Exercise 1.1

Robot manipulators have multiple degrees of freedom and are described by complicated nonlinear models. Therefore, a one-degree of freedom robot with a flexible joint is considered in this exercise. A sketch of the robot is shown in Figure 1 from which it is seen that the robot moves in a horizontal plane; thus, gravity has no influence on the dynamics of the system.

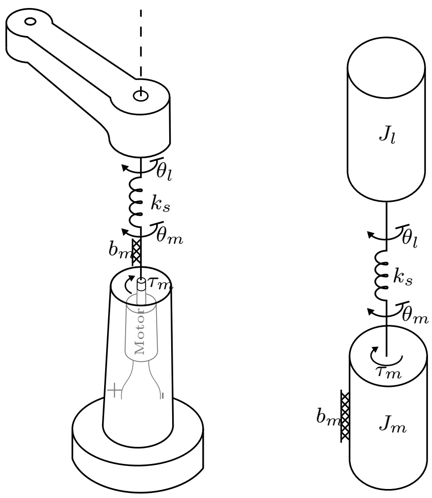

Figure 1: Sketch of a flexible joint with stiffness k_s and damping b_m.

The input to the system is a motor torque τ_m and the output (measurement) is the joint speed $\dot{\theta}_l$ [rad/s] on the link side. Study the dynamics of the system according to the following steps.

1. Setup a model (nth-order differential equation) of the system.
2. Put the system into state space form.
3. Simulate the system in MATLAB with two different inputs (Make a model-object with the function `ss` and use `ode45` or `lsim` for the simulation)

   (a) $\tau_m(t) = 1$ and (b) $\tau_m(t) = \sin(t)$
4. Setup a transfer function of the system (Verify your result by using the functions `ss2tf` or `tf2ss`)
5. Make a step response of the transfer function in MATLAB (Use the function `step`).
6. Discretize the state space model with an appropriate sampling time T in MATLAB (Use the function `c2d`).
7. Simulate the discrete model in MATLAB with the inputs given in Step 3, and compare the two simulations.
8. Create and compare Bode plots of the continuous and discrete systems in MATLAB (use the function `bode`).

Name	Symbol	Value	Unit
Moment of inertia of motor	J_m	1	kgm^2
Moment of inertia of link	J_l	1	kgm^2
Shaft stiffness	k_s	1	Nm/rad
Motor damping	b_m	1	Nm/(rad/s)
Motor torque	τ_m	-	Nm
Angle (motor side)	θ_m	-	rad
Angle (link side)	θ_l	-	rad

Table 1: Parameters and variables of robot with a flexible joint.