```
% LIMPIEZA DE PANTALLA
clear all
close all
clc

% ================================
% DEFINICIÓN DE VARIABLES SIMBÓLICAS
% ================================
syms theta1 theta2 theta3 theta4 real
syms L1 L2 L3 L4 real

% ================================
% MATRICES HOMOGÉNEAS SIMBÓLICAS H1, H2, H3, H4
% ================================
Rt = @(R, t) [R, t; 0 0 0 1];  % Función para construir matrices homogéneas

% Matriz H1: Rz(theta1) + Tz(L1)
Rz1 = [cos(theta1), -sin(theta1), 0;
       sin(theta1),  cos(theta1), 0;
       0          ,  0          , 1];
H1 = Rt(Rz1, [0; 0; L1]);

% Matriz H2: Ry(theta2) + Tx(L2)
Ry2 = [cos(theta2), 0, sin(theta2);
       0          , 1, 0;
      -sin(theta2), 0, cos(theta2)];
H2 = Rt(Ry2, [L2; 0; 0]);

% Matriz H3: Ry(theta3) + Tx(L3)
Ry3 = [cos(theta3), 0, sin(theta3);
       0          , 1, 0;
      -sin(theta3), 0, cos(theta3)];
H3 = Rt(Ry3, [L3; 0; 0]);

% Matriz H4: Ry(theta4) + Tx(L4)
Ry4 = [cos(theta4), 0, sin(theta4);
       0          , 1, 0;
      -sin(theta4), 0, cos(theta4)];
H4 = Rt(Ry4, [L4; 0; 0]);

% ================================
% MATRIZ DE TRANSFORMACIÓN GLOBAL SIMBÓLICA T
% ================================
T = simplify(H1 * H2 * H3 * H4);

disp('==============================')
```

```
==============================
```

```
disp('Matrices homogéneas simbólicas H1, H2, H3, H4:')
```

Matrices homogéneas simbólicas H1, H2, H3, H4:

```
disp('H1 ='), disp(H1)
```

H1 =

$$\begin{pmatrix} \cos(\theta_1) & -\sin(\theta_1) & 0 & 0 \\ \sin(\theta_1) & \cos(\theta_1) & 0 & 0 \\ 0 & 0 & 1 & L_1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

```
disp('H2 ='), disp(H2)
```

H2 =

$$\begin{pmatrix} \cos(\theta_2) & 0 & \sin(\theta_2) & L_2 \\ 0 & 1 & 0 & 0 \\ -\sin(\theta_2) & 0 & \cos(\theta_2) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

```
disp('H3 ='), disp(H3)
```

H3 =

$$\begin{pmatrix} \cos(\theta_3) & 0 & \sin(\theta_3) & L_3 \\ 0 & 1 & 0 & 0 \\ -\sin(\theta_3) & 0 & \cos(\theta_3) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

```
disp('H4 ='), disp(H4)
```

H4 =

$$\begin{pmatrix} \cos(\theta_4) & 0 & \sin(\theta_4) & L_4 \\ 0 & 1 & 0 & 0 \\ -\sin(\theta_4) & 0 & \cos(\theta_4) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

```

disp('==============================')
```

==============================

```
disp('Matriz de transformación homogénea global T =')
```

Matriz de transformación homogénea global T =

```
disp(T)
```

$$\begin{pmatrix} \sigma_3 \cos(\theta_1) & -\sin(\theta_1) & \sigma_2 \cos(\theta_1) & \cos(\theta_1)\, \sigma_1 \\ \sigma_3 \sin(\theta_1) & \cos(\theta_1) & \sigma_2 \sin(\theta_1) & \sin(\theta_1)\, \sigma_1 \\ -\sigma_2 & 0 & \sigma_3 & L_1 - L_4 \sin(\theta_2 + \theta_3) - L_3 \sin(\theta_2) \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

where

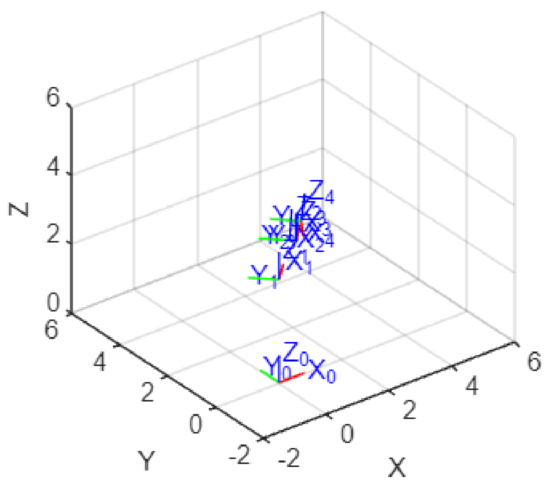
$$\sigma_1 = L_2 + L_4 \cos(\theta_2 + \theta_3) + L_3 \cos(\theta_2)$$

$$\sigma_2 = \sin(\theta_2 + \theta_3 + \theta_4)$$

$$\sigma_3 = \cos(\theta_2 + \theta_3 + \theta_4)$$

```
% ================================
% SIMULACIÓN NUMÉRICA DE LAS TRAMAS
% ================================
theta1_val = pi/4;   % 45°
theta2_val = pi/6;   % 30°
theta3_val = -pi/6;  % -30°
theta4_val = pi/3;   % 60°
L1_val = 3;
L2_val = 2;
L3_val = 1.5;
L4_val = 1;

% Evaluar con valores numéricos
H1n = double(subs(H1, [theta1, L1], [theta1_val, L1_val]));
H2n = double(subs(H2, [theta2, L2], [theta2_val, L2_val]));
H3n = double(subs(H3, [theta3, L3], [theta3_val, L3_val]));
H4n = double(subs(H4, [theta4, L4], [theta4_val, L4_val]));

% Tramas intermedias
H0 = eye(4);
H0_1 = H1n;
H1_2 = H0_1 * H2n;
H2_3 = H1_2 * H3n;
H3_4 = H2_3 * H4n;

% ================================
% VISUALIZACIÓN DE LAS TRAMAS
% ================================
figure
axis equal
view(3)
grid on
xlabel('X')
```

```
ylabel('Y')
zlabel('Z')
axis([-2 6 -2 6 0 6])
hold on

trplot(H0, 'frame', '0', 'rgb', 'length', 0.8)

trplot(H0_1, 'frame', '1', 'rgb', 'length', 0.8)

trplot(H1_2, 'frame', '2', 'rgb', 'length', 0.8)

trplot(H2_3, 'frame', '3', 'rgb', 'length', 0.8)

trplot(H3_4, 'frame', '4', 'rgb', 'length', 0.8)
```




```
% ================================
% CINEMÁTICA DIFERENCIAL SIMBÓLICA
% ================================
syms t
syms theta1(t) theta2(t) theta3(t) theta4(t)

% Redefinir matrices con theta(t)
Rz1t = [cos(theta1(t)), -sin(theta1(t)), 0;
        sin(theta1(t)),  cos(theta1(t)), 0;
        0             ,  0             , 1];
H1t = Rt(Rz1t, [0; 0; L1]);

Ry2t = [cos(theta2(t)), 0, sin(theta2(t));
         0            , 1, 0;
       -sin(theta2(t)), 0, cos(theta2(t))];
H2t = Rt(Ry2t, [L2; 0; 0]);

Ry3t = [cos(theta3(t)), 0, sin(theta3(t));
         0            , 1, 0;
```

```
       -sin(theta3(t)), 0, cos(theta3(t))];
H3t = Rt(Ry3t, [L3; 0; 0]);

Ry4t = [cos(theta4(t)), 0, sin(theta4(t));
         0            , 1, 0;
       -sin(theta4(t)), 0, cos(theta4(t))];
H4t = Rt(Ry4t, [L4; 0; 0]);

% MATRIZ TOTAL SIMBÓLICA DEPENDIENTE DEL TIEMPO
Tt = simplify(H1t * H2t * H3t * H4t);

% VELOCIDAD LINEAL: v = dp/dt
pt = Tt(1:3,4);
v = simplify(diff(pt, t));

% VELOCIDAD ANGULAR: w_skew = Ṙ * Rᵀ
Rt3 = Tt(1:3,1:3);
R_dot = simplify(diff(Rt3, t));
w_skew = simplify(R_dot * Rt3.');

% EXTRAEMOS VECTOR DE VELOCIDAD ANGULAR w = [wx; wy; wz]
wx = (w_skew(3,2) - w_skew(2,3))/2;
wy = (w_skew(1,3) - w_skew(3,1))/2;
wz = (w_skew(2,1) - w_skew(1,2))/2;
w = simplify([wx; wy; wz]);

% ================================
% RESULTADOS COMPLETOS
% ================================
disp('==============================')
```

```
==============================
```

```
disp('Matriz simbólica dependiente del tiempo Tt =')
```

```
Matriz simbólica dependiente del tiempo Tt =
```

```
disp(Tt)
```

$$\begin{pmatrix} \cos(\theta_1(t))\cos(\sigma_1) & -\sin(\theta_1(t)) & \cos(\theta_1(t))\sin(\sigma_1) & \cos(\theta_1(t))\,\sigma_2 \\ \sin(\theta_1(t))\cos(\sigma_1) & \cos(\theta_1(t)) & \sin(\theta_1(t))\sin(\sigma_1) & \sin(\theta_1(t))\,\sigma_2 \\ -\sin(\sigma_1) & 0 & \cos(\sigma_1) & L_1 - L_3\sin(\theta_2(t)) - L_4\sin(\sigma_3) \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

where

$$\sigma_1 = \theta_2(t) + \theta_3(t) + \theta_4(t)$$

$$\sigma_2 = L_2 + L_4\cos(\sigma_3) + L_3\cos(\theta_2(t))$$

$$\sigma_3 = \theta_2(t) + \theta_3(t)$$

```
disp('==============================')
```

```
==============================
```

```
disp('Vector de velocidad lineal v =')
```

```
Vector de velocidad lineal v =
```

```
disp(v)
```

$$\begin{pmatrix} -\cos(\theta_1(t))\,\sigma_2 - \sin(\theta_1(t))\,\sigma_1\,\frac{\partial}{\partial t}\,\theta_1(t) \\ \cos(\theta_1(t))\,\sigma_1\,\frac{\partial}{\partial t}\,\theta_1(t) - \sin(\theta_1(t))\,\sigma_2 \\ -L_4\cos(\theta_2(t)+\theta_3(t))\,\sigma_3 - L_3\cos(\theta_2(t))\,\frac{\partial}{\partial t}\,\theta_2(t) \end{pmatrix}$$

where

$$\sigma_1 = L_2 + L_4\cos(\theta_2(t)+\theta_3(t)) + L_3\cos(\theta_2(t))$$

$$\sigma_2 = L_4\sin(\theta_2(t)+\theta_3(t))\,\sigma_3 + L_3\sin(\theta_2(t))\,\frac{\partial}{\partial t}\,\theta_2(t)$$

$$\sigma_3 = \frac{\partial}{\partial t}\,\theta_2(t) + \frac{\partial}{\partial t}\,\theta_3(t)$$

```
disp('==============================')
```

```
==============================
```

```
disp('Matriz antisimétrica de velocidad angular w_skew =')
```

```
Matriz antisimétrica de velocidad angular w_skew =
```

```
disp(w_skew)
```

$$\begin{pmatrix} 0 & -\frac{\partial}{\partial t}\,\theta_1(t) & \sigma_2 \\ \frac{\partial}{\partial t}\,\theta_1(t) & 0 & \sigma_1 \\ -\sigma_2 & -\sigma_1 & 0 \end{pmatrix}$$

where

$$\sigma_1 = \sin(\theta_1(t))\,\left(\frac{\partial}{\partial t}\,\theta_2(t) + \frac{\partial}{\partial t}\,\theta_3(t) + \frac{\partial}{\partial t}\,\theta_4(t)\right)$$

$$\sigma_2 = \cos(\theta_1(t))\,\left(\frac{\partial}{\partial t}\,\theta_2(t) + \frac{\partial}{\partial t}\,\theta_3(t) + \frac{\partial}{\partial t}\,\theta_4(t)\right)$$

```

disp('==============================')
```

```
==============================
```

```
disp('Vector de velocidad angular w =')
```

```
Vector de velocidad angular w =
```

```
disp(w)
```

$$\begin{pmatrix} -\sin(\theta_1(t))\,\left(\frac{\partial}{\partial t}\,\theta_2(t) + \frac{\partial}{\partial t}\,\theta_3(t) + \frac{\partial}{\partial t}\,\theta_4(t)\right) \\ \cos(\theta_1(t))\,\left(\frac{\partial}{\partial t}\,\theta_2(t) + \frac{\partial}{\partial t}\,\theta_3(t) + \frac{\partial}{\partial t}\,\theta_4(t)\right) \\ \frac{\partial}{\partial t}\,\theta_1(t) \end{pmatrix}$$

```

%{
==============================
DESCRIPCIÓN DEL PROCEDIMIENTO Y RESULTADOS
==============================

Cinemática Directa:
Se construyó el modelo cinemático directo utilizando matrices de transformación
homogénea (H1 a H4), cada una representando una rotación (R) y una traslación (T)
entre eslabones del sistema. Al multiplicarlas secuencialmente se obtuvo la matriz
global T, que expresa la posición y orientación del efector final respecto al marco
base. Esto permite conocer cómo se desplaza el extremo del robot dado un conjunto
de ángulos articulares.

```

```
Cinemática Diferencial:
Se reformuló el modelo considerando las variables articulares como funciones del
tiempo. A partir de la matriz simbólica T(t), se calcularon:
- La velocidad lineal (v): derivada temporal de la posición del efector.
- La velocidad angular (w): obtenida a partir de la derivada de la matriz de
rotación y su transpuesta.

Estos resultados proporcionan información sobre la rapidez y dirección del
movimiento del efector final, fundamentales para tareas de control y planificación
de trayectorias.

%}
```