Solutions to Tutorial 4 - 2023 Exercises

Exercise 1

```
q1 = 90
P=[7 3 1 1]'

tr1 = [cosd(q1)  -sind(q1) 0 0; sind(q1)  cosd(q1) 0 0; 0 0 1 0; 0 0 0 1]
tr2 = [cosd(q1) 0 sind(q1) 0; 0 1 0 0; -sind(q1) 0 cosd(q1) 0; 0 0 0 1]
tr3 = [1 0 0 4; 0 1 0 -3; 0 0 1 7; 0 0 0 1]

tr3*tr2*tr1*P
```

Exercise 2

```
syms theta r d alpha

A = [cos(theta) -sin(theta) 0 0; sin(theta) cos(theta) 0 0; 0 0 1 0; 0 0 0 1]
B = [1 0 0 0; 0 1 0 0; 0 0 1 d; 0 0 0 1]
C = [1 0 0 r; 0 1 0 0; 0 0 1 0; 0 0 0 1]
D = [1 0 0 0; 0 cos(alpha) -sin(alpha) 0; 0 sin(alpha) cos(alpha) 0; 0 0 0 1]

A*B*C*D

DH = [cos(theta) -sin(theta)*cos(alpha) sin(theta)*sin(alpha) r*cos(theta);
      sin(theta) cos(theta)*cos(alpha) -cos(theta)*sin(alpha) r*sin(theta);
      0 sin(alpha) cos(alpha) d
      ; 0 0 0 1]

isequal(A*B*C*D, DH)
```

Exercise 3

```
syms theta1 theta2 d1 d2 r1 r2 alpha1 alpha2

A = [cos(theta1) -sin(theta1) 0 0; sin(theta1) cos(theta1) 0 0; 0 0 1 0; 0 0
0 1]
B = [1 0 0 0; 0 1 0 0; 0 0 1 d1; 0 0 0 1]
C = [1 0 0 r1; 0 1 0 0; 0 0 1 0; 0 0 0 1]
D = [1 0 0 0; 0 cos(alpha1) -sin(alpha1) 0; 0 sin(alpha1) cos(alpha1) 0; 0 0
0 1]

% First joint homogeneous transformation
A1 = A*B*C*D
```

```
% Now do the same for the second joint
E = [cos(theta2) -sin(theta2) 0 0; sin(theta2) cos(theta2) 0 0; 0 0 1 0; 0 0
0 1]
F = [1 0 0 0; 0 1 0 0; 0 0 1 d2; 0 0 0 1]
G = [1 0 0 r2; 0 1 0 0; 0 0 1 0; 0 0 0 1]
H = [1 0 0 0; 0 cos(alpha2) -sin(alpha2) 0; 0 sin(alpha2) cos(alpha2) 0; 0 0
0 1]

A2 = E*F*G*H

% Overall homogeneous transformation matrix for both joints
A1*A2
```

Exercise 4

```
syms theta1 theta2 theta3 d3 r1

% all calculations below assume angles in degrees therefore cosd() and
% sind() are used

% Joint 1
A = [cosd(theta1) -sind(theta1) 0 0; sind(theta1) cosd(theta1) 0 0; 0 0 1 0;
0 0 0 1]
B = [1 0 0 0; 0 1 0 0; 0 0 1 0; 0 0 0 1]
C = [1 0 0 r1; 0 1 0 0; 0 0 1 0; 0 0 0 1]
D = [1 0 0 0; 0 cos(0) -sin(0) 0; 0 sin(0) cos(0) 0; 0 0 0 1]

Joint1_Homog_Transf = A*B*C*D

% Joint 2
A = [cosd(90+theta2) -sind(90+theta2) 0 0; sind(90+theta2) cosd(90+theta2) 0
0; 0 0 1 0; 0 0 0 1]
B = [1 0 0 0; 0 1 0 0; 0 0 1 0; 0 0 0 1]
C = [1 0 0 0; 0 1 0 0; 0 0 1 0; 0 0 0 1]
D = [1 0 0 0; 0 0 -1 0; 0 1 0 0; 0 0 0 1]  % 90 degrees

Joint2_Homog_Transf = A*B*C*D

% Joint 3
A = [cosd(theta3) -sind(theta3) 0 0; sind(theta3) cosd(theta3) 0 0; 0 0 1 0;
0 0 0 1]
B = [1 0 0 0; 0 1 0 0; 0 0 1 d3; 0 0 0 1]
C = [1 0 0 0; 0 1 0 0; 0 0 1 0; 0 0 0 1]
D = [1 0 0 0; 0 1 0 0; 0 0 1 0; 0 0 0 1]

Joint3_Homog_Transf = A*B*C*D
```

Exercise 5

See the last section for the first definition of the function **dh**.

```
result = dh(0, 1, 2, pi/2)
```

Exercise 6

```
syms theta1 theta2 theta3 theta4 theta5 theta6 r2 r3 d3 d4
result_ex6 = dh2(theta1, 0, 0, 0)*dh2(theta2, 0, 0, -90)*dh2(theta3, r2, d3,
0)*dh2(theta4, r3, d4, -90)* ...
             dh2(theta5, 0, 0, 90)*dh2(theta6, 0, 0, -90)
```

Functions used in this Tutorial

```
function y = dh(theta, d, r, alpha)  % Exercise 5
    A = [cos(theta) -sin(theta) 0 0; sin(theta) cos(theta) 0 0; 0 0 1 0; 0 0
0 1]
    B = [1 0 0 0; 0 1 0 0; 0 0 1 d; 0 0 0 1]
    C = [1 0 0 r; 0 1 0 0; 0 0 1 0; 0 0 0 1]
    D = [1 0 0 0; 0 cos(alpha) -sin(alpha) 0; 0 sin(alpha) cos(alpha) 0; 0 0
0 1]

    y = A*B*C*D
end


% **** Exercise 6 - new version of dh ******
function y = dh2(theta1, d1, r1, alpha1)  % Exercise 5
    syms f(theta, d, r, alpha2)
    f(theta, d, r, alpha2) = [cosd(theta) -sind(theta) 0 0; sind(theta)
cosd(theta) 0 0; 0 0 1 0; 0 0 0 1]* ...
                            [1 0 0 0; 0 1 0 0; 0 0 1 d; 0 0 0 1]* [1 0 0 r;
0 1 0 0; 0 0 1 0; 0 0 0 1]* ...
                            [1 0 0 0; 0 cosd(alpha2) -sind(alpha2) 0; 0
sind(alpha2) cosd(alpha2) 0; 0 0 0 1];
    % call the symbolic function
    y = f(theta1, d1, r1, alpha1);
end
```