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Scheme of Valuation/Answer Key

(Scheme of evaluation (marks in brackets) and answers of problems/key)

APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY

SIXTH SEMESTER B.TECH DEGREE EXAMINATION, APRIL 2018

Course Code: EC368

Course Name: Robotics

Max. Marks: 100		Duration: 3 Hours

PART A

		Answer any two full questions, each carries 15 marks	Marks
1	a)	Diagram of robotic arm(2 marks) Explanation of components and structure of robotic arm (3 marks)	
	b)	Explanation of linear actuator (3 marks) and Diagram (2 marks) Explanation of rotary actuator (3 marks) and Diagram (2 marks)	
2	a)	Characteristics of sensors.(3 marks) Explaining any 2 sensors (2 marks for each sensor)	
	b)	Speed control of motors (4 marks) Direction control of electric motors (4 marks)	
3	a)	Working of stepper motors (3 marks) Working of brushless DC motors. (3 marks) Advantages and disadvantages(2 marks)	
	b)	Cartesian coordinate system with figure (2 Marks) Cylindrical coordinate system with figure (2 Marks) Spherical coordinate system with figure (3 Marks)	

PART B

		Answer any two full questions, each carries 15 marks	
4	a)	Explain any 3 image processing techniques (10 marks)	
	b)	$T^{-1} = \begin{bmatrix} 0.5 & 0.866 & 0 & -(3\times0.5+2\times0.866+5\times0) \\ 0 & 0 & 1 & -(3\times0+2\times0+5\times1) \\ 0.866 & -0.5 & 0 & -(3\times0.866+2\times-0.5+5\times0) \\ 0 & 0 & 0 & 1 \end{bmatrix}$ $= \begin{bmatrix} 0.5 & 0.866 & 0 & -3.23 \\ 0 & 0 & 1 & -5 \\ 0.866 & -0.5 & 0 & -1.598 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ (5 marks for correct answer)	

5 a) a) Rot(z,90). Rot(x,90). Trans(0,0,3)Trans(0,5,0) (2 marks)

b)
$$\begin{bmatrix}0&-1&0&0\\1&0&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}\begin{bmatrix}1&0&0&0\\0&0&-1&0\\0&1&0&0\\0&0&0&1\end{bmatrix}\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&3\\0&0&0&1\end{bmatrix}\begin{bmatrix}1&0&0&0\\0&1&0&5\\0&0&1&0\\0&0&0&1\end{bmatrix}\begin{bmatrix}1\\5\\4\\1\end{bmatrix}=\begin{bmatrix}7\\1\\10\\1\end{bmatrix}$$

(4 marks for 4 transformation matrices and 2 marks for final answer)

b) Matrix representing the orientation change with Euler angles **(4 marks)**

$$\text{Euler}(\phi,\theta,\psi)=Rot(a,\phi)Rot(o,\theta),Rot(a,\psi)$$
$$=\begin{bmatrix}C\phi C\theta C\psi-S\phi S\psi & -C\phi C\theta S\psi-S\phi C\psi & C\phi S\theta & 0\\ S\phi C\theta C\psi+C\phi S\psi & -S\phi C\theta S\psi+C\phi C\psi & S\phi S\theta & 0\\ -S\theta C\psi & S\theta S\psi & C\theta & 0\\ 0&0&0&1\end{bmatrix}$$

Three fundamental rotations involved in this **(3 marks for three fundamental rotations)**

Rotation of ϕ about the a-axis (z-axis of the moving frame) followed by,
Rotation of θ about the o-axis (y-axis of the moving frame) followed by,
Rotation of ψ about the a-axis (z-axis of the moving frame).

6 a) **Asssigning frames (1 mark)**

Parameter table (2 marks)

#	θ	d	a	α
0–1	θ_1	0	a_1	0
1–H	θ_2	0	a_2	0

Writing A$_1$ and A$_2$ (2 marks)

Final transformation matrix (3 marks)

$$A_1=\begin{bmatrix}C_1&-S_1&0&a_1C_1\\S_1&C_1&0&a_1S_1\\0&0&1&0\\0&0&0&1\end{bmatrix}\quad\text{and}\quad A_2=\begin{bmatrix}C_2&-S_2&0&a_2C_2\\S_2&C_2&0&a_2S_2\\0&0&1&0\\0&0&0&1\end{bmatrix}$$

$$^0T_H=A_1\times A_2=\begin{bmatrix}C_1C_2-S_1S_2 & -C_1S_2-S_1C_2 & 0 & a_2(C_1C_2-S_1S_2)+a_1C_1\\ S_1C_2+C_1S_2 & -S_1S_2+C_1C_2 & 0 & a_2(S_1C_2+C_1S_2)+a_1S_1\\ 0&0&1&0\\0&0&0&1\end{bmatrix}$$

b)

$$ {}^{R}T_p = T_{cyl}(r,\alpha,l) = Trans(0,0,l)Rot(z,\alpha)Trans(r,0,0) $$

$$ {}^{R}T_p = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & l \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} C\alpha & -S\alpha & 0 & 0 \\ S\alpha & C\alpha & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & r \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{R}T_p = T_{cyl}(r,\alpha,l) = \begin{bmatrix} C\alpha & -S\alpha & 0 & rC\alpha \\ S\alpha & C\alpha & 0 & rS\alpha \\ 0 & 0 & 1 & l \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

4 marks for final matrix $^{R}T_{P}$

3 marks for the 3 transformations

i) Translation about x-axis by r

ii) Rotation about z-axis by α

iii) Translation about z-axis by l

PART C

Answer any two full questions, each carries 20 marks

7 a)

The kinetic energy of the system is comprised of the kinetic energies of the cart and the pendulum. Notice that the velocity of the pendulum is the summation of the velocity of the cart and of the pendulum relative to the cart, or:

$$\mathbf{v}_p = \mathbf{v}_c + \mathbf{v}_{p/c} = (\dot{x})\mathbf{i} + \left(l\dot{\theta}\cos\theta\right)\mathbf{i} + \left(l\dot{\theta}\sin\theta\right)\mathbf{j} = \left(\dot{x} + l\dot{\theta}\cos\theta\right)\mathbf{i} + \left(l\dot{\theta}\sin\theta\right)\mathbf{j}$$

and $v_p^2 = \left(\dot{x} + l\dot{\theta}\cos\theta\right)^2 + \left(l\dot{\theta}\sin\theta\right)^2$

Therefore:

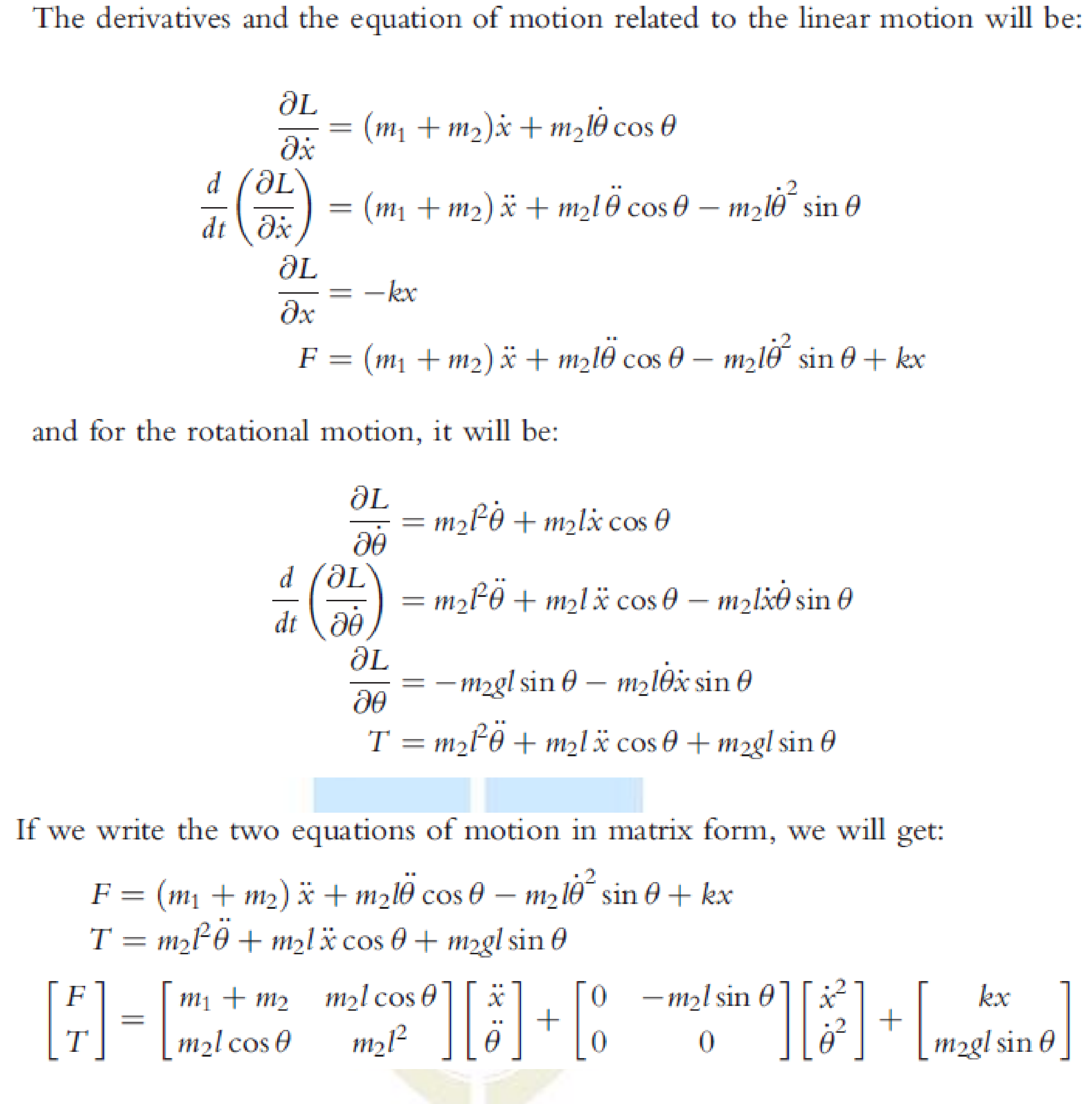
$$\begin{aligned} K &= K_{cart} + K_{pendulum} \\ K_{cart} &= \frac{1}{2}m_1\dot{x}^2 \\ K_{pendulum} &= \frac{1}{2}m_2\left(\left(\dot{x} + l\dot{\theta}\cos\theta\right)^2 + \left(l\dot{\theta}\sin\theta\right)^2\right) \\ K &= \frac{1}{2}(m_1 + m_2)\dot{x}^2 + \frac{1}{2}m_2(l^2\dot{\theta}^2 + 2l\dot{\theta}\dot{x}\cos\theta) \end{aligned}$$

Likewise, the potential energy is the summation of the potential energies in the spring and in the pendulum, or:

$$P = \frac{1}{2}kx^2 + m_2gl(1 - \cos\theta)$$

Notice that the zero potential energy line (datum) is chosen at $\theta = 0°$. The Lagrangian will be:

$$L = K - P = \frac{1}{2}(m_1 + m_2)\dot{x}^2 + \frac{1}{2}m_2(l^2\dot{\theta}^2 + 2l\dot{\theta}\dot{x}\cos\theta) - \frac{1}{2}kx^2 - m_2gl(1 - \cos\theta)$$

		 The derivatives and the equation of motion related to the linear motion will be: $\frac{\partial L}{\partial \dot{x}} = (m_1 + m_2)\dot{x} + m_2 l\dot{\theta}\cos\theta$ $\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}}\right) = (m_1 + m_2)\ddot{x} + m_2 l\ddot{\theta}\cos\theta - m_2 l\dot{\theta}^2\sin\theta$ $\frac{\partial L}{\partial x} = -kx$ $F = (m_1 + m_2)\ddot{x} + m_2 l\ddot{\theta}\cos\theta - m_2 l\dot{\theta}^2\sin\theta + kx$ and for the rotational motion, it will be: $\frac{\partial L}{\partial \dot{\theta}} = m_2 l^2\dot{\theta} + m_2 l\dot{x}\cos\theta$ $\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\theta}}\right) = m_2 l^2\ddot{\theta} + m_2 l\ddot{x}\cos\theta - m_2 l\dot{x}\dot{\theta}\sin\theta$ $\frac{\partial L}{\partial \theta} = -m_2 gl\sin\theta - m_2 l\dot{\theta}\dot{x}\sin\theta$ $T = m_2 l^2\ddot{\theta} + m_2 l\ddot{x}\cos\theta + m_2 gl\sin\theta$ If we write the two equations of motion in matrix form, we will get: $F = (m_1 + m_2)\ddot{x} + m_2 l\ddot{\theta}\cos\theta - m_2 l\dot{\theta}^2\sin\theta + kx$ $T = m_2 l^2\ddot{\theta} + m_2 l\ddot{x}\cos\theta + m_2 gl\sin\theta$ $\begin{bmatrix} F \\ T \end{bmatrix} = \begin{bmatrix} m_1 + m_2 & m_2 l\cos\theta \\ m_2 l\cos\theta & m_2 l^2 \end{bmatrix}\begin{bmatrix} \ddot{x} \\ \ddot{\theta} \end{bmatrix} + \begin{bmatrix} 0 & -m_2 l\sin\theta \\ 0 & 0 \end{bmatrix}\begin{bmatrix} \dot{x}^2 \\ \dot{\theta}^2 \end{bmatrix} + \begin{bmatrix} kx \\ m_2 gl\sin\theta \end{bmatrix}$	
	b)	Explain the structure of robot programming language.	
8	a)	Jacobian operator and explanation (2 marks) linear velocity Jv of end-effector (4 marks) and angular velocity Jw of end-effector (4 marks)	
	b)	Textual programming (5 marks) Lead through programming (5 marks)	
9	a)	Write VAL commands for controlling end-effector motion of a robot.	
	b)	What is the role of inverse Jacobian operator (5 marks) Significance of singularities (5 marks)	
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