MPR213 200601 SOLUTIONS

QUESTION 1

Teach-in (1p)

What you see is what you get.
Easiest way

Board (6p)

No need to stop production during programing
Easier to optimise trajectories
To simplify collaboration
To program robots from different brands in one system
To program different processes in one system
More efficient programming
Create digital twin of factory
Test different layouts/concepts

Recommendation (1p)

Motivate which system to use

QUESTION 2

(**bold are more important**)
Sharp suggestions qualify for full points!!
Higher quality on welds
Higher productivity (robots are faster)
Program different brands in one system
Reduce health hazard operations from emplyees
Reduce manual work labour
Documentation
Complex assembly breakdown requires virtual planning for MBOM
Abstraction level of programming
Batch production is not possible requires effective online calibration (you have to discuss calibration at least)

QUESTION 3 (9p)

3a - What are the most important challanges for the companies who develop new industrial robots?

Lack of calibration
No senses (ear, feel, smell, vision)
Reduce cost without loosing quality
To reach out to new markets and find new applications of industrial robots
Cannot do assembly so well (difficult to automate C-factory)
Difficult to robotize machining processes
Since the robot itself is only small part of the solution, focus must be to reduce system overall cost to be more competitive.

3b - Explain what is difficult in order to deliver a good quality robot.

To reach high accuracy and stiffness
- Geometic inaccuracies in the fabricated parts in the robot
- Thermal expansion of robot structure
- Dynamic issues due to loads and structural resonance
- System issues due to calibration, sensors, drive train, backlash etc.

3c - If you were responsible for the development of new industrial robots, in what way would you manage your resources in order to make your company a successful international robot supplier?

Increase the abstraction level of programming, which will require:
- Smarter robots
- Emphasy on sensors and connectibity to IoT
- Machine learning

Increase Collaboration
Industry 4.0 readiness
Virtual Commissioning
Develop new architectures

QUESTION 4 (2p) and QUESTION 5 (3p)

See lecture notes and comments in your exam

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```
BINPICKING:SUBR;
--Subroutines
PICKANDPLACE:SUBR(VAR);
PICK(VAR);
PLACE(VAR);
END;

FIXTHEOTHERTWOITEMS:SUBR(VAR1,VAR2,VAR3);
PICKANDPLACE(VAR1);
IGEN:;
TESTI(VAR2,1,ITEM2);
TESTI(VAR3,1,ITEM3);
BRANCH(IGEN);
ITEM2:;
PICKANDPLACE(VAR2);
WAITI(VAR3,1,0);
PICKANDPLACE(VAR3);
BRANCH(SLUT);
ITEM3:;
PICKANDPLACE(VAR3);
WAITI(VAR2,1,0);
PICKANDPLACE(VAR2);
SLUT:;
END;

--MAIN--
WAITI(99,1,0);
WRITEO(99,0);
IGEN:;
TESTI(1,1,ITEM1);
TESTI(2,1,ITEM2);
TESTI(3,1,ITEM3);
BRANCH(IGEN);
ITEM1:;
FIXTHEOTHERTWOITEMS(1,2,3);
BRANCH(PALLET);
ITEM2:;
FIXTHEOTHERTWOITEMS(2,1,3);
BRANCH(PALLET);
ITEM3:;
FIXTHEOTHERTWOITEMS(3,1,2);
PALLET:;
WRITEO(99,1);
END;
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a) $T=Rot(z,\theta_1)Trans(x,a)Trans(z,b)Rot(y,\theta_2)Trans(x,d)Rot(x,\theta_3)Trans(x,e)\ Rot(z,\theta_4)Trans(z,f)$

Note: Other alternatives gives the same result

$$T=\begin{bmatrix} c_1 & -s_1 & 0 & ac_1 \\ s_1 & c_1 & 0 & as_1 \\ 0 & 0 & 1 & b \\ 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} c_2 & 0 & s_2 & 0 \\ 0 & 1 & 0 & 0 \\ -s_2 & 0 & c_2 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 & d+e \\ 0 & c_3 & -s_3 & 0 \\ 0 & s_3 & c_3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} c_4 & -s_4 & 0 & 0 \\ s_4 & c_4 & 0 & 0 \\ 0 & 0 & 1 & f \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T=\begin{bmatrix} c_1c_2 & -s_1 & c_1s_2 & ac_1 \\ s_1c_2 & c_1 & s_1s_2 & as_1 \\ -s_2 & 0 & c_2 & b \\ 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} c_4 & -s_4 & 0 & d+e \\ c_3s_4 & c_3c_4 & -s_3 & -fs_3 \\ s_3s_4 & s_3c_4 & c_3 & fc_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T=\begin{bmatrix} c_1c_2c_4-s_1c_3s_4+c_1s_2s_3s_4 & c_1s_2s_3c_4-c_1c_2s_4-s_1c_3c_4 & s_1s_3+c_1s_2c_3 & c_1c_2(d+e)+f(s_1s_3+c_1s_2c_3)+ac_1 \\ s_1c_2c_4+c_1c_3s_4+s_1s_2s_3s_4 & s_1s_2s_3c_4+c_1c_3c_4-s_1c_2s_4 & s_1s_2c_3-c_1s_3 & s_1c_2(d+e)+f(s_1s_2c_3-c_1s_3)+as_1 \\ c_2s_3s_4-s_2c_4 & s_2s_4+c_2s_3c_4 & c_2c_3 & fc_2c_3-s_2(d+e)+b \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

b) NO – not for a 6DOF target position. The construction and workspace limits the robot so that it is impossible to reach a position in more than one way. If the target only includes a point (X,Y,Z) then we would have a degenerate robot.

8 Solution:

a) With the new TCP:

$$T = \begin{bmatrix} c_\theta c_\beta & -s_\theta & c_\theta s_\beta & x c_\theta \\ s_\theta c_\beta & c_\theta & s_\theta s_\beta & x s_\theta \\ -s_\beta & 0 & c_\beta & z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & p \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} c_\theta c_\beta & -s_\theta & c_\theta s_\beta & p c_\theta c_\beta + x c_\theta \\ s_\theta c_\beta & c_\theta & s_\theta s_\beta & p s_\theta c_\beta + x s_\theta \\ -s_\beta & 0 & c_\beta & z - p s_\beta \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The translation is described by the last column and the rotation vector for joint 4 is described by the second column. The complete reorientation is:

$$\omega = \dot{\theta}\mathbf{e}_z + \dot{\beta}\mathbf{e}_4 = \dot{\theta}\mathbf{e}_z - \dot{\beta}s_\theta\mathbf{e}_x + \dot{\beta}c_\theta\mathbf{e}_y$$

Matching these components in the Jacobian together with the partial derivatives for the translation gives:

$$J = \begin{bmatrix} -p s_\theta c_\beta - x s_\theta & c_\theta & 0 & -p c_\theta s_\beta \\ p c_\theta c_\beta + x c_\theta & s_\theta & 0 & -p s_\theta s_\beta \\ 0 & 0 & 1 & -p c_\beta \\ 0 & 0 & 0 & -s_\theta \\ 0 & 0 & 0 & c_\theta \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

b) The robot is fixed with $\theta=0 \Rightarrow \dot{\theta} = 0$ and no reorientation about x and z will let us delete the first column + row 4 and 6 (only zeros in row 2) resulting in:

$$J = \begin{bmatrix} 1 & 0 & -p s_\beta \\ 0 & 1 & -p c_\beta \\ 0 & 0 & 1 \end{bmatrix}$$

The determinant = 1 so **no singularities**. The inverse is J^{-1}:

$$J^{-1} = \begin{bmatrix} 1 & 0 & p s_\beta \\ 0 & 1 & p c_\beta \\ 0 & 0 & 1 \end{bmatrix} \Rightarrow \begin{bmatrix} \dot{x} \\ \dot{z} \\ \dot{\beta} \end{bmatrix} = \begin{bmatrix} 1 & 0 & p s_\beta \\ 0 & 1 & p c_\beta \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{p}_x \\ \dot{p}_z \\ \omega_y \end{bmatrix}$$ and $\dot{p}_x = \dot{p}_z = 0$ so we will have:

$$\begin{bmatrix} \dot{x} \\ \dot{z} \\ \dot{\beta} \end{bmatrix} = \begin{bmatrix} 1 & 0 & p s_\beta \\ 0 & 1 & p c_\beta \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \omega_y \end{bmatrix} = \begin{bmatrix} \omega_y p s_\beta \\ \omega_y p c_\beta \\ \omega_y \end{bmatrix}$$