

```

1
2 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
3 %
4 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
5 disp('
    #####
    ')
6 disp('                                PROBLEM 1
                                ')
7 disp('
    #####
    ')
8
9 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
10 %                                FORWARD KINEMATICS
11 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
12
13 %Matlab Code
14 syms alpha theta a d
15
16 A(theta,d,a,alpha)= [cos(theta), -sin(theta)*cos(alpha) ...
17 sin(theta)*sin(alpha), a*cos(theta);
18 sin(theta), cos(theta)*cos(alpha), ...
19 -cos(theta)*sin(alpha), a*sin(theta);
20 0 sin(alpha) cos(alpha) d;
21 0 0 0 1];
22
23 syms d1 t1 t2 t3 t5 t6 l1 l2 l3 l4 l5 l6 d4
24 A_0_1 = simplify(A(t1+pi/2,l1,0,-pi/2));
25 A_1_2 = simplify(A(t2+pi/2,0, 0, pi/2));
26 A_2_3 = simplify(A(t3-pi/2, l2+l3 , -l4 ,0));
27 A_3_4 = simplify(A(-pi/2, l5+d4, 0 ,-pi/2));
28 A_4_5 = simplify(A(t5, l4, 0, pi/2));
29 A_5_n = simplify(A(t6, l6, 0, 0));
30
31 T_0_1 = A_0_1;
32 T_0_2 = T_0_1*A_1_2;
33 T_0_3 = T_0_2*A_2_3;
34 T_0_4 = T_0_3*A_3_4;
35 T_0_5 = T_0_4*A_4_5;
36 T_0_n = simplify(T_0_5*A_5_n);
37

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38
39 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
40 %      Testing Configuration
41 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
42 disp( '
      #####
      ')
43 disp( '      T_0_n formula (EndEffector frame wrt to base
      frame      ')
44 disp( '
      #####
      ')
45 T_0_n
46
47 disp( 'Testing endeffector frame in 0 configuration');
48 t1 = 0; t2 = 0; t3 = 0; t5 = 0; t6 = 0;
49 l1 = 4; l2 =4; l3 =4; l4 =4;l5=4; l6 =4;
50 subs(T_0_n)
51
52
53 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
54 %      Q1 Configuration
55 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
56 %substituting values into variables
57 t1 = pi/4; t2 = pi/6; t3 = 0; d4 =5 ; t5 = pi/3; t6 = 0;
58 l1 = 4; l2 =4; l3 =4; l4 =4;l5=4; l6 =4;
59 T_0_n1=subs(T_0_n);
60
61 disp( '
      #####
      ')
62 disp( '      q1 configuration is given as follows
      ')
63 disp( '
      #####
      ')
64 disp( 'q1 fraction representation')
65 T_0_n1
66 disp( 'q1 decimal representation')
67 double(T_0_n1)
68
69
70 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
71 %      Finding values of q2 configuration
72 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
73

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74 %New orientation can be obtained as follows
75 %   -Translation about current end effector frame followed
      by
76 %   -Rotation about current z axis followed by
77 %   -Rotation about current y axis followed by
78 %   -Rotation about current z axis
79
80 % translation
81 trans = [1 0 0 1;
82           0 1 0 2;
83           0 0 1 3;
84           0 0 0 1];
85
86 % Rotation
87 syms th1
88
89 R_z(th1) = [cos(th1) -sin(th1) 0 0;
90             sin(th1)  cos(th1) 0 0;
91             0 0 1 0;
92             0 0 0 1];
93
94 R_y(th1) = [cos(th1) 0 sin(th1) 0;
95             0 1 0 0;
96             -sin(th1) 0 cos(th1) 0;
97             0 0 0 1];
98
99 disp('
      #####
      ')
100 disp('          q2 configuration is given as follows
      ')
101 disp('
      #####
      ')
102 disp('q2 fraction representation')
103 q2 = simplify(T_0_n1 * trans*R_z(pi/6)*R_y(pi/4)*R_z(pi/3))
104 disp('q2 decimal representation')
105 q2 = double(q2)
106
107
108 %
      %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
109 %
      %
110 %
      %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

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111 disp( '
        #####
        ')
112 disp( '                                PROBLEM 2
        ')
113 disp( '
        #####
        ')

114
115 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
116 %           Finding the jacobian
117 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
118 %substituting values into variables
119 t1 = pi/4; t2 = pi/6; t3 = 0; d4 =5 ; t5 = pi/3; t6 = 0;
120 l1 = 4; l2 =4; l3 =4; l4 =4;l5=4; l6 =4;
121
122 T_0_1 = subs(T_0_1);
123 T_0_2 = subs(T_0_2);
124 T_0_3 = subs(T_0_3);
125 T_0_4 = subs(T_0_4);
126 T_0_5 = subs(T_0_5);
127 T_0_n = subs(T_0_n)
128
129 z0 = [0 0 1]';
130 z1 = T_0_1(1:3,3);
131 z2 = T_0_2(1:3,3);
132 z3 = T_0_3(1:3,3);
133 z4 = T_0_4(1:3,3);
134 z5 = T_0_5(1:3,3);
135 zn = T_0_n(1:3,3);
136
137 O0 = [0 0 0]';
138 O1 = T_0_1(1:3,4);
139 O2 = T_0_2(1:3,4);
140 O3 = T_0_3(1:3,4);
141 O4 = T_0_4(1:3,4);
142 O5 = T_0_5(1:3,4);
143 On = T_0_n(1:3,4);
144
145 J = [cross(z0,On-O0) cross(z1,On-O1) cross(z2,On-O2) ...
146      z3 cross(z4,On-O4) cross(z5,On-O5);
147      z0 z1 z2 0 z4 z5;
148      ];
149
150 disp( '

```

```

#####
    ')
151 disp('                                Jacobian                                ')
152 disp('#####
    ')
153 disp('Jacobian fraction representation')
154 J = simplify(J)
155 disp('Jacobian decimal representation')
156 double(J)
157
158
159 %
#####

160 % Equivalent representation of F(wrench) in End Effector
    frame
161 %
#####

162 T_d_e =[0 1 0 0;
163         -1 0 0 -2;
164         0 0 1 -1;
165         0 0 0 1 ];
166
167 T_d_t =[1 0 0 0;
168         0 1 0 2;
169         0 0 1 10;
170         0 0 0 1 ];
171
172 %Finding inverse of T_d_e
173 R= T_d_e(1:3,1:3);
174 d= T_d_e(1:3,4);
175 R_T = transpose(R);
176
177 disp('#####
    ')
178 disp('                                T_e_d(drill frame expressed in end effector frame)                                ')
179 disp('#####
    ')
180 T_e_d = [R_T -R_T*d;
181          0 0 0 1]

```

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182
183
184 disp( '
    #####
    ')
185 disp( '      T_e_t(tip frame expressed in end effector frame)
      ')
186 disp( '
    #####
    ')
187 T_e_t = T_e_d * T_d_t
188
189 F =[0; 0; 10; 132.3876; 132.3876; 0]
190 disp( 'Wrench(Force vector')
191 F1 = [ F(1:3,1) ] %Wrench(Force vector)
192 disp( 'Wrench(Torque vector')
193 T1 = [ F(4:6,1) ] %Wrench(Torque vector)
194
195 % Not complete
196
197 %
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

198 %
    Finding joint torques
199 %
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

200 disp( 'Wrench at end effector wrt to base frame')
201 Fe = [ F1 ; T1] %end effector wrench wrt to base frame
202 Jt = double(transpose(J)*Fe)
203
204
205 %
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

206 %
    PART B
207 %
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

208 %skew matrix
209 syms a b c
210
211 disp( 'display force')
212 F = [0; 0; 10; 132.3876; 132.3876;0]
213
214 S(a,b,c) = [0 -c b;

```

```

215             c 0 -a;
216             -b a 0];
217
218 T_d_e =[0 1 0 0;
219         -1 0 0 -2;
220         0 0 1 -1;
221         0 0 0 1 ];
222
223 T_d_t=[1 0 0 0;
224        0 1 0 2;
225        0 0 1 10;
226        0 0 0 1 ];
227
228 disp('Finding T_n_0')
229 R= T_0_n(1:3,1:3);
230 d= T_0_n(1:3,4);
231 R_T = transpose(R);
232 T_n_0 = [R_T -R_T*d;
233          0 0 0 1];
234
235 disp('Finding T_t_d')
236 R= T_d_t(1:3,1:3);
237 d= T_d_t(1:3,4);
238 R_T = transpose(R);
239 T_t_d = [R_T -R_T*d;
240          0 0 0 1];
241
242
243 T_t_0 = T_n_0 * T_d_e * T_t_d
244
245 R_t_0 = double(T_t_0(1:3,1:3));
246 P_t_0 = double(T_t_0(1:3,4));
247 disp('Wrench at end effector wrt to tip frame')
248 Ft = [R_t_0 zeros(3);
249       S(P_t_0(1),P_t_0(2),P_t_0(3))*R_t_0 R_t_0] *F;
250
251 double(Ft)

```