Robotic Systems Engineering
Coursework 3: Actuators, Mechanisms and Robot Dynamics

Prof. Danail Stoyanov
Department of Computer Science
University College London
Gower Street, London, WC1E 6BT

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To get full credit for an answer, you are *required* to provide a full working solution. For some questions, you will be asked to write code; for these you are expected to include a *full print out* of any requested results or graphs in the report, as well as a simple breakdown of the algorithms used in the coding solution. Furthermore, you will be required to *upload* your code to Moodle along with your submitted coursework manuscript in .zip extension. The necessary packages are available on https://github.com/surgical-vision/comp0127_lab. The * in this coursework means either py or cpp.

Robot mechanisms

1. Assume the following scenario: A conveyor belt inside a candy factory carries colourful hard candy of quasi-spherical shape (e.g. Skittles, MMs etc.). The candy is assumed to be stationary with respect to the conveyor, which moves at a constant velocity which cannot be altered. The conveyor belt is approximately 20cm wide and the candy appears randomly along its width. Assume the weight and shape of the candy is known. You are asked to implement a robotic system in addition to the conveyor belt to extract a candy of any given colour and place it in a separate basket. The system should be able to perform the task as fast as possible. Ensure that you are designing a minimum viable system to solve the task, hence, avoid for example redundancy in your manipulator design as well as your actuator and sensor choices. Propose a robotic system to perform the task. In your answer, address the following. (**Recommended answer is up to 50 words per sub-question and the words count for the whole question must not exceed 300 words.**)

   a. Required degrees of freedom of your manipulator in Cartesian space. [2 mark]

   b. Manipulator topology (serial/parallel) and design. You are free to reference commonly utilised designs and robot types. Also state a reasonable choice of end-effector. [2 marks]

   c. Choice of actuators (e.g. stepper motors, AC motors, brushed or brushless DC motors, pneumatics, hydraulics etc.) and transmission. This will vary greatly with your manipulator design. [2 marks]

d. Choice of sensors (both, required for driving the manipulator as well as determining the correct object). [2 marks]

e. Discuss a component of the proposed system (e.g. joints, actuators, sensors) which would be prone to wear from repeated task execution. How could the wear be minimised? [3 mark]

f. Assume, only candy with the previously specified colour above a certain weight threshold (e.g. > 5 grams) should be placed in the basket. How could you modify your system to be able to consider this additional factor without modifying the conveyor? [4 marks]

Robot kinematics and dynamics

2. Implement a robot class for the KUKA LBR iiwa14 robot in the package cw3q2. Your class should include the methods for computing the forward kinematics at the centre of mass, the Jacobian at the centre of mass, the iterative inverse kinematic and the dynamic components. The DH parameters are already given below. The marking criteria for this question is shown below. You can find the physical properties of the robot arm in iiwa_description/urdf/iiwa14.xacro. A simple code breakdown in the report is required for all subquestions, except for the subquestion about the closed-form inverse kinematics, which is report only. **Please note that finding the closed-form solution of this manipulator is very challenging and it will require you to do some further research. For the coding part, you can use the iterative solution to solve the other questions. If you do not manage to solve for the iterative solution, you are free to use KDL.**

Table 1: DH parameters for KUKA iiwa

i	a_i	α_i	d_i	θ_i
1	0	$-\frac{\pi}{2}$	0.2025	θ_1
2	0	$\frac{\pi}{2}$	0	θ_2
3	0	$\frac{\pi}{2}$	0.42	θ_3
4	0	$-\frac{\pi}{2}$	0	θ_4
5	0	$-\frac{\pi}{2}$	0.4	θ_5
6	0	$\frac{\pi}{2}$	0	θ_6
7	0	0	0.126	θ_7

- Forward kinematic at the centre of mass [2 (report) + 3 (code) marks]
- Jacobian at the centre of mass [2 (report) + 3 (code) marks]
- Iterative inverse kinematic [2 (report) + 3 (code) marks]
- Closed-form inverse kinematic (theoretical question in the report) [10 (report) marks]
- Dynamic component $\mathbf{B}(\mathbf{q})$ [3 (report) + 7 (code) marks]
- Dynamic component $\mathbf{C}(\mathbf{q}, \dot{\mathbf{q}})$ [2 (report) + 3 (code) marks]

- Dynamic component $\mathbf{g}(\mathbf{q})$ [2 (report) + 3 (code) marks]

3. Explain what the forward dynamics is. Your explanation should include what the difficulty of the problem is and its applications. [5 marks]

4. Explain what the inverse dynamics is. Your explanation should include what the difficulty of the problem is and its applications. [5 marks]

5. For this question, you will need to fill in the code in the package cw3q5 to solve the robot dynamics problem. You can use the KDL library to complete this question. Please note that the robot has an overshoot in some configuration. Once you command the robot to move to one configuration, you may have to wait for a short time until the robot stabilises itself before calculating the value.

   a. Write a script in cw3q5a.* to use dynamic components to compute the joint accelerations throughout the pre-defined trajectory defined in cw3_launch/bags/cw3bag1.bag. Plot the computed accelerations as part of the report. The marking criteria for this question is given below. (Hint: Once you run the trajectory, you can obtain the torque from the field "effort" in the JointState message.)

      - The computed acceleration is somewhat similar to the trajectory. [4 marks]
      - The explanation in the report on how you calculate the acceleration. [4 marks]
      - Is this problem forward dynamics or inverse dynamics? [2 mark]

   b. Write a script in cw3q5b.* to determine the mass and the centre of mass of an object attached to the KUKA iiwa robot (with respected to the last frame as defined by the given parameters). The mass and centre of mass should be output to the **ROS info log** when the submitted launch file is executed. The output should contain the calculated masses and centres of masses for each configuration and the average among the configurations. The marking criteria of this question is shown below.

$$\mathbf{q}_a = [45°, -35°, 55°, -30°, -25°, 65°, -10°]^T$$
$$\mathbf{q}_b = [5°, 40°, 80°, 10°, 8°, -50°, -10°]^T$$
$$\mathbf{q}_c = [-50°, 60°, 0°, -15°, 60°, -25°, -50°]^T$$

      - The calculated mass has less than 5 percents error. [4 marks]
      - The calculated centre of mass has less than 7 percents error [4 marks]
      - Calculate the external torque exerting on each joint when the joint position $\mathbf{q}_d$ is $[0°, -90°, -90°, 90°, -90°, 90°, -30°]^T$ [4 marks]
      - The explanation in the report on how you calculate these values (3 marks for the mass, 2 for the centre of mass and 3 for the external torque). [8 marks]

END OF COURSEWORK