SSY156 - Modeling and Control of Mechatronic Systems
Winter 2019
Lab 3 - Control
Due date: 13/03/2018 @23:55
Total Points: 26 p
MAX NUMBER OF PAGES: 6
Important Info for the Lab Assignment evaluation: When you submit answers for each block of questions, they will be graded and you can get from 0 to Total Points. After the evaluation, we will send you back the report, so you can correct the wrong answers. Of course, this correction will not affect the grade that you get in your first submission; it is only intended to give you feedback. In this way you can continue to work on the next parts of the assignment, avoiding that wrong answers in a block will affect the upcoming one.

Assignment Part 3 Control in configuration and operational space

Aim of this task is to control the motion of the end-effector of OmniBundle. In **questions 1-5** we consider the path in Fig. 3 (order of the points on the board: $1 \rightarrow 5 \rightarrow 9 \rightarrow 3 \rightarrow 5 \rightarrow 7 \rightarrow 1$, in loop). In **questions 6-11** we consider the path between to points.

Question 1 . . . . *3 points*

IN THE LAB: Place the end effector at the points indicated in Fig. 1 (with some margin from the board) and take note of corresponding values in the configuration space.

Given the points in the configuration space, design a feasible trajectory such that the end-effector follows the given path. Requested specifications on the trajectory: MAX ACCELERATION at the joints = 15 rad/s^2. In the report, show figure where you plot positions, velocities and accelerations of this trajectory for q_1, q_2, q_3.

Question 2 . . . . *5 points*

Introduce the following friction terms to each of the equations of motion of your model:

$$b_1\dot{q}_1(t), \quad b_2\dot{q}_2(t), \quad b_3\dot{q}_3(t)$$

where $b1 = 0.0089$ Nms/rad, $b2 = 0.0170$ Nms/rad, $b3 = 0.0058$ Nms/rad.

Using the simulation model derived in Lab Assignment 2, implement the decentralized linear control scheme with position, velocity feedback plus feedforward actions, in order to follow the designed trajectory. Requested specs: static performance (stability, rejection of constant disturbance), dynamical performance (freely decided by you). In the report, answer the following questions:

(a) (3 points) Which linear models do you use in order to design the PID controllers? How do you choose the coefficients of the PID controllers in order to meet the required specification? (Use a transfer function representation for describing the linear model and describe how you use the nonlinear Euler-Lagrange equations from lab Assignment 2 to come up with these linear models).

(b) (2 points) Show plots of the comparison between reference trajectory and controlled position from your Simulation.

Question 3 . . . . *5 points*

IN THE LAB: Apply your decentralized control scheme to the robot in the LAB. Most likely you will need to re-tune to make the controller work. In the report show:

(a) (3 points) Numerical values of the coefficients of the PID controllers and comparison with the one used in simulation.

(b) (2 points) Plots comparing reference trajectory and controlled position from your Experiment.

Question 4 . . . . *2 points*

Design a centralized control using the inverse dynamics scheme in order to follow the configuration (joint) space trajectory. In the report show both simulation and experiments plots of your trajectory tracking, and the tracking errors.

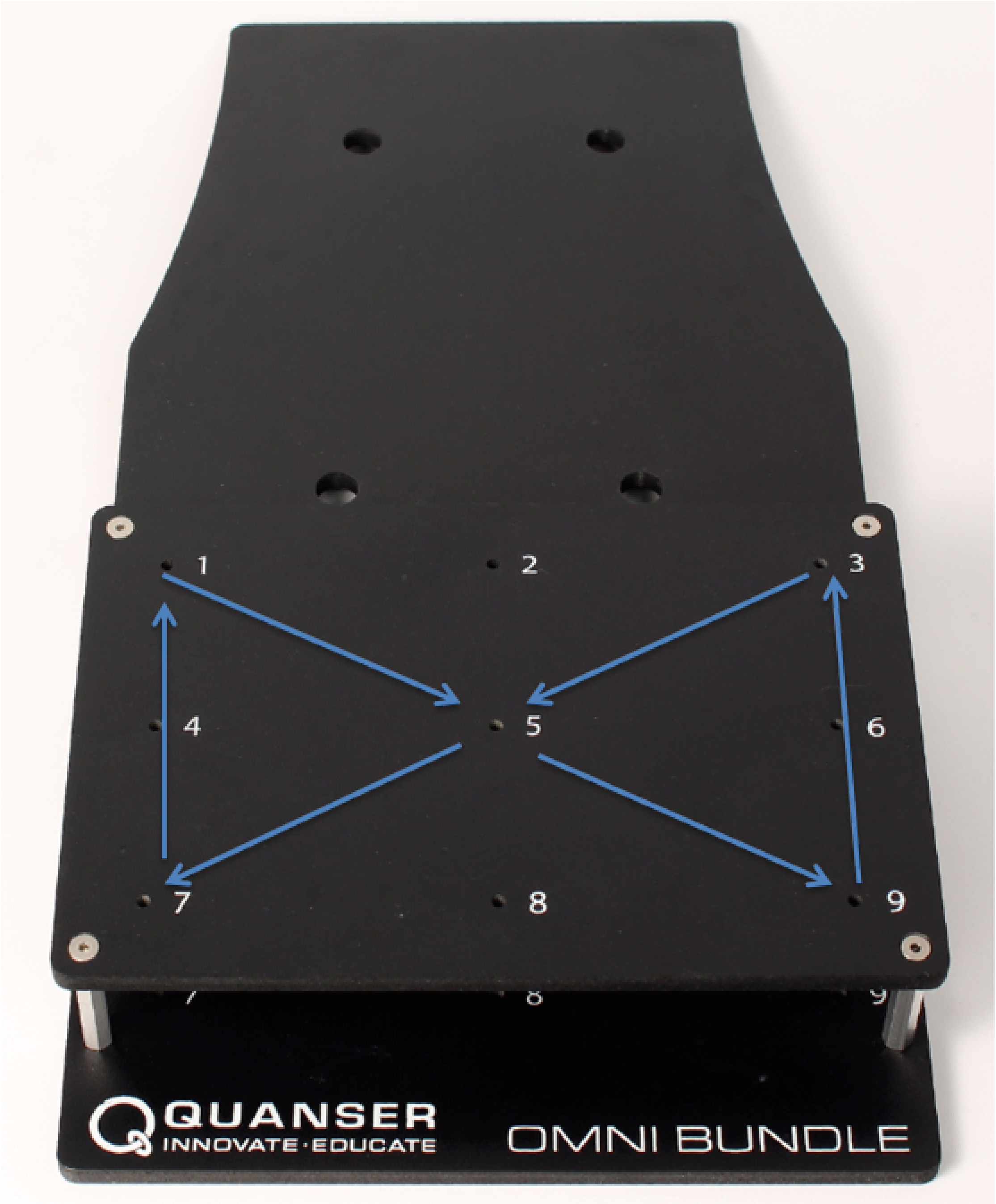

Figure 1: Path

Question 5 . . . . *2 points*

Assume a disturbance d on the input torque of the second joint:

$$\tau_d = \begin{bmatrix} 0 \\ d \\ 0 \end{bmatrix}$$

How will the disturbance d affect the error dynamics of the first joint, when the inverse dynamics scheme is deployed? Write down the error dynamics expression for the first joint and check the error in simulation, where you freely decide a disturbance d.

Question 6 . . . . *1 points*

Given the following 2 points in the operational space $P_1 = [0.098\ \ -0.078\ \ -0.1]$ m, $P_2 = [0.2\ 0.0\ 0.0]$ m, design an operational space trajectory that goes from P_1 to P_2 in T seconds, with T decided by you, and then stays in P_2 (as a set-point) for 20 seconds. In the report show the generated trajectory.

Question 7 . . . . *2 points*

Design a centralized control using the inverse dynamics scheme in order to follow the trajectory in the operational space. In the report show both simulation and experiment plots of your trajectory tracking, and the tracking errors.

Question 8 . . . . *1 points*

Design the impedance control scheme without force measurements for our robot and for the trajectory designed in task 6. In particular choose the controller parameters in order to achieve two behaviors: under-damped and over-damped. Show the needed calculations to derive those parameters.

Question 9 . . . . *1 points*

Consider the impedance control scheme without force measurements and assume that a constant external force is acting on the X-direction of the operational space. Which are the analytic expressions of the forces affecting the error dynamics of the X-coordinate?

Question 10 . . . . *2 points*

Implement, in simulation, the trajectory tracking designed in task 6, using the impedance control design in task 8. When the robot is tracking the constant set-point of the trajectory, introduce the external force considered in task 9 and test the different behaviors of the controller (under-damped and over-damped). Show simulation plots of the operational space variables, showing the two different responses when the external force is applied.

Question 11 . . . . *2 points*

Implement the previous task in the LAB as well. In this case the external force is not simulated but you can actually, and **gently**, push the robot along the X-direction. Show operational variables plots for the two different set of controller parameters (over-damped and under-damped behavior). Compare these plots with the simulation plots and comment on the results.