KOLEJ UNIVERSITI TEKNOLOGI TUN HUSSEIN ONN

PEPERIKSAAN AKHIR SEMESTER I SESI 2006/2007

NAMA MATAPELAJARAN	:	ROBOT INDUSTRI
KOD MATAPELAJARAN	:	BER 4243
KURSUS	:	4 BER
TARIKH PEPERIKSAAN	:	NOVEMBER 2006
JANGKA MASA	:	3 JAM
ARAHAN	:	JAWAB LIMA **(5)** SOALAN SAHAJA DARIPADA ENAM (6) SOALAN.

KERTAS SOALAN INI MENGANDUNGI **15** MUKA SURAT

SOALAN DALAM BAHASA MELAYU

S1 (a) Apakah definisi robot mengikut RIA?

(3 markah)

(b) Dua klasifikasi robot adalah berdasarkan jenis kawalan dan sistem koordinat. Terangkan kedua-dua klasifikasi ini.

(6 markah)

(c) Terangkan dua kebaikan dan kelemahan pengolah Cartesian.

(4 markah)

(d) Apakah definisi "*work envelope/volume*"?

(4 markah)

(e) Lukiskan ruang kerja bagi konfigurasi Cartesian seperti yang ditunjukkan di dalam Rajah S1 (e).

(3 markah)

S2 (a) Untuk kerangka yang berikut, cari elemen-elemen yang tertinggal untuk melengkapkan perwakilan matrik kerangka.

$$F = \begin{bmatrix} ? & 0 & ? & 5 \\ 0.707 & ? & ? & 3 \\ ? & ? & 0 & 2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(6 markah)

(b) Cari titik koordinat $P(3,5,7)^T$ relatif kepada kerangka rujukan selepas putaran 30^o pada paksi-x.

(3 markah)

(c) Titik P diruang koordinat didefinisikan sebagai ${}^{B}P = [2, 3, 5]^{T}$ relatif kepada kerangka B, dimana bersangkutan kepada kerangka rujukan asal dan ianya selari. Cari ${}^{A}P$ dengan mengenakan transformasi-transformasi berikut. Dengan menggunakan tiga grid dimensi, plotkan transformasi-transforamsi tersebut untuk membuat pengesahan.

(i) Putaran 90^{o} pada paksi-x.

(ii) Putaran 90^{o} pada paksi tempatan-a.

(iii) Alihan 3 unit pada paksi-y, 6 unit pada paksi-z dan 5 unit pada paksi-x.

(11 markah)

S3 (a) Perwakilan matrik bagi perubahan orientasi bagi sudut-sudut Euler adalah

$$\text{Euler}(\phi, \theta, \psi) = \text{Rot}(a, \phi)\text{Rot}(o, \theta)\text{Rot}(a, \psi)$$

$$\text{Euler}(\phi, \theta, \psi) = \begin{bmatrix} C\phi C\theta C\psi - S\phi S\psi & -C\phi C\theta S\psi - S\phi C\psi & C\phi S\theta & 0 \\ S\phi C\theta C\psi + C\phi S\psi & -S\phi C\theta S\psi + C\phi C\psi & S\phi S\theta & 0 \\ -S\phi C\psi & S\phi S\psi & C\theta & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Tunjukkan bahawa

(i) $-a_x S\phi + a_y C\phi = 0$

(ii) $S\psi = -n_x S\phi + n_y C\phi$

(iii) $C\psi = -o_x S\phi + o_y C\phi$

(iv) $S\theta = a_x C\phi + a_y S\phi$

(v) $C\theta = a_z$

(16 markah)

(b) Orientasi terakhir bagi tangan robot Cartesian Euler telah diberikan. Cari sudut-sudut Euler yang diperlukan:

$$ {}^{R}T_{H} = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0.579 & -0.548 & -0.604 & 5 \\ 0.540 & 0.813 & -0.220 & 7 \\ 0.611 & -0.199 & 0.766 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

(4 markah)

S4 Satu lengan robot yang mempunyai tiga sudut-sudut kebebasan telah direkabentuk untuk mengecat dinding rumah pangsa seperti yang ditunjukkan di dalam Rajah S4.

(a) Tandakan kerangka koordinat yang diperlukan berdasarkan perwakilan D-H.

(6 markah)

(b) Isikan jadual parameter-parameter.

(6 markah)

(c) Tuliskan semua matrik-matrik *A*.

(6 markah)

(d) Tuliskan matrik ${}^{U}T_{H}$ dalam sebutan matrik *A*.

(2 markah)

S5 (a) Matriks jacoban bagi sebuah robot pada masa yang tertentu telah diberikan seperti dibawah. Kira gerakan lelurus dan kebezaan halaju kerangka tangan robot bagi pergerakan kebezaan sambungan yang telah diberikan.

$$J = \begin{bmatrix} 2 & 0 & 0 & 0 & 1 & 0 \\ -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \qquad D_\theta = \begin{bmatrix} 0 \\ 0.1 \\ -0.1 \\ 0 \\ 0 \\ 0.2 \end{bmatrix}$$

(5 markah)

(b) Lokasi dan orientasi mula bagi tangan robot diberikan sebagai T_1, dan lokasi dan orientasi yang baru selepas perubahan diberikan sebagai T_2.

(i) Cari transfomasi matrik Q bagi menyempurnakan transfom (di dalam kerangka Universe).

(5 markah)

(ii) Anggapkan perubahan adalah kecil, cari pengendali Δ yang akan melakukan perkara yang sama.

(5 markah)

(iii) Cari kebezaan peralihan dan kebezaan putaran yang mengandungi pengendali ini.

$$T_1 = \begin{bmatrix} 1 & 0 & 0 & 5 \\ 0 & 0 & -1 & 3 \\ 0 & 1 & 0 & 6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad T_2 = \begin{bmatrix} 1 & 0 & 0.1 & 4.8 \\ 0.1 & 0 & -1 & 3.5 \\ 0 & 1 & 0 & 6.2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(5 markah)

S6 Pertimbangkan titik jisim - jisim m_1 dan m_2 masing - masing di hujung lengan 1 dan lengan 2 pada pengolah robot $\theta - r$ dengan satu sendi jenis putaran dan satu jenis sendi prisma seperti dalam Rajah S6. Dapatkan persamaan pembezaan pergerakan bagi $\theta - r$ pengolah dengan menggunakan persamaan *Lagrange*.

(20 markah)

SOALAN DALAM BAHASA INGGERIS

Q1 (a) What is the RIA definition of a robot?

(3 marks)

(b) Two classifications of the robots are according to the types of control and coordinate systems. Explain these two classifications.

(6 marks)

(c) State two advantages and disadvantages of Cartesian manipulator.

(4 marks)

(d) What is the definition of the work envelope/volume?

(4 marks)

(e) Draw the approximate workspace for Cartesian configuration as shown in Figure Q1 (e).

(3 marks)

Q2 (a) For the following frame, find the values of the missing elements and complete the matrix representation of the frame

$$F = \begin{bmatrix} ? & 0 & ? & 5 \\ 0.707 & ? & ? & 3 \\ ? & ? & 0 & 2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(6 marks)

(b) Find the coordinates of point P $(3, 5, 7)^T$ relative to the reference frame after a rotation of 30^o about the z-axis.

(3 marks)

(c) A point P in space is defined as $^{B}P = [2, 3, 5]^{T}$ relative to frame B, which is attached to the origin of the reference frame A and is parallel to it. Apply the following transformations to frame B and find ^{A}P. Using the three dimensional grid, plot the transformations and the result and verify it:

(i) Rotate 90° about the x-axis.

(ii) Rotate 90° about the local a-axis.

(iii) Translate 3 units about the y-axis, 6 units about the z-axis, and 5 units about the x-axis.

(11 marks)

Q3 (a) The matrix representing the Euler angles orientation change is

$$\text{Euler}(\phi,\theta,\psi) = \text{Rot}(a,\phi)\text{Rot}(o,\theta)\text{Rot}(a,\psi)$$

$$\text{Euler}(\phi,\theta,\psi) = \begin{bmatrix} C\phi C\theta C\psi - S\phi S\psi & -C\phi C\theta S\psi - S\phi C\psi & C\phi S\theta & 0 \\ S\phi C\theta C\psi + C\phi S\psi & -S\phi C\theta S\psi + C\phi C\psi & S\phi S\theta & 0 \\ -S\phi C\psi & S\phi S\psi & C\theta & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Show that

(i) $-a_x S\phi + a_y C\phi = 0$

(ii) $S\psi = -n_x S\phi + n_y C\phi$

(iii) $C\psi = -o_x S\phi + o_y C\phi$

(iv) $S\theta = a_x C\phi + a_y S\phi$

(v) $C\theta = a_z$

(16 marks)

(b) The desired final orientation of the hand of a Cartesian-Euler robot given. Find the necessary Euler angles:

$$ {}^{R}T_{H} = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0.579 & -0.548 & -0.604 & 5 \\ 0.540 & 0.813 & -0.220 & 7 \\ 0.611 & -0.199 & 0.766 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

(4 marks)

Q4 A robot arm with three degrees of freedom has been designed for applying paint on flat wall as shown in Figure Q4.

(a) Assign coordinate frames as necessary based on D-H representation.

(6 marks)

(b) Fill out the parameters table.

(6 marks)

(c) Write all the *A* matrices.

(6 marks)

(d) Write the ${}^{U}T_{H}$ matrix in terms of the *A* matrices

(2 marks)

Q5 (a) The Jacobian of a robot at a particular time is given below. Calculate the linear and angular differential motions of the robot's hand frame for the given joint differential motions.

$$J = \begin{bmatrix} 2 & 0 & 0 & 0 & 1 & 0 \\ -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \qquad D_\theta = \begin{bmatrix} 0 \\ 0.1 \\ -0.1 \\ 0 \\ 0 \\ 0.2 \end{bmatrix}$$

(5 marks)

(b) The initial location and orientation of a robot's hand is given by T_1, and its new locations and orientation after a change is given by T_2.

(i) Find a transformation matrix Q that will accomplish this transform (in Universe frame).

(5 marks)

(ii) Assuming that the change is small, find a differential operator Δ that will do the same.

(5 marks)

(iii) Find a differential translation and differential rotation that constitute this operator.

$$T_1 = \begin{bmatrix} 1 & 0 & 0 & 5 \\ 0 & 0 & -1 & 3 \\ 0 & 1 & 0 & 6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad T_2 = \begin{bmatrix} 1 & 0 & 0.1 & 4.8 \\ 0.1 & 0 & -1 & 3.5 \\ 0 & 1 & 0 & 6.2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(5 marks)

Q6 Consider the point masses m_1 and m_2 at the end of links of the following $\theta - r$ robot manipulator with a revolute joint and a prismatic joint in Figure Q6. Obtain the differential equations of motion of the $\theta - r$ manipulator using the Lagrange equations.

(20 marks)

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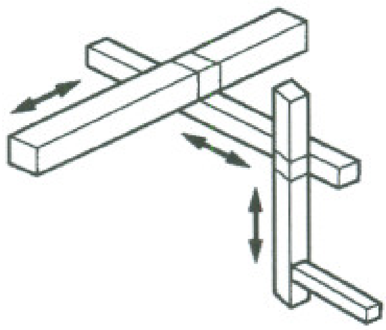
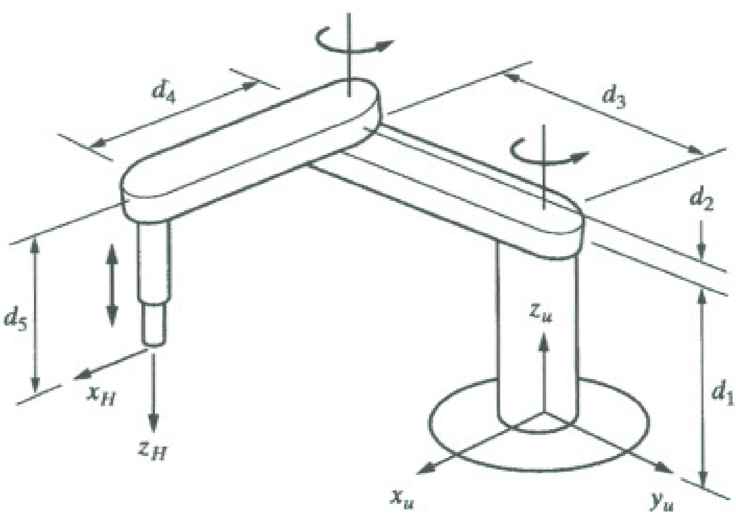


Rajah S1(e)/ Figure Q1(e)



Rajah S4/ Figure Q4

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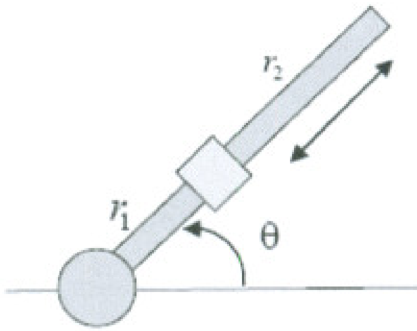

Rajah S6/ Figure Q6

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LAMPIRAN 1/ APPENDIX 1

Six constraint equations:

(1) $\bar{n} \bullet \bar{o} = 0$

(2) $\bar{n} \bullet \bar{a} = 0$

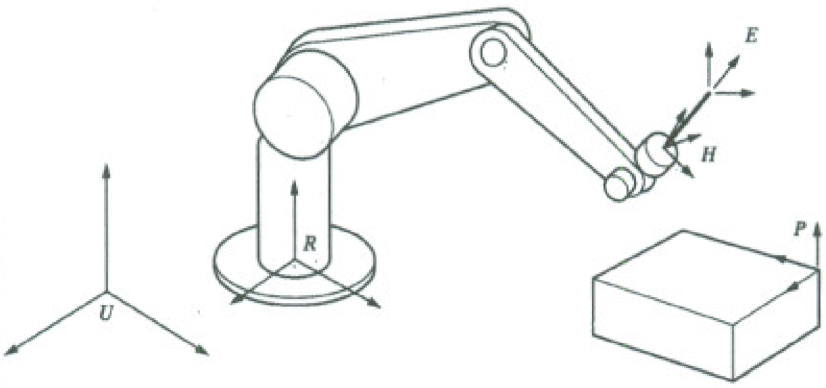
(3) $\bar{a} \bullet \bar{o} = 0$

(4) $|n| = 1$

(5) $|o| = 1$

(6) $|a| = 1$

Transformation from reference frame U to end effector:



$$^{U}\mathbf{T}_{E} = {}^{U}\mathbf{T}_{R}\,{}^{R}\mathbf{T}_{H}\,{}^{H}\mathbf{T}_{E} = {}^{U}\mathbf{T}_{P}\,{}^{P}\mathbf{T}_{E}$$

$$^{R}\mathbf{T}_{H} = {}^{U}\mathbf{T}_{R}^{-1}\,{}^{U}\mathbf{T}_{P}\,{}^{P}\mathbf{T}_{E}\,{}^{H}\mathbf{T}_{E}^{-1}$$

- ${}^{U}\mathbf{T}_{R}$ is the transformation of frame R relative to U.
- ${}^{H}\mathbf{T}_{E}$ the transformation of the end effector relative to robot's hand.
- ${}^{U}\mathbf{T}_{P}$ the transformation of the part relative to the universe.
- ${}^{P}\mathbf{T}_{E}$ is the transformation of the end effector relative to the part's position.
- ${}^{R}\mathbf{T}_{H}$ is the transformation of the robot's hand relative to the robot's base (unknown).

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LAMPIRAN 2 / APPENDIX 2

Representation of the rotation matrix

$$\mathrm{Rot}(x,\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix}$$

$$\mathrm{Rot}(y,\theta) = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix}$$

$$\mathrm{Rot}(z,\theta) = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Denavit-Hartenberg Representation

- θ represent the rotations about the z-axis.
- *d* represents the distance on the z-axis between two successive common normals.
- *a* represents the length of each common normal (also called joint offset).
- α represents the angles between two successive z-axis (also called joint twist).

Representation of A matrices

$${}^{n}T_{n+1} = A_{n+1} = \mathrm{Rot}(z,\theta_{n+1})\mathrm{Tran}(0,0,d_{n+1})\mathrm{Trans}(a_{n+1},0,0)(\mathrm{Rot}(x,\alpha_{n+1})$$

$$= \begin{bmatrix} C\theta_{n+1} & -S\theta_{n+1}C\alpha_{n+1} & S\theta_{n+1}S\alpha_{n+1} & a_{n+1}C\theta_{n+1} \\ S\theta_{n+1} & C\theta_{n+1}C\alpha_{n+1} & -C\theta_{n+1}S\alpha_{n+1} & a_{n+1}S\theta_{n+1} \\ 0 & S\alpha_{n+1} & C\alpha_{n+1} & d_{n+1} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

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LAMPIRAN 3 / APPENDIX 3

Jacobian Matrix

$$D = JD_\theta$$

$$\begin{bmatrix} dx \\ dy \\ dz \\ \delta x \\ \delta y \\ \delta z \end{bmatrix} = \begin{bmatrix} \\ \\ \text{Robot} \\ \text{Jacobian} \\ \\ \\ \end{bmatrix} \begin{bmatrix} d\theta_1 \\ d\theta_2 \\ d\theta_3 \\ d\theta_4 \\ d\theta_5 \\ d\theta_6 \end{bmatrix}$$

Differential transforamtion

$$dT = [\Delta][T]$$

Differential operator

$$\Delta = [\text{Trans}(dx, dy, dz)\text{Rot}(k, d\theta) - I]$$

Lagrange function

$$L = K(q, \dot{q}) - P(q)$$

Total kinetic energy

$$K = \sum_{i=1}^{n} \frac{m1(\dot{x}_t^2 + \dot{y}_t^2 + \dot{z}_t^2)}{2}$$

Potential energy

$$P = mgh$$

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LAMPIRAN 4 / APPENDIX 4

General Lagrangian equation for the *i*th particle

$$Fi = \frac{d}{dt}\left(\frac{\delta L}{\delta \dot{X}i}\right) - \left(\frac{\delta L}{\delta Xi}\right), i = 1,2......n$$

$$Ti = \frac{d}{dt}\left(\frac{\delta L}{\delta \dot{\theta}i}\right) - \left(\frac{\delta L}{\delta \theta i}\right), i = 1,2......n$$