College of Engineering
Department of Electronics Engineering

MECHATRONICS ENGINEERING - 3201

Second Semester, A.Y. 2023-2024

Midterm Project in Robotics 2

Presented to

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Instructor

In Partial Fulfillment

of the Requirements for the course

MExE 409 - Robotics 2

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GRUBLER'S CRITERION

MOBILITY / DOF OF SPATIAL MANIPULATOR

C_1: CONNECTIVITY OF I-TH JOINT; I, 2, 3..., m

NO. OF CONSTRAINT PUT BY I-TH JOINT = $(6-C_i)$

TOTAL NO. OF CONSTRAINTS = $\sum_{i=1}^{m}(6-C_i)$

MOBILITY OF THE MANIPULATOR: $M = 6n - \sum_{i=1}^{m}(6-C_i)$

MOBILITY / DOF OF PLANAR MANIPULATOR

C_i: CONNECTIVITY OF I-TH JOINT; I, 2, 3..., m

NO. OF CONSTRAINT PUT BY I TH JOINT = $(3-C_i)$

TOTAL NO. OF CONSTRAINTS = $\sum_{i=1}^{m}(3-C_i)$

MOBILITY OF THE MANIPULATOR: $M = 3n - \sum_{i=1}^{m}(3-C_i)$

KINEMATIC DIAGRAM AND D-H FRAME ASSIGNMENT OF SCARA MANIPULATOR

D-H FRAME PRELIMINARY RULES

RULE 1: DECIDE FIRST THE 3 VIEWS YOU WANT TO PROJECT ON YOUR ISOMETRIC DRAWING.

RULE 2: IDENTIFY THE CENTER OF YOUR FRAMES.

RULE 3: DRAW THE COLOR-CODED ARROWS BASED ON YOUR DECIDED THREE (3) VIEWS.

(BLUE FOR Z-AXIS, GREEN FOR Y-AXIS, AND RED FOR X-AXIS)

RULE 4: REMEMBER TO MAKE THE ARROWS OF Z AND X AXES EASY TO SEE FOR THE FUTURE COMPUTATIONS.

D-H FRAME RULES

RULE 1: THE Z AXIS MUST BE THE AXIS OF ROTATION FOR A REVOLUTE/TWISTING, OR THE DIRECTION OF TRANSLATION FOR A PRISMATIC JOINT.

RULE 2: THE X AXIS MUST BE PERPENDICULAR BOTH TO ITS OWN Z AXIS, AND THE Z AXIS OF THE FRAME BEFORE IT.

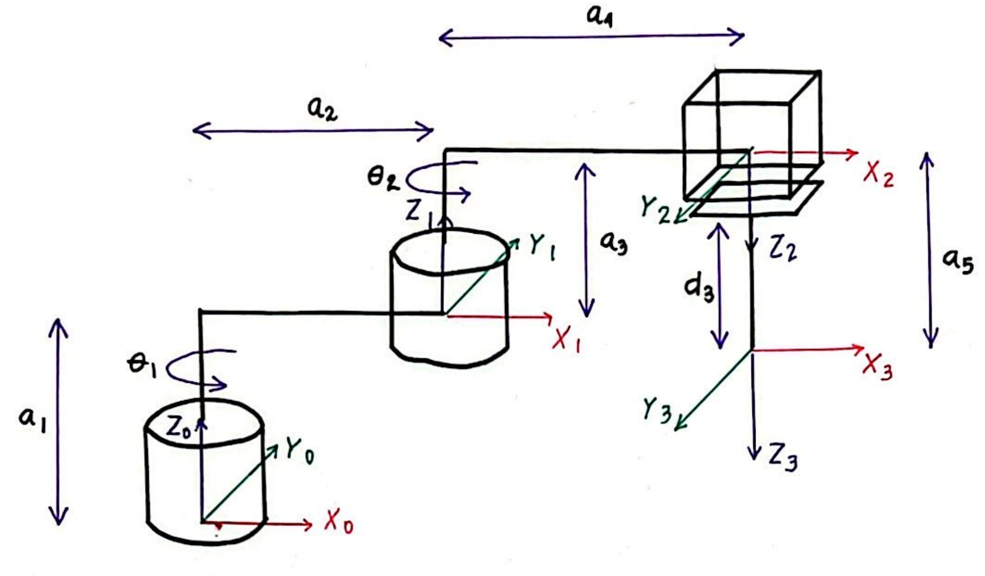
RULE 3: EACH X AXIS MUST INTERSECT THE Z AXIS OF THE FRAME BEFORE IT.

IF THIS THIRD RULE WAS NOT FOLLOWED, THERE ARE RULES FOR COMPLYING IT:

- ROTATE THE AXIS UNTIL IT HITS THE OTHER.
- OR TRANSLATE THE AXIS UNTIL IT HITS THE OTHER.

RULE 4: ALL FRAMES MUST FOLLOW THE RIGHT-HAND RULE.

SCARA RRP VARIANT



D-H PARAMETRIC TABLE OF SCARA MANIPULATOR

θ – THIS IS THE ROTATION AROUND ZN-1 THAT IS REQUIRED TO GET THE XN WITH THE JOINT VARIABLE θ IF THE JOINT IS REVOLUTE OR TWISTING.

α – THIS IS THE ROTATION AROUND XN THAT IS REQUIRED TO MATCH ZN-1 TO ZN.

r – THE DISTANCE BETWEEN THE ORIGINS OF N-1 AND N FRAMES ALONG THE XN DIRECTION.

d – THE DISTANCE BETWEEN THE ORIGINS OF N-1 AND N FRAMES ALONG THE ZN-1 DIRECTION, WITH JOINT VARIABLES IF JOINT IS PRISMATIC.

PARAMETRIC TABLE

n	θ	α	r	d
^0_1H	θ_1	$0°$	a_2	a_1
^1_2H	θ_1	$180°$	a_4	a_3
^2_3H	$0°$	$0°$	0	a_5

INVERSE KINEMATICS SOLUTION USING GRAPHICAL METHOD OF SCARA MANIPULATOR

DEGREES OF FREEDOM CALCULATION

GIVEN:

$m = 3$

$n = 3$

FORMULA:

$$M = 6n - \sum_{i=1}^{m}(6 - C_i)$$

$$M = 6(3) - [5 + 5 + 5]$$

$$M = 18 - 15$$

$$M = 3$$

SOLUTION:

$R_1 = (6 - 1) = 5$

$R_2 = (6 - 1) = 5$

$R_3 = (6 - 1) = 5$

∴ THIS IS AN UNDER-ACTUATED SPATIAI MANIPULATOR 3-DOF

DEGREES OF FREEDOM (DOF) OF SCARA MANIPULATOR

JOINT TYPE	DEGREES OF FREEDOM	CONSTRAINT C BETWEEN TWO PLANAR RIGID BODIES	CONSTRAINT C BETWEEN TWO PLANAR RIGID BODIES
REVOLUTE (R)	1	2	5
PRISMATIC (P)	1	2	5
HELICAL (H)	1	N/A	5
CYLINDRICAL (C)	2	N/A	4
UNIVERSAL (U)	2	N/A	4
CYLINDRICAL (C)	3	N/A	3

HOMOGENEOUS TRANSFORMATION MATRIX (HTM) OF SCARA MANIPULATOR

STANDARD FORMULA

$$
{}^{n-1}_{n}T = {}^{n-1}_{n}H = \begin{vmatrix} \cos(\theta_n) & -\sin(\theta_n)\cos(\alpha_n) & \sin(\theta_n)\sin(\alpha_n) & r_n(0+\theta_1) \\ \sin(\theta_n) & \cos(\theta_n)\cos(\alpha_n) & -\cos(\theta_n)\sin(\alpha_n) & r_n(0+\theta_1) \\ 0 & \sin(\alpha_n) & \cos(\alpha_n) & d_n \\ 0 & 0 & 0 & 1 \end{vmatrix}
$$

$$
{}^{0}_{1}H = \begin{vmatrix} \cos(0+\theta_1) & -\sin(0+\theta_1)\cos(0) & \sin(0+\theta_1)\sin(0) & a_2\cos(0+\theta_1) \\ \sin(0+\theta_1) & \cos(0+\theta_1)\cos(0) & -\cos(0+\theta_1)\sin(0) & a_2\sin(0+\theta_1) \\ 0 & \sin(0) & \cos(0) & a_1 \\ 0 & 0 & 0 & 1 \end{vmatrix}
$$

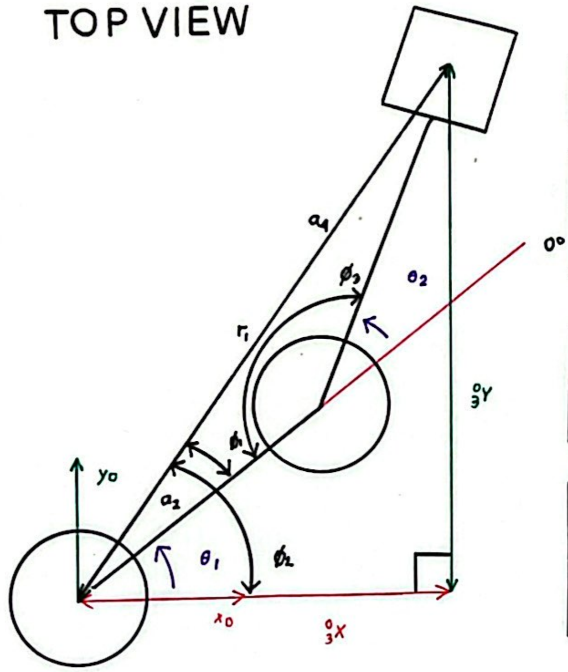
$$
{}^{0}_{1}H = \begin{vmatrix} 1 & 0 & 0 & a_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & a_1 \\ 0 & 0 & 0 & 1 \end{vmatrix}
$$

$$
{}^{1}_{2}H = \begin{vmatrix} \cos(0+\theta_2) & -\sin(0+\theta_2)\cos(180) & \sin(0+\theta_2)\sin(180) & a_4\cos(0+\theta_2) \\ \sin(0+\theta_2) & \cos(0+\theta_1)\cos(180) & -\cos(0+\theta_2)\sin(180) & a_4\sin(0+\theta_2) \\ 0 & \sin(1800) & \cos(180) & a_4 \\ 0 & 0 & 0 & 1 \end{vmatrix}
\qquad
{}^{1}_{2}H = \begin{vmatrix} 1 & 0 & 0 & a_4 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & a_4 \\ 0 & 0 & 0 & 1 \end{vmatrix}
$$

$$
{}^{2}_{3}H = \begin{vmatrix} \cos(0) & -\sin(0)\cos(0) & \sin(0)\sin(0) & 0\cos(0) \\ \sin(0) & \cos(0)\cos(0) & -\cos(0)\sin(0) & 0\sin(0) \\ 0 & \sin(0) & \cos(0) & a_5+d_3 \\ 0 & 0 & 0 & 1 \end{vmatrix}
\qquad
{}^{2}_{3}H = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & a_5+d_3 \\ 0 & 0 & 0 & 1 \end{vmatrix}
$$

Inverse Kinematics solution using Graphical Method of SCARA Manipulator

TOP VIEW



$$\phi_2 = \theta_1 + \phi_1$$

$$\boxed{\theta_1 = \phi_2 - \phi_1} \quad 4$$

$$180^\circ = \phi_3 + \theta_2$$

$$\boxed{\theta_2 = 180^\circ - \phi_3} \quad 5$$

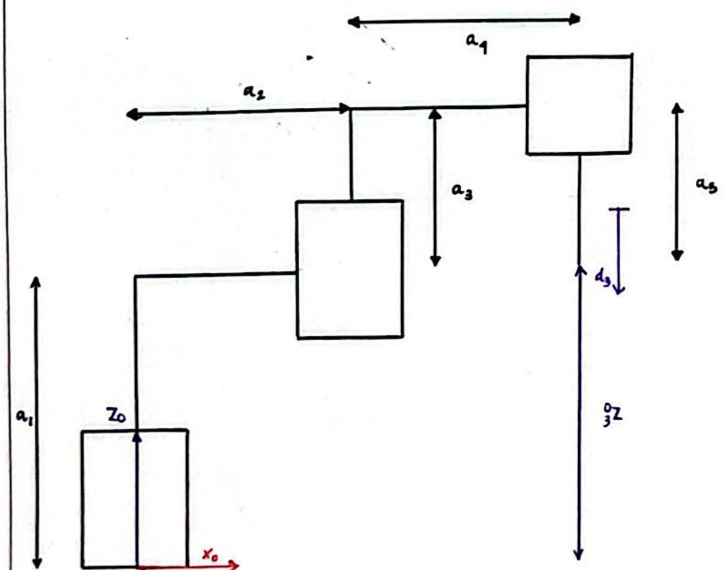
$$\boxed{\phi_2 = \tan^{-1}\left(\frac{{}^0_3Y}{{}^0_3X}\right)}$$

$$\boxed{\phi_3 = \cos^{-1}\left(\frac{r_1^2 - a_2^2 - a_4^2}{2a_2a_4}\right)} \quad 6$$

$$\boxed{r_1 = \sqrt{({}^0_3Y)^2 + ({}^0_3X)^2}}$$

$$\boxed{\phi_1 = \cos^{-1}\left(\frac{a_4^2 - r_1^2 - a_2^2}{-2r_1a_2}\right)} \quad 3$$

FRONT VIEW



$${}^0_3Z = a_1 + a_3 - a_5 - d_3$$

$$\boxed{d_3 = a_1 + a_3 - a_5 - {}^0_3Z} \quad 7$$