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Name: _____

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Note: Please do not forget to write your name and student number.
Return THESE sheets with your ANSWERS

Question 1:

A) Describe the concepts of **path** and **trajectory**

B) Explain how the singularity of a manipulator can be computed by using its Jacobian

C) The general dynamic equation (dynamic state-space form) is composed by the Mass matrix (M), the Coriolis/Centrifugal Vector (V) and the Gravity vector (G). Obtain M,V and G when for the next torque equations of a manipulator.

$$\tau_1 = (m_1 l_1^2 + I_{ZZ1} + I_{ZZ2} + m_2 d_2^2)\ddot{\theta}_1 + 2m_2 d_2 \dot{\theta}_1 \dot{d}_2 + (m_1 l_1 + m_2 d_2) g \cos(\theta_1)$$

$$\tau_2 = m_2 \ddot{d}_2 - m_2 d_2 \dot{\theta}_1^2 + m_2 g \sin(\theta_1)$$

Question 2:

A single-link manipulator with a rotary joint is motionless at 40 degrees. It is desired to move the joint in a smooth manner to a final position of 120 degrees in 10 seconds. (i) Find the **coefficients of a cubic polynomial**, which accomplishes this motion and brings the manipulator to rest at the goal. (ii) **Plot** (sketch) **the position, velocity and acceleration** of the joint as a function of time.

What is a **via point**? Why those may be needed?

Question 3:

A) Given the manipulator defined with the robotics toolbox, sketch its structure and assign the frames to it using standard Denavit-Hartenberg notation.

```
L1 = link([0 0 0 0 1]); %alpha a theta d sigma
L2 = link([pi/2 2 0 0 0]);
L3 = link([-pi/2 1 0 0 0]);

r = SerialLink({L1 L2 L3});
```

B) What is the position of the end-effector for the following joint variables? (It can be solved analytically.)

- [1 0 pi/2]

C) Explain what is obtained with the *gravload* command of the Robotic Toolbox of Matlab?