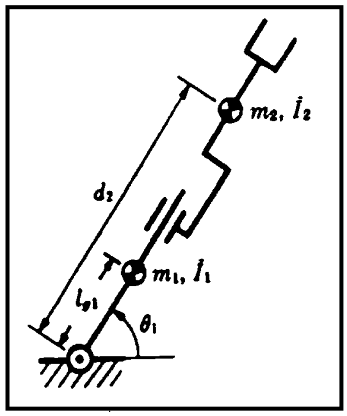
Due date: Thursday, April 21, 2016
(Before lecture starts)

ME4524 – Robotics and Automation

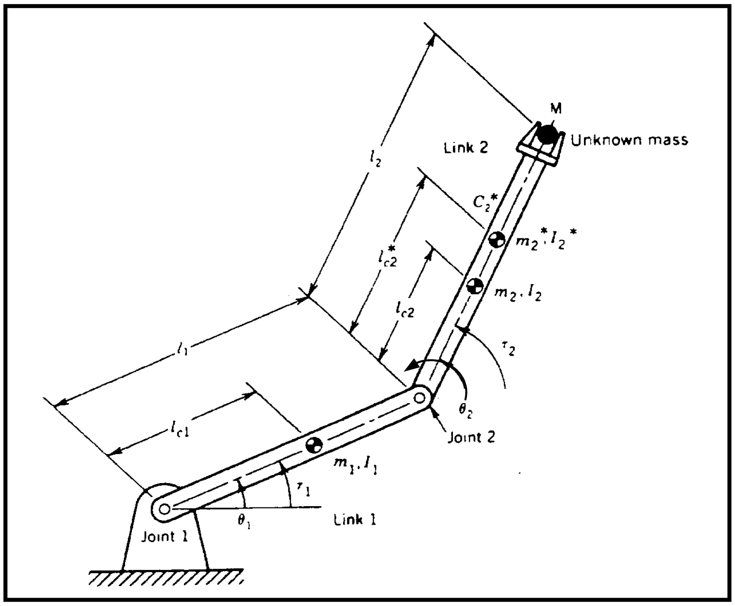
Exercise # 6

1. Derive the equations of motion for the two-link manipulator shown in the Figure below, using the Lagrangian formulation. Assume that the gravity acts vertically downwards. (Note that $\tilde{I}_i$ is the moment of inertia about the center of mass of link *i*).

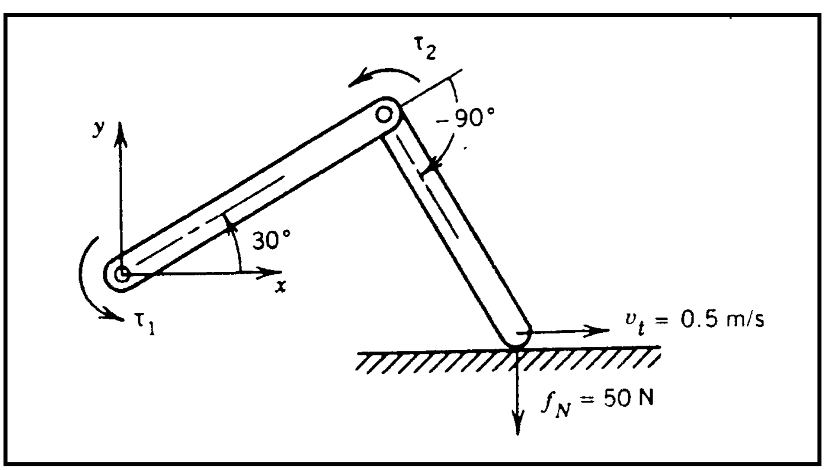


2. Consider the two-degree of freedom manipulator shown in the Figure below. When the manipulator grasps an unknown mass particle M at the tip of link 2, the mass properties of link 2 change from known values m_2, l_{c2}, I_2 to m_2^*, l_{c2}^*, I_2^* where $m_2^* = m_2 + M$. It is required to identify the unknown mass properties by experiments.
   (a) The unknown mass M is modeled as a point mass, and the centroids are assumed to be located on the centerline of each link. Derive the distance to l_{c2}^* and the centroidal moment of inertia to I_2^* as functions of the unknown mass.

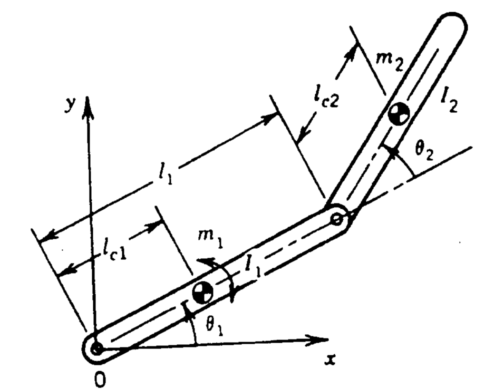
(b) Assume that the generalized coordinates are θ_1 and θ_2, the actuators exert torques τ_1 and τ_2, and the manipulator with unknown mass moves at angular velocities $\dot{\theta}_1, \dot{\theta}_2$ and accelerations $\ddot{\theta}_1, \ddot{\theta}_2$. Determine the unknown mass M at the tip of link 2 from this set of data.



3. The figure below shows the same manipulator from the previous problem. The end-point of the manipulator is in contact with a smooth surface and while applying a normal force f_N to the surface, the manipulator is moving in a constant speed v_t along the tangential direction. Compute the required joint torques τ_1 and τ_2 in the case shown in the figure. The length of each link is 1 m and the mass of each link is 1 kg. (<u>Hint:</u> you need to consider both the static and dynamic effects).



4. The table below shows the link dimensions and mass properties of the two-degree of freedom manipulator shown in the Figure. Using Lagrangian formulation, compute the joint torques required to move the arm with the specified joint velocities and accelerations at the configuration given below.



	link 1	link 2
l_i [m]	1	1
l_{ci} [m]	0.5	0.5
m_i [kg]	20	10
I_i [kgm^2]	0.8	0.2
θ_i [deg]	30	30
$\dot{\theta}_i$ [deg/s]	15	45
$\ddot{\theta}_i$ [deg/s^2]	-30	30