**ME192 Final Examination**

December 15, 2014

Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Score \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

10

1. (a) Interpret the below motion equation from Chapter 6 for a position vector Q in a linked frame:

  (1)

 *The velocity of vector Q in frame {B} as seen from {A} is a sum of the velocity of Q in {B} and the*

 *rotational velocity of {B} cross multiplied by the position vector, expressed with respect to {A}.*

(b) How is frame {B} related to {A} in the above equation?

*Frame {B} and {A} share the same origin (their origins are coincidental).*

(c) What does the cross multiplication of *ΩB* and *BQ* represent? Provide a physical interpretation.

*The linear velocity of Q projected on a plane perpendicular to the axis of rotation of {B}.*

(d) Carry out the differentiation of (1) to find the linear acceleration of *BQ*. Note that the expression used for the velocity terms in (1) also applies to (2).

  (2)

=

1. Interpret the expression for the angular velocities of two linked frames from Chapter 6.

  (3)

*Frame {B} rotates relative to {A} at velocity ΩB and frame {C} rotates relative to {B} at ΩC.*

1. Differentiate (3) to find angular acceleration, applying the same method used in (1) and (2).

 (4)

=

1. Set up the equation for finding the diagonal element of the inertia tensor of an upright cylinder of radius r, height h, and density ρ with its frame origin at the center of mass and the Z axis pointing upward. Use polar substitution in the form of, x = r sin θ, y = r sin θ. Show the integral limits, but do not evaluate.

9

(a) 

  

Y

X

Z

 (b) What will be the values of the non-diagonal elements of the inertia tensor?

ZEROs

(c) If frame {A} is located away from the center radially. Find the distance d from the center at which . Use from (a) and the parallel axis theorem

Answer: 🡪 d =

(d) How is mass moment of inertia used in robotics and what is the governing equation?

To evaluate the torque acting on the center of mass at each link. The equation is Euler’s .

1. Given    ={Z axis rotation by *θ1*}

8

Evaluate + Use the back of the page as needed.

 =



1. What do the terms of the configuration space equation represent and what are the dimensions of the coefficients?

6

 (8)

 = n x n. Mass matrix of the manipulator joints.

 = n x n(n-1)/2. Joint velocity products attributable to the Coriolis force.

 = n x n. Joint velocities attributable to the centrifugal force.

 = n x1. Joint velocities attributable to gravity.

1. Given the equation for finding the blending time of a linear-parabolic path function below,

9

v

θf

where *T* = *tf -t0*, and the solution for *tb*is,

v

t0  tb th

θh

θb

 θ0

tf,-tb tf,

1. What is the condition that the path between two blending regions contains a linear segment?

1. What needs to be done to make the parabolic regions shorter relative to the linear region?

Use a large acceleration rate.

1. Evaluate the angular velocity and position at tb under a constant inside the blend region?

Answer:  

1. Knowing that a sudden sharp turn at the vias causes a jerky motion, what strategy should be used to attain a sharp turn, as needed, without increasing the motion duration time T?

Answer: Decrease the speed in the blend region, but accelerate between the turns.

1. State a method to allow the arm to pass through the vias in smooth motion without stop?

Answer: Use pseudo via points located between actual via points.

6. Sketch the angular acceleration, velocity, and disposition of a rotating robot arm as a function of time. Provide the plots for a fixed and a linear acceleration rate. Use (t0, t1, t2, t3, …) as the transition points and label the curves with “F” for fixed or “V” for variable acceleration.

8

Position

Velocity

Accelerationn

**θ**



t1

t2

t

t

t

Discuss how a user can uniformly and concurrently apply the above motion scheme to all joint movements using a TEACH command and setting fixed or variable acceleration.

*Determine the values (θ0, θ1, θ2, θ3) for each joint defining the time segments (t01, t12, t23).*

*Simultaneously control the joint motions per the acceleration scheme set over time. Precise control such as duration of acceleration or deceleration may not be allowed for a path with multiple vias. Teach command is for defining vias.*

1. How many degrees of freedom do the following robots have? Assign 1 d.o.f. for the wrist joint.

8.5

1. A four leg parallel with a motor at the base of each leg and a free knee joint. 🡪 4 or 5
2. A three-link wafer handler with a belt connecting Joint 2 and Joint 3. 🡪 3 or 4
3. A two inverted SCARA with a common joint wrist with no elbow motors. 🡪 2 or 3
4. A polar or spherical with a linear joint between joint 2 and the wrist joint. 🡪 3 or 4
5. A human arm including the wrist joint. Enumerate the d.o.f. at each joint. 🡪 7 total:

Shoulder (Pitch/yaw/roll), elsbow(pitch), wrist (yaw-pitch), elbow-wrist(roll).

1. Redo (a) and (c) using the Grubler’s formula:

(a) F = 6(10 – 12 -1) + 4(3 + 1 +2) = 6 *Note: The numbers may not match*

(c) F = 3(5 – 5 – 1) + 5=2 *depending on the assumptions made.*

8. The Z axis of a Cartesian robot has a leadscrew driven by a servo motor and a timing belt. If the leadscrew’s pitch = 20 mm, the encoder graduation = 7.2 °, and the gear ratio = 4:1, find

8

Control resolution of the leadscrew: \_\_0.10\_\_mm

 Repeatability at ±**3σ** (99%) level (σ =0.02mm) : \_\_0.06 mm (*Repeatability = Precision*)

Pulse count for a 100mm lineal move: \_1,000

Maximum error (Accuracy + 3σ): \_\_\_0.11 mm

Comment on the setting of the control resolution in light of the maximum error or precision:

 The control resolution is set too tight considering the relatively high positional variability.

9. Robot structures, operation, and terminology..

8

a) State the main differences between optical encoders and resolvers as applied in robotics:

Distance measured: Relative vs. Absolute

Signal: Analog vs. Digital

Positioning via pulse count vs, Positioning via the angular position of the commutator

Linear vs. non-linear response

b) When does a singularity occur in robot kinematics, mathematically and physically? What happens at a singularity point?

 Mathematically - When the determinant of the transformation matrix is zero, there will be no solution in the kinematics equations.

Physically - The robot arm stretches out to an outer workspace boundary. This causes a loss of one degree of freedom, and the robot cannot move in the radial direction.

c) When does a singularity occur on the wrist joints with intersecting axes of rotation?

When all three axes lie on a plane.

d) State the benefit of having a closed loop structure for a robot such as Steward mechanism?

It adds rigidity to the structure, so that a higher payload may be handled.

10. True or False on location transformation and robot framing. Elaborate if the answer is False.

7.5

 ( ) A location transformation matrix (P0) with respect to the robot base contains joint by joint displacement data. (False. The data only contains a compound rotation matrix and Z value)

6

( ) P1 translates from P0 in a straight line move retaining its roll angle. Therefore the rotation part of the T matrix (or the first 9 values of the vector) of P1 will be the same as that of P0. (False. The robot joint angles must change to keep the roll angle constant.)

( ) The non-compliancy of a SCARA stems from that it is rigidly supported by it joint frames in vertical direction. (False. The end effector is non-compliant in horizontal direction.

( ) The main advantage of a SCARA over a Cartesian is a SCARA can operate much faster. (False. SCARA is less intrusive in the work space that Cartesian).

( ) It is necessary to follow the Devavit-Hartenburg notations in robot framing analysis.

 False) Decoupled framing will help avoid confusion and errors in using the D-H parameters.)

11. Which of the following will yield the best edge extraction for a solid core binary image {A} obtained from a grey scale image? Note that , (*A* *AND NOT* *B*), yields an edge contour.

5

 Answer: a) Partial: b) 1.5 points, c) 2.5 points

B

1. Erode {A} to yield {B}🡪 Perform
2. Dilate {A} to yield {B}🡪 Erode {A} to yield {C}🡪Perform
3. Dilate {A} to yield {B}🡪 Perform

12. Give a step by step development of a transformation equation for the lab’s SCARA station with a camera at an upstream conveyor location. The camera finds the orientation and lateral offset of a moving object. The gripper is offset from the Z axis by. Use the notations: B = robot Base, C = Camera, Z = Z axis, G = Gripper, O = Object location in camera frame, P = Pickup location.

8

 The origin of the camera frame and the (0,0) pick up position is related by 

where  represents the distance between the camera home position and the corresponding gripper home position on the conveyor. With the object offset on the camera frame and thereby the pickup position offset, the transformation equation becomes:



where and . The pairs of the terms represent a parallel positional offset and the distance applicable to the camera and the gripper pickup position.

13. a) Name the below ladder logic circuit and describe its operation.

5

Y 

X2

X1

Out

Y

*It is a two button on-off switch circuit uith retentive memory. If X1 is pressed, Y turns on and stays on until X2 is pressed. X1 is a N.O. and X2 is a N.C. switch. Y is a momentary output.*

1. **EXTRA CREDIT**-

6

What does the below ladder logic circuit represent in terms of acting on input conditions?

 Describe the logic and how it operates. X0 is a normally closed momentary switch. Y0 and

 Y1 are a latch (set/reset) type output.

Y0

Y1

X0

* Y1

Set

Y0

RST

Y0

X0

Set

Answer: It emulates a Rising Edge condition. In the scanning cycle when X0 is pushed, Y1 does not turn on, but Y0 gets turned on. On the next cycle, Y1 turns on since both X0 and Y0 are on. Y0 is reset to avoid Y1 being turned on again as it is already set.