Midterm Robotics

December 1, 2022 (Open Book)

1.(36%) For a robot manipulator with the following kinematic table, (a) please draw its structure with the coordinate frames (6%), and also find its T_3 (6%). (b) Please solve its corresponding joint solutions from T_3 using both algebraic and geometric approaches (20%). (c) With the presence of joint range, please describe what the workspace will be like (4%).

Joint	d	a	α	θ
1(r)	d_1	0	90°	θ_1
2(r)	0	0	90°	θ_2
3(p)	d_3	0	0°	0°

2.(20%) (a) Explain why the singular points are present for a multi-DOF robot manipulator, and what are their mathematical and physical meaning (8%). (b) What is the definition of the wrist-partitioned type of robot manipulator (3%)? What is its benifit in solving the inverse kinematic solutions (3%)? Is the Mitsubishi type of robot manipulator for the course project wrist-partitioned, and how about human arm (3%)? (c) Describe the singular point for the robot manipulator in Problem 1 (3%).

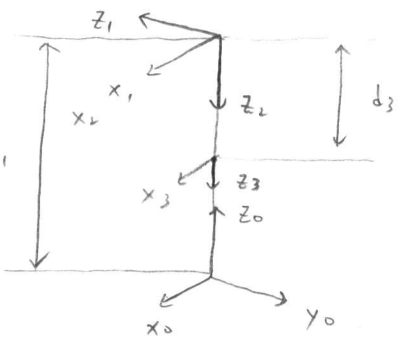
3.(18%) (a) What are the main factors needed to be considered in desinging a feasible path for a robot manipulator (4%)? (b) Describe how to plan a feasible path in the presence of static obstacle(s) for (i) a mobile robot and (ii) a multi-DOF robot manipulator (10%). (c) If the workspaces of two multi-DOF robot manipulators are overlapping, what will be your design for them to work together when considering both safety and efficiency (4%)?

4.(18%) (a) Please give the general dynamic equation for a multi-DOF robot manipulator, describe the four main components, and also evaluate their importance on control (8%). For this dynamic equation to be realistic, what should be done (4%)? (b) Explain what the learning approach is ? Why it is not effective in dealing with inverse kinematic and inverse Jacobian problems for a multi-DOF robot manipulator (4%)? (c) This question is about human-robot cooperation. If you want to have a robot to work with a human, what will be your main considerations for system design (4%)? Please name at least two items.

safe

5.(12%) Please just use a few words to describe what "Control" is. What is the benifit of "Feedfoward Control" ? How to achieve "Feedforward Control" ? Why the industry usually adopts "Feedbacl Control" instead of more advanced "Feedforward Control" for controller design ? For all the questions, please just describe the concept.

1. (a)



$$T_3 = A_1 A_2 A_3$$

$$= \begin{bmatrix} C_1 & 0 & S_1 & 0 \\ S_1 & 0 & -C_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_2 & 0 & S_2 & 0 \\ S_2 & 0 & -C_2 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= A_1 \begin{bmatrix} C_2 & 0 & S_2 & S_2 d_3 \\ S_2 & 0 & -C_2 & -C_2 d_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} C_1 C_2 & S_1 & C_1 S_2 & C_1 S_2 d_3 \\ S_1 C_2 & -C_1 & S_1 S_2 & S_1 S_2 d_3 \\ S_2 & 0 & -C_2 & -C_2 d_3 + d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(b)

Algebraic

$$\begin{bmatrix} C_1 C_2 & S_1 & C_1 S_2 & C_1 S_2 d_3 \\ S_1 C_2 & -C_1 & S_1 S_2 & S_1 S_2 d_3 \\ S_2 & 0 & -C_2 & -C_2 d_3 + d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_p & a_p & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{cases} p_x = C_1 S_2 d_3 \\ p_y = S_1 S_2 d_3 \\ p_z = -C_2 d_3 + d_1 \end{cases}, \quad \text{if } S_2 d_3 \neq 0, \quad \theta_{11} = \tan^{-1}\left(\frac{p_y}{p_x}\right) = \tan^{-1}\left(\frac{S_1}{C_1}\right)$$

$$\theta_{12} = \tan^{-1}\left(\frac{p_y}{p_x}\right) + 180^\circ$$

$$A^{-1} T_3 = \begin{bmatrix} C_1 & S_1 & 0 & 0 \\ 0 & 0 & 1 & -d_1 \\ S_1 & -C_1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} C_2 & 0 & S_2 & S_2 d_3 \\ S_2 & 0 & -C_2 & -C_2 d_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{cases} C_1 p_x + S_1 p_y = S_2 d_3 \\ p_z - d_1 = -C_2 d_3 \end{cases} \Rightarrow \theta_{21} = \tan^{-1}\left(\frac{C_1 p_x + S_1 p_y}{d_1 - p_z}\right)$$

$$\theta_{22} = \tan^{-1}\left(\frac{-C_1 p_x - S_1 p_y}{d_1 - p_z}\right)$$

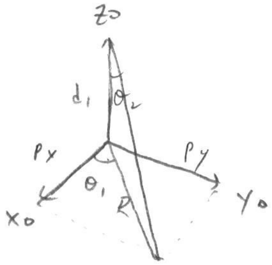
$$A_2^{-1}A_1^{-1}T_3 = \underbrace{\begin{bmatrix} C_2 & S_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ S_2 & -C_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} C_1 & S_1 & 0 & 0 \\ 0 & 0 & 1 & -d_1 \\ S_1 & -C_1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{\shortparallel}\begin{bmatrix} n & o & a & p \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} C_2C_1 & C_2S_1 & S_2 & -d_1S_2 \\ S_1 & -C_1 & 0 & 0 \\ C_1S_2 & S_1S_2 & -C_2 & d_1C_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$C_1S_2P_x + S_1S_2P_y - C_2P_z + d_1C_2 = d_3$$

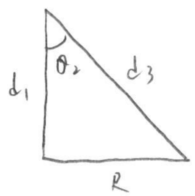
$$\Rightarrow \quad S_2(C_1P_x + S_1P_y) - C_2(P_z - d_1) = d_3$$

Geometric



$$\theta_{11} = \tan^{-1}\left(\frac{\sin\theta_{11}}{\cos\theta_{11}}\right) = \tan^{-1}\left(\frac{P_y}{P_x}\right)$$

$$\theta_{12} = \tan^{-1}\left(\frac{\sin\theta_{12}}{\cos\theta_{12}}\right) = \tan^{-1}\left(\frac{P_y}{P_x}\right) + 180^\circ$$



$$'' \quad R = P_xC_1 + P_yS_1$$

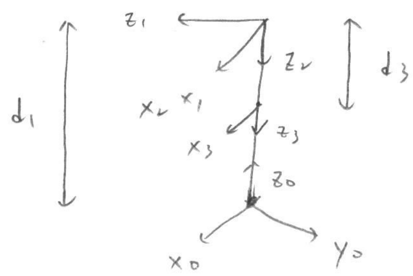
$$P_x = P_xC_1 + P_yS_1 = d_3S_2$$

$$P_y = d_1 - P_z = d_3C_2$$

$$d_3 > 0 \quad \Rightarrow \quad \theta_2 = \tan^{-1}\left(\frac{P_xC_1 + P_yS_1}{d_1 - P_z}\right)$$

$$d_3 = \sqrt{(P_xC_1 + P_yS_1)^2 + (d_1 - P_z)^2}$$

(c)



3(P) 可伸縮 d_3 的距離

1(Y) 擁有 d_1 的移動距離.

背面有

第2題

2. (a) why present

在移動上可能會有某些角度或位置抵達不了，即需要 singular point 來表示 -2

physical meaning:

從幾何結構上，機械手臂的某一個末端點可能因為長度變數為 0，或轉動變數的 joint 投影回原點，使其在某個運動方向喪失自由度

mathematical meaning:

從解 differential kinematic 的角度出發，當透過坐標間轉換在解 Jacobian 時，如果其行列式值 $\det J=0$，意味著無法做出 inverse Jacobian 的運算，則此點為奇異點

(b) Definition:

工業機器人常使用的設計方式，將所有軸分兩種

Primary joints: for the positional workspace (多為前三軸)

Minor joints: for the orientational workspace (多為剩下後幾軸)

⇒ 前三軸決定末端點位置，後幾軸決定末端點朝向角

Benefits:

求解 inverse kinematic solutions 一定有 closed form solutions，在不考慮 tool 長度情況下，可先用前三軸找到 wrist 的位置，將前三軸矩陣利用 inverse 轉開，用後三軸決定方向，方便計算

Mitsubishi type:

是，人的手臂是更為精密的 wrist-partitioned

~~Human?~~

(c)

singularity 意味在路徑移動上失去某部分自由度

當無法計算出inverse Jacobian，即存在singular point

-3

8

(3) (a)

Easy to specify

smoothness

configuration

singularity

2 task, kinematics, dynamics, obstacle

(b)

(i) 定位空間中障礙物位置與範圍

在不碰撞到物體情況下，連線出一條路徑

在移動時不斷偵測與修正，具體方法？

3

(ii) 定位空間中障礙物位置範圍

在不碰撞物體情況下，連線出一條路徑

?

(c)

做好完善的路徑規劃與同步控制，使手臂間能順暢合作，不會互相碰撞，同時建立Master與slave，在互相重疊時，master priority較高

3

ok!

4\. (a)

4

$\tau = H(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q) + K^T(q) f_{ext}$

4 速度，加速度，角加速度，位置 → 確認移動軌跡與方向，方便控制

$L(\theta,\dot{\theta}) = k(\theta,\dot{\theta}) - p(\theta)$

(b) (1) 學習控制是透過量化學習 不一定! 不斷調整自身控制參數，達到最佳化控制的方式

3、

(2) 計算複雜，且無法確認是否收斂與穩定.

say more.

(c)

2

碰撞到人的判斷機制

路徑上有人時修正路徑或停止的方法

for safety, other?

8

5. 機器 可動的系統

①確保依循人類所制定的規則(定值，路徑……)運行，

即為控制

②

能預先就做好補償，不需事後才不斷修正

OK!

③

feed forward 需對系統有足夠了解，且應用上成本較高，

故多使用 feed backward

OK!