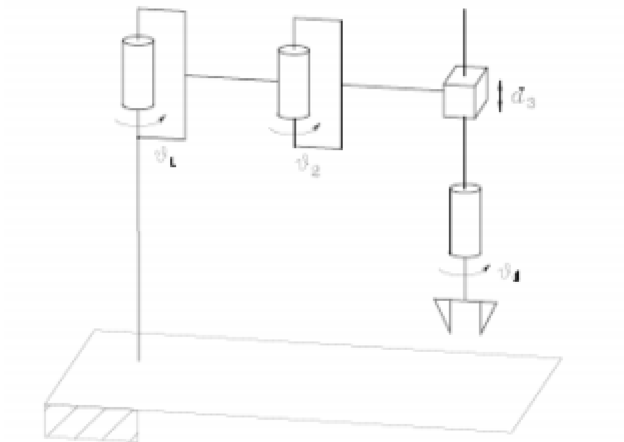
Dynamics and Control (100 points)

Consider the SCARA manipulator depicted below used during project 1.



The manipulator parameters are

$$d_0 = 1\ m,\ a_1 = a_2 = 0.5\ m,\ l_1 = l_2 = 0.25\ m$$
$$\theta_{1_{min}} = -\pi/2\ rad,\ \theta_{1_{max}} = \pi/2\ rad,\ \theta_{2_{min}} = -\pi/2\ rad,\ \theta_{2_{max}} = \pi/4\ rad$$
$$m_{l1} = m_{l2} = 25\ kg,\ m_{l3} = 10\ kg, Il1 = I_{l2} = 5\ kgm^2,\ I_{l4} = 1\ kgm^2$$
$$k_{r1} = k_{r2} = 1,\ k_{r3} = 50\ rad/m,\ k_{r4} = 20,$$
$$I_{m1} = I_{m2} = 0.0001\ kgm^2,\ I_{m3} = 0.01\ kgm^2, I_{m4} = 0.005\ kgm^2$$
$$F_{m1} = F_{m2} = 0.0001\ N \cdot m \cdot s/rad, F_{m3} = 0.01\ N \cdot m \cdot s/rad, F_{m4} = 0.005\ N \cdot m \cdot s/rad$$
$$d_{3_{min}} = 0.25\ m,\ d_{3_{max}} = 1\ m,\ \theta_{4_{min}} = -2\pi\ rad,\ \theta_{4_{max}} = 2\pi\ rad$$

Questions: Similarly to project 1 a init.m and *kinematic_traj* files are provided.

- Design a a second order inversion kinematic algorithm. Test that the performances of the system similarly to project 1. Please show the same plots you showed during project 1.
- Consider a 5 kg load placed at the end effector. Generate an inverse dynamic control approach. The setpoints for each joint have to be generated considering a second order inversion kinematic algorithm, where the Cartesian values are given by the trajectory provided during project 1.
- Generate a trajectory in the robot operational space of 4 s with trapezoidal velocity profile for each segment passing trough the following waypoints $p_0 = \begin{bmatrix} 0 & -0.80 & 0 \end{bmatrix}$ at time $t_0 = 0.0$, $p_1 = \begin{bmatrix} 0 & -0.80 & 0.5 \end{bmatrix}$ at time $t_1 = 0.6$, $p_2 = \begin{bmatrix} 0.5 & -0.6 & 0.5 \end{bmatrix}$ at time $t_2 = 2.0$, $p_3 = \begin{bmatrix} 0.8 & 0.0 & 0.5 \end{bmatrix}$ at time $t_3 = 3.4$, $p_4 = \begin{bmatrix} 0.8 & 0.0 & 0.0 \end{bmatrix}$ at time $t_4 = 4.0$. The trajectory should be generated such that the robot should not stop at each waypoint so that the waypoints are via points. The anticipation time for each segment should be 0.2 s.

Optional questions. You cannot go over 100 with these questions:

- Consider a 5 kg load placed at the end effector. Generate a robust controller. The setpoints for each joint have to be generated considering a second order inversion kinematic algorithm, where the Cartesian values are given by the trajectory provided during project 1. You will need to add 3 files $\hat{B}.m$, $\hat{n}.m$, $dynamic_model.m$, and $robustness.m$. The mass at the end effector will be assumed known in your dynamic model and considered as m_{l4}, but not in your $\hat{B}.m$ compensation function, where it should be set to 0.

- Show the performances of the robust controller with your new trajectory

Instructions:

- Submit the code and the report in an unique compressed file.
- Files you need in the submission
  - Part 1: Jacobian.m, $Jacobian\_dot.m$, $plot_output.m$ to visualize the errors
  - Part 2: B.m, n.m, $dynamic_model.m$, and $plot_output.m$
  - Part 3: At least 2 key files such as trajectory.m and p.m. In the first one s and its derivatives are generated, whereas in the second one the 3D positions is generated
  - Optional part: $\hat{B}.m$, $\hat{n}.m$, robustness.m, $dynamic_model.m$
- Implement in Matlab/Simulink the algorithms for control and kinematic inversion adopting the Euler integration rule with integration time 1ms.
- Each part should be provided in separate folders.
- For part 3 you need to provide the error plots between the desired joint values and the current ones. You do not need to generate any orientation trajectory.
- For the optional part show again the error plots as in part 3.