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

Question 1:

- (a) Which kinematic configuration of robot manipulators is most attractive to the Original Equipment Manufacturer (OEM)? Why?
- (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 ($0^{\circ} \le \theta_1 < 360^{\circ}$, $-90^{\circ} \le \theta_2 < +270^{\circ}$, and $d_3 \ge 0$):

(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.

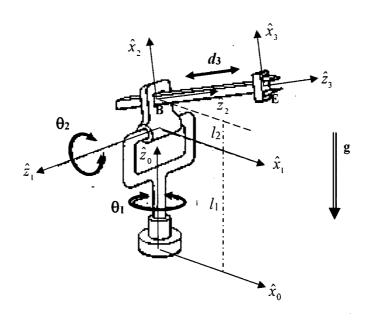
(10)

- (b) How must the torque/force at the joints vary with the joint variables θ_1 and θ_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 ẑ₃. It records the motion of an object A as heading right toward the camera (i.e., along ẑ₃) 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 θ₁ = θ₂ = 0? Obtain the answer as a function of d₃, l₂, 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_{Cyv}) 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 η .

 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 ω_n . (10)



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