Final Exam, Version B

May 10, 2016 Intro to Robotics

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| --- | --- | --- |
| Problem | Score | Possible |
| 1 |  | 15 |
| 2 |  | 25 |
| 3 |  | 15 |
| 4 |  | 25 |
| 5 |  | 25 |
| 6 |  | 20 |
| Totals |  | 125 |

You may have on your desk:

* Your student ID card
* 2 handwritten 8.5”x11” double-sided crib sheets
* This exam (provided by Professor)

Grading: (problem difficulty)

Concepts: Covers chapters 1-4, 11.1--11.2

*Rotations & transformations*

* Composition of rotations about world or current frame
* Construct a homogenous transform

*Kinematics*

* Assign DH parameters
* Given DH parameters, construct A matrix
* Given two A matrices, construct T matrix

*Inverse Kinematics*

* Two-argument arc tangent function
* Solve inverse position kinematics for a 3-link arm

*Jacobian*

* Construct Jacobian given sketch and T matrices
* Solve Jacobian to find singularities

*Computer Vision*

* Move from camera frame to world frame

Problem 1: \_\_\_\_\_\_/15

1. (5 pt.s) Write the matrix product that will give the resulting rotation matrix

(*Do not perform the matrix multiplications*):

* 1. Rotate by *β* about the world *z*-axis
  2. Rotate by *α* about the world *x*-axis
  3. Rotate by *Φ* about the current *y*-axis
  4. Rotate by γ about the world *z*-axis
  5. Rotate by *ψ* about the current *y*-axis

1. (5 pts.) Suppose the three coordinate frames

, , and are given, and suppose

, and .

 Find the matrix

1. (5 pts.) Consider the diagram at right. Robot is 1 meter from a table. The tabletop is 1 m high and 1 m square. A frame is fixed to the side of the table as shown. A cube measuring 20 cm on a side is placed in the center of the table with frame established at the center of the cube as shown. A camera is situated directly above the center of the block 2 meters above the table top with frame attached as shown. Find the **homogenous transform** relating the frame to the camera frame, that is, .

Problem 2: \_\_\_\_\_\_/25 Jacobian Singularities

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Link |  |  |  |  |
| 1 | 1 |  |  |  |
| 2 | 0 |  |  |  |
| 3 | 1 |  |  |  |

a.) a robot has the DH parameters and velocity Jacobian below.

(5 pts.) What are the singularities? (Give the determinant)

(5 pts.) What configuration variables result in singularities?

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(5 pts.) Draw configurations for each type of singularity

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Link |  |  |  |  |
| 1 | 1 |  |  |  |
| 2 | 0 |  |  |  |
| 3 | 1 |  |  |  |

b.) A robot has the DH parameters and velocity Jacobian below.

(5 pts.)What are the singularities? (Give the determinant). Hint:

(5 pts.) What configuration variables result in singularities?

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Problem 3: \_\_\_\_\_\_/15, Forward Kinematics

a.) (5 pts.) For the 3-link RPR robot below, draw the *z* and *x*-axis according to the DH convention.

Parallel-jaw

gripper

 origin

b.) (5 pts.) Give the DH parameters for this PRR robot.

variable

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3

­

2

\* indicates variable

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Link |  |  |  |  |
| 1 |  |  |  |  |
| 2 |  |  |  |  |
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|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Link |  |  |  |  |
| 1 | 3 |  |  |  |
| 2 | 4 |  |  |  |
| 3 | 5 |  |  |  |
| 4 | 3 |  |  |  |

c.) (5pt) Compute the transformation matrix *A2* using the DH parameters:

\* indicates variable

*A2* =,

Problem 4: \_\_\_\_\_\_/25 Inverse kinematics

1

RRP robot for inverse kinematics.

*Note that in the drawing*

1. (5pt) Draw cross section of the manipulator’s *workspace* at

*x*0

*y*0

1

1

2

2

-3

-1

-2

-1

-2

*x*0

*z*0

1

2

2

-2

1

-1

1. (5pt) Draw cross section of the manipulator’s *workspace* at

What joint variables place the end-effector at point [*xc,yc,zc*] specified in the frame ? Assume the point is reachable. Let .

1. (5 pts.) =
2. (5 pts.) =
3. (5 pts.) =

Problem 5: \_\_\_\_\_\_/25

Calculate the manipulator Jacobian of the 2-link RR arm at the position o2 = oc.

* 1. (10 pts.) Write out the *J* matrix in terms of *zi* and *oi*.
  2. (5 pts.) Write out the *zi* and *oi* values needed for part a. Don’t forget *o0*.
  3. (10 pts.) Write out the *J* values. Calculate the cross products.

Problem 6: \_\_\_\_\_\_/20 Computer Vision

1. (5 pts.) Two frames and are related by the homogenous transformation

A particle has position relative to frame .

What is the position of the particle in frame ?

1. (5 pts.) For a camera with focal length , find the image plane coordinates for the 3D points in the camera frame

(15,20,50)c 🡪 (*u,v*) =

1. Astronomers are trying to measure the distance to a non-moving *object*. From a ground based observatory they take an image at June and another image at December, both times pointing their telescope orthogonally to the sun. The *object* appears to move against the field of much more distant stars and galaxies.

The telescope has focal length , assume earth orbital radius is 150x109 m and is a perfect circle.

June (-0.7,-0.2)

December (0.3,-0.2)

(5 pts.) If both images are aligned, what is the homogenous transform from camera frame 1 to 2?

(5 pts.) If the image coordinates are (-0.7,-0.2) and then (0.3,-0.2), what is the distance to the object?