FACULTY OF ENGINEERING, UNIVERSITY OF BENIN
2018/2019 SESSION
CPE526: ROBOTICS AND AUTOMATION

Time: Three (3) hours
Instructions:

1. **Answer a total of five (5) questions. Question one (1) is compulsory.**
2. **Clearly show all steps and workings.**
3. **Use diagrams and/or equations where applicable especially in explanations.**

Q1.

a. Define and explain the following:
 i. Robot ii. Robotics iii. Automation

b. Clearly explain why a line-following toy robot is not generally considered as automation. In addition, describe a situation where this toy robot can be considered as automation?

c. The table below shows a distinct set of Denavit-Hartenberg parameters of a three-link planar manipulator. Compute the individual transformations for each link and the single homogenous transform matrix ${}^{0}_{n}T$ that relates the end effector frame n to the base frame 0.

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	0
2	0	5	0	90
3	0	3	0	45

Q2.

a. Define and explain the following:
 i. Kinematics ii. Workspace iii. Degree of freedom

b. Clearly explain how the location of objects in 3-D space is described.

c. A frame $\{B\}$ is rotated relative to a second frame $\{A\}$ about the Z-axis by 30 degrees. Frame $\{B\}$ is also translated by 5 units and 10 units in the X-axis and Y-axis, respectively with reference to frame $\{A\}$. Given a point p that is located relative to a frame $\{B\}$ by ${}^{B}P = \begin{bmatrix} 3.0 \\ 7.0 \\ 0.0 \end{bmatrix}$, compute ${}^{A}P$.

Q3.

a. Define and explain the following:
 i. Joints ii. Links iii. End-effector

b. For the two-link planar manipulator in Fig. Q3B, assuming no joint limits, sketch the reachable workspace when $L_1 > L_2$.

c. Given the frame definitions below, compute ${}^{U}_{B}T$

$$
{}^{U}_{A}T = \begin{bmatrix} 0.866 & -0.500 & 0.000 & 11.000 \\ 0.500 & 0.866 & 0.000 & -1.000 \\ 0.000 & 0.000 & 1.000 & 8.000 \\ 0.000 & 0.000 & 0.000 & 1.000 \end{bmatrix} \quad {}^{B}_{A}T = \begin{bmatrix} 0.500 & -0.866 & 0.000 & 20.000 \\ 0.866 & 0.500 & 0.000 & 10.000 \\ 0.000 & 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 0.000 & 1.000 \end{bmatrix}
$$

Q4.

a. Define and explain the following:
 i. Forward kinematics ii. Inverse kinematics iii. Reachable workspace

b. Given the following homogenous matrix transformation relating frame {A} and frame {B}, clearly explain what can be surmised about their relative location.

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

c. Fid. Q4C shows a number of frames. Determine the homogenous matrix transform ${}^{A}_{B}T$

Q5.

2A space in which the manipulator workspace

a. Define and explain the following:
   i. Subspace ii. Joint variable iii. Dextrous workspace

a. Clearly explain Revolute and Prismatic joints, indicating the type of position information of interest in each joint type.

b. Given the following rotation matrix, compute the Euler angles

$$ {}^{A}_{B}R = \begin{bmatrix} 0.866 & -0.433 & 0.250 \\ 0.500 & 0.750 & -0.433 \\ 0.000 & 0.500 & 0.866 \end{bmatrix} $$

Q6.

a. Define and explain the following
   i. Goal Frame ii. Wrist Frame iii. Base Frame

b. Clearly explain why some industrial robots are designed such that a number of frames are mutually orthogonal and intersect at a common point.

c. Given the following transformation matrix relating frames {1} and {2} of a manipulator, determine the Denavit-Hartenberg parameters.

$$ {}^{1}_{2}T = \begin{bmatrix} 0.000 & -1 & 0.000 & 1.000 \\ 0.500 & 0 & -0.866 & -3.464 \\ 0.866 & 0 & 0.500 & 2.000 \\ 0.000 & 0 & 0.000 & 1.000 \end{bmatrix} $$

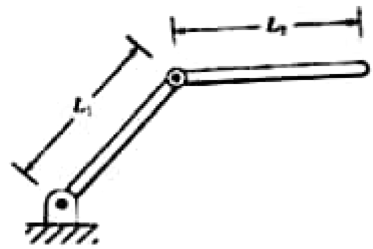

Fig. Q3B

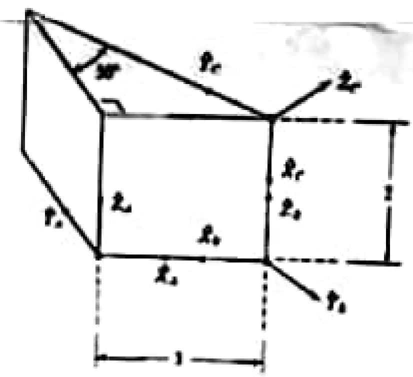

Fig. Q4C

$$ \beta = \operatorname{atan2}\left(-r_{31}, \sqrt{r_{11}^2 + r_{21}^2}\right) $$

$$ \alpha = \operatorname{atan2}\left({}^{r_{21}}/_{\cos\beta}, {}^{r_{11}}/_{\cos\beta}\right) $$

$$ \gamma = \operatorname{atan2}\left({}^{r_{32}}/_{\cos\beta}, {}^{r_{33}}/_{\cos\beta}\right) $$

$$ {}^{B}_{A}T = \begin{bmatrix} {}^{A}_{B}R^{T} & -{}^{A}_{B}R^{T}\,{}^{A}P_{BORG} \\ 0 \;\; 0 \;\; 0 & 1 \end{bmatrix} $$

$$ R_{ZYX} = R_Z(\theta_z)\, R_Y(\theta_y)\, R_X(\theta_x) $$

$$ {}^{0}_{3}T = \begin{bmatrix} \cos(\theta_1+\theta_2+\theta_3) & -\sin(\theta_1+\theta_2+\theta_3) & 0 & L_1\cos(\theta_1) + L_2\cos(\theta_1+\theta_2) \\ \sin(\theta_1+\theta_2+\theta_3) & \cos(\theta_1+\theta_2+\theta_3) & 0 & L_1\sin(\theta_1) + L_2\sin(\theta_1+\theta_2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{i-1}_{i}T = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{i-1} \\ \sin\theta_i\cos\alpha_{i-1} & \cos\theta_i\cos\alpha_{i-1} & -\sin\alpha_{i-1} & -\sin\alpha_{i-1}\,d_i \\ \sin\theta_i\sin\alpha_{i-1} & \cos\theta_i\sin\alpha_{i-1} & \cos\alpha_{i-1} & \cos\alpha_{i-1}\,d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} $$