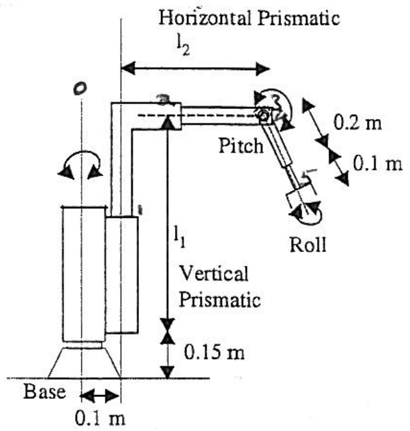
SUM 00

5. A five-axis robot is of a modified cylindrical structure, where the vertical prismatic joint is offset by 0.1 m, as shown in the diagram. The offset is in the plane of the paper only. The minor (pitch and roll) joints are of standard type, the pitch joint of the wrist having a horizontal axis. You can assume that the joints also have no offsets in a plane perpendicular to the paper. A gripper acts as the end effector, as shown. The prismatic length l_1 can vary from 0.3 m to 0.6 m, and l_2 from 0.2 m to 0.4 m. If the dimensions of the system are as on the diagram, use the Denavit-Hartenberg



algorithm and matrix (available as Appendix I at the end of this paper) to

(a) Assign suitable frames to the robot, using a link-coordinate diagram.

(b) Tabulate the kinematic parameters associated with the first three joints of the robot (i.e. those from the base to the wrist).

(c) Write down an expression for $T_{\text{base}}^{\text{wrist}}$ for this robot, based on your frame assignments; (i.e. you need not write down the transformations relating frames from tool to wrist). Your answer can take the form of a product of a number of matrices, i.e. you are *not* required to perform the multiplication.

(d) Perform a sanity check on T_1^2.

6. A five-axis articulated robot (Alpha II) has a tool matrix of the following form:

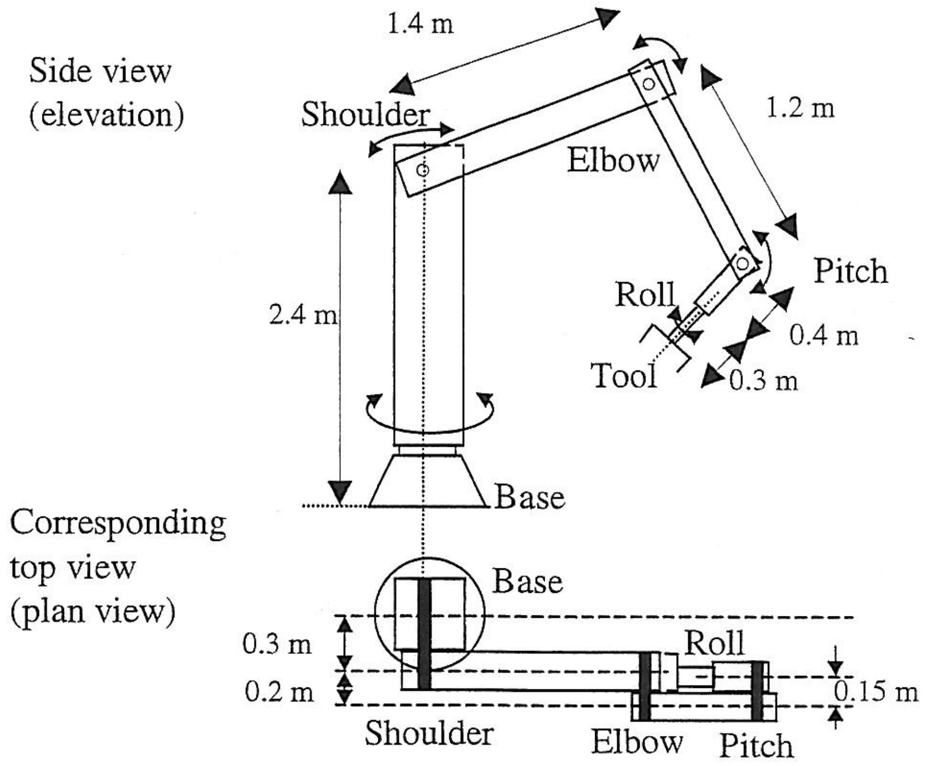
$$T_{\text{base}}^{\text{tool}} = T_{\text{base}}^{\text{wrist}}\, T_{\text{wrist}}^{\text{tool}} =$$

$$\begin{bmatrix} C_1C_{23} & -C_1S_{23} & -S_1 & C_1(a_2C_2 + a_3C_{23}) \\ S_1C_{23} & -S_1S_{23} & C_1 & S_1(a_2C_2 + a_3C_{23}) \\ -S_{23} & -C_{23} & 0 & d_1 - a_2S_2 - a_3S_{23} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_4C_5 & -C_4S_5 & -S_4 & -d_5S_4 \\ S_4C_5 & -S_4S_5 & C_4 & d_5C_4 \\ -S_5 & -C_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} C_1C_{234}C_5 + S_1S_5 & -C_1C_{234}S_5 + S_1C_5 & -C_1S_{234} & C_1(a_2C_2 + a_3C_{23} - d_5S_{234}) \\ S_1C_{234}C_5 - C_1S_5 & -S_1C_{234}S_5 - C_1C_5 & -S_1S_{234} & S_1(a_2C_2 + a_3C_{23} - d_5S_{234}) \\ -S_{234}C_5 & S_{234}S_5 & -C_{234} & d_1 - a_2S_2 - a_3S_{23} - d_5C_{234} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Derive the inverse kinematic equations and comment on the uniqueness, or otherwise, of your solution.

5. A five-axis robot includes five revolute joints. It is an economical structure in which offsets exist along some joint axes, as shown. The shoulder, elbow and pitch joints have horizontal axes, while the axis of the base joint is vertical. A gripper acts as the end-effector, as shown.



If the dimensions of the system are as on the diagram, use the Denavit-Hartenberg algorithm and matrix (available as Appendix I at the end of this paper) to:

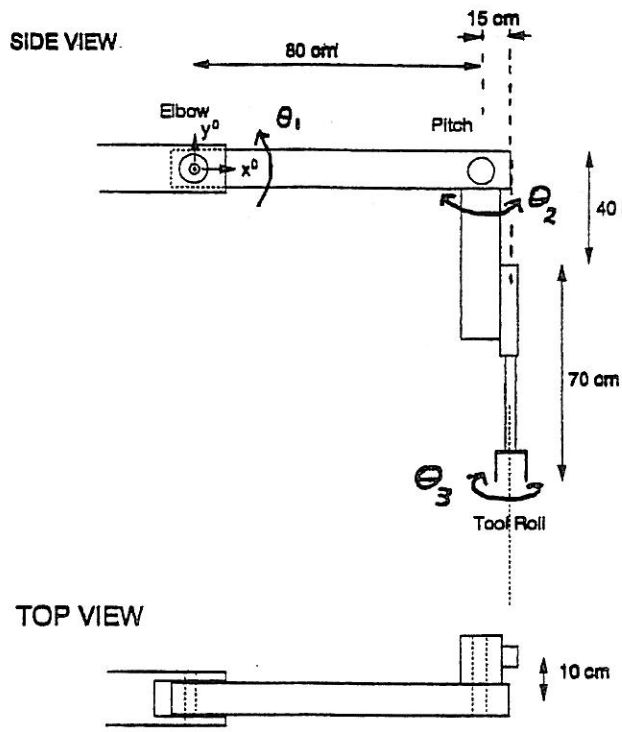
(a) Assign suitable frames to the robot, using a link-coordinate diagram. [*11 marks*]

(b) Tabulate the kinematic parameters associated with the robot. [*5 marks*]

(c) Write down an expression for $T_{\text{base}}^{\text{tool}}$ for this robot, based on your frame assignments. Your answer can take the form of a product of a number of matrices, i.e. you are *not* required to perform the multiplication. [*2 marks*]

(d) Perform a sanity check on T_3^4. [*2 marks*]

2. Part of a five-axes articulated robot is shown below. This robot has offsets in the tool roll axis and in the pitch joint. The elbow and pitch joints are both revolute and have horizontal axes. A gripper acts as the end effector, as shown.



If the dimensions of the system are as on the diagram, and assuming that the frame that is attached to the previous link is located at the elbow joint (denoted 'frame 0' below), as shown, use the Denavit-Hartenberg algorithm and matrix (available as Appendix I at the end of this paper) to

(a) Assign suitable frames to the remaining illustrated parts of the robot, using a link-coordinate diagram.

(b) Tabulate the kinematic parameters associated with the robot.

(c) Write down an expression for T_0^{tool} for this robot, based on your frame assignments. Your answer can take the form of a product of a number of matrices, i.e. you are *not* required to perform the multiplication.

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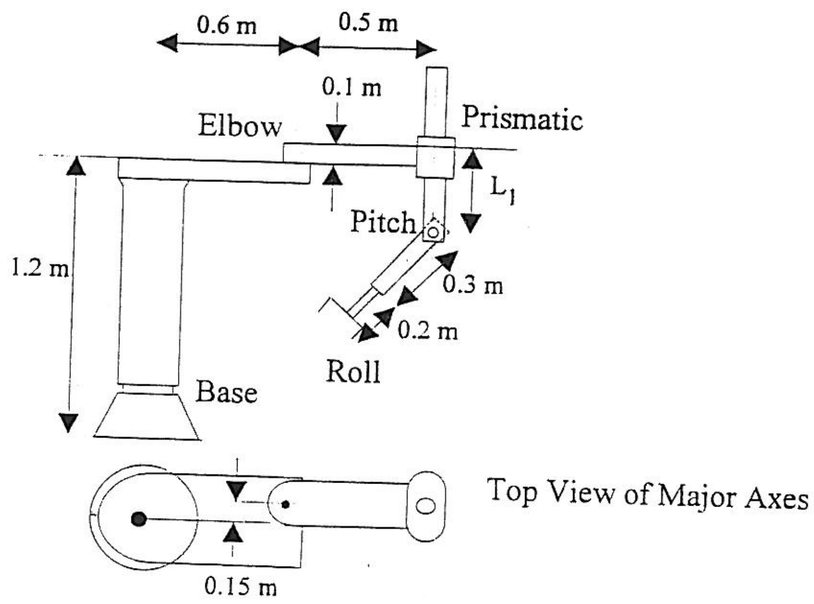
2. A five axis robot is of a modified SCARA structure, where a pitch joint is added and the link supporting the elbow joint has an asymmetric construction, as shown in the diagram below. The minor (pitch and roll) joints are of standard type, the pitch joint of the wrist having a horizontal axis. A gripper acts as the end effector, as shown. The prismatic length l_1 can vary from 0 m to 0.7 m.



If the dimensions of the system are as on the diagram, use the Denavit-Hartenberg algorithm and matrix (available as Appendix I at the end of this paper) to

(a) Assign suitable frames to the robot, using a link-coordinate diagram.

(b) Tabulate the kinematic parameters associated with the robot, including the home parameters.

(c) Write down an expression for $T_{\text{base}}^{\text{tool}}$ for this robot, based on your frame assignments. Your answer can take the form of a product of a number of matrices, i.e. you are *not* required to perform the multiplication.

(d) Perform a sanity check on T_4^5.

3. (a) Describe the operation of the various types of in-line robotic work cells.

(b) Describe the Open Systems Integration Model of MAP for factory automation purposes.