MPR213 220530 - SOLUTIONS

1. Describe the different sections of a robot manipulator? (2p)
    - Body-and-arm, which usually consists of three joints connected by large links - for positioning of objects in the robot's work volume
    - Wrist assembly, consisting of two or three compact joints – for orientation of objects

2. Which are the two main joint types in an industrial robot (2p)

Revolute and Prismatic

3. What does Professor Bolmsjö state must be included to be defined as a robot simulation system? (4p)

- World model. Define and create a 3D model through inbuilt modeling capability or import models to define the world model.
- Hierarchical link mechanisms. Define and build link mechanisms, which can be part of the simulation as robots or other devices.
- Kinematics and dynamics simulation of robots and other mechanisms.
- Analysis to detect collisions and other events such as configuration solution of a robot manipulator, joint motions of a device or cycle times.
- Translator of a task program for a robot to a target robot system.
- Calibration module to support varius forms of calibration of models of programs to represent a real physical robot system.

4. What is the difference between platform-based simulation systems and silo-based systems? (2p)

Platform-based simulation system enable single-source of truth and collaboration

5. What is the difference between deterministic simulation systems and stochastic simulation systems, and when do you choose one over the other? (4p)

Deterministic always gives the same result. Deterministic is typical for robot simulation. Stocchastic is used in descrete event simulaition

6. What is the difference between joint movements and linear movements, and when do you choose to use one over the other? (2p)

Joint-move does not move on line/curves, but is easier for robot to handle. Less risk for singularities.

7. What is a singularity in the context of industrial robots, and how can they be avoided? (3p)

Singularity is a position that cannot be calculated by the inverse kinematics.

8. What is virtual commissioning and why is it difficult? What is different between the traditional approach and the virtual approach? (2p)

Virtual commissioning enables activities to be done in parallel; hence giving more time for the Production ramp.

9. What is Machine Learning in an industrial robotics context? (2p)

Machine Learning at its most basic is the practice of using algorithms to parse data, learn from it, and then make a determination or prediction about something in the world.

10. What is the difference between realistic robot simulation 2 (RRS-2) compared to RRS-1? (3p)

- I/O: Transfer of binary, analog and serial communication lines
- File System: Transfer of single files and complete file systems
- User Interface: Generic functions like start/stop and handling of controller specific (native) user interfaces

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Safety Monitored Stop
Hand guiding method
Speed and Separations monitoring
Power and Force Limiting
Along with a brief description of the above

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Ideally, an answer should contain one of the four levels of collaboration, the definition of the chosen level of collaboration and why one intended to use that particular collaboration within the context of the given case. Furthermore, the description of how the tasks will be divided for the given case

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```
-- No declarations needed
-- Subroutines

TABLESTART:SUBR;
WRITEO(10, 1);
WRITEO(9, 1);
END;

TABLESTOP:SUBR;
WRITEO(9, 0);
WRITEO(10, 0);
END;

CHECKSTOP:SUBR(INDEX);
TESTI(INDEX, 0, CONTINUE);
TABLESTOP;
CONTINUE:;
END;

HAMTA:SUBR(VAR, VARZ, INDEX, UP);
CHECKSTOP(INDEX);
PMOVE(VAR);
CHECKSTOP(INDEX);
ZMOVE(VARZ);
CHECKSTOP(INDEX);
GRASP;
ZMOVE(UP);
CHECKSTOP(INDEX);
END;

LAMNA:SUBR(VAR, VARZ, INDEX, UP);
PMOVE(VAR);
WAITI(INDEX, 1, 25,5);
ZMOVE(VARZ);
RELEASE;
ZMOVE(UP);
END;

GETROTPUT:SUBR(FROM, FROMZ, INDEX, TO, TOZ, UP);
TABLESTART;
HAMTA(FROM, FROMZ, INDEX, UP);
LAMNA(TO, TOZ, INDEX, UP);
END;
```

Solution:

14 a) One of several ways to end up in the TCS:

$$T = \mathrm{Trans}(x,a)\mathrm{Rot}(z,\varphi)\mathrm{Rot}(y,-\theta)\mathrm{Trans}(x,b)\mathrm{Rot}(y,90°)\mathrm{Rot}(z,90°)\mathrm{Rot}(z,\psi)$$

$$= \begin{bmatrix} c_\varphi & -s_\varphi & 0 & a \\ s_\varphi & c_\varphi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_\theta & 0 & -s_\theta & bs_\theta \\ 0 & 1 & 0 & 0 \\ s_\theta & 0 & c_\theta & bc_\theta \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 0 & 1 & b \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_\psi & -s_\psi & 0 & 0 \\ s_\psi & c_\psi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} -c_\varphi s_\theta s_\psi - s_\varphi c_\psi & s_\varphi s_\psi - c_\varphi s_\theta c_\psi & c_\varphi c_\theta & a + bc_\varphi c_\theta \\ c_\varphi c_\psi - s_\varphi s_\theta s_\psi & -c_\varphi s_\psi - s_\varphi s_\theta c_\psi & s_\varphi c_\theta & bs_\varphi c_\theta \\ c_\theta s_\psi & c_\theta c_\psi & s_\theta & bs_\theta \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

b)

$$\begin{bmatrix} -c_\varphi s_\theta s_\psi - s_\varphi c_\psi & s_\varphi s_\psi - c_\varphi s_\theta c_\psi & c_\varphi c_\theta & a + bc_\varphi c_\theta \\ c_\varphi c_\psi - s_\varphi s_\theta s_\psi & -c_\varphi s_\psi - s_\varphi s_\theta c_\psi & s_\varphi c_\theta & bs_\varphi c_\theta \\ c_\theta s_\psi & c_\theta c_\psi & s_\theta & bs_\theta \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} -\frac{1}{\sqrt{2}} & \frac{1}{2} & -\frac{1}{2} & a - \frac{b}{2} \\ -\frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{1}{2} & \frac{b}{2} \\ 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{b}{\sqrt{2}} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Based on the TCP from the 4th column and the workspace gives only one solution for θ, but for the other two joints we have an additional solution combination:

φ = 135° and φ = -225°

$\theta = 45°$

$\psi = 0°$ and trivial extra solutions ψ = 360° and ψ = -360°

c)
The second joint's rotation axis is the negative direction of the new y-axis after $\mathrm{Rot}(z,\varphi)$:

$$\mathbf{e_{1y}} = \mathrm{Rot}(z,\varphi)\begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix} = \begin{bmatrix} c_\varphi & -s_\varphi & 0 \\ s_\varphi & c_\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix} = \begin{bmatrix} s_\varphi \\ -c_\varphi \\ 0 \end{bmatrix}$$

$${}^{B}R_2 = \mathrm{Rot}(z,\varphi)\mathrm{Rot}(y,-\theta)\mathrm{Rot}(y,90°) = \begin{bmatrix} c_\varphi & -s_\varphi & 0 \\ s_\varphi & c_\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} c_\theta & 0 & -s_\theta \\ 0 & 1 & 0 \\ s_\theta & 0 & c_\theta \end{bmatrix}\begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \end{bmatrix}$$

$$= \begin{bmatrix} c_\varphi c_\theta & -s_\varphi & -c_\varphi s_\theta \\ s_\varphi c_\theta & c_\varphi & -s_\varphi s_\theta \\ s_\theta & 0 & c_\theta \end{bmatrix}\begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \end{bmatrix} = \begin{bmatrix} c_\varphi s_\theta & -s_\varphi & c_\varphi c_\theta \\ s_\varphi s_\theta & c_\varphi & s_\varphi c_\theta \\ -c_\theta & 0 & s_\theta \end{bmatrix}$$

$$\boldsymbol{\omega} = \mathbf{e_z}\omega_\varphi + \mathbf{e_{1y}}\omega_\theta + \mathbf{e_{2z}}\omega_\psi = \mathbf{e_x}\left[c_\varphi c_\theta \omega_\psi + s_\varphi \omega_\theta\right] + \mathbf{e_y}\left[s_\varphi c_\theta \omega_\psi - c_\varphi \omega_\theta\right] + \mathbf{e_z}\left[\omega_\varphi + s_\theta \omega_\psi\right]$$

15 Solution:

a)

$$T = \mathrm{Rot}(y,\theta_1)\mathrm{Trans}(z,a)\mathrm{Rot}(z,\theta_2)\mathrm{Rot}(y,-90°)\mathrm{Trans}(z,d)$$

$$T = \begin{vmatrix} c\theta_1 & 0 & s\theta_1 & 0 \\ 0 & 1 & 0 & 0 \\ -s\theta_1 & 0 & c\theta_1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix} \begin{vmatrix} c\theta_2 & -s\theta_2 & 0 & 0 \\ s\theta_2 & c\theta_2 & 0 & 0 \\ 0 & 0 & 1 & a \\ 0 & 0 & 0 & 1 \end{vmatrix} \begin{vmatrix} 0 & 0 & -1 & -d \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

$$= \begin{vmatrix} s\theta_1 & -c\theta_1 s\theta_2 & -c\theta_1 c\theta_2 & as\theta_1 - dc\theta_1 c\theta_2 \\ 0 & c\theta_2 & -s\theta_2 & -ds\theta_2 \\ c\theta_1 & s\theta_1 s\theta_2 & s\theta_1 c\theta_2 & ac\theta_1 + ds\theta_1 c\theta_2 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

$p_x = as\theta_1 – dc\theta_1c\theta_2$

$p_y = – ds\theta_2$

$p_z = ac\theta_1 + ds\theta_1c\theta_2$

$$J = \begin{bmatrix} \frac{\partial p_x}{\partial\theta_1} & \frac{\partial p_x}{\partial\theta_2} & \frac{\partial p_x}{\partial d} \\ \frac{\partial p_y}{\partial\theta_1} & \frac{\partial p_y}{\partial\theta_2} & \frac{\partial p_y}{\partial d} \\ \frac{\partial p_z}{\partial\theta_1} & \frac{\partial p_z}{\partial\theta_2} & \frac{\partial p_z}{\partial d} \end{bmatrix} = \begin{bmatrix} ac\theta_1 + ds\theta_1c\theta_2 & dc\theta_1s\theta_2 & -c\theta_1c\theta_2 \\ 0 & -dc\theta_2 & -s\theta_2 \\ -as\theta_1 + dc\theta_1c\theta_2 & -ds\theta_1s\theta_2 & s\theta_1c\theta_2 \end{bmatrix}$$

$\theta_1 = 60°$, $\theta_2 = 90°$, $a = 1\text{m}$, $d = 0.5\text{m}$

$\dot\theta_1 = 2$ rad/s, $\dot\theta_2 = 0.5$ rad/s, $\dot d = \frac{\sqrt{63}}{4}$m/s

$$\begin{bmatrix} \dot x \\ \dot y \\ \dot z \end{bmatrix}_{TCP} = J\begin{bmatrix} \dot\theta_1 \\ \dot\theta_2 \\ \dot d_3 \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & \frac{1}{4} & 0 \\ 0 & 0 & -1 \\ -\frac{\sqrt3}{2} & -\frac{\sqrt3}{4} & 0 \end{bmatrix}\begin{bmatrix} 2 \\ \frac{1}{2} \\ \frac{\sqrt{63}}{4} \end{bmatrix} = \begin{bmatrix} \frac{9}{8} \\ -\frac{\sqrt{63}}{4} \\ -\frac{9\sqrt3}{8} \end{bmatrix} = \sqrt{\frac{81+252+243}{64}} = 3\text{m/s}$$

b)

$\det J = (ac\theta_1 + ds\theta_1c\theta_2)(-dc\theta_2)(s\theta_1c\theta_2) + (dc\theta_1s\theta_2)(-s\theta_2)(-as\theta_1 + dc\theta_1c\theta_2) -$

$– (-as\theta_1 + dc\theta_1c\theta_2)(-dc\theta_2)(-c\theta_1c\theta_2) – (-ds\theta_1s\theta_2)(-s\theta_2)(ac\theta_1 + ds\theta_1c\theta_2) = -d^2c\theta_2$

A singularity exists if J is not invertable, i e if detJ = 0 => if d = 0 or $\theta_2 = \pm 90°$.

So…we are in a singularity in a)…but no problem since joint interpolated motion can be assumed. If linear motion would have been specified then we would end up with infinite velocities for the joints.