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

ENMC 532: Robotics
Date of Examination: 29/10/2017
Instructor: Eng. Sima Rishmawi

Student ID: ____________________
Time duration: 90 minutes
Total Marks: 100

This exam contains 6 pages (including this cover page) and 4 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 each page.

You may *not* use your books, notes, or any other reference on this exam, except for a one-sided A4 cheat sheet (to be handed in with your exam). You can use your own calculator only. Borrowing calculators is not allowed.

You are required to show your work on each problem on this exam.
Do not write in the table to the right.

Problem	Points	Score
1	25	
2	25	
3	30	
4	20	
Total:	100	

1) Calculate the matrix H corresponding to the following transformation:

(a) Rotate by $\frac{\pi}{2}$ about the fixed $y-axis$. Call the new Frame F_1.

(b) Translate 7 cm along the current $y-axis$. Call the new Frame F_2.

(c) Rotate by $\frac{\pi}{4}$ about the current $z-axis$. Call the new Frame F_3.

(d) Translate 5 cm along the fixed $z-axis$. Call the new frame F_4.

Draw the transformations and verify your answer.

25 marks

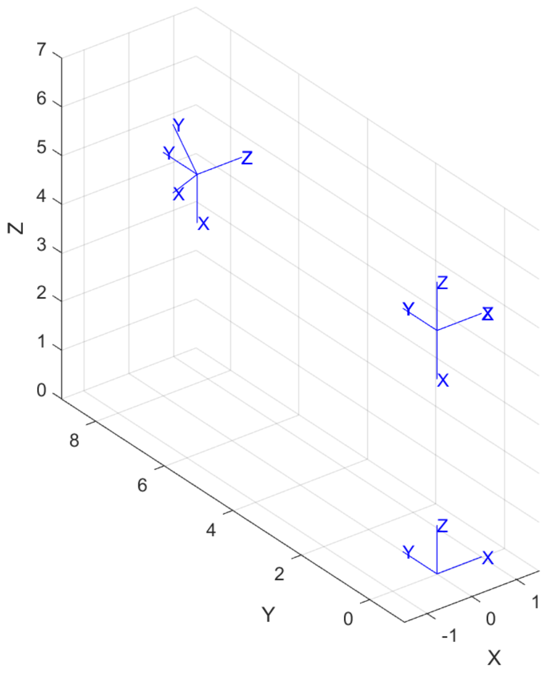
Solution:

$$H = transl_z(5) \times R_y(\frac{\pi}{2}) \times transl_y(7) \times R_z(\frac{\pi}{4})$$

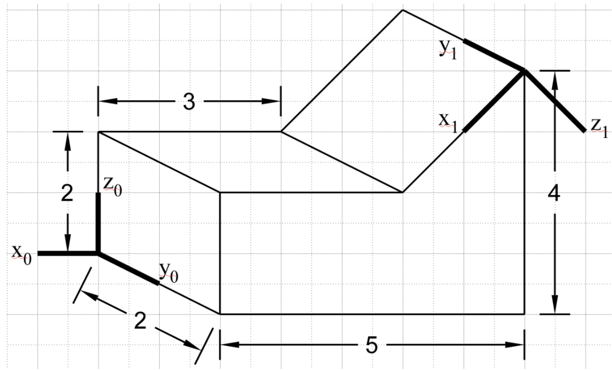
$$H = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} \cos\frac{\pi}{2} & 0 & \sin\frac{\pi}{2} & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\frac{\pi}{2} & 0 & \cos\frac{\pi}{2} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 7 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} \cos\frac{\pi}{4} & -\sin\frac{\pi}{4} & 0 & 0 \\ \sin\frac{\pi}{4} & \cos\frac{\pi}{4} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 7 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 0.707 & -0.707 & 0 & 0 \\ 0.707 & 0.707 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$H = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0.707 & 0.707 & 0 & 7 \\ -0.707 & 0.707 & 0 & 5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



2) Find the homogeneous Transformation matrix ${}^0_1T$ (If you use intermediate frames, just list the Transformation Matrices in the correct order without multiplication)



25 marks

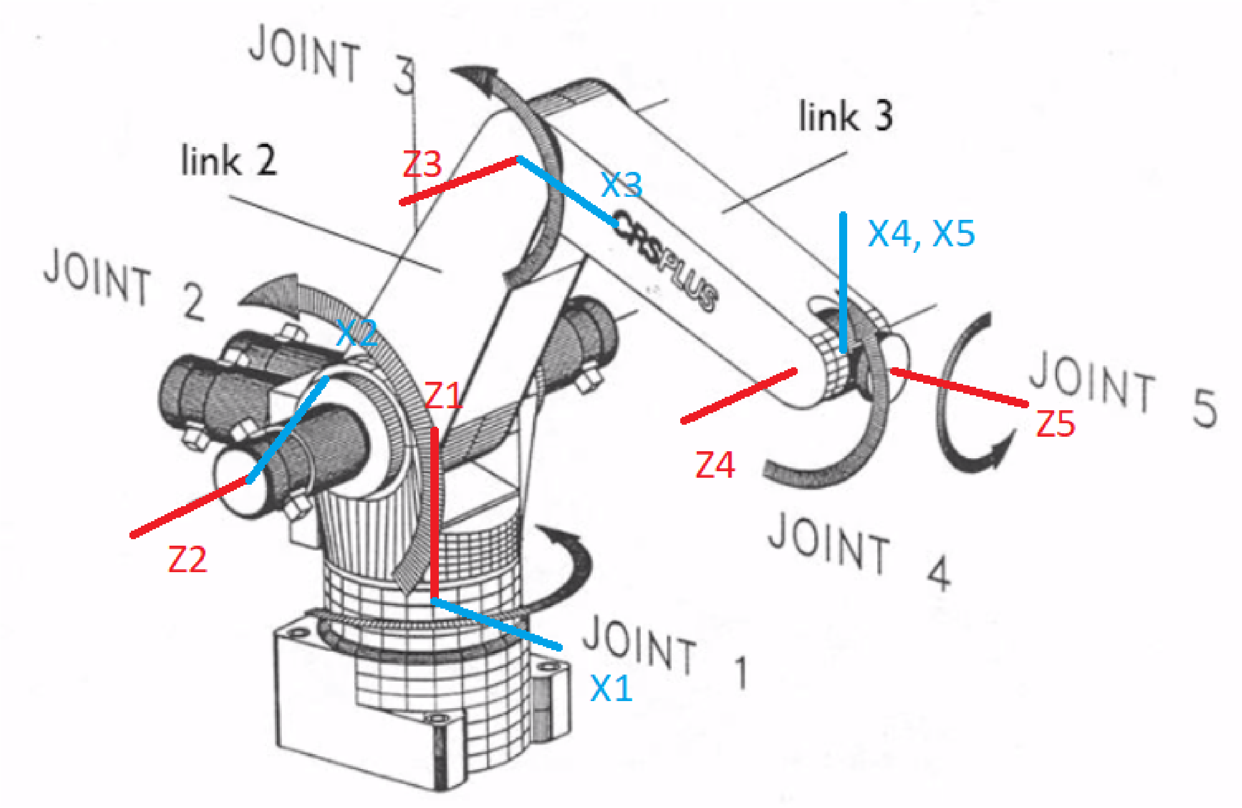
Solution:

$$ {}^0_1T = transl(-5,2,4)R_x(\pi)R_y(-\frac{\pi}{4}) $$

$$ {}^0_1T = \begin{bmatrix} 1 & 0 & 0 & -5 \\ 0 & 1 & 0 & 2 \\ 0 & 0 & 1 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\pi & -\sin\pi & 0 \\ 0 & \sin\pi & \cos\pi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} \cos -\frac{\pi}{4} & 0 & \sin -\frac{\pi}{4} & 0 \\ 0 & 1 & 0 & 0 \\ -\sin -\frac{\pi}{4} & 0 & \cos -\frac{\pi}{4} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^0_1T = \begin{bmatrix} 0.707 & 0 & -0.707 & -5 \\ 0 & -1 & 0 & 2 \\ -0.707 & 0 & -0.707 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

3) Carefully examine the 5R manipulator arm in the figure below:



The arrows indicate the positive direction of rotation for each joint. Link 2 has a length of L_2, and Link 3 has a length of L_3.

(a) Assign frames to all joints. (Shown on the Figure)

(b) Create the DH-parameter table for this manipulator.
Solution:

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	$\frac{\pi}{2}$	0	0	θ_2
3	0	L_2	0	θ_3
4	0	L_3	0	θ_4
5	$\frac{\pi}{2}$	0	0	θ_5

(c) Use the DH parameters to find all the transformation matrices ${}^{i-1}_{i}T$
Solution:

$${}^{0}_{1}T = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$ {}^1_2T = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^2_3T = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & L_2 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^3_4T = \begin{bmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & L_3 \\ \sin\theta_4 & \cos\theta_4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^4_5T = \begin{bmatrix} \cos\theta_5 & -\sin\theta_5 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \sin\theta_5 & \cos\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

(d) Write the transformation matrices in the correct order to get ${}^0_5T$

Solution:

$$ {}^0_5T = {}^0_1T\,{}^1_2T\,{}^2_3T\,{}^3_4T\,{}^4_5T $$

30 marks

4) Circle the correct answer.

1. What are the three Ds that makes a certain task a robot's job?
   A. Different, Dull, Difficult B. **Dirty, Dull, Dangerous**
   C. Dangerous, Difficult, Destructive D. Dirty, Dull, Difficult
2. The base joint of a manipulator arm corresponds to the:
   A. Wrist B. End-effector C. **Shoulder** D. Elbow
3. How many Degrees of Freedom does a cylindrical joint have?
   A. One B. **Two** C. Three D. None of the above
4. A spacial manipulator arm has 3 links, and 3 joints: 2 revolute joints and 1 spherical), how many degrees of freedom does it have?
   A. 3DOF B. **5DOF** C. 6DOF D. None of the above
5. When the joint variables are given, and used to calculate the position and orientation of the end-effector, the problem is called:
   A. **Forward Kinematics Problem** B. Inverse Kinematics Problem
   C. Jacobian Problem D. None of the above
6. The shape and size of the workspace does NOT depend on:
   A. Link Lengths B. Joint Limits C. Number of Joints D. **Joint Torques**
7. For a prismatic joint, all DH parameters are constant except:
   A. α_{i-1} B. a_{i-1} C. $\boldsymbol{d_i}$ D. θ_i
8. The angle between $\hat{Z}_{i-1}$ and $\hat{Z}_i$ is called:
   A. $\boldsymbol{\alpha_{i-1}}$ B. α_i C. θ_{i-1} D. θ_i
9. A point has the coordinates ${}^0P = [1\ 1\ 1]^T$, if it is rotated about the $x_0 - axis$ by 90^o counterclockwise, what are its new coordinates?
   A. ${}^0P = [1\ 1\ -1]^T$ B. $\boldsymbol{{}^0P = [1\ -1\ 1]^T}$
   C. ${}^0P = [-1\ 1\ 1]^T$ D. ${}^0P = [1\ -1\ -1]^T$
10. If frame $\{A\}$ is concident with frame $\{B\}$, then frame $\{B\}$ is translated 2 units in the positive $x - axis$ and 2 units in the negative $y - axis$, then ${}^A_BT$ is given by:

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

20 marks