UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING
**ROBOTICS (AER 525)**
**M.R. EMAMI**
FINAL EXAMINATION
April 18, 2018

Note: Rulers may be used in this test.

**2.5 Hours**
**Exam Type: X**

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## Question 1:

**(a)** Which kinematic configuration of robot manipulators is most attractive to the Original Equipment Manufacturer (OEM)? Why? **(5)**

**(b)** Compare the following three gearing mechanisms for the joint transmission system: spur, helical, and herringbone. **(5)**

**(c)** Why are harmonic-drive transmission systems frequently used for industrial robot manipulators, and what are their shortcomings (if any)? **(5)**

**(d)** Explain how increasing each of the three PID gains of a joint servo controller would affect its motion tracking performance. What are the upper-bound limits for these gains? **(5)**

**(e)** Given a certain wrench at the end-effector and that the robot manipulator is stationary at a specific configuration, explain the difference between the joint torque computed from "Statics" and "Inverse Dynamics" formulations. **(5)**

**(f)** Discuss 3 reasons why one must adopt a closed-loop control system for the joint-space motion control of a robot manipulator, despite having an inverse dynamics model of the robot. **(5)**

## Question 2:

For the spatial 3 d.o.f. manipulator shown in the figure ($0^\circ \leq \theta_1 < 360^\circ$, $-90^\circ \leq \theta_2 < +270^\circ$, and $d_3 \geq 0$):

**(a)** Find and show those configurations where an external force on the end-effector in at least one direction can be totally borne by the structure, i.e., no joint torque/force is needed to balance it. **(10)**

**(b)** How must the torque/force at the joints vary with the joint variables $\theta_1$ and $\theta_2$ so that whenever the end-effector rests on the floor, it only applies force with the unit magnitute in the direction of $\hat{x}_0$? **(10)**

**(c)** A camera is attached to the end-effector at Point E with its view along the direction of $\hat{z}_3$. It records the motion of an object A as heading right toward the camera (i.e., along $\hat{z}_3$) with a speed of $v$. What is the absolute velocity of the object when it is 1m away from the camera and the manipulator configuration is at $\theta_1 = \theta_2 = 0$? Obtain the answer as a function of $d_3$, $l_2$, $v$, and joint speeds. **(15)**

**(d)** Assuming that joint 1 is fixed ($\theta_1, \dot{\theta}_1 = 0$) and there is no wrench at the end-effector, derive the Lagrangian of the system. Assume links 2 and 3 as rigid bodies with masses $m_2$ and $m_3$, moments of inertia ($I_{Cyy}$) $I_2$ and $I_3$, and centres of mass located at B and E, respectively. **(15)**

**(e)** Considering conditions in **(d)**, obtain the torque equation for joint #2. **(10)**

**(f)** Suppose that a DC brush motor with the following characteristics is available for driving joint #2 (under conditions in **(d)**) using a gearbox with the ratio of $\eta$.

$r_a$: armature resistance $b_m$: motor bearing viscous friction coefficient

$K_m$: torque constant $K_b$: back emf constant $I_m$: motor inertia

Assuming that the motor inductance and load bearing friction are negligible, find the values of the proportional and derivative gains of a PD controller for joint #2 rotational displacement, if the closed-loop system response is critically damped with the natural frequency of $\omega_n$. **(10)**