Midterm Exam 1, Version C

March 31, 2016, Intro to Robotics

|  |  |  |
| --- | --- | --- |
| Problem | Score | Possible |
| 1 |  | 15 |
| 2 |  | 25 |
| 3 |  | 15 |
| 4 |  | 25 |
| 5 |  | 25 |
| 6 |  | 25 |
| EC |  | 25 |
| Totals |  | 130 |

You may have on your desk:

* Your student ID card
* 1 handwritten 8.5”x11” double-sided crib sheet
* 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

*Computer Vision*

* Move from camera frame to world frame

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

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

(*do not perform the matrix multiplications*):

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

1. (5 pt) Suppose the three coordinate frames

, , and are given, and suppose

, .

Find the matrix

1. (5 pt) 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 Rotation matrices

Let =

If and are not both zero, then , , and .

If >0, , and

* 1. (5 pt)
  2. (5pt)
  3. (15 pts) Matrix Identification, state **Yes** or **No**. +1 for each correctly listed

|  |  |  |  |
| --- | --- | --- | --- |
|  | valid so(*k*) | valid SE(3) | valid SO(3) |
|  | Yes | No | No |
|  | No | No | Yes |
|  | No | No | No |
|  | No | No | No |
|  | No | Yes | No |

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

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

Parallel-jaw

gripper

 origin

This is one possible answer. *x0* can be at any orientation in the plane, and the other *x* axis can be inverted.

b.) (5pt) Give the DH parameters for this RPR robot.

4

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3

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\* indicates variable

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Link |  |  |  |  |
| 1 | 0 |  | 4 |  |
| 2 | 0 |  |  | 0 |
| 3 | 0 | 0 | 3 |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Link |  |  |  |  |
| 1 | 3 |  |  |  |
| 2 | 0 |  |  |  |
| 3 | 5 |  |  |  |
| 4 | 3 |  |  |  |

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

\* indicates variable

*A2* =,

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

RPR robot for inverse kinematics.

1

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

*x*0

*y*0

1

2

1

2

*x*0

*z*0

2

1

3

1

0

2

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

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

Hint for d&e: **law of cosines**

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

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

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

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

(10 pts) Write out the *J* values. Calculate the cross products.

Problem 6: \_\_\_\_\_\_/25 Computer Vision

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

(14,21,28)c 🡪 (*u,v*) =(2,3)

,

1. Our underwater robot has two parallel laser beams located at [-1,0,0], [1,0,0], and pointing in the direction [0,0,1]. They are used to measure the distance to objects and walls. The camera has focal length , and the images of the laser beams are located at [-1/10,0,], and [1/6,0,].

(5 pt) How far is the wall from the laser at [1,0,0]?

3

(5 pt) How far is the wall from the laser at [-1,0,0]?

5

(5 pt) What angle is the wall with regard to the *x*-axis of the camera frame?

Atan(2,2) = 45 degree =

For Fun \_\_\_\_\_\_/25 Extra Credit

At *Frontier Fiesta* Li Huang got on a carnival ride that can be modeled as an RRR planar robot. The links are 4,2,1 units long.

Joint rotation speeds are limited to , and .

(5 pt) What are the DH parameters? (10 pts) What is the Jacobian?

(5 pt) What is the maximum angular velocity (give values and values)?

doesn’t matter. Maximum when , or

Maximum = or

(5 pt) What is the maximum linear velocity (give values and values)?

doesn’t matter. Maximum when

, or

Maximum =

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ink |  |  |  |  |
| 1 | 4 | 0 | 0 |  |
| 2 | 2 | 0 | 0 |  |
| 3 | 1 | 0 | 0 |  |

*x*1

*y*1

­

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a­

Li Huang will be sick if the maximum linear velocity > 15. If Li is sick, draw this on the image