Introduction to Robotics
Homework 3 & Homework 4

Modified Denavit Hartenberg Parameters and Forward Kinematics Verification
Use the Matlab file, mfkinesym, (modified forward kinematics symbolic) provided by Dr. Shiakolas

The analysis was performed in Matlab and the results copied and pasted in this file.
Once the analysis is performed and the individual homogeneous transformations and forward kinematics are evaluated symbolically, **YOU MUST** verify the results.

VERIFICATION OF RESULTS
Do the results make sense ?

- forward kinematics transformation
- assign zero value to the joint variables – does the result makes sense – is it correct?

- If yes, then we can assume that at least we are confident in our analysis.
- If not, then we must go back and re-assess the frames, MDH table or our Matlab analysis.

Note that the MDH table corresponds to the assigned frames.
The MDH Table is the form alpha, a, theta, D (α, a, θ, d)

PROBLEM 1

```
» syms q1 q2 q3 t1 t2
» hw3p1 =
[  0,  0, q1,  0]
[  0, t1, q2,  0]
[  0, t2, q3,  0]

» [tjkp1, tfkp1] = mfkinesym(hw3p1) ;
» tjkp1
tjkp1 =
[  cos(q1), -sin(q1),        0,        0]
[  sin(q1),  cos(q1),        0,        0]
[        0,        0,        1,        0]
[        0,        0,        0,        1]
[  cos(q2), -sin(q2),        0,       t1]
[  sin(q2),  cos(q2),        0,        0]
[        0,        0,        1,        0]
[        0,        0,        0,        1]
[  cos(q3), -sin(q3),        0,       t2]
[  sin(q3),  cos(q3),        0,        0]
[        0,        0,        1,        0]
[        0,        0,        0,        1]

» pretty(simple(tfkp1))
 [ cos(q1 + q2 + q3) , -sin(q1 + q2 + q3) ,  0 ,    cos(q1 + q2) t2 + cos(q1) t1]
 [ sin(q1 + q2 + q3)  ,  cos(q1 + q2 + q3) , 0 ,     sin(q1 + q2) t2 + sin(q1) t1]
 [ 0 , 0 , 1 , 0]
 [ 0 , 0 , 0, 1]
```

PROBLEM 2

```
» syms d1 d2
» hw3p2 =[0 0 0 d1; pi/2, 0 0 d2];
» [tjkp2, tfkp2] = mfkinesym(hw3p2)

tjkp2 =
[  1,  0,  0,  0]
[  0,  1,  0,  0]
[  0,  0,  1, d1]
[  0,  0,  0,  1]
[  1,  0,  0,  0]
[  0,  0, -1, -d2]
[  0,  1,  0,  0]
[  0,  0,  0,  1]

tfkp2 =
[  1,  0,  0,  0]
[  0,  0, -1, -d2]
[  0,  1,  0, d1]
[  0,  0,  0,  1]
```

PROBLEM 3 (as a 2-D)

```
» syms q1 d2 t1 d3
» hw3p3=[ 0 0 q1+pi 0; pi2 0 3*pi2 d2+t1; pi2 0 0 d3]

hw3p3 =
[     0,     0,  q1+pi,      0]
[  pi/2,     0, 3*pi/2,  d2+t1]
[  pi/2,     0,      0,     d3]

» [tjkp3, tfkp3] = mfkinesym(hw3p3);
» tjkp3
tjkp3 =
[ -cos(q1),  sin(q1),        0,        0]
[ -sin(q1), -cos(q1),        0,        0]
[        0,        0,        1,        0]
[        0,        0,        0,        1]
[        0,        1,        0,        0]
[        0,        0,       -1,   -d2-t1]
[       -1,        0,        0,        0]
[        0,        0,        0,        1]
[        1,        0,        0,        0]
[        0,        0,       -1,      -d3]
[        0,        1,        0,        0]
[        0,        0,        0,        1]

» pretty(simple(tfkp3))
       [ 0   -sin(q1)   cos(q1)   cos(q1) d3 + sin(q1) (-d2 - t1)]
       [ 0    cos(q1)   sin(q1)   sin(q1) d3 - cos(q1) (-d2 - t1)]
       [-1       0         0                  0                  ]
       [ 0       0         0                  1                  ]
```

PROBLEM 3 (as a 3-D)

```
» syms q1 d2 t1 d3
» hw3p3b=[ 0 0 q1 0; 0 0 0 d2+t1; pi2 0 0 d3]
hw3p3b =
[     0,     0,    q1,     0]
[     0,     0,     0, d2+t1]
[  pi/2,     0,     0,    d3]

» [tjkp3b, tfkp3b] = mfkinesym(hw3p3b);
» tjkp3b
tjkp3b =
[  cos(q1), -sin(q1),        0,        0]
[  sin(q1),  cos(q1),        0,        0]
[        0,        0,        1,        0]
[        0,        0,        0,        1]
[        1,        0,        0,        0]
[        0,        1,        0,        0]
[        0,        0,        1,    d2+t1]
[        0,        0,        0,        1]
[        1,        0,        0,        0]
[        0,        0,       -1,      -d3]
[        0,        1,        0,        0]
[        0,        0,        0,        1]

» pretty(simple(tfkp3b))
                [cos(q1)    0    sin(q1)     sin(q1) d3 ]
                [sin(q1)    0    -cos(q1)    -cos(q1) d3]
                [   0       1       0          d2 + t1  ]
                [   0       0       0             1     ]
```

PROBLEM 4

```
» syms q1 t2 d2 t1
» hw3p4=[0 0 q1 0; pi2 t2 0 d2+t1]
hw3p4 =
[     0,     0,    q1,     0]
[  pi/2,    t2,     0, d2+t1]

» [tjkp4, tfkp4] = mfkinesym(hw3p4);
» tjkp4
tjkp4 =
[  cos(q1), -sin(q1),        0,        0]
[  sin(q1),  cos(q1),        0,        0]
[        0,        0,        1,        0]
[        0,        0,        0,        1]
[        1,        0,        0,       t2]
[        0,        0,       -1,   -d2-t1]
[        0,        1,        0,        0]
[        0,        0,        0,        1]
```

```
» pretty(simple(tfkp4))
        [cos(q1)    0    sin(q1)     cos(q1) t2 - sin(q1) (-d2 - t1)]
        [sin(q1)    0    -cos(q1)    sin(q1) t2 + cos(q1) (-d2 - t1)]
        [   0       1       0                    0                  ]
        [   0       0       0                    1                  ]
```

PROBLEM 5

```
» syms q1 q2 d3 t3 q4
» hw3p5=[ 0 0 q1 0; pi2 0  q2+pi2 0; pi2 0 pi d3+t3; pi2 0 q4 0]

hw3p5 =
[         0,         0,        q1,         0]
[      pi/2,         0, q2+1/2*pi,         0]
[      pi/2,         0,        pi,     d3+t3]
[      pi/2,         0,        q4,         0]

» [tjkp5, tfkp5] = mfkinesym(hw3p5);
» tjkp5
tjkp5 =
[  cos(q1), -sin(q1),        0,        0]
[  sin(q1),  cos(q1),        0,        0]
[        0,        0,        1,        0]
[        0,        0,        0,        1]
[ -sin(q2), -cos(q2),        0,        0]
[        0,        0,       -1,        0]
[  cos(q2), -sin(q2),        0,        0]
[        0,        0,        0,        1]
[       -1,        0,        0,        0]
[        0,        0,       -1,   -d3-t3]
[        0,       -1,        0,        0]
[        0,        0,        0,        1]
[  cos(q4), -sin(q4),        0,        0]
[        0,        0,       -1,        0]
[  sin(q4),  cos(q4),        0,        0]
[        0,        0,        0,        1]

» pretty(simple(tfkp5))
[cos(q1) (cos(q2) sin(q4) + sin(q2) cos(q4)) , -cos(q1) (-cos(q2) cos(q4) + sin(q2) sin(q4)) ,
sin(q1) ,  cos(q1) cos(q2) (d3 + t3)]
[sin(q1) (cos(q2) sin(q4) + sin(q2) cos(q4)) , -sin(q1) (-cos(q2) cos(q4) + sin(q2) sin(q4)) , -
cos(q1) ,  sin(q1) cos(q2) (d3 + t3)]
[-cos(q2) cos(q4) + sin(q2) sin(q4) ,              cos(q2) sin(q4) + sin(q2) cos(q4) ,
0 ,            sin(q2) (d3 + t3)]
[0 , 0 , 0 , 1]
```

PROBLEM 6

```
» syms q1 t1 q2 phi t2 d3 sfi cfi
» hw3p6=[0 0 q1 0; 0 t1 q2+phi+pi2 0; pi2 -t2*sfi 0 d3+t2*cfi]
```

```
hw3p6 =
[            0,             0,            q1,             0]
[            0,            t1, q2+phi+1/2*pi,             0]
[         pi/2,      -t2*sfi,             0,    d3+t2*cfi]

» [tjkp6, tfkp6] = mfkinesym(hw3p6);
» tjkp6
tjkp6 =
[      cos(q1),     -sin(q1),            0,            0]
[      sin(q1),      cos(q1),            0,            0]
[           0,            0,            1,            0]
[           0,            0,            0,            1]
[ -sin(q2+phi), -cos(q2+phi),            0,           t1]
[  cos(q2+phi), -sin(q2+phi),            0,            0]
[           0,            0,            1,            0]
[           0,            0,            0,            1]
[           1,            0,            0,      -t2*sfi]
[           0,            0,           -1,   -d3-t2*cfi]
[           0,            1,            0,            0]
[           0,            0,            0,            1]

» pretty(simple(tfkp6))
 [-sin(q1 + q2 + phi) , 0 , cos(q1 + q2 + phi) ,  sin(q1 + q2 + phi) t2 sfi + cos(q1 + q2 + phi) d3
        + cos(q1 + q2 + phi) t2 cfi + cos(q1) t1]
[cos(q1 + q2 + phi) , 0 , sin(q1 + q2 + phi) ,   -cos(q1 + q2 + phi) t2 sfi + sin(q1 + q2 + phi) d3
        + sin(q1 + q2 + phi) t2 cfi + sin(q1) t1]
[0 , 1 , 0 , 0]
[0 , 0 , 0 , 1]
```