Robótica de Manipulação 2022/2023

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Trabalho Laboratorial : Da Vinci Xi Surgical Robot

Mestrado Integrado em Engenharia Mecânica

The proposed work consists in the Kinematic and Dynamic analysis of the *Da Vinci Xi* surgical manipulator by *INTUITIVE*. In your report, provide complete, concise answers to the points below, using your own code. For developing your computational models, a Symbolic Robotics Matlab Toolbox is provided in the course webpage, as the starting point.

Kinematics: (Due on May 28th)

1. Analyze the robot's technical drawing in Appendix A and build its kinematic model according to the Denavit-Hartenberg convention. To do so, draw your own joints diagram with the link reference frames and the corresponding table of parameters.
2. Using the provided Toolbox, create a Simulink model for the direct kinematics of the robot. Validate your model by placing the robot in configurations for which the end-effector's position and orientation can be easily determined.
3. Following a kinematic decoupling approach present one closed-form solution for the inverse kinematics of the robot. Create the Simulink model and validate your model against the direct kinematics model implemented in Point 2.
4. Create a Simulink model for the geometric Jacobian of the robot. Validate the result through numerical differentiation of the direct kinematics in Point 2. Determine the kinematic singularities of the robot and show their effect on the rank of the Jacobian matrix.
5. Using the direct kinematics and the geometric Jacobian models, determined in Points 2 and 4, implement a Simulink model for the Closed Loop Inverse Kinematics of the robot. Validate your model against the results of Point 3.

Dynamics and Control: (Due on June 18th)

1. Using simple solid shapes (bars, cylinders, etc), calculate approximate values for the mass, center of mass, and inertia tensor for each link. Neglect the motions of joints 6, 7 and 8 due to their relative lower mass, when compared to the arm.
2. Create a Simulink model for the dynamics of the robot (See Appendix B). You are free to choose either the Lagrange-Euler or the Newton-Euler method (Note: The Newton-Euler formulation is quicker to build the Simulink blocks for the dynamics).
3. Calculate the worst-case inertia configuration for each link of the robot manipulator. Then, design and implement decentralized PID type joint controllers for the robotic arm.
4. Design and implement a centralized inverse dynamics controller for the robot arm.
5. Choose a task for the end-effector and design the corresponding task-space trajectory. Compare the performance of the controllers in points 3 and 4 for your task.

Note on Matlab toolboxes

To verify that to you have the necessary Matlab and Simulink toolboxes, you may execute the following commands in Matlab's command window.

```
>> syms x
>> y=x^2
>> new_system('model_name')
>> open_system('model_name')
>> matlabFunctionBlock('model_name/parabola',y)
>> vredit
```

Appendix A. Technical Drawing

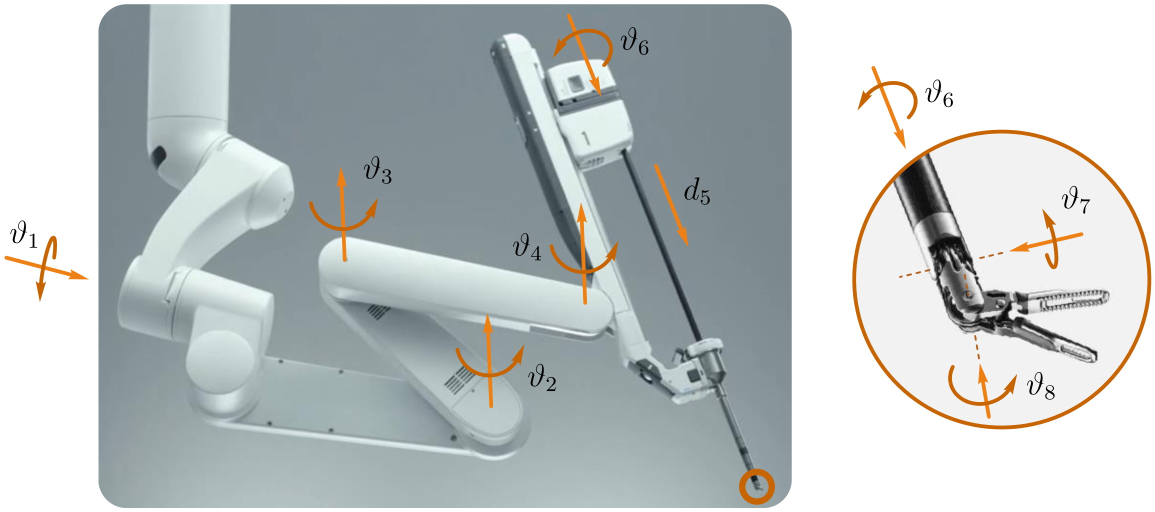


Figure A1. Rotation axes for ϑ_1 and ϑ_2 are orthogonal. Rotation axes for ϑ_2, ϑ_3 and ϑ_4 are parallel. Rotation axes for ϑ_6 and ϑ_7 intersect at a common point and are orthogonal. Rotation axes for ϑ_7 and ϑ_8 are orthogonal and they are spaced by 10 mm.

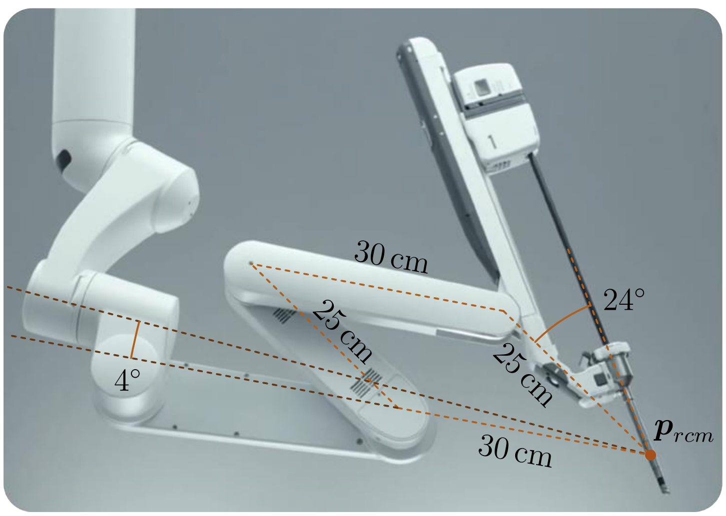
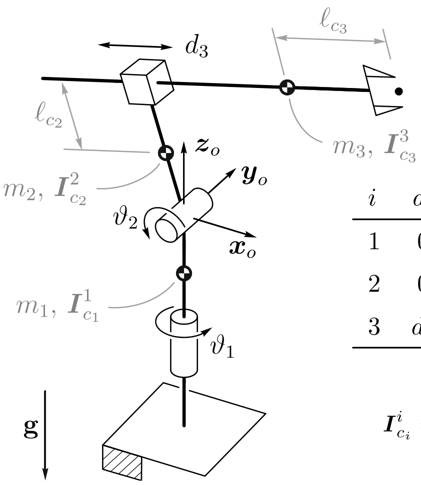


Figure A2. Additional dimensions and geometry. Joints 2, 3 and 4 are mechanically coupled, so that the parallelogram edges are always kept parallel. The rotation axis for ϑ_1 always intersects a fixed point in the manipulator, $\boldsymbol{p}_{rcm}$, termed the *remote center of motion*.

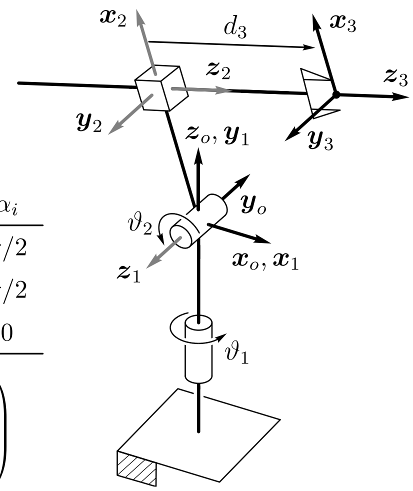
Appendix B. Validating the Dynamics Implementation

Before building the model for your robot, test your algorithm on the simpler system given below:



i	d_i	ϑ_i	a_i	α_i
1	0	ϑ_1	0	$\pi/2$
2	0	ϑ_2	a_2	$\pi/2$
3	d_3	0	0	0

$$\boldsymbol{I}^i_{c_i} = \begin{pmatrix} I^i_x & I^i_{xy} & I^i_{xz} \\ I^i_{xy} & I^i_y & I^i_{yz} \\ I^i_{xz} & I^i_{yz} & I^i_z \end{pmatrix}$$



$$\begin{aligned}
B_{11} =& \left(I^2_z - I^2_x + I^3_z - I^3_x + m_2\,(a_2 - \ell_{c_2})^2 + m_3\,a_2^2 - m_3\,(d_3 - \ell_{c_3})^2\right)\cos(\vartheta_2)^2 \\
&+ \left(m_3\,a_2\,(d_3 - \ell_{c_3}) - I^2_{xz} - I^3_{xz}\right)\sin(2\,\vartheta_2) + I^1_y + I^2_x + I^3_x + m_3\,(d_3 - \ell_{c_3})^2 \\
B_{12} = B_{21} =& \left(I^2_{xy} + I^3_{xy}\right)\sin(\vartheta_2) - \left(I^2_{yz} + I^3_{yz}\right)\cos(\vartheta_2) \\
B_{13} = B_{31} =& \, 0 \\
B_{22} =& \, I^2_y + I^3_y + m_3\,(d_3 - \ell_{c_3})^2 + (a_2 - \ell_{c_2})\,(m_3\,a_2 + m_2\,(a_2 - \ell_{c_2})) + m_3\,a_2\,\ell_{c_2} \\
B_{23} = B_{32} =& -m_3\,a_2 \\
B_{33} =& \, m_3
\end{aligned}$$

$$\begin{aligned}
\phi_1 =& -\left(I^2_z - I^2_x + I^3_z - I^3_x + m_2\,(a_2 - \ell_{c_2})^2 + m_3\,a_2^2 - m_3\,(d_3 - \ell_{c_3})^2\right)\sin(2\,\vartheta_2)\,\dot\vartheta_1\,\dot\vartheta_2 \\
&+ 2\left(m_3\,a_2\,(d_3 - \ell_{c_3}) - I^2_{xz} - I^3_{xz}\right)\cos(2\,\vartheta_2)\,\dot\vartheta_1\,\dot\vartheta_2 \\
&+ \left[\left(I^2_{xy} + I^3_{xy}\right)\cos(\vartheta_2) + \left(I^2_{yz} + I^3_{yz}\right)\sin(\vartheta_2)\right]\dot\vartheta_2^2 \\
&+ m_3\left[(d_3 - \ell_{c_3})\,(1 - \cos(2\,\vartheta_2)) + a_2\,\sin(2\,\vartheta_2)\right]\dot\vartheta_1\,\dot d_3 \\
\phi_2 =& \left(I^2_{xz} + I^3_{xz} - m_3\,a_2\,d_3 + m_3\,a_2\,\ell_{c_3}\right)\dot\vartheta_1^2\,\cos(2\,\vartheta_2) + 2\,m_3\,\dot\vartheta_2\,\dot d_3\,(d_3 - \ell_{c_3}) \\
&+ \frac{1}{2}\left(I^2_z - I^2_x + I^3_z - I^3_x + m_2\,(a_2 - \ell_{c_2})^2 + m_3\,a_2^2 - m_3\,(d_3 - \ell_{c_3})^2\right)\dot\vartheta_1^2\,\sin(2\,\vartheta_2) \\
\phi_3 =& -\frac{1}{2}\,m_3\left(a_2\,\sin(2\,\vartheta_2) + 2\,(d_3 - \ell_{c_3})\sin(\vartheta_2)^2\right)\dot\vartheta_1^2 - m_3\,(d_3 - \ell_{c_3})\,\dot\vartheta_2^2
\end{aligned}$$

$$\begin{aligned}
g_1 =& \, 0 \\
g_2 =& \, m_3\,|\mathrm{g}|\,(a_2\,\cos(\vartheta_2) + (d_3 - \ell_{c_3})\sin(\vartheta_2)) + m_2\,|\mathrm{g}|\,(a_2 - \ell_{c_2})\cos(\vartheta_2) \\
g_3 =& -m_3\,|\mathrm{g}|\cos(\vartheta_2)
\end{aligned}$$

$$\begin{pmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{pmatrix}\begin{pmatrix} \ddot\vartheta_1 \\ \ddot\vartheta_2 \\ \ddot d_3 \end{pmatrix} + \begin{pmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \end{pmatrix} + \begin{pmatrix} g_1 \\ g_2 \\ g_3 \end{pmatrix} = \boldsymbol{\tau}$$