# Simulations on MATLAB
# Industrial Robotics 2018/19

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## 1 Task 1 - Joint space and manipulability

The plots represent the joint trajectories in the joint space and with respect to time. Since the trajectory was defined with respect to the position of the end-effector, the relative orientation of the manipulator is not of interest, and therefore it has not been plotted.

Regarding the the inverse kinematics, the manipulability measure is high when the manipulator is capable of equal motion in all directions and low when the manipulator is close to a singularity.

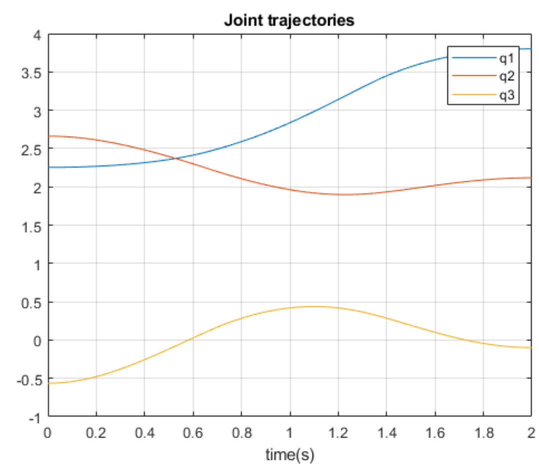


Figure 1: Task 1 Joint evolution in time, with a line as reference

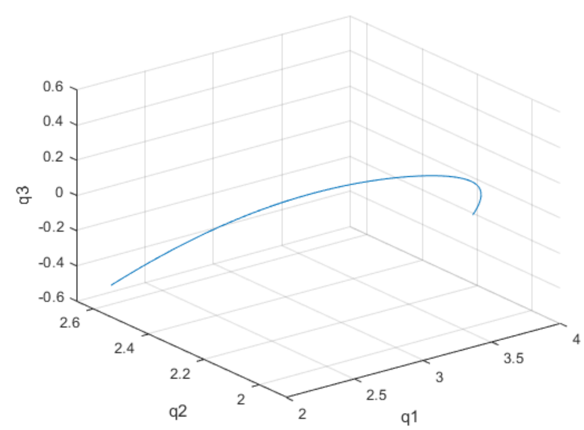


Figure 2: Task 1 Joint trajectory in the joint space, with a line as reference

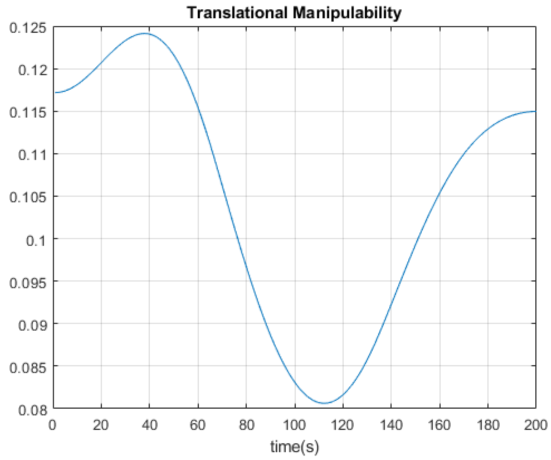


Figure 3: Task 1 Manipulability measure, with a line as reference

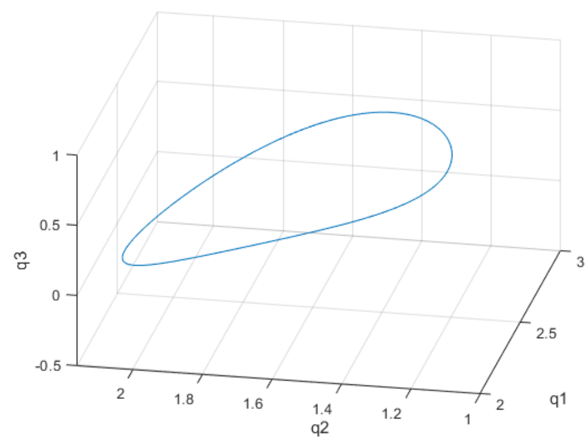


Figure 5: Task 1Joint trajectory in the joint space, with a circle as reference

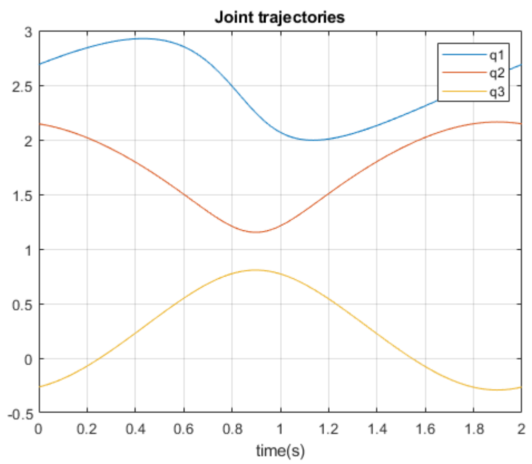


Figure 4: Task 1 Joint evolution in time, with a circle as reference

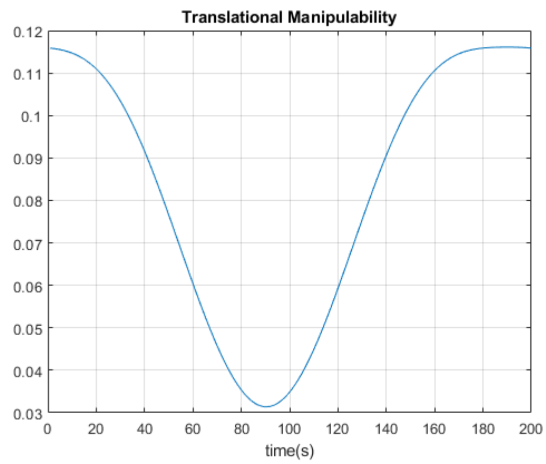


Figure 6: Task 1 Manipulability measure, with a circle as reference

## 2 Task 2 - PD + gravity compensation

The PD controller with gravity compensation has been implemented with both small and high gains. The results show, as expected, that for high gains the error tends to be smaller with respect to small gain scenarios.

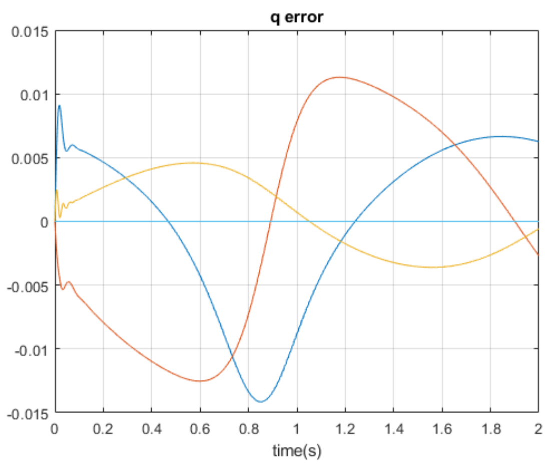


Figure 7: Task 2 Joint Error evolution in time, with a circle as reference, high gains

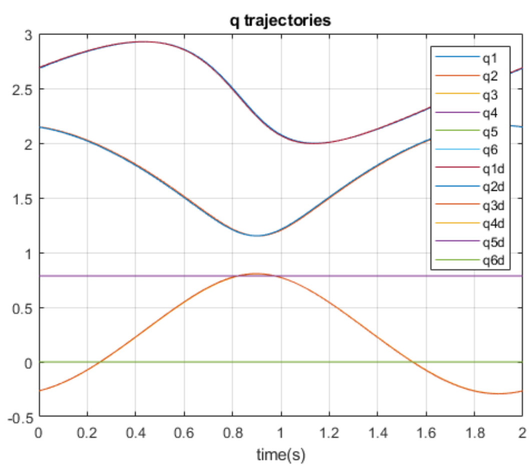


Figure 8: Task 2 Joint evolution in time, with a circle as reference, high gains

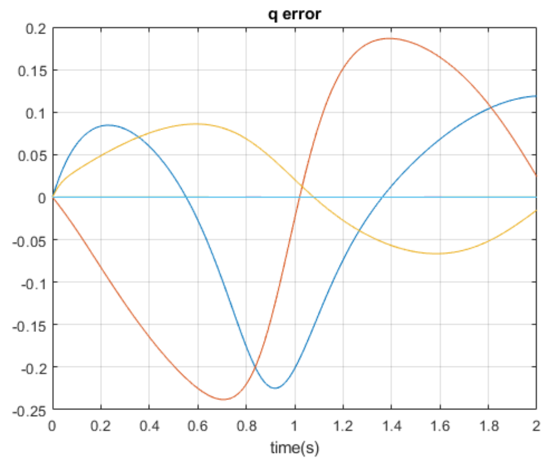


Figure 9: Task 2 Joint Error evolution in time, with a circle as reference, small gains

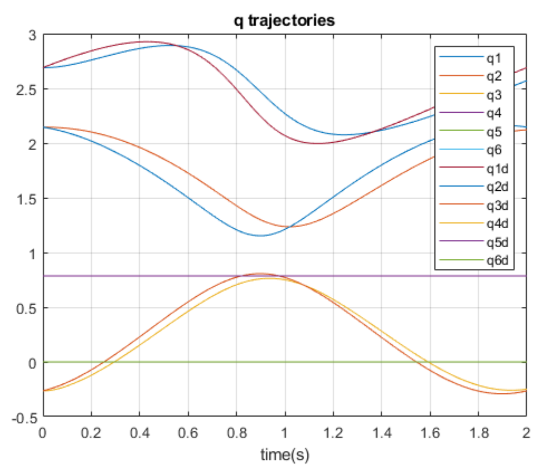


Figure 10: Task 2 Joint evolution in time, with a circle as reference, small gains

# 3 Task 3 - Inverse Dynamics and uncertainties

The smoother trajectory chosen as reference is a line in the workspace. The condition of parameter uncertainties has been considered, and as expected the error doesn't converge to zero. As a matter of fact, the uncertainties in the parameters play a huge role in the control of a manipulator through Inverse Dynamics, as from the Lyapunov expression::

$$\ddot{\tilde{q}} + K_D\dot{\tilde{q}} + K_P\tilde{q} = \eta$$

$$\dot{V}(\xi) = -\xi^T P\xi + 2\xi^T QD\eta \qquad \xi = [\tilde{q}, \dot{\tilde{q}}]^T$$

$$\eta = (I - M^{-1}\hat{M})y - M^{-1}\tilde{n}$$

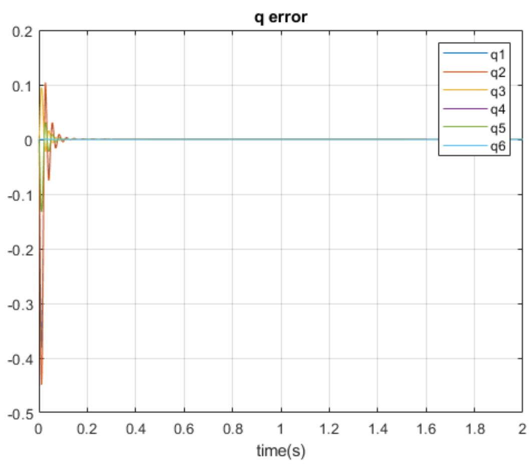


Figure 11: Task 3 Joint Error evolution in time, with a line as reference

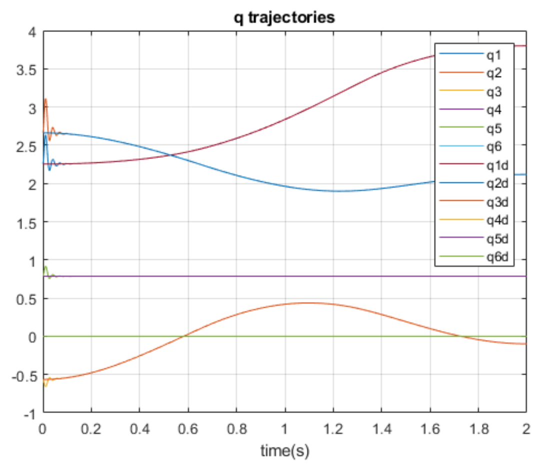


Figure 12: Task 3 Joint evolution in time, with a line as reference

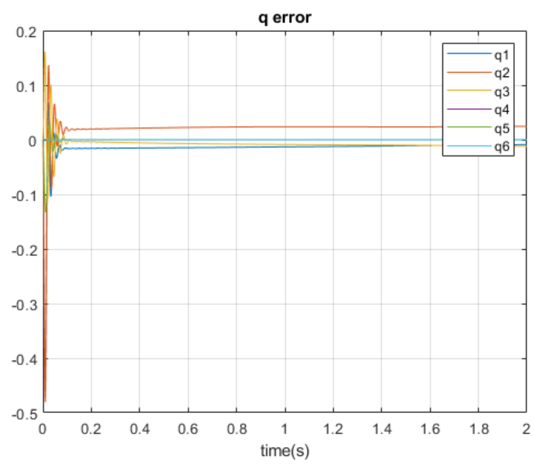


Figure 13: Task 3 Joint Error evolution in time, with a line as reference, with uncertainties

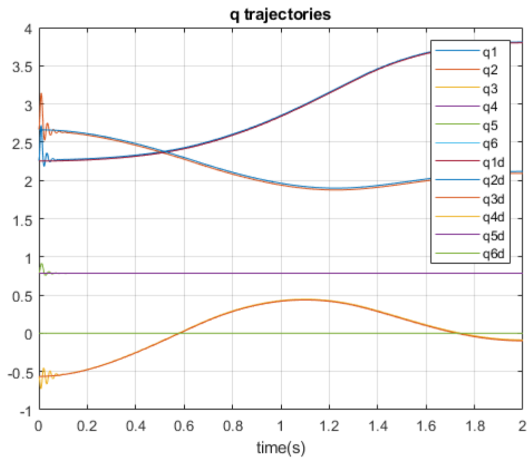


Figure 14: Task 3 Joint evolution in time, with a line as reference, with uncertainties

# 4 Task 4 - Robust Sliding-Mode and uncertainties

For this sliding mode robust controller, the adopted law is:

$$\tau = K * \frac{u}{\|u\|} \text{ for } \|u\| > p$$

$$\tau = K/p * u \text{ for } \|u\| <= p$$

This is a sort of boundary layers approach applied to the multi dof alternative approach presented during the classes.

The $/p$ introduced in the second law is for ensuring the continuity of the control action.

The sliding surface has been chosen stable and decoupling each joint, meaning

$$A * e + B * \dot{e} = 0$$

with $A$ and $B$ diagonal.

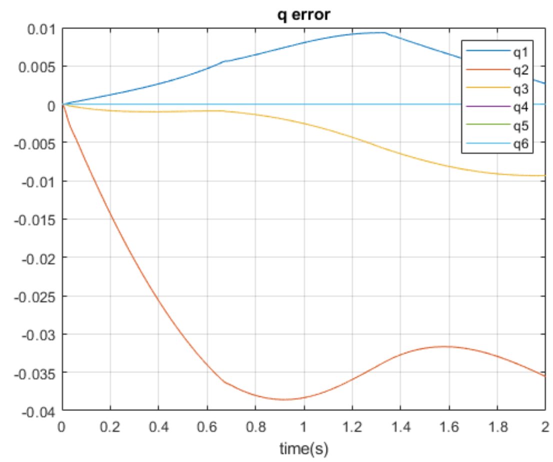


Figure 15: Task 4 Joint Error evolution in time, with a line as reference and strong control gain

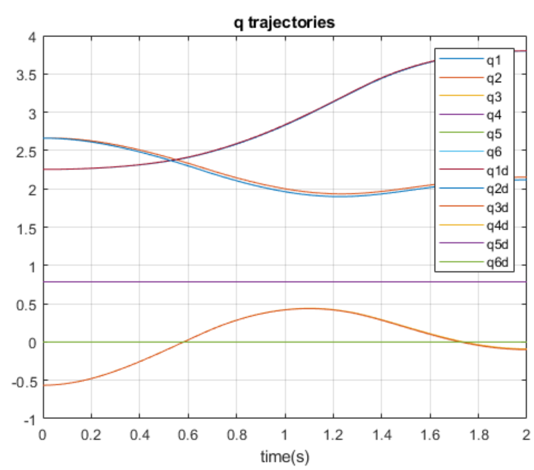


Figure 16: Task 4 Joint evolution in time, with a line as reference and strong control gain

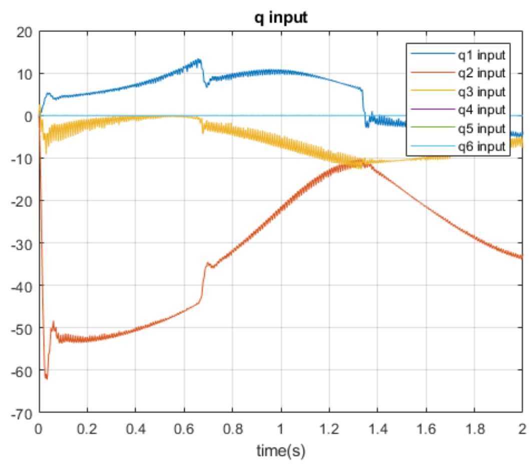


Figure 17: Task 4 Input torques for the joints in time, with a line as reference and strong control gain

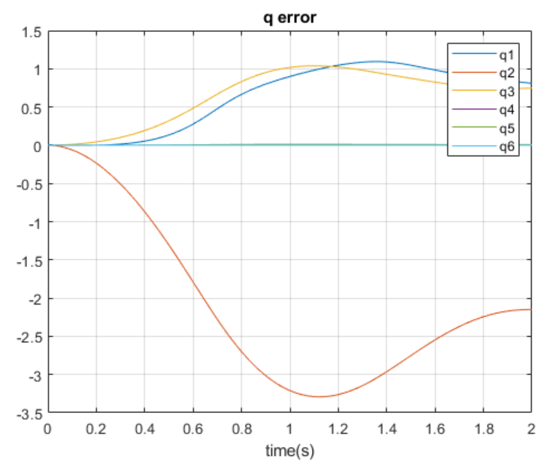


Figure 19: Task 4 Joint Error evolution in time, with a line as reference and weak control gain

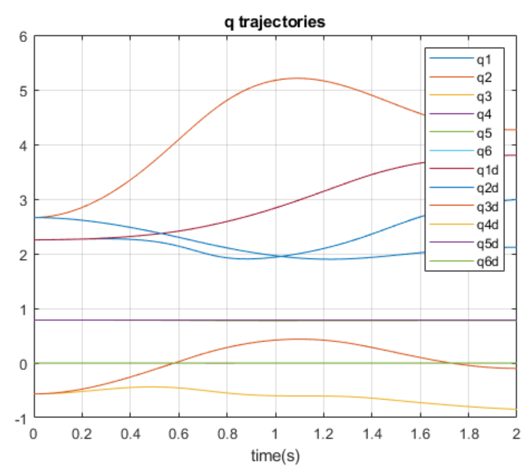


Figure 18: Task 4 Joint evolution in time, with a line as reference and weak control gain

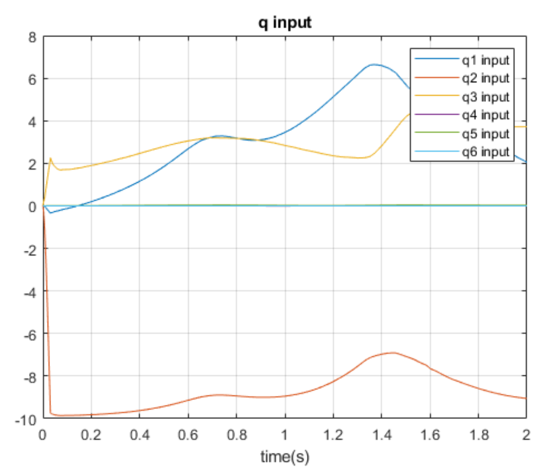


Figure 20: Task 4 Input torques for the joints in time, with a line as reference and weak control gain

# 5 Task 5 - Sliding mode in Workspace

A slight initial offset of $[0.1\ 0.1\ 0.1\ 0.1\ 0.1\ 0.1]^T$ for the joints has been introduced for the sake of simulation.

A similar reasoning with respect to Task 4 has been used, but with no boundary layer strategy. This control scheme in the work space is computationally less efficient. At each sampling instance many more computations are required: it is necessary to derive the direct kinematics of the manipulator, and different Jacobians are involved in the scheme.

However, a control in the joint space is not suitable when interaction is involved: the robot must know when to stop or proceed based on information coming from the external environment. This is the case in which a workspace control is preferred over a joint space control, when force control is involved. A control scheme in the joint space is more suitable when the robot is implementing a position control, when no interaction with the environment is allowed or considered.

The simulation has been run until $t = 0.3s$ due to the computational burden.

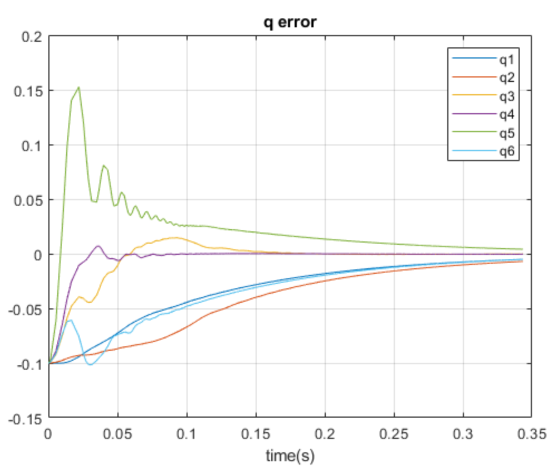


Figure 21: Task 5 Joint Error evolution in time, with a line as reference

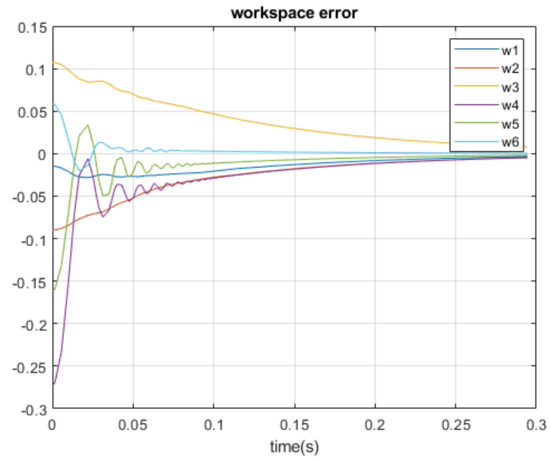


Figure 22: Task 5 Workspace error evolution in time, with a line as reference

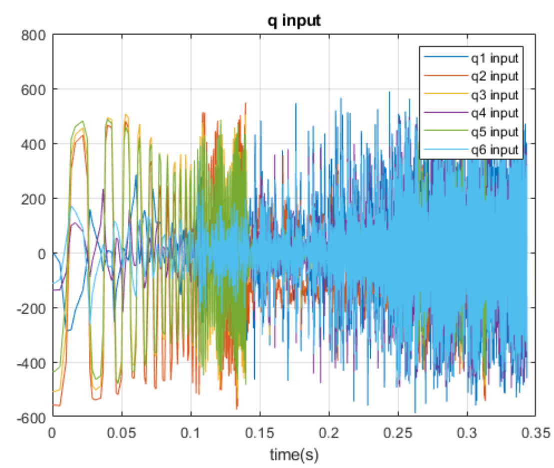


Figure 23: Task 5 Input torques for the joints in time, with a line as reference

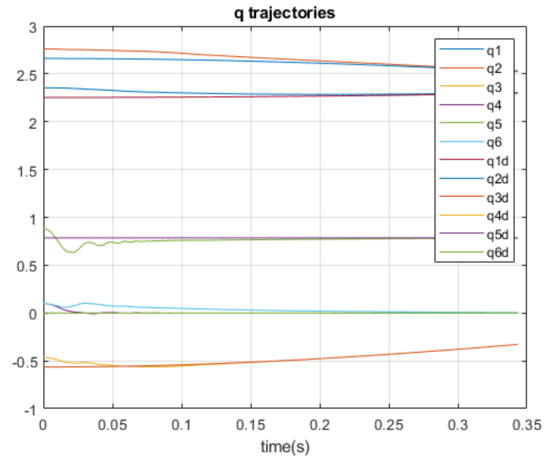


Figure 24: Task 5 Joint evolution in time, with a line as reference

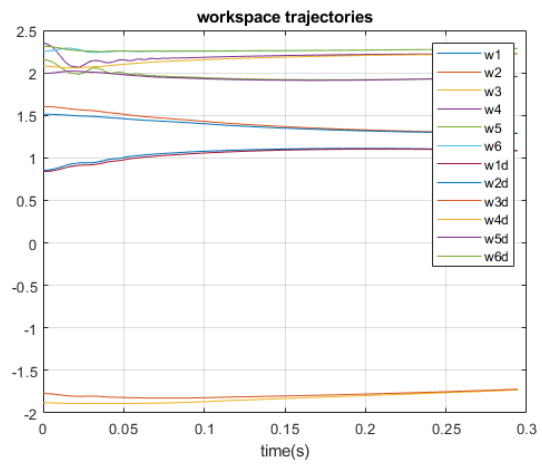


Figure 25: Task 5 Workspace evolution in time, with a line as reference