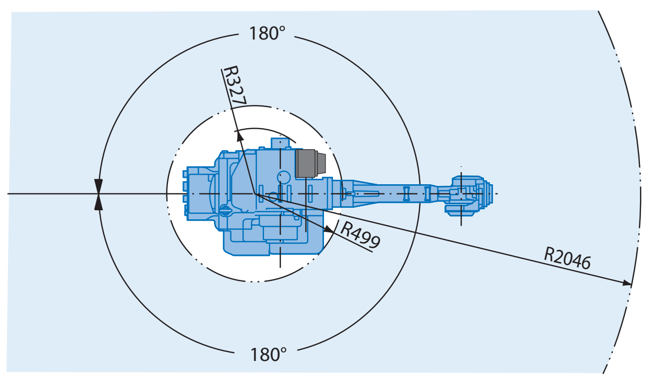


View A

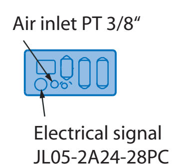


View B





View C



Notice

- These dimensions are for reference purposes only. Please request detailed drawings for all design/engineering requirements, at www.motoman.de.
- All dimensions in mm

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Technical data may be subject to change without previous notice, UP50N, C-05-2008

Specifications UP50N

Axes	Maximum motion range [°]	Maximum speed [°/sec.]	Allowable moment [Nm]	Allowable moment of inertia [kg/m²]
S	±180	170	–	–
L	+135/–90	170	–	–
U	+280/–160	170	–	–
R	±360	250	196	13
B	±125	250	196	13
T	±360	350	127	5,5

Controlled axes	6
Max. payload [kg]	50
Repet. pos. accuracy [mm]	±0,07
Max. working range [mm]	R = 2046
Temperature [°C]	0 bis +45
Humidity [%]	20 – 80
Weight [kg]	550
Power supply, average [KVA]	5,0

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