Assignment 1 - MEEN 689 - Design and Control of Autonomous Vehicles

Evaluate 1 : Computation time of the algorithm for the different resolutions

For Dijkstra's Shortest Path Algorithm:

For Map with resolution 1 -

```
Results_resolution_1
```

	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	Dijkstra	(224, 158)	(232, 1468)	1	Path Found!!!	5.388074
1	Dijkstra	(224, 158)	(964, 870)	1	Path Found!!!	4.362585
2	Dijkstra	(224, 158)	(304, 72)	1	Goal is an Obstacle!!	1.035298
3	Dijkstra	(224, 158)	(274, 840)	1	Path not Found!!	5.266897
4	Dijkstra	(436, 892)	(232, 1468)	1	Path Found!!!	2.269343
5	Dijkstra	(436, 892)	(964, 870)	1	Path Found!!!	2.622849
6	Dijkstra	(436, 892)	(304, 72)	1	Goal is an Obstacle!!	1.027488
7	Dijkstra	(436, 892)	(274, 840)	1	Path not Found!!	4.978446

For Map with resolution 2 -

```
Results_resolution_2
```

	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	Dijkstra	(224, 158)	(232, 1468)	2	Path Found!!!	1.512998
1	Dijkstra	(224, 158)	(964, 870)	2	Path Found!!!	0.938658
2	Dijkstra	(224, 158)	(304, 72)	2	Goal is an Obstacle!!	0.199598
3	Dijkstra	(224, 158)	(274, 840)	2	Path not Found!!	1.290413
4	Dijkstra	(436, 892)	(232, 1468)	2	Path Found!!!	0.582752
5	Dijkstra	(436, 892)	(964, 870)	2	Path Found!!!	0.486360
6	Dijkstra	(436, 892)	(304, 72)	2	Goal is an Obstacle!!	0.168878
7	Dijkstra	(436, 892)	(274, 840)	2	Path not Found!!	1.107074

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For Map with resolution 5 -

```
Results_resolution_5
```

	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	Dijkstra	(224, 158)	(232, 1468)	5	Path Found!!!	0.351576
1	Dijkstra	(224, 158)	(964, 870)	5	Path Found!!!	0.131513
2	Dijkstra	(224, 158)	(304, 72)	5	Goal is an Obstacle!!	0.023716
3	Dijkstra	(224, 158)	(274, 840)	5	Path not Found!!	0.152447
4	Dijkstra	(436, 892)	(232, 1468)	5	Path Found!!!	0.063537
5	Dijkstra	(436, 892)	(964, 870)	5	Path Found!!!	0.070319
6	Dijkstra	(436, 892)	(304, 72)	5	Goal is an Obstacle!!	0.021995
7	Dijkstra	(436, 892)	(274, 840)	5	Path not Found!!	0.154414

For Map with resolution 10 -

```
Results_resolution_10
```

	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	Dijkstra	(224, 158)	(232, 1468)	10	Path not Found!!	0.055202
1	Dijkstra	(224, 158)	(964, 870)	10	Path Found!!!	0.028538
2	Dijkstra	(224, 158)	(304, 72)	10	Goal is an Obstacle!!	0.007061
3	Dijkstra	(224, 158)	(274, 840)	10	Path not Found!!	0.045143
4	Dijkstra	(436, 892)	(232, 1468)	10	Path not Found!!	0.006442
5	Dijkstra	(436, 892)	(964, 870)	10	Path not Found!!	0.005460
6	Dijkstra	(436, 892)	(304, 72)	10	Goal is an Obstacle!!	0.004744
7	Dijkstra	(436, 892)	(274, 840)	10	Path not Found!!	0.005178

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For A* Shortest Path Algorithm:

For Map with resolution 1 -

```
Results_resolution_1_AStar
```

	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	AStar	(224, 158)	(232, 1468)	1	Path Found!!!	3.401065
1	AStar	(224, 158)	(964, 870)	1	Path Found!!!	3.937195
2	AStar	(224, 158)	(304, 72)	1	Goal is an Obstacle!!	1.052952
3	AStar	(224, 158)	(274, 840)	1	Path not Found!!	5.647136
4	AStar	(436, 892)	(232, 1468)	1	Path Found!!!	1.304051
5	AStar	(436, 892)	(964, 870)	1	Path Found!!!	1.188024
6	AStar	(436, 892)	(304, 72)	1	Goal is an Obstacle!!	0.990525
7	AStar	(436, 892)	(274, 840)	1	Path not Found!!	6.023928

For Map with resolution 2 -

```
Results_resolution_2_AStar
```

	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	AStar	(224, 158)	(232, 1468)	2	Path Found!!!	1.053640
1	AStar	(224, 158)	(964, 870)	2	Path Found!!!	1.003197
2	AStar	(224, 158)	(304, 72)	2	Goal is an Obstacle!!	0.208587
3	AStar	(224, 158)	(274, 840)	2	Path not Found!!	1.235978
4	AStar	(436, 892)	(232, 1468)	2	Path Found!!!	0.242156
5	AStar	(436, 892)	(964, 870)	2	Path Found!!!	0.243706
6	AStar	(436, 892)	(304, 72)	2	Goal is an Obstacle!!	0.169197
7	AStar	(436, 892)	(274, 840)	2	Path not Found!!	1.151671

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For Map with resolution 5 -

`Results_resolution_5_AStar`

	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	AStar	(224, 158)	(232, 1468)	5	Path Found!!!	0.300188
1	AStar	(224, 158)	(964, 870)	5	Path Found!!!	0.127403
2	AStar	(224, 158)	(304, 72)	5	Goal is an Obstacle!!	0.024707
3	AStar	(224, 158)	(274, 840)	5	Path not Found!!	0.167815
4	AStar	(436, 892)	(232, 1468)	5	Path Found!!!	0.031208
5	AStar	(436, 892)	(964, 870)	5	Path Found!!!	0.038357
6	AStar	(436, 892)	(304, 72)	5	Goal is an Obstacle!!	0.020911
7	AStar	(436, 892)	(274, 840)	5	Path not Found!!	0.170472

For Map with resolution 10 -

`Results_resolution_10_AStar`

	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	AStar	(224, 158)	(232, 1468)	10	Path not Found!!	0.053861
1	AStar	(224, 158)	(964, 870)	10	Path Found!!!	0.030414
2	AStar	(224, 158)	(304, 72)	10	Goal is an Obstacle!!	0.005914
3	AStar	(224, 158)	(274, 840)	10	Path not Found!!	0.038757
4	AStar	(436, 892)	(232, 1468)	10	Path not Found!!	0.008257
5	AStar	(436, 892)	(964, 870)	10	Path not Found!!	0.006017
6	AStar	(436, 892)	(304, 72)	10	Goal is an Obstacle!!	0.005493
7	AStar	(436, 892)	(274, 840)	10	Path not Found!!	0.005568

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Evaluate 2: Computation time and results of both the algorithms. Are either of them optimal?

Comparison of time for map with resolution 1 :

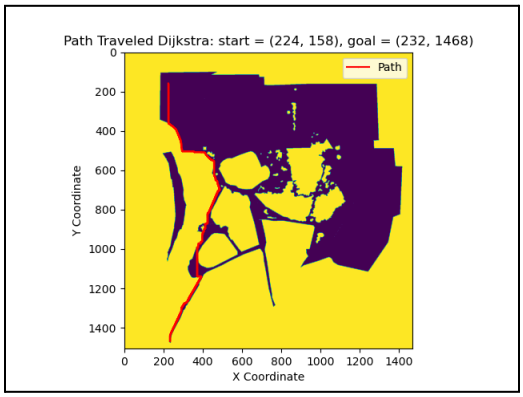
Results_resolution_1

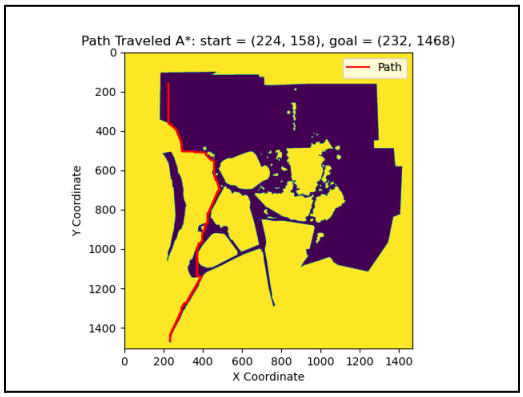
	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	Dijkstra	(224, 158)	(232, 1468)	1	Path Found!!!	5.388074
1	Dijkstra	(224, 158)	(964, 870)	1	Path Found!!!	4.362585
2	Dijkstra	(224, 158)	(304, 72)	1	Goal is an Obstacle!!	1.035298
3	Dijkstra	(224, 158)	(274, 840)	1	Path not Found!!	5.266897
4	Dijkstra	(436, 892)	(232, 1468)	1	Path Found!!!	2.269343
5	Dijkstra	(436, 892)	(964, 870)	1	Path Found!!!	2.622849
6	Dijkstra	(436, 892)	(304, 72)	1	Goal is an Obstacle!!	1.027488
7	Dijkstra	(436, 892)	(274, 840)	1	Path not Found!!	4.978446

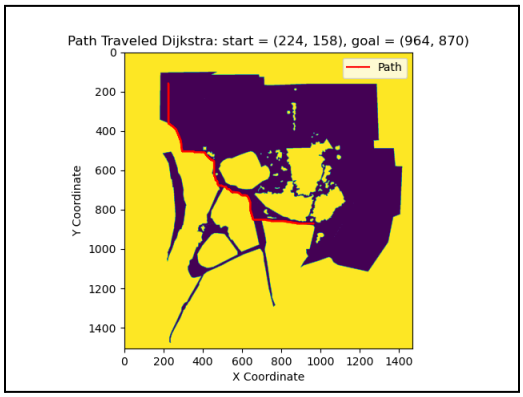
Results_resolution_1_AStar

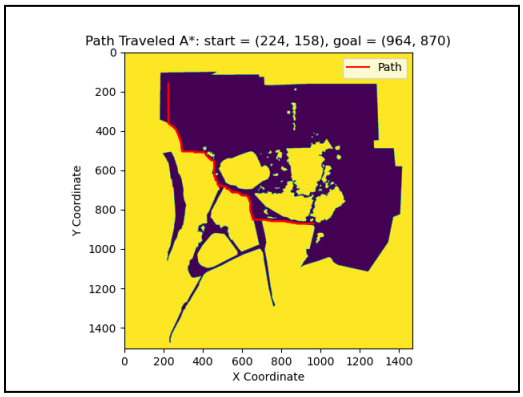
	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	AStar	(224, 158)	(232, 1468)	1	Path Found!!!	3.401065
1	AStar	(224, 158)	(964, 870)	1	Path Found!!!	3.937195
2	AStar	(224, 158)	(304, 72)	1	Goal is an Obstacle!!	1.052952
3	AStar	(224, 158)	(274, 840)	1	Path not Found!!	5.647136
4	AStar	(436, 892)	(232, 1468)	1	Path Found!!!	1.304051
5	AStar	(436, 892)	(964, 870)	1	Path Found!!!	1.188024
6	AStar	(436, 892)	(304, 72)	1	Goal is an Obstacle!!	0.990525
7	AStar	(436, 892)	(274, 840)	1	Path not Found!!	6.023928

Results for Resolution 1:









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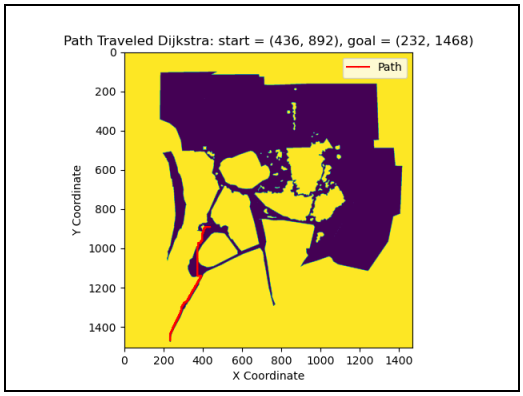
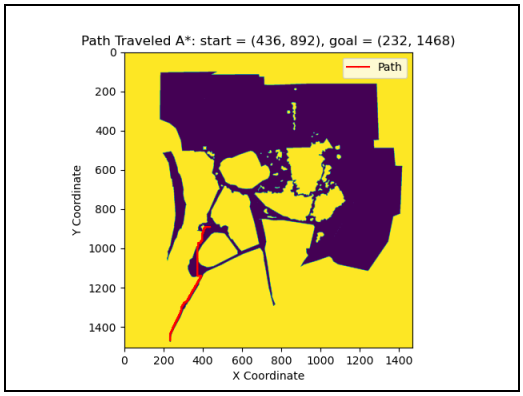
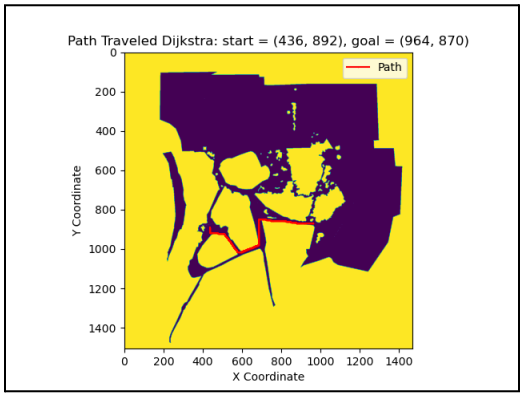
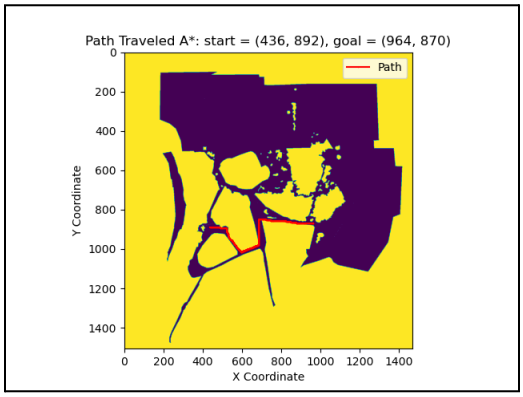








Comparison of time for map with resolution 2 :

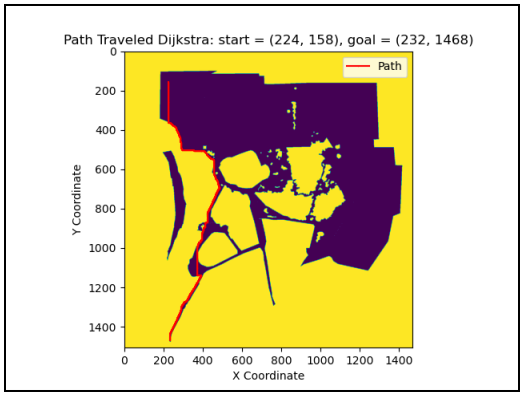
Results_resolution_2

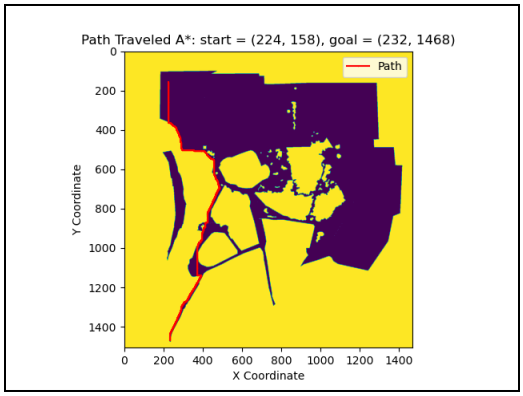
	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	Dijkstra	(224, 158)	(232, 1468)	2	Path Found!!!	1.512998
1	Dijkstra	(224, 158)	(964, 870)	2	Path Found!!!	0.938658
2	Dijkstra	(224, 158)	(304, 72)	2	Goal is an Obstacle!!	0.199598
3	Dijkstra	(224, 158)	(274, 840)	2	Path not Found!!	1.290413
4	Dijkstra	(436, 892)	(232, 1468)	2	Path Found!!!	0.582752
5	Dijkstra	(436, 892)	(964, 870)	2	Path Found!!!	0.486360
6	Dijkstra	(436, 892)	(304, 72)	2	Goal is an Obstacle!!	0.168878
7	Dijkstra	(436, 892)	(274, 840)	2	Path not Found!!	1.107074

Results_resolution_2_AStar

	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	AStar	(224, 158)	(232, 1468)	2	Path Found!!!	1.053640
1	AStar	(224, 158)	(964, 870)	2	Path Found!!!	1.003197
2	AStar	(224, 158)	(304, 72)	2	Goal is an Obstacle!!	0.208587
3	AStar	(224, 158)	(274, 840)	2	Path not Found!!	1.235978
4	AStar	(436, 892)	(232, 1468)	2	Path Found!!!	0.242156
5	AStar	(436, 892)	(964, 870)	2	Path Found!!!	0.243706
6	AStar	(436, 892)	(304, 72)	2	Goal is an Obstacle!!	0.169197
7	AStar	(436, 892)	(274, 840)	2	Path not Found!!	1.151671

Results for Resolution 2:





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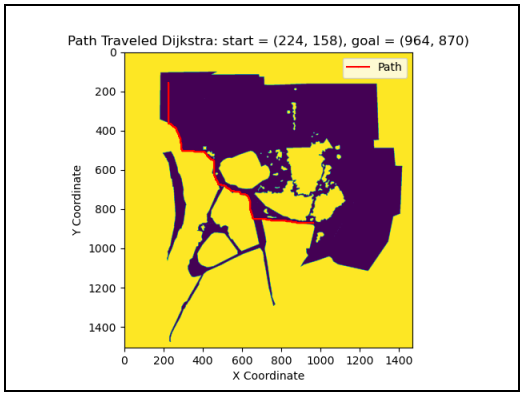

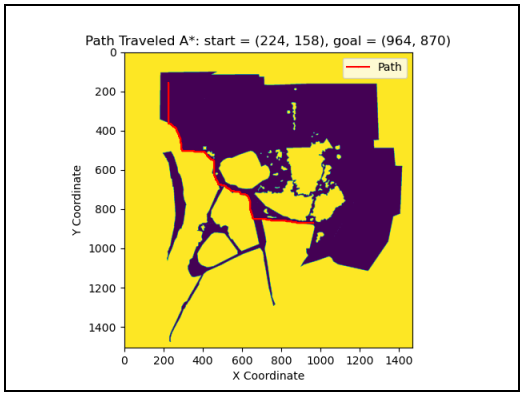

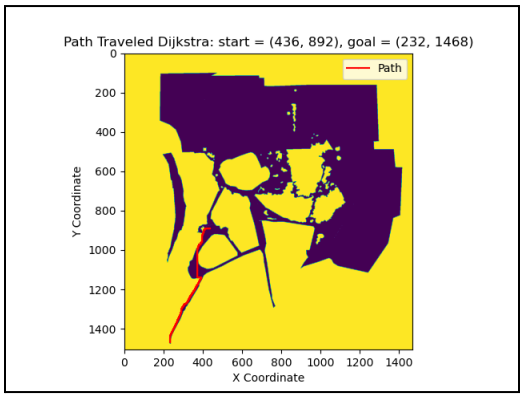

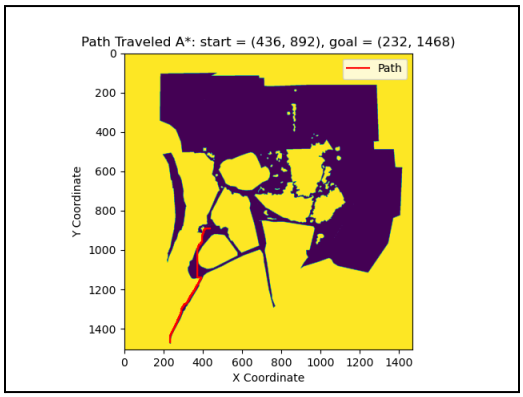

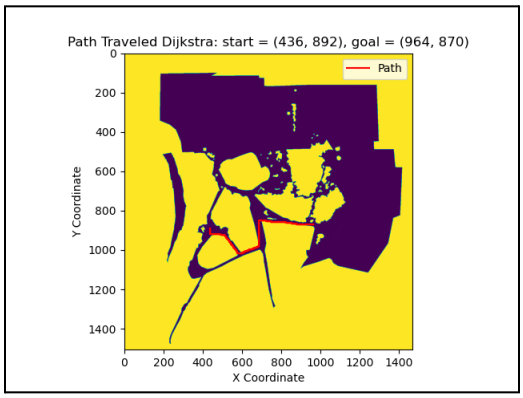

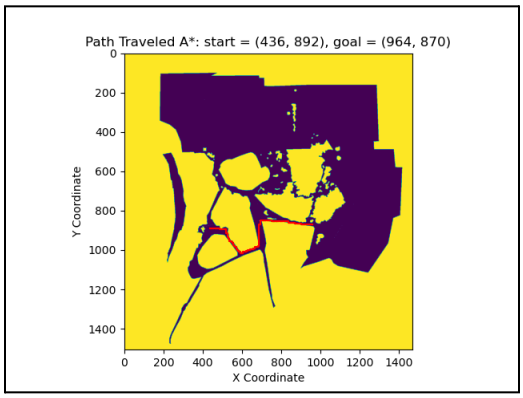

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Comparison of time for map with resolution 5 :

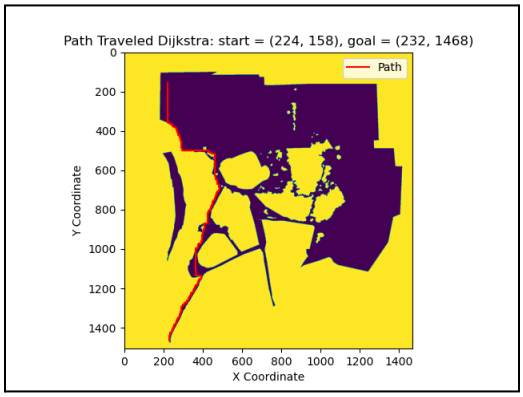
Results_resolution_5

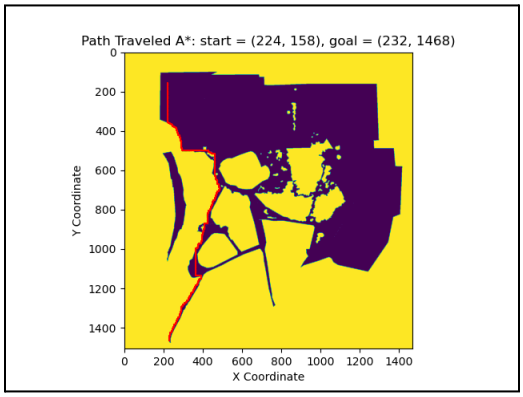
	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	Dijkstra	(224, 158)	(232, 1468)	5	Path Found!!!	0.351576
1	Dijkstra	(224, 158)	(964, 870)	5	Path Found!!!	0.131513
2	Dijkstra	(224, 158)	(304, 72)	5	Goal is an Obstacle!!	0.023716
3	Dijkstra	(224, 158)	(274, 840)	5	Path not Found!!	0.152447
4	Dijkstra	(436, 892)	(232, 1468)	5	Path Found!!!	0.063537
5	Dijkstra	(436, 892)	(964, 870)	5	Path Found!!!	0.070319
6	Dijkstra	(436, 892)	(304, 72)	5	Goal is an Obstacle!!	0.021995
7	Dijkstra	(436, 892)	(274, 840)	5	Path not Found!!	0.154414

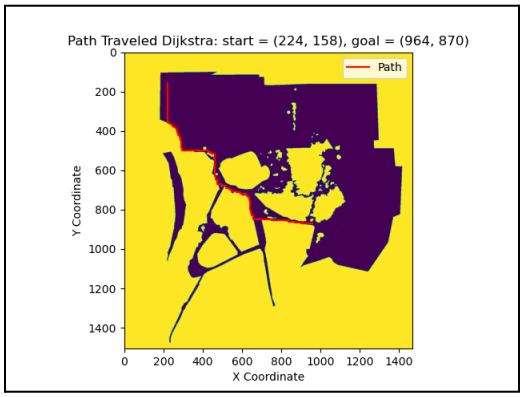
Results_resolution_5_AStar

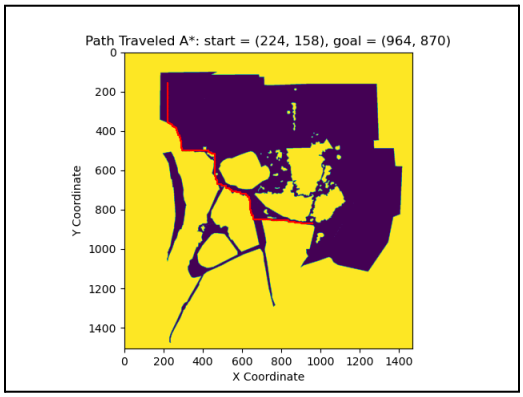
	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	AStar	(224, 158)	(232, 1468)	5	Path Found!!!	0.300188
1	AStar	(224, 158)	(964, 870)	5	Path Found!!!	0.127403
2	AStar	(224, 158)	(304, 72)	5	Goal is an Obstacle!!	0.024707
3	AStar	(224, 158)	(274, 840)	5	Path not Found!!	0.167815
4	AStar	(436, 892)	(232, 1468)	5	Path Found!!!	0.031208
5	AStar	(436, 892)	(964, 870)	5	Path Found!!!	0.038357
6	AStar	(436, 892)	(304, 72)	5	Goal is an Obstacle!!	0.020911
7	AStar	(436, 892)	(274, 840)	5	Path not Found!!	0.170472

Results for Resolution 5:









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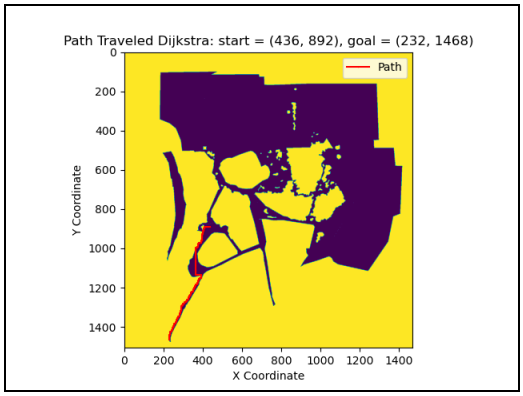
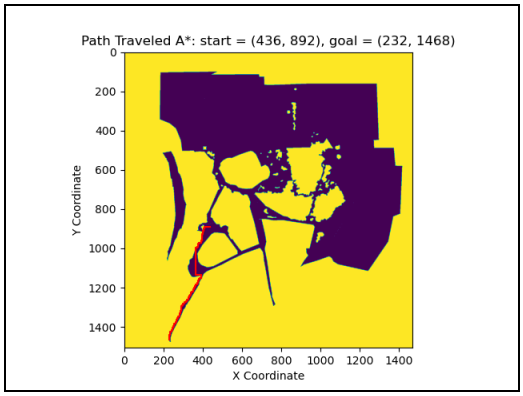
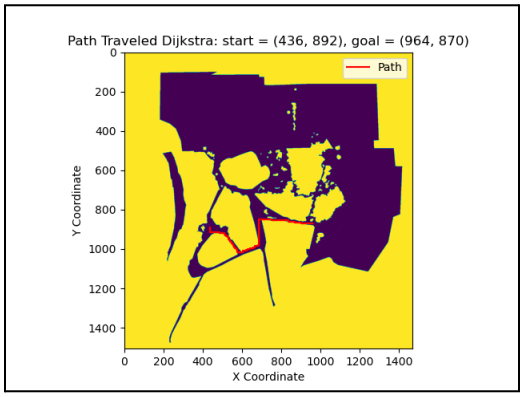
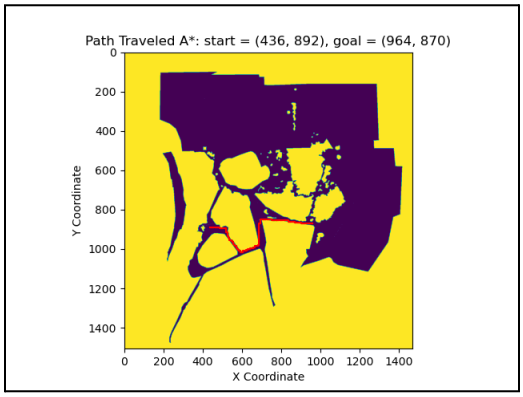








Comparison of time for map with resolution 10 :

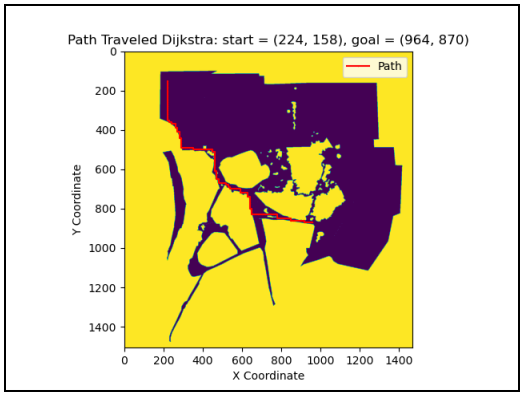
Results_resolution_10

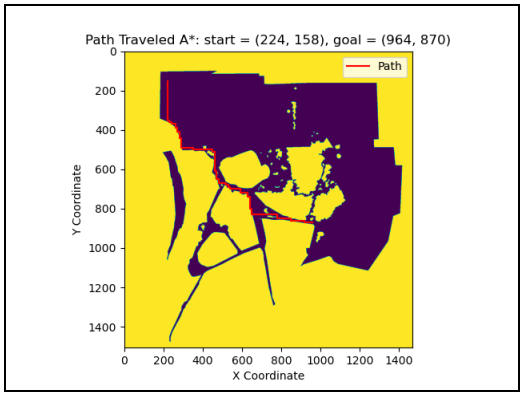
	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	Dijkstra	(224, 158)	(232, 1468)	10	Path not Found!!	0.055202
1	Dijkstra	(224, 158)	(964, 870)	10	Path Found!!!	0.028538
2	Dijkstra	(224, 158)	(304, 72)	10	Goal is an Obstacle!!	0.007061
3	Dijkstra	(224, 158)	(274, 840)	10	Path not Found!!	0.045143
4	Dijkstra	(436, 892)	(232, 1468)	10	Path not Found!!	0.006442
5	Dijkstra	(436, 892)	(964, 870)	10	Path not Found!!	0.005460
6	Dijkstra	(436, 892)	(304, 72)	10	Goal is an Obstacle!!	0.004744
7	Dijkstra	(436, 892)	(274, 840)	10	Path not Found!!	0.005178

Results_resolution_10_AStar

	Algorithm	Start	Goal	Resolution	Result	Time(s)
0	AStar	(224, 158)	(232, 1468)	10	Path not Found!!	0.053861
1	AStar	(224, 158)	(964, 870)	10	Path Found!!!	0.030414
2	AStar	(224, 158)	(304, 72)	10	Goal is an Obstacle!!	0.005914
3	AStar	(224, 158)	(274, 840)	10	Path not Found!!	0.038757
4	AStar	(436, 892)	(232, 1468)	10	Path not Found!!	0.008257
5	AStar	(436, 892)	(964, 870)	10	Path not Found!!	0.006017
6	AStar	(436, 892)	(304, 72)	10	Goal is an Obstacle!!	0.005493
7	AStar	(436, 892)	(274, 840)	10	Path not Found!!	0.005568

Results for Resolution 10:





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Conclusion:

As can be seen from the comparison of computation times for the two algorithms, **for higher resolution maps A* converges faster as compared to Dijkstra's Algorithm (when the path exists).** This is because the A* algorithm takes into account the heuristic function which makes the algorithm reach the goal faster. This heuristic cost is zero in case of the Dijkstra algorithm. I chose **Manhattan distance** as the heuristic function in case of A* algorithm. Manhattan distance is the sum of the absolute difference between the x-coordinates and y-coordinates of the current node and the goal node.
(d = | x - x_g| + |y - y_g|)

Both the Dijkstra and A* gives us the optimal solution i.e., the shortest path from the start node to the goal node (if the path exists). As can be seen in the plots attached above, we can see the paths for both Dijkstra and A* side by side. For higher resolutions (like 1x1) maps A* converges faster because of the heuristic cost included in the overall cost (f). [f(x) = g(x) + h(x)].

In case of lower resolution maps the convergence time is approximately the same for both the algorithms.

Note: The plots are there in the Python notebook as well along with the tables showing the computation times for both the algorithms.

Interpretation of Results:

In my algorithm the results are interpreted as mentioned below:

1. **Start/goal node is an obstacle**: This means the start node/ goal node is an obstacle and the algorithm returns no path.
2. **Path not found**: This means that the algorithm tried to search for a path but was not able to find the goal because either the start or the goal is surrounded by the obstacle.
3. **Path Found**: The algorithm converges and outputs a path, which is shown in the plots (all the paths are outputted as coordinates in the 1x1 frame independent of the resolution to avoid confusion)