2.3 (10 points)

Consider an environment with two obstacles:

- $\theta_{start} = [0,0]^T$ and $\theta_{goal} = [1,1]^T$
- First obstacle with center $c_1 = [0.4, 0.6]^T$ and radius $r_1 = 0.2$
- Second obstacle with center $c_2 = [0.6, 0.4]^T$ and radius $r_2 = 0.2$
- The trajectory ξ should have $k = 20$ waypoints

Modify the initial trajectory ξ^0 so that the optimal trajectory goes around both obstacles. Submit a **plot** of your result and **list** the initial trajectory that you used.

```
clear
clc
close all

% Start and Goal orientations
theta_start = [0;0];
theta_goal = [1;1];

% Initial trajectory variables
n = 2; % No. of joints/ 2-D trajectory
k = 20; % No. of waypoints

% Obstacles 1 and 2 parameters
% First obstacle's radius and center
r1 = 0.2;
center1 = [0.4;0.6];
% Second obstacle's radius and center
r2 = 0.2;
center2 = [0.6;0.4];


% MY INITIAL TRAJECTORY
% Create initial trajectory that arches above the first and below the second
obstacle
mid_point1 = [0.5; 0.7]; % A point above the first obstacle
mid_point2 = [0.5; 0.3]; % A point below the second obstacle

% Construct initial trajectory xi_0
xi_0 = [linspace(theta_start(1), mid_point1(1), floor(k/4)), ...
        linspace(mid_point1(1), mid_point2(1), floor(k/4)), ...
        linspace(mid_point2(1), theta_goal(1), floor(k/2));
        linspace(theta_start(2), mid_point1(2), floor(k/4)), ...
        linspace(mid_point1(2), mid_point2(2), floor(k/4)), ...
        linspace(mid_point2(2), theta_goal(2), floor(k/2))];
```

```
xi_0_vec = reshape(xi_0, [],1); % Reshape for the need of optimization

% Equality constraints for start and goal positions
A = [eye(n), zeros(n,n*(k-1)) ;...
    zeros(n,n*(k-1)), eye(n) ];

B = [theta_start;theta_goal];

% Nonlinear optimization
options = optimoptions('fmincon','Display','iter',...
    'Algorithm','sqp','MaxFunctionEvaluations',1e5);
xi_star_vec = fmincon(@(xi) cost(xi), xi_0_vec, ...
    [], [], A, B, [], [], [], options);
```

Iter	Func-count	Fval	Feasibility	Step Length	Norm of step	First-order optimality
0	41	5.259554e+03	0.000e+00	1.000e+00	0.000e+00	1.096e+05
1	105	4.223578e+03	0.000e+00	2.737e-04	4.063e+01	1.276e+02
2	148	3.412082e+03	0.000e+00	4.900e-01	5.225e+01	6.299e+01
3	192	3.360310e+03	0.000e+00	3.430e-01	3.162e+01	5.050e+01
4	235	2.233704e+03	0.000e+00	4.900e-01	4.734e+01	4.379e+01
5	277	2.038745e+03	0.000e+00	7.000e-01	4.050e+01	4.369e+01
6	319	1.634861e+03	0.000e+00	7.000e-01	3.146e+01	4.701e+01
7	361	1.474206e+03	0.000e+00	7.000e-01	2.980e+01	4.114e+01
8	403	1.231450e+03	0.000e+00	7.000e-01	2.418e+01	3.427e+01
9	445	1.088206e+03	0.000e+00	7.000e-01	2.383e+01	2.818e+01
10	487	8.968974e+02	0.000e+00	7.000e-01	1.633e+01	3.109e+01
11	529	8.627004e+02	0.000e+00	7.000e-01	1.607e+01	3.496e+01
12	570	8.115329e+02	0.000e+00	1.000e+00	1.311e+01	3.023e+01
13	612	7.938560e+02	0.000e+00	7.000e-01	1.131e+01	2.958e+01
14	654	7.564874e+02	0.000e+00	7.000e-01	8.699e+00	2.532e+01
15	696	7.526249e+02	0.000e+00	7.000e-01	1.009e+01	3.439e+01
16	738	7.157127e+02	0.000e+00	7.000e-01	6.660e+00	2.719e+01
17	781	6.971369e+02	0.000e+00	4.900e-01	5.646e+00	2.547e+01
18	823	6.915785e+02	0.000e+00	7.000e-01	5.370e+00	2.606e+01
19	864	6.850450e+02	0.000e+00	1.000e+00	5.187e+00	2.610e+01
20	907	6.800388e+02	0.000e+00	4.900e-01	3.493e+00	2.574e+01
21	948	6.734686e+02	0.000e+00	1.000e+00	4.238e+00	2.490e+01
22	990	6.702804e+02	0.000e+00	7.000e-01	2.494e+00	2.499e+01
23	1032	6.700025e+02	0.000e+00	7.000e-01	2.931e+00	2.569e+01
24	1073	6.678741e+02	0.000e+00	1.000e+00	2.594e+00	2.246e+01
25	1116	6.659580e+02	0.000e+00	4.900e-01	1.618e+00	2.449e+01
26	1157	6.653640e+02	0.000e+00	1.000e+00	2.031e+00	2.418e+01
27	1199	6.646424e+02	0.000e+00	7.000e-01	1.344e+00	2.494e+01
28	1241	6.641004e+02	0.000e+00	7.000e-01	1.438e+00	2.383e+01
29	1283	6.634615e+02	0.000e+00	7.000e-01	1.177e+00	2.363e+01
Iter	Func-count	Fval	Feasibility	Step Length	Norm of step	First-order optimality
30	1325	6.629003e+02	0.000e+00	7.000e-01	1.062e+00	2.427e+01
31	1366	6.628434e+02	0.000e+00	1.000e+00	1.375e+00	2.398e+01
32	1407	6.619820e+02	0.000e+00	1.000e+00	1.157e+00	2.400e+01
33	1450	6.614425e+02	0.000e+00	4.900e-01	9.162e-01	2.403e+01
34	1491	6.606951e+02	0.000e+00	1.000e+00	1.131e+00	2.384e+01
35	1532	6.604600e+02	0.000e+00	1.000e+00	1.532e+00	2.336e+01
36	1573	6.588206e+02	0.000e+00	1.000e+00	1.592e+00	2.433e+01
37	1614	6.573849e+02	0.000e+00	1.000e+00	2.664e+00	2.437e+01
38	1655	6.518431e+02	0.000e+00	1.000e+00	1.921e+00	2.343e+01
39	1696	6.489891e+02	0.000e+00	1.000e+00	4.700e+00	2.312e+01
40	1737	6.336788e+02	0.000e+00	1.000e+00	3.550e+00	2.315e+01
41	1778	6.033210e+02	0.000e+00	1.000e+00	1.219e+01	2.257e+01
42	1819	5.694327e+02	0.000e+00	1.000e+00	2.000e+01	2.132e+01

Iter	Func-count	Fval	Feasibility	Step Length	Norm of step	First-order optimality
43	1860	5.419120e+02	0.000e+00	1.000e+00	2.405e+01	2.087e+01
44	1901	5.130550e+02	0.000e+00	1.000e+00	1.533e+01	1.806e+01
45	1942	4.815863e+02	0.000e+00	1.000e+00	6.172e+00	1.772e+01
46	1983	4.172338e+02	0.000e+00	1.000e+00	1.844e+01	1.641e+01
47	2024	3.660126e+02	0.000e+00	1.000e+00	1.398e+01	1.472e+01
48	2065	2.799702e+02	0.000e+00	1.000e+00	2.394e+01	1.187e+01
49	2106	1.993409e+02	0.000e+00	1.000e+00	2.148e+01	8.503e+00
50	2147	1.067375e+02	0.000e+00	1.000e+00	2.682e+01	6.370e+00
51	2188	4.091122e+01	0.000e+00	1.000e+00	2.207e+01	4.335e+00
52	2229	1.048690e+01	0.000e+00	1.000e+00	1.308e+01	1.630e+00
53	2274	8.018335e+00	0.000e+00	2.401e-01	1.430e+00	8.118e+01
54	2328	7.347262e+00	0.000e+00	9.689e-03	1.375e+01	1.669e+00
55	2370	1.097989e+00	0.000e+00	7.000e-01	5.140e+00	7.712e-01
56	2415	7.610732e-01	0.000e+00	2.401e-01	5.129e-01	6.305e-01
57	2465	7.142845e-01	0.000e+00	4.035e-02	7.061e-02	5.781e-01
58	2508	3.783916e-01	0.000e+00	4.900e-01	2.229e+00	9.066e-01
59	2550	2.837937e-01	0.000e+00	7.000e-01	4.384e-01	6.868e-01
60	2598	2.761461e-01	0.000e+00	8.235e-02	3.710e-02	6.671e-01
61	2660	2.761138e-01	0.000e+00	5.585e-04	3.755e-04	6.498e-01
62	2701	2.478416e-01	0.000e+00	1.000e+00	6.738e-01	4.716e-01
63	2742	2.409657e-01	0.000e+00	1.000e+00	1.254e-01	5.045e-01
64	2783	2.397934e-01	0.000e+00	1.000e+00	5.216e-02	5.065e-01
65	2824	2.388920e-01	0.000e+00	1.000e+00	8.271e-02	5.010e-01
66	2865	2.384171e-01	0.000e+00	1.000e+00	3.175e-02	4.974e-01
67	2906	2.366505e-01	0.000e+00	1.000e+00	7.353e-02	4.862e-01
68	2947	2.330986e-01	0.000e+00	1.000e+00	8.224e-02	4.681e-01
69	2988	2.239409e-01	0.000e+00	1.000e+00	1.234e-01	4.277e-01
70	3029	2.044408e-01	0.000e+00	1.000e+00	1.961e-01	3.485e-01
71	3070	1.695681e-01	0.000e+00	1.000e+00	3.956e-01	2.111e-01
72	3117	1.632345e-01	0.000e+00	1.176e-01	7.236e-02	1.931e-01
73	3169	1.613184e-01	0.000e+00	1.977e-02	2.029e-02	1.891e-01
74	3225	1.608086e-01	0.000e+00	4.748e-03	5.210e-03	1.882e-01
75	3287	1.607826e-01	0.000e+00	5.585e-04	6.126e-04	9.220e-01
76	3340	1.576940e-01	0.000e+00	1.384e-02	2.306e-02	3.361e-01
77	3398	1.575542e-01	0.000e+00	2.326e-03	4.382e-03	2.892e+00
78	3450	1.530685e-01	0.000e+00	1.977e-02	3.235e-02	1.156e+00
79	3513	1.527830e-01	0.000e+00	3.910e-04	5.222e-03	2.748e+00
80	3566	1.488220e-01	0.000e+00	1.384e-02	3.137e-02	1.653e+00
81	3620	1.485773e-01	0.000e+00	9.689e-03	4.376e-03	2.114e+00
82	3667	1.374998e-01	0.000e+00	1.176e-01	1.254e-01	8.428e-02
83	3716	1.370526e-01	0.000e+00	5.765e-02	6.377e-03	8.142e-02
84	3771	1.370384e-01	0.000e+00	6.782e-03	5.299e-04	6.803e-01
85	3816	1.363245e-01	0.000e+00	2.401e-01	2.885e-02	3.660e+00
86	3858	1.358079e-01	0.000e+00	7.000e-01	5.693e-02	6.425e-02
87	3899	1.354108e-01	0.000e+00	1.000e+00	2.733e-02	6.110e-02
88	3940	1.353238e-01	0.000e+00	1.000e+00	4.185e-03	6.199e-02
89	3981	1.352314e-01	0.000e+00	1.000e+00	6.652e-03	2.948e-01
90	4022	1.352247e-01	0.000e+00	1.000e+00	3.110e-03	5.841e-01
91	4063	1.351975e-01	0.000e+00	1.000e+00	3.594e-03	1.137e-01
92	4104	1.351787e-01	0.000e+00	1.000e+00	4.676e-03	5.817e-02
93	4145	1.351556e-01	0.000e+00	1.000e+00	9.711e-03	6.129e-02
94	4186	1.351515e-01	0.000e+00	1.000e+00	1.984e-03	2.771e-01
95	4227	1.351451e-01	0.000e+00	1.000e+00	1.355e-03	1.289e-01
96	4268	1.351332e-01	0.000e+00	1.000e+00	2.024e-03	5.817e-02
97	4309	1.351067e-01	0.000e+00	1.000e+00	2.590e-03	6.245e-02
98	4350	1.349986e-01	0.000e+00	1.000e+00	6.796e-03	6.328e-02
99	4398	1.349758e-01	0.000e+00	8.235e-02	7.998e-04	6.343e-02
100	4455	1.349745e-01	0.000e+00	3.323e-03	7.367e-05	1.255e-01
101	4496	1.349109e-01	0.000e+00	1.000e+00	6.940e-03	6.938e-02
102	4537	1.348704e-01	0.000e+00	1.000e+00	7.177e-03	7.343e-02

Iter	Func-count	Fval	Feasibility	Step Length	Norm of step	First-order optimality
103	4578	1.348570e-01	0.000e+00	1.000e+00	2.583e-03	7.289e-02
104	4619	1.348484e-01	0.000e+00	1.000e+00	2.501e-03	2.266e-01
105	4660	1.348408e-01	0.000e+00	1.000e+00	1.604e-03	7.255e-02
106	4701	1.348253e-01	0.000e+00	1.000e+00	1.468e-03	7.316e-02
107	4742	1.347446e-01	0.000e+00	1.000e+00	3.980e-03	7.400e-02
108	4787	1.346992e-01	0.000e+00	2.401e-01	3.591e-03	1.056e+00
109	4828	1.346650e-01	0.000e+00	1.000e+00	2.307e-03	3.534e-01
110	4869	1.346184e-01	0.000e+00	1.000e+00	1.993e-03	2.572e-01
111	4910	1.343492e-01	0.000e+00	1.000e+00	7.262e-03	1.047e-01
112	4954	1.338188e-01	0.000e+00	3.430e-01	1.902e-02	6.290e-02
113	5003	1.337811e-01	0.000e+00	5.765e-02	3.580e-03	1.285e+00
114	5047	1.332554e-01	0.000e+00	3.430e-01	4.998e-02	2.335e+00
115	5088	1.332550e-01	0.000e+00	1.000e+00	2.496e-02	6.907e-02
116	5129	1.328924e-01	0.000e+00	1.000e+00	3.013e-02	5.675e-02
117	5170	1.328221e-01	0.000e+00	1.000e+00	5.945e-03	5.771e-02
118	5211	1.327140e-01	0.000e+00	1.000e+00	1.843e-02	8.661e-01
119	5255	1.326857e-01	0.000e+00	3.430e-01	7.882e-03	3.943e-01
Iter	Func-count	Fval	Feasibility	Step Length	Norm of step	First-order optimality
120	5299	1.326816e-01	0.000e+00	3.430e-01	8.766e-03	6.336e-02
121	5340	1.326646e-01	0.000e+00	1.000e+00	1.853e-03	6.425e-02
122	5382	1.326294e-01	0.000e+00	7.000e-01	3.863e-03	2.170e-01
123	5424	1.326281e-01	0.000e+00	7.000e-01	7.558e-04	6.625e-02
124	5465	1.326165e-01	0.000e+00	1.000e+00	8.699e-04	1.337e-01
125	5506	1.326124e-01	0.000e+00	1.000e+00	3.070e-03	6.615e-02
126	5549	1.326104e-01	0.000e+00	4.900e-01	2.433e-03	2.039e-01
127	5590	1.326089e-01	0.000e+00	1.000e+00	4.985e-04	6.610e-02
128	5631	1.326070e-01	0.000e+00	1.000e+00	5.233e-04	5.521e-02
129	5674	1.326062e-01	0.000e+00	4.900e-01	6.620e-04	2.265e-01
130	5715	1.325987e-01	0.000e+00	1.000e+00	1.487e-03	8.263e-02
131	5756	1.325803e-01	0.000e+00	1.000e+00	2.052e-03	9.593e-02
132	5797	1.325565e-01	0.000e+00	1.000e+00	1.991e-03	6.397e-02
133	5838	1.324966e-01	0.000e+00	1.000e+00	1.193e-02	5.768e-02
134	5879	1.324875e-01	0.000e+00	1.000e+00	1.414e-03	5.865e-02
135	5922	1.324837e-01	0.000e+00	4.900e-01	1.285e-03	3.863e-01
136	5963	1.324589e-01	0.000e+00	1.000e+00	2.071e-03	4.183e-01
137	6004	1.324050e-01	0.000e+00	1.000e+00	5.423e-03	4.190e-01
138	6045	1.323216e-01	0.000e+00	1.000e+00	1.141e-02	1.536e-01
139	6086	1.322846e-01	0.000e+00	1.000e+00	1.298e-02	5.423e-01
140	6130	1.322814e-01	0.000e+00	3.430e-01	7.826e-03	4.648e-01
141	6171	1.322640e-01	0.000e+00	1.000e+00	5.919e-03	1.559e-01
142	6212	1.322471e-01	0.000e+00	1.000e+00	6.140e-03	2.388e-01
143	6253	1.322138e-01	0.000e+00	1.000e+00	3.740e-03	7.074e-02
144	6294	1.321767e-01	0.000e+00	1.000e+00	1.019e-02	8.938e-01
145	6335	1.320802e-01	0.000e+00	1.000e+00	1.669e-02	6.824e-02
146	6376	1.319997e-01	0.000e+00	1.000e+00	7.566e-03	6.682e-02
147	6417	1.318375e-01	0.000e+00	1.000e+00	3.686e-02	1.504e+00
148	6463	1.317930e-01	0.000e+00	1.681e-01	4.448e-02	5.508e-02
149	6504	1.316783e-01	0.000e+00	1.000e+00	4.334e-02	5.772e-02
Iter	Func-count	Fval	Feasibility	Step Length	Norm of step	First-order optimality
150	6545	1.316363e-01	0.000e+00	1.000e+00	1.208e-02	5.534e-02
151	6586	1.316105e-01	0.000e+00	1.000e+00	9.372e-03	5.355e-02
152	6627	1.316028e-01	0.000e+00	1.000e+00	3.012e-03	5.345e-02
153	6668	1.315921e-01	0.000e+00	1.000e+00	3.226e-03	5.380e-02
154	6709	1.315715e-01	0.000e+00	1.000e+00	3.839e-03	5.481e-02
155	6752	1.315641e-01	0.000e+00	4.900e-01	1.735e-03	4.688e-01
156	6793	1.315536e-01	0.000e+00	1.000e+00	5.503e-03	5.486e-02
157	6834	1.315446e-01	0.000e+00	1.000e+00	2.373e-03	5.523e-02
158	6875	1.315318e-01	0.000e+00	1.000e+00	7.598e-03	4.115e-01
159	6916	1.315277e-01	0.000e+00	1.000e+00	2.477e-03	5.707e-02
160	6957	1.315238e-01	0.000e+00	1.000e+00	6.287e-04	5.780e-02
161	6999	1.315213e-01	0.000e+00	7.000e-01	1.758e-03	3.106e-01
162	7040	1.315174e-01	0.000e+00	1.000e+00	5.865e-04	5.959e-02

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 163        7081    1.315163e-01     0.000e+00     1.000e+00     5.606e-04     6.020e-02
 164        7122    1.315152e-01     0.000e+00     1.000e+00     9.284e-04     6.132e-02
 165        7163    1.315149e-01     0.000e+00     1.000e+00     1.527e-04     6.152e-02
 166        7204    1.315132e-01     0.000e+00     1.000e+00     5.911e-04     6.221e-02
 167        7253    1.315131e-01     0.000e+00     5.765e-02     6.512e-05     4.250e-02
 168        7294    1.315072e-01     0.000e+00     1.000e+00     1.649e-03     6.148e-02
 169        7335    1.314774e-01     0.000e+00     1.000e+00     7.751e-03     5.613e-02
 170        7376    1.314580e-01     0.000e+00     1.000e+00     3.943e-03     4.992e-02
 171        7417    1.314545e-01     0.000e+00     1.000e+00     2.191e-03     4.834e-02
 172        7458    1.314528e-01     0.000e+00     1.000e+00     1.624e-03     4.835e-02
 173        7499    1.314502e-01     0.000e+00     1.000e+00     1.798e-03     4.849e-02
 174        7540    1.314434e-01     0.000e+00     1.000e+00     2.851e-03     4.880e-02
 175        7587    1.314419e-01     0.000e+00     1.176e-01     4.900e-04     6.165e-02
 176        7628    1.314370e-01     0.000e+00     1.000e+00     3.648e-03     4.791e-02
 177        7669    1.314324e-01     0.000e+00     1.000e+00     4.363e-03     4.696e-02
 178        7710    1.314294e-01     0.000e+00     1.000e+00     2.514e-03     4.673e-02
 179        7754    1.314290e-01     0.000e+00     3.430e-01     7.735e-04     8.150e-02
Iter  Func-count            Fval   Feasibility   Step Length       Norm of   First-order
                                                                      step    optimality
 180        7795    1.314283e-01     0.000e+00     1.000e+00     6.412e-04     4.645e-02
 181        7836    1.314279e-01     0.000e+00     1.000e+00     4.671e-04     4.626e-02
 182        7877    1.314267e-01     0.000e+00     1.000e+00     1.067e-03     4.576e-02
 183        7918    1.314244e-01     0.000e+00     1.000e+00     1.080e-03     4.519e-02
 184        7959    1.314185e-01     0.000e+00     1.000e+00     1.823e-03     4.396e-02
 185        8001    1.314102e-01     0.000e+00     7.000e-01     1.988e-03     6.251e-02
 186        8042    1.314097e-01     0.000e+00     1.000e+00     1.705e-03     7.835e-02
 187        8083    1.314053e-01     0.000e+00     1.000e+00     2.404e-03     9.585e-02
 188        8128    1.314049e-01     0.000e+00     2.401e-01     7.786e-04     1.758e-01
 189        8169    1.314026e-01     0.000e+00     1.000e+00     3.760e-04     4.089e-02
 190        8210    1.314007e-01     0.000e+00     1.000e+00     1.660e-03     3.991e-02
 191        8251    1.313978e-01     0.000e+00     1.000e+00     2.895e-03     4.771e-02
 192        8292    1.313944e-01     0.000e+00     1.000e+00     7.428e-04     4.849e-02
 193        8333    1.313756e-01     0.000e+00     1.000e+00     2.408e-03     2.095e-01
 194        8374    1.312825e-01     0.000e+00     1.000e+00     8.847e-03     3.612e-01
 195        8421    1.311865e-01     0.000e+00     1.176e-01     1.120e-02     6.012e-02
 196        8476    1.311854e-01     0.000e+00     6.782e-03     1.527e-04     6.018e-02
 197        8517    1.311080e-01     0.000e+00     1.000e+00     1.897e-02     5.915e-02
 198        8558    1.310675e-01     0.000e+00     1.000e+00     2.273e-02     5.804e-02
 199        8599    1.310645e-01     0.000e+00     1.000e+00     2.145e-03     5.793e-02
 200        8640    1.310610e-01     0.000e+00     1.000e+00     2.391e-03     5.781e-02
 201        8681    1.310566e-01     0.000e+00     1.000e+00     1.833e-03     5.773e-02
 202        8722    1.310456e-01     0.000e+00     1.000e+00     3.826e-03     2.308e-01
 203        8763    1.310431e-01     0.000e+00     1.000e+00     7.277e-03     5.732e-02
 204        8804    1.310345e-01     0.000e+00     1.000e+00     1.368e-03     5.736e-02
 205        8845    1.309973e-01     0.000e+00     1.000e+00     6.340e-03     5.730e-02
 206        8889    1.309921e-01     0.000e+00     3.430e-01     6.756e-03     7.952e-01
 207        8931    1.309615e-01     0.000e+00     7.000e-01     2.564e-02     5.648e-02
 208        8972    1.309499e-01     0.000e+00     1.000e+00     1.236e-02     5.638e-02
 209        9013    1.309438e-01     0.000e+00     1.000e+00     4.252e-04     5.626e-02
Iter  Func-count            Fval   Feasibility   Step Length       Norm of   First-order
                                                                      step    optimality
 210        9054    1.309181e-01     0.000e+00     1.000e+00     1.336e-03     2.420e-01
 211        9095    1.308842e-01     0.000e+00     1.000e+00     1.999e-02     5.499e-02
 212        9145    1.308832e-01     0.000e+00     4.035e-02     2.168e-04     5.497e-02
 213        9202    1.308830e-01     0.000e+00     3.323e-03     4.944e-05     9.254e-02
 214        9246    1.308735e-01     0.000e+00     3.430e-01     4.298e-03     1.029e+00
 215        9287    1.308557e-01     0.000e+00     1.000e+00     4.807e-03     5.684e-02
 216        9328    1.308427e-01     0.000e+00     1.000e+00     8.681e-04     5.665e-02
 217        9370    1.308296e-01     0.000e+00     7.000e-01     4.052e-03     6.904e-01
 218        9411    1.308206e-01     0.000e+00     1.000e+00     1.888e-03     5.590e-02
 219        9452    1.308095e-01     0.000e+00     1.000e+00     1.338e-03     5.648e-02
 220        9493    1.308008e-01     0.000e+00     1.000e+00     4.130e-03     6.366e-01
 221        9534    1.307838e-01     0.000e+00     1.000e+00     1.749e-03     4.755e-01
 222        9580    1.307648e-01     0.000e+00     1.681e-01     2.980e-03     3.541e-01
```

Iter	Func-count	Fval	Feasibility	Step Length	Norm of step	First-order optimality
223	9621	1.307593e-01	0.000e+00	1.000e+00	1.282e-03	4.911e-02
224	9665	1.307573e-01	0.000e+00	3.430e-01	3.762e-04	1.065e-01
225	9706	1.307560e-01	0.000e+00	1.000e+00	1.465e-03	4.990e-02
226	9747	1.307545e-01	0.000e+00	1.000e+00	9.728e-04	5.067e-02
227	9788	1.307526e-01	0.000e+00	1.000e+00	3.132e-04	1.039e-01
228	9830	1.307435e-01	0.000e+00	7.000e-01	1.317e-03	2.494e-01
229	9871	1.307382e-01	0.000e+00	1.000e+00	1.322e-03	1.091e-01
230	9914	1.307329e-01	0.000e+00	4.900e-01	1.261e-03	1.525e-01
231	9956	1.307327e-01	0.000e+00	7.000e-01	1.470e-03	5.721e-02
232	9997	1.307315e-01	0.000e+00	1.000e+00	4.729e-04	5.686e-02
233	10044	1.307310e-01	0.000e+00	1.176e-01	3.663e-04	5.682e-02
234	10085	1.307305e-01	0.000e+00	1.000e+00	3.219e-04	5.678e-02
235	10126	1.307300e-01	0.000e+00	1.000e+00	2.117e-04	5.677e-02
236	10168	1.307292e-01	0.000e+00	7.000e-01	2.208e-04	9.346e-02
237	10209	1.307288e-01	0.000e+00	1.000e+00	5.770e-04	5.713e-02
238	10250	1.307282e-01	0.000e+00	1.000e+00	1.098e-04	4.524e-02
239	10294	1.307282e-01	0.000e+00	3.430e-01	1.924e-04	7.055e-02
Iter	Func-count	Fval	Feasibility	Step Length	Norm of step	First-order optimality
240	10335	1.307279e-01	0.000e+00	1.000e+00	1.019e-04	2.345e-02
241	10376	1.307277e-01	0.000e+00	1.000e+00	9.715e-05	2.344e-02
242	10417	1.307270e-01	0.000e+00	1.000e+00	3.635e-04	5.135e-02
243	10458	1.307255e-01	0.000e+00	1.000e+00	6.331e-04	5.808e-02
244	10499	1.307191e-01	0.000e+00	1.000e+00	3.418e-03	5.944e-02
245	10540	1.307140e-01	0.000e+00	1.000e+00	3.756e-03	6.041e-02
246	10581	1.307103e-01	0.000e+00	1.000e+00	3.718e-03	6.074e-02
247	10622	1.307088e-01	0.000e+00	1.000e+00	1.887e-03	6.052e-02
248	10663	1.307080e-01	0.000e+00	1.000e+00	8.023e-04	6.028e-02
249	10704	1.307064e-01	0.000e+00	1.000e+00	9.788e-04	5.996e-02
250	10748	1.307063e-01	0.000e+00	3.430e-01	5.011e-04	9.820e-02
251	10789	1.307044e-01	0.000e+00	1.000e+00	1.489e-03	6.048e-02
252	10830	1.307029e-01	0.000e+00	1.000e+00	1.230e-03	6.107e-02
253	10871	1.307001e-01	0.000e+00	1.000e+00	2.250e-03	6.219e-02
254	10912	1.306990e-01	0.000e+00	1.000e+00	1.134e-03	6.263e-02
255	10953	1.306963e-01	0.000e+00	1.000e+00	2.549e-03	6.342e-02
256	11001	1.306961e-01	0.000e+00	8.235e-02	2.800e-04	6.687e-02
257	11042	1.306950e-01	0.000e+00	1.000e+00	1.185e-03	4.862e-02
258	11083	1.306940e-01	0.000e+00	1.000e+00	1.173e-03	7.113e-02
259	11124	1.306934e-01	0.000e+00	1.000e+00	7.057e-04	2.324e-02
260	11165	1.306931e-01	0.000e+00	1.000e+00	1.458e-03	2.329e-02
261	11206	1.306929e-01	0.000e+00	1.000e+00	6.141e-04	2.328e-02
262	11247	1.306928e-01	0.000e+00	1.000e+00	4.213e-04	2.327e-02
263	11288	1.306922e-01	0.000e+00	1.000e+00	8.927e-04	2.319e-02
264	11329	1.306909e-01	0.000e+00	1.000e+00	1.114e-03	3.249e-02
265	11370	1.306880e-01	0.000e+00	1.000e+00	1.456e-03	9.447e-02
266	11411	1.306844e-01	0.000e+00	1.000e+00	2.295e-03	6.549e-02
267	11452	1.306724e-01	0.000e+00	1.000e+00	1.464e-02	6.196e-02
268	11493	1.306631e-01	0.000e+00	1.000e+00	3.640e-03	6.096e-02
269	11534	1.306630e-01	0.000e+00	1.000e+00	6.257e-03	6.083e-01
Iter	Func-count	Fval	Feasibility	Step Length	Norm of step	First-order optimality
270	11580	1.306531e-01	0.000e+00	1.681e-01	2.553e-03	3.486e-01
271	11629	1.306524e-01	0.000e+00	5.765e-02	9.251e-04	2.641e-01
272	11677	1.306512e-01	0.000e+00	8.235e-02	5.867e-03	5.820e-02
273	11718	1.306469e-01	0.000e+00	1.000e+00	2.252e-03	5.807e-02
274	11759	1.306468e-01	0.000e+00	1.000e+00	3.914e-03	2.747e-01
275	11800	1.306433e-01	0.000e+00	1.000e+00	2.674e-03	5.842e-02
276	11841	1.306416e-01	0.000e+00	1.000e+00	2.907e-04	5.852e-02
277	11882	1.306388e-01	0.000e+00	1.000e+00	1.164e-03	1.928e-01
278	11923	1.306361e-01	0.000e+00	1.000e+00	2.583e-03	5.793e-02
279	11964	1.306347e-01	0.000e+00	1.000e+00	6.615e-04	5.811e-02
280	12008	1.306334e-01	0.000e+00	3.430e-01	8.278e-04	7.544e-02
281	12049	1.306332e-01	0.000e+00	1.000e+00	5.557e-04	6.702e-02
282	12090	1.306329e-01	0.000e+00	1.000e+00	2.378e-04	3.331e-02

```
  283       12131    1.306329e-01     0.000e+00     1.000e+00     1.261e-04     1.738e-02
  284       12172    1.306327e-01     0.000e+00     1.000e+00     3.175e-04     7.882e-03
  285       12213    1.306325e-01     0.000e+00     1.000e+00     1.024e-03     2.337e-02
  286       12254    1.306324e-01     0.000e+00     1.000e+00     3.314e-04     1.400e-02
  287       12295    1.306323e-01     0.000e+00     1.000e+00     4.633e-04     7.764e-03
  288       12336    1.306323e-01     0.000e+00     1.000e+00     2.313e-04     7.824e-03
  289       12377    1.306323e-01     0.000e+00     1.000e+00     3.206e-04     7.955e-03
  290       12418    1.306322e-01     0.000e+00     1.000e+00     1.985e-04     7.974e-03
  291       12459    1.306322e-01     0.000e+00     1.000e+00     1.010e-04     7.989e-03
  292       12500    1.306322e-01     0.000e+00     1.000e+00     1.313e-04     7.956e-03
  293       12541    1.306322e-01     0.000e+00     1.000e+00     1.937e-04     7.896e-03
  294       12582    1.306322e-01     0.000e+00     1.000e+00     2.567e-04     1.286e-02
  295       12625    1.306321e-01     0.000e+00     4.900e-01     1.962e-04     1.677e-02
  296       12680    1.306321e-01     0.000e+00     6.782e-03     1.791e-05     1.712e-02
  297       12721    1.306321e-01     0.000e+00     1.000e+00     1.054e-04     1.262e-02
  298       12762    1.306319e-01     0.000e+00     1.000e+00     3.476e-04     7.859e-03
  299       12803    1.306319e-01     0.000e+00     1.000e+00     1.258e-04     7.899e-03
 Iter   Func-count            Fval   Feasibility   Step Length       Norm of   First-order
                                                                        step    optimality
  300       12844    1.306318e-01     0.000e+00     1.000e+00     5.684e-04     2.269e-02
  301       12885    1.306317e-01     0.000e+00     1.000e+00     1.176e-03     1.123e-02
  302       12926    1.306317e-01     0.000e+00     1.000e+00     6.812e-04     1.314e-02
  303       12967    1.306317e-01     0.000e+00     1.000e+00     2.771e-05     1.540e-02
  304       13015    1.306317e-01     0.000e+00     8.235e-02     4.358e-05     2.296e-02
  305       13056    1.306316e-01     0.000e+00     1.000e+00     2.064e-04     8.264e-03
  306       13097    1.306316e-01     0.000e+00     1.000e+00     1.826e-04     6.522e-03
  307       13138    1.306316e-01     0.000e+00     1.000e+00     1.140e-04     5.881e-03
  308       13179    1.306316e-01     0.000e+00     1.000e+00     5.220e-05     7.956e-03
  309       13220    1.306316e-01     0.000e+00     1.000e+00     4.432e-05     1.129e-02
  310       13261    1.306315e-01     0.000e+00     1.000e+00     6.967e-05     1.956e-02
  311       13302    1.306315e-01     0.000e+00     1.000e+00     1.183e-04     3.241e-02
  312       13343    1.306313e-01     0.000e+00     1.000e+00     2.447e-04     5.180e-02
  313       13384    1.306307e-01     0.000e+00     1.000e+00     8.555e-04     8.655e-02
  314       13425    1.306301e-01     0.000e+00     1.000e+00     6.550e-04     9.446e-02
  315       13466    1.306288e-01     0.000e+00     1.000e+00     1.497e-03     7.034e-02
  316       13507    1.306283e-01     0.000e+00     1.000e+00     1.162e-03     1.804e-02
  317       13548    1.306282e-01     0.000e+00     1.000e+00     1.844e-04     8.669e-03
  318       13589    1.306282e-01     0.000e+00     1.000e+00     1.043e-04     8.549e-03
  319       13630    1.306282e-01     0.000e+00     1.000e+00     1.170e-04     8.433e-03
  320       13671    1.306281e-01     0.000e+00     1.000e+00     2.371e-04     1.140e-02
  321       13712    1.306280e-01     0.000e+00     1.000e+00     3.620e-04     3.253e-02
  322       13754    1.306280e-01     0.000e+00     7.000e-01     2.036e-04     1.654e-02
  323       13795    1.306279e-01     0.000e+00     1.000e+00     1.069e-04     1.343e-02
  324       13837    1.306279e-01     0.000e+00     7.000e-01     2.846e-04     2.406e-02
  325       13879    1.306279e-01     0.000e+00     7.000e-01     5.796e-05     1.301e-02
  326       13920    1.306278e-01     0.000e+00     1.000e+00     7.094e-05     3.839e-03
  327       13927    1.306278e-01     0.000e+00     8.235e-02     2.523e-06     3.839e-03

Local minimum possible. Constraints satisfied.

fmincon stopped because the size of the current step is less than
the value of the step size tolerance and constraints are
satisfied to within the value of the constraint tolerance.

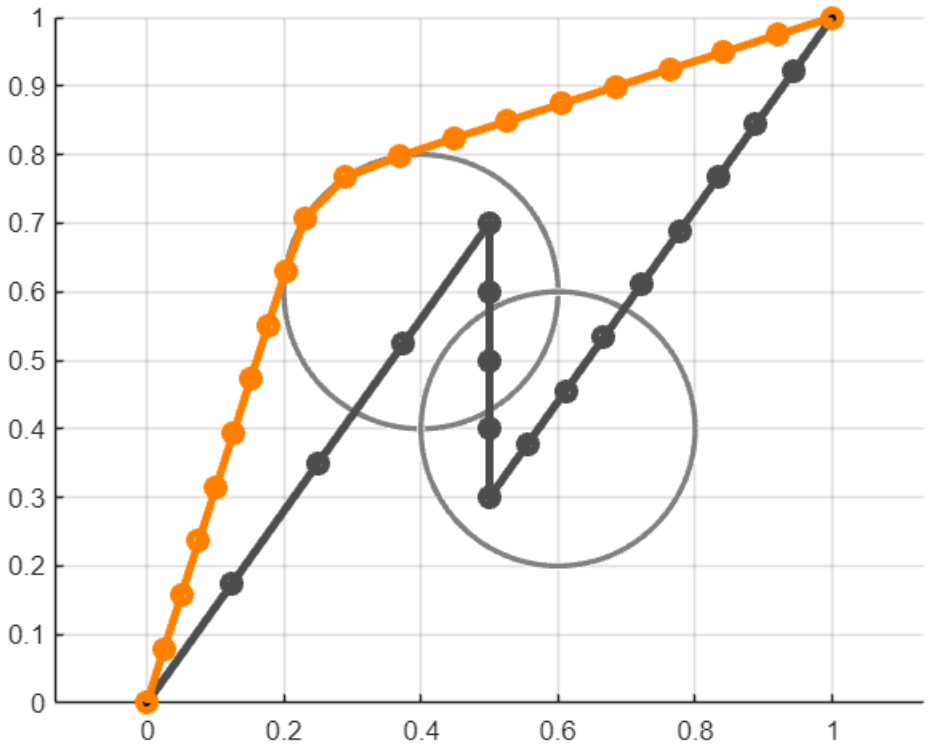
<stopping criteria details>
```

```
xi_star = reshape(xi_star_vec,2,[]); % final optimized trajectory

% Plot obstacles
figure
grid on
```

```
hold on
axis([0, 1, 0, 1])
axis equal
viscircles(center1', r1, 'Color', [0.5, 0.5, 0.5]);
viscircles(center2', r2, 'Color', [0.5, 0.5, 0.5]);
plot(0, 0, 'ko', 'MarkerFaceColor', 'k')
plot(1, 1, 'ko', 'MarkerFaceColor', 'k')

% Plot result
grid on
hold on
axis equal
plot(xi_0(1,:), xi_0(2,:), 'o-', 'Color', [0.3, 0.3, ...
 0.3], 'LineWidth', 3);
plot(xi_star(1,:), xi_star(2,:), 'o-',...
    'Color', [1, 0.5, 0], 'LineWidth', 3);
```




```
% Cost function to minimize
```

```
function C = cost(xi)
    gamma = 20; % Repulsion coefficient
    xi = reshape(xi, 2, []);
    C = 0;
    epsilon = 1e-6; % Small constant to prevent division by zero
```

```
    % Define obstacles with correct centers and radii
    obstacles = [
        0.4, 0.6, 0.2; % First obstacle
        0.6, 0.4, 0.2; % Second obstacle
        % Add more obstacles if needed
    ];

    for idx = 2:length(xi)
        Urep = 0;
        for obs = 1:size(obstacles, 1)
            center = obstacles(obs, 1:2)';
            r = obstacles(obs, 3);
            dist_to_center = norm(xi(:, idx) - center);

            % Calculate repulsive potential if within the obstacle's influence
            if dist_to_center < r
                % Add a small value epsilon to prevent division by zero
                Urep = Urep + 0.5 * gamma * ((1 / (dist_to_center + epsilon)) -
(1 / r))^2;
            end
        end

        % Sum the repulsive potential and the path length cost
        C = C + norm(xi(:, idx) - xi(:, idx - 1))^2 + Urep;
    end
end


% MY INITIAL TRAJECTORY
% % Create initial trajectory that arches above the first and below the second
obstacle
% mid_point1 = [0.5; 0.7]; % A point above the first obstacle
% mid_point2 = [0.5; 0.3]; % A point below the second obstacle
%
% % Construct initial trajectory xi_0
% xi_0 = [linspace(theta_start(1), mid_point1(1), floor(k/4)), ...
%         linspace(mid_point1(1), mid_point2(1), floor(k/4)), ...
%         linspace(mid_point2(1), theta_goal(1), floor(k/2));
%         linspace(theta_start(2), mid_point1(2), floor(k/4)), ...
%         linspace(mid_point1(2), mid_point2(2), floor(k/4)), ...
%         linspace(mid_point2(2), theta_goal(2), floor(k/2))];
```