Exercise Problems for Module 8

[P8.1] Consider a rigid single link manipulator with $l_1 = 1.241$ m, $m_1 = 20.15$ kg, the location of the centre of mass $r_1 = 1.2$ m from the rotary joint and the moment of inertia about the centre of mass as 9.6 kg/m^2 moving the horizontal plane. The link is connected to the actuator by a spring of spring constant $K_s = 0.1$ N-m/rad. Using the theory of model-based controller in Module 7, design a PD controller such that the link can rotate 150° in 5 seconds.

[P8.2] By refering to Marino and Spong (1986), obtain the feedback linearization scheme for a single rigid link, flexible-joint manipulator moving under gravity.

[P8.3] In this Module we have used clamped conditions at the actuator end. What would change in kinematic modelling if free or pinned conditions are used at the actuator end?

[P8.4] For a planar 2R manipulator, with both links flexible, derive the symbolic dynamic equations of motion using the assumed mode method. Take two modes for discretising each flexible link and assume that there is no gravity.

[P8.5] For a planar 2R manipulator, with both links flexible, derive the symbolic dynamic equations of motion using the finite element method. Take two elements in each flexible link and assume there is no gravity.

[P8.6] Numerically simulate the equations of motion obtained in exercise problems **P8.3** and **P8.4** for the same link, mass and inertial parameters, and actuator torques. Compare and comment on the results.

[P8.7] Show that the equivalent mass matrix $([\mathbf{M}_{rr}] - [\mathbf{M}_{rf}]^T[\mathbf{M}_{ff}]^{-1}[\mathbf{M}_{rf}])$ used in the trajectory following control law has full rank n.

[P8.8] Similar to a rigid manipulator (see Module 6 and 7), show that the flexible Coriolis/centripetal vector $\mathbf{C}_f$ can be written as $[\mathbf{C}_{ff}]\dot{\mathbf{q}}_f$. Also show that $\left[[\dot{\mathbf{M}}_{ff}] - 2[\mathbf{C}_{ff}]\right]$ is skew symmetric.