BIRZEIT UNIVERSITY

Faculty of Engineering and Technology
Department of Mechanical and Mechatronics Engineering
First Examination – Spring 2017

ENME 532: Robotics	Student ID: ______________
Date of Examination: 26/3/2017	Time duration: 1 hour 30 minutes
Instructor: Eng. Sima Rishmawi	Total Marks: 100

This exam contains 8 pages (including this cover page) and 5 problems. Check to see if any pages are missing. Enter your Student ID number on the top of this page, and at the bottom of every page, in case the pages become separated.

You may *not* use your books, notes, or any other reference on this exam, except for a one-sided A4 cheat sheet, a coordinate frame, and the paper robot. You can use your own calculator only. Borrowing calculators is not allowed.

The following rules apply:

- **Organize your work**, in a reasonably neat and coherent way. Work scattered all over the page without a clear ordering will receive very little credit.
- **Mysterious or unsupported answers will not receive full credit**. A correct answer, unsupported by calculations, explanation, or algebraic work will receive no credit; an incorrect answer supported by substantially correct calculations and explanations might still receive partial credit.
- If you need more space, use the back of the pages; clearly indicate when you have done this.

Do not write in the table to the right.

Problem	Points	Score
1	15	
2	20	
3	15	
4	30	
5	20	
Total:	100	

1) (a) Identify the DH parameters for this matrix:

$$\begin{bmatrix} 1 & 0 & 0 & 3 \\ 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & -\frac{10}{\sqrt{2}} \\ 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{10}{\sqrt{2}} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$a_{i-1} = 3$

$\alpha_{i-1} = 45^o$

$d_i = 10$

$\theta_i = 0^o$

(b) Forward kinematics determines the position and orientation of the end-effector from which of the following: (Circle all that apply)

(a) Forces on links

(b) Joint angles

(c) Joint torques

(d) Link geometry

(e) Link moment of inertia

15 marks

2) (a) For the following rotation matrix, determine the missing elements.

$$\begin{bmatrix} -0.4370 & 0.8555 & -0.2778 \\ a & b & c \\ -0.4061 & 0.0879 & d \end{bmatrix}$$

(a) $a = \sqrt{1 - (-0.437)^2 - (-0.4061)^2} = \pm 0.8026$

(b) $b = \sqrt{1 - (0.8555)^2 - (0.0879)^2} = \pm 0.5103$

(c) $c = \sqrt{1 - (0.8026)^2 - (0.5103)^2} = \pm 0.3089$

(d) $d = \sqrt{1 - (-0.2778)^2 - (0.3089)^2} = \pm 0.9096$

(b) The following trasformation matrices are known, ${}^B_A R$, ${}^C_A R$, and ${}^D_B R$. Given the vector ${}^D P_2$ find an expression for ${}^C P_2$.

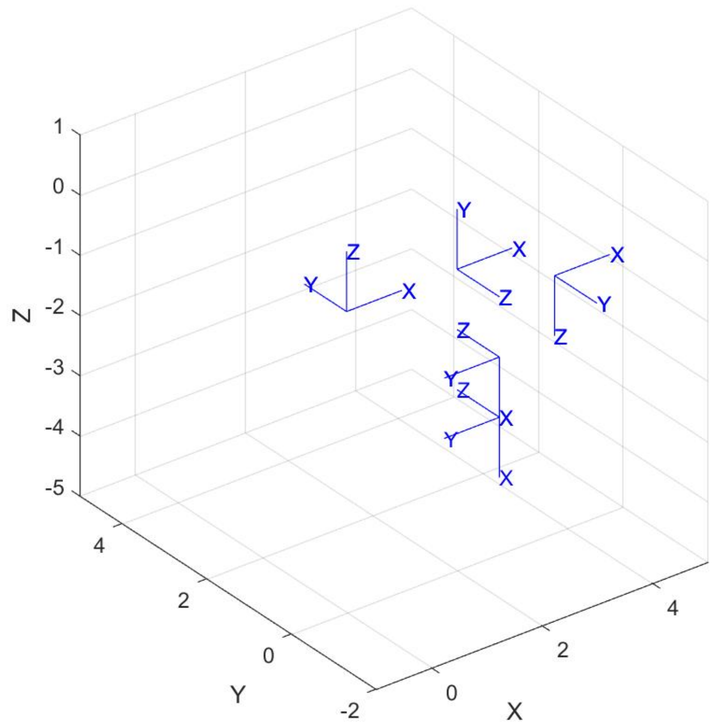
$${}^C P_2 = {}^C_A R^T \, {}^B_A R \, {}^D_B R \, {}^D P_2$$

20 marks

3) The following table gives the Denavit-Hartenberg parameters for a 4 DOF manipulator.

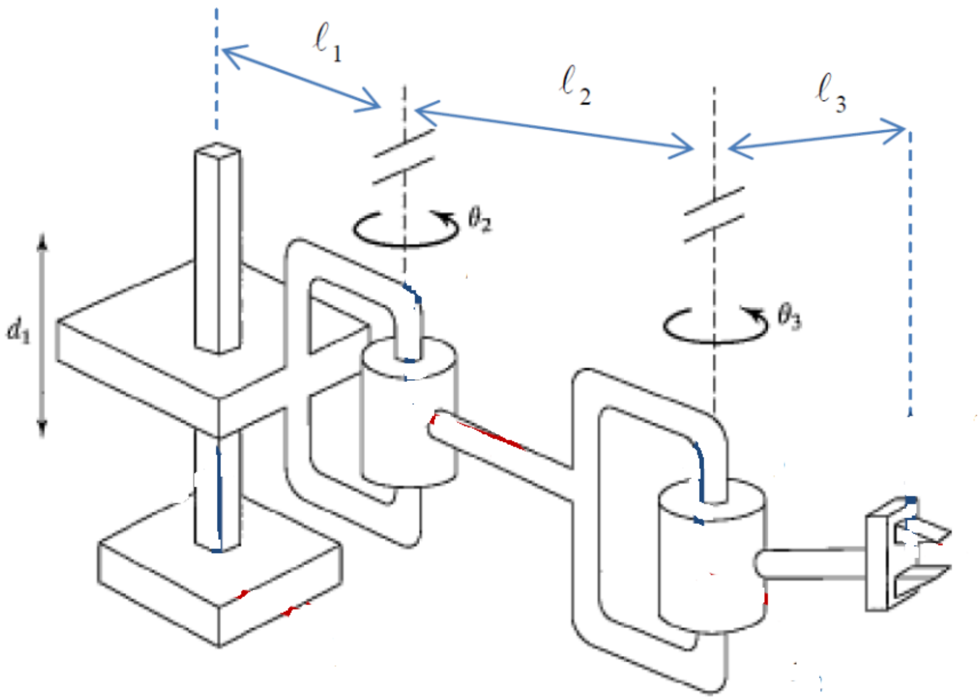
Joint	Variable	θ_i	a_{i-1}	d_i	α_{i-1}
1	fixed	0	0	2	$\pi/2$
2	angle	θ_2	0	0	$\pi/2$
3	angle	θ_3	0	0	$\pi/2$
4	angle	θ_4	0	1	0

Draw a sketch of the manipulator, showing the coordinate frames for each joint, when the angle of joint 3 is $\pi/2$, and all other joint angles are 0. Since some coordinate frames share a common origin you should slightly shift each frame to ensure your diagram is clear.



15 marks

4) For the three-link PRR manipulator shown in the Figure:



(a) Assign appropriate frames to the links on the figure.

(b) Fill out the DH parameter table.

Link	a_{i-1}	α_{i-1}	d_i	θ_i
1	0	0	d_1	0
2	l_1	0	0	θ_2
3	l_2	0	0	θ_3

(c) Write all the transformation matrices ${}^{i-1}_{i}T$.

$$ {}^{0}_{1}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{1}_{2}T = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & l_1 \\ \sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{2}_{3}T = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & l_2 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Question 4 continues on the next page...

$$ {}^{3}_{e}T = \begin{bmatrix} 1 & 0 & 0 & l_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

(d) Give an expression for the transformation matrix describing the position and orientation of the end-effector with respect to the base frame.

$ {}^{0}_{e}T = {}^{0}_{1}T \; {}^{1}_{2}T \; {}^{2}_{3}T \; {}^{3}_{e}T $

30 marks

5) Circle the correct answer:

(1) What is the name of the space inside which the robot operates?
A. Danger Zone B. Environment C. Spatial Base D. Work Space

(2) The number of movable joints in the base, arm and end-effector of the robot determines:
A. Operational Limits B. Degrees of Freedom C. Flexibility D. Cost

(3) The inverse kinematics problem is a transformation of ... to ...
A. Cartesian Space , Workspace B. Cartesian Space , Joint Space
C. Joint Space , Cartesian Space D. Joint Space , end-effector Space

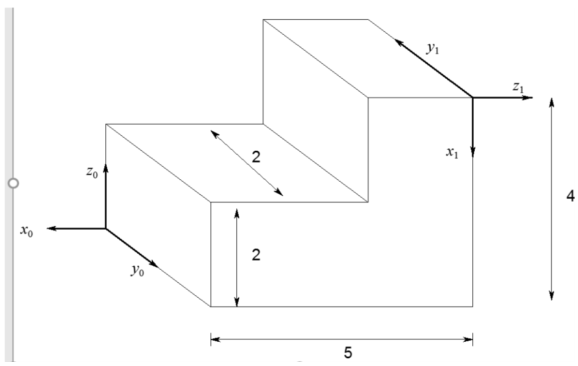
(4) Which of the following is a 3DOF joint?
A. Revolute B. Cylindrical C. Planar D. Prismatic

(5) Which of the following quatities is usually represented by a "free vector"?
A. Position B. Velocity C. Displacement D. Force

(6) Starting from frame 0, rotate first by θ_1 about the fixed $x - axis$, then by θ_2 about the current $z - axis$, then rotate by θ_3 about the current $y - axis$. Which of the following expressions represents ${}^0_1R$?
A. $R_x(\theta_1)R_z(\theta_2)R_y(\theta_3)$ B. $R_x(\theta_1)R_y(\theta_3)R_z(\theta_2)$
C. $R_y(\theta_3)R_z(\theta_2)R_x(\theta_1)$ D. None of the above.

(7) A point has the coordinates ${}^0P = [1\ 2\ 3]^T$ with respect to frame 0. If it is rotated about z_0 with an angle 90^o clockwise, what are its new coordinates?
A. ${}^0P = [-2\ 1\ 3]^T$ B. ${}^0P = [2\ -1\ 3]^T$ C. ${}^0P = [3\ 2\ -1]^T$ D. ${}^0P = [3\ -2\ 1]^T$

(8) For the following figure, ${}^0_1T$ is:



A. $\begin{bmatrix} 0 & 0 & -1 & -5 \\ 0 & -1 & 0 & 2 \\ -1 & 0 & 0 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ B. $\begin{bmatrix} 0 & 0 & 1 & -5 \\ 0 & 1 & 0 & 2 \\ 1 & 0 & 0 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ C. $\begin{bmatrix} 0 & 0 & -1 & 5 \\ 0 & -1 & 0 & 2 \\ -1 & 0 & 0 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ D. $\begin{bmatrix} 0 & 0 & 1 & 2 \\ 0 & -1 & 0 & -5 \\ 1 & 0 & 0 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

(9) What is the result of this transformation ${}^A_BR\,{}^A_BR^T$:
A. ${}^A_BR^2$ B. ${}^B_AR^2$ C. I D. None of the above

(10) For a robot unit to be considered a functional industrial robot, typically, how many degrees of freedom would the robot have?
A. Three B. Four C. Six D. Eight

 Question 5 continues on the next page...

20 marks