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Performance Analysis of Various Path Planning Algorithms for the Reliable Navigation of Unmanned Ground Vehicles

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Abstract: Unmanned Ground Vehicles (UGV) provides a major boom in the area of vehicular technology by making it safer, fast, reliable and trouble-free. The navigation of UGV is associated with three major segments that are mapping, localization and path planning. This research work is primarily focused on developing a time efficient path planning technique to achieve reliable autonomous navigation of UGV. A number of path planning techniques had been examined and implemented in the past to achieve reliable navigation of UGV but still the optimality in the path planning has not been achieved. In this research, various path planning techniques such as A*, D*, Breadth First Search (BFS) and Orthogonal Jump Point Search (OJPS) are experimentally analyzed based on different parameters in simulator and in real world experiments. This research paper provides a simulation based performance analysis of the path planning techniques based on various parameters such as path length, computational time, number of operations required and trajectory analysis. Based on the performance analysis and the results obtained by performing experiments, A* turns comes out as better option for path planning in complex environment. The trajectory selected by the A* still suffer from path smoothness which is removed by B Spline method that reduce the time lag by 9.87% by reducing the number of sharp turns w.r.t conventional approaches.

Keywords: *Path planning, autonomous navigation, unmanned ground vehicles*

1. Introduction

This template, modified in MS Word 2007 and saved as a "Word 97-2003 Document" for the PC, provides authors with most of the formatting specifications needed for preparing electronic versions of their papers. Unmanned Ground Vehicle (UGV) is an intelligent machine that is capable of navigating in the environment without any human interaction [1]. To navigate in the environment, UGV required three prerequisites that is mapping, localization and path planning [2]. The term mapping illustrated by getting the spatial information of the environment via using set of range sensor or GPS while, localization indicate the current pose or position of the vehicle in the environment (map) [2-4]. Path planning is defined as finding the shortest path to reach the destination in least time while avoiding the obstacles in the path with smooth trajectory [3-4]. This research work is focuses on performance analysis of path planning techniques such as A*, Breadth First Search (BFS), D* and Orthogonal Jump Point Search (OJPS) to select the best fit path for time efficient navigation of UGV [5-6]. The performance analysis is done on the basis of various parameters such as path length, computational time, number of sharp turns and number of operations. These stated path planning techniques provide upright performance but still the optimality in the path planning is not achieved because of the high computational load, zigzag trajectory and variation in the path length [7]. Therefore, at initial phase of this proposed research, experimental based comparative analysis of these stated techniques is done and in second phase B- Spline method is implemented on best fit path planning techniques selected in initial phase to make the trajectory smoother. This proposed research work offers an assist to select the best fit path planning techniques with smoother trajectory planning for the reliable autonomous navigation of the UGV.

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2. Literature Survey

Path planning techniques are implementing for navigating the UGV in the environment and it assists the UGV to reach the destination. A number of path planning techniques are implemented in the past such as A*, D*, Jump point search, Rapidly-Exploring Random Trees (RRT), Genetic Algorithms, Breadth First Search (BFS), etc. [5-10]. These stated techniques provide quite decent performance but, still lagging in terms of high computational load, path length optimization problems, time and space complexity problems, high number of sharp turns, etc. which reduce the reliability of the stated path planning techniques [5-7]. A* algorithm provide the shortest path to reach the destination but the path selected by the A* lag in smoothness similarly, D* undergo form high computational load because each node has to be checked for the comparison that increase the computational load which resulted in low efficiency. Another technique such as RRT and Genetic algorithm also draws attentions of the robotics researcher because of its reliable outcomes but both also suffer from the high computational load problems [5-7]. There were many path planning techniques that has been developed in the past and it is not easy to select the best fit path planning technique for the reliable operation of UGV therefore a performance analysis is done to assist the researcher for selecting the best fit path planning technique for the UGV operation.

3. Performance analysis of the path planning techniques

Path planning techniques provides an optimal solution for the UGV to reach the destination and the optimality in the path planning rely on four parameters that are length minimization problem, obstacle free path, smoother trajectories and time/space complexity [7-8]. Length minimization problem associated with finding the shortest path to reach the destination while obstacle free path indicate that the selected path should not contain any obstacles [7]. If the path length is large then the UGV take extra time to reach the destination while, if the path contain obstacle then the UGV will collide with the obstacle which reduces the reliability of path planning technique. UGV require smoother trajectory as if the path contains high number of sharp turns that will resulted in the jerky motion of the UGV and similarly if the time/space complexity is increased that will have increased the computation load which will put time lag in the processing. Therefore, to achieve the optimality in the path, it should be shortest, obstacle free, smooth and low computational load. This research work is focused on these stated parameters for checking the reliability of the path planning technique. The selected four path planning techniques that are A*, D*, BFS and OJPS and they are selected because they are easy to implemented, low complexity, reliable, always find the path, low computational load, low time/space complexity, etc.

The performance analysis is done in a simulator in which all these stated path planning techniques are implemented one by one and three trials are done [9]. In each trial, a start (green color cell) and destination (red color cell) point as given to assist the UGV to navigate in the environment (grid map) as shown in Table.1. Each trial has different set of occupied and occupied cell that varies the complexity of the grid map. In Trial #1, the complexity of the environment in terms of occupied cells in the grid is very low therefore each algorithm gives optimal results in term of shortest path selection and path smoothness (no sharp turns) but other parameters such as time elapsed and number of operation varies as shown in Table.1. The optimal path length of 130cm is achieved by all the algorithms but other parameters such as number of operations and computational time varied as shown in Table.1. Therefore, if the complexity of the environment is low each algorithm gives competent results in terms of path length and smoother trajectory but if the complexity of the environment is increased as shown in Table.2 and Table.3, the reliability of each path planning techniques reduces. In trill #2 and #3 complexity of the environment is increased by increasing number of occupied cells (grey color cells). An experimental analysis of the 4 stated path planning techniques is done for checking the reliability of the techniques as shown in Table. 4, 5, 6 and 7.

*** Dark Green Color represent start node and red color represent goal node*

***Grey color cell represent occupied node and white color represent free space node*

***Light green color cells are under consideration node and light blue color node are the node which are closed node*

As per the simulated results, the A* algorithm perform better in all the (3) trials as compare to the other path planning techniques as shown in Table.8. With the implementation of the A* algorithm, the selected path is always the shortest (304cm) that solve the path length minimization problem. The computational time (8.96ms) and number of operations (251.33) is also the least when A* is implemented as compare to other techniques but if the smoothness of trajectory is the key requirement then the OJPS techniques provide better results as 7.67 (number of sharp turns) as shown in Table. 8. However, if the OJPS is implemented for the path planning, the path length, computational time and number of operations increase that reduces the reliability of the path planning of path length, computational load and number of operations but in term of path smoothness, the OJPS provides better results as shown in Table.8. The performance index of the A* only lag in term of technique as shown in Table. 8. Therefore, as per the performance analysis shown in Table. 8, A* provide the better results in terms path smoothness while OJPS lag in three aspects therefore, A* is selected as superior algorithm over the other three algorithms. Now the key problem while implementing A* is the high number of sharp turns in the trajectory selected by A* and this is further resolved in this research work by implementing Method of Splines.

Table 1. Trial test #1 in low complexity environment

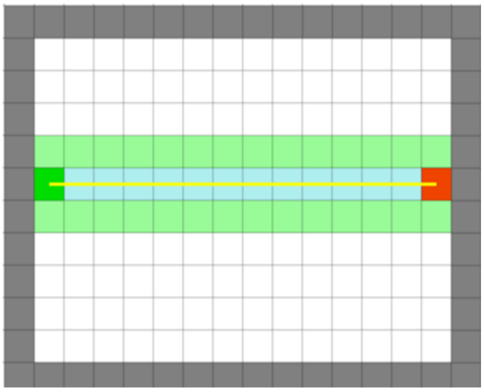
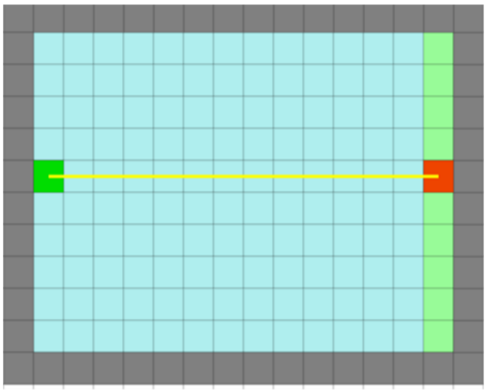
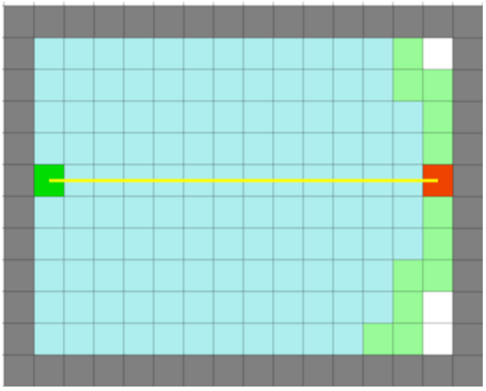
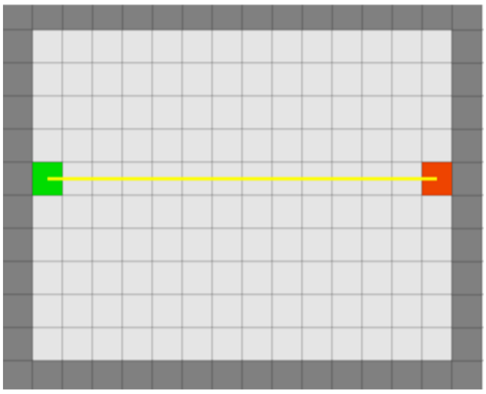
Algorithm	*Causal organism*	*Result*
A* Algorithm	Path Length = 130cm Time Elapsed = 2.85ms Number of Operation = 56	
Breadth First Search	Path Length = 130cm Time Elapsed = 8.5ms Number of Operation = 271	
D* Algorithm	Path Length = 130cm Time Elapsed = 7.23ms Number of Operation = 252	
Orthogonal Jump Point Search	Path Length = 130cm Time Elapsed = 5.23ms Number of Operation = 243	

Table 2. Trial test #2 in high complexity environment

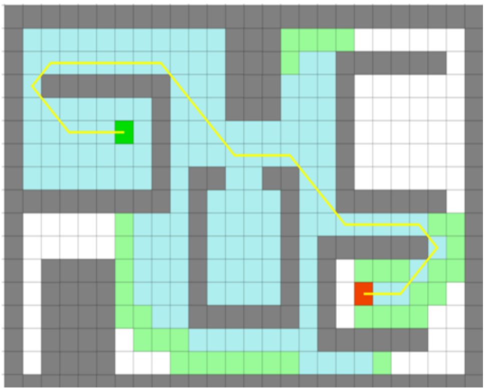
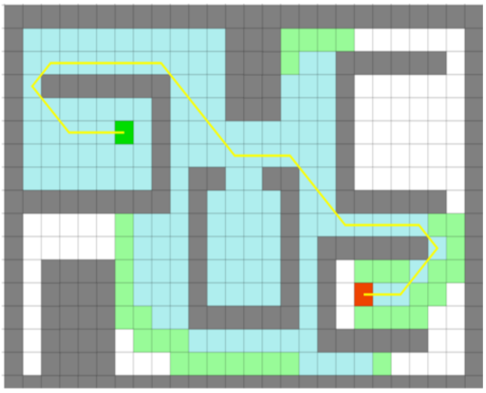
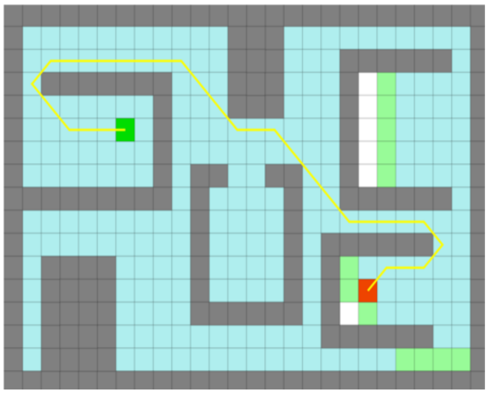
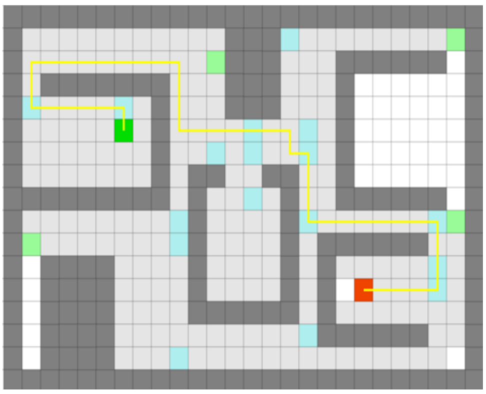
Algorithm	***Causal organism***	***Result***
A* Algorithm	Path Length = 363.8cm Time Elapsed = 10.26ms Number of Operation = 340 Number of turns = 12	
Breadth First Search	Path Length = 363.8cm Time Elapsed = 15.98ms Number of Operation = 490 Number of turns = 13	
D* Algorithm	Path Length = 363.8cm Time Elapsed = 15.19ms Number of Operation = 488 Number of turns = 13	
Orthogonal Jump Point Search	Path Length = 440cm Time Elapsed = 17.23ms Number of Operation = 503 Number of turns = 13	

Table 3. Trial test #3 in high complexity environment

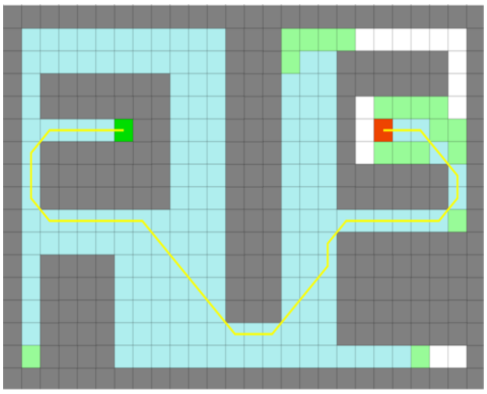
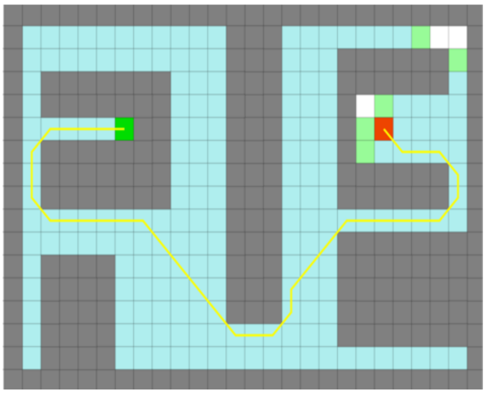
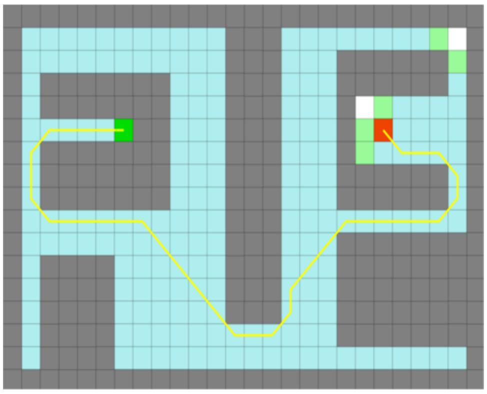
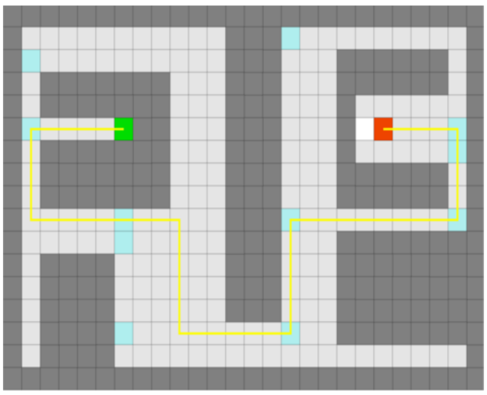
Algorithm	***Causal organism***	***Result***
A* Algorithm	Path Length = 418.2cm Time Elapsed = 13.78 Number of Operation = 358 Number of turns = 16	
Breadth First Search	Path Length = 418.2cm Time Elapsed = 15.88ms Number of Operation = 393 Number of turns = 17	
D* Algorithm	Path Length = 418.2cm Time Elapsed = 16.15 Number of Operation = 395 Number of turns = 17	
Orthogonal Jump Point Search	Path Length = 501.2cm Time Elapsed = 16.8 Number of Operation = 412 Number of turns = 10	

Table 4. Summarize result in all trials w.r.t implementation of A*

Trials	*Path Length*	*Computational time in millisecond*	*Number of operations*	*Number of sharp turns*
#1	130	2.85	56	2
#2	363.8	10.26	340	12
#3	418.2	13.78	358	16
Average Values	**304**	**8.96**	**251.33**	**10**

Table 5. Summarize result in all trials w.r.t implementation of Breadth First Search

Trials	*Path Length*	*Computational time in millisecond*	*Number of operations*	*Number of sharp turns*
#1	130	8.5	271	2
#2	363.8	15.98	490	13
#3	418.2	15.88	393	17
Average Values	**304**	**13.45**	**384.66**	**10.66**

Table 6. Summarize result in all trials w.r.t implementation of D*

Trials	*Path Length*	*Computational time in millisecond*	*Number of operations*	*Number of sharp turns*
#1	130	7.21	252	0
#2	363.8	15.19	488	13
#3	418.2	16.15	395	17
Average Values	**304**	**12.85**	**378.33**	**10**

Table 7. Summarize result in all trials w.r.t implementation of Orthogonal Jump Point Search

Trials	*Path Length*	*Computational time in millisecond*	*Number of operations*	*Number of sharp turns*
#1	130	5.23	143	0
#2	440	17.23	503	13
#3	501.2	16.8	412	10
Average Values	**357.06**	**13.08**	**352.66**	**7.67**

Table 8. Comparative analysis of the path planning techniques

Algorithms	*Path Length*	*Computational time in millisecond*	*Number of operations*	*Number of sharp turns*
A*	304	8.96	251.33	10
BFS	304	13.45	384.66	10.66
D*	304	12.85	378.33	10
OJPS	357.06	13.08	352.66	7.67
Best performance based on Performing Index	**A* , BFS and D***	**A***	**A***	**OJPS**

A* algorithm reduce the computational load, number of operation and the path length minimization problems however, the number of sharp turn are high that resulted in the jerky motion of the UGV. Therefore, to reduce the angles of the sharp turns B Spline method is implemented. The B Spline method is based on the control point whose values are varied to make the trajectory smoother. In the proposed research work, the control point is linked with the sharp turns and while implementing the B Spline methods the angle of the sharp turn become reduced that result in the smother trajectory as shown in Figure.1.

Trajectory planning with A*	Trajectory planning with A* and B Spline method

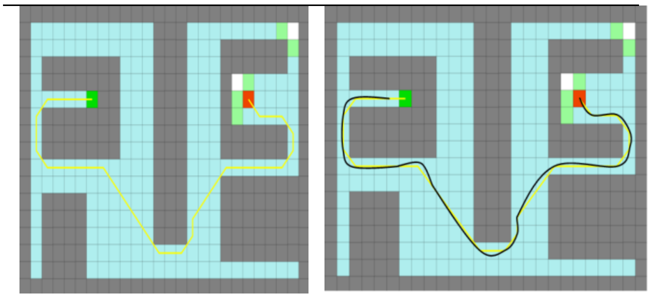


Figure.1 Trajectory planning with conventional A* and A*+ B Spline method

5. Real world Experiment

The proposed technique is implemented in real time experiment in which the mobile robot is permitted to follow the two trajectories generated with A* and (A* + B Spline method) as shown in Figure.1 and this experiment is repeated for several time in different environmental setup. The time taken by the mobile robot to reach from start of destination is noted using stop watch and it is experimentally obtained that the time taken by the mobile robot while following the trajectory obtained by A* with B Spline method is less as shown in Table .9. The decrease in time lag is because of smooth trajectory as with the implementation of A* the trajectory contains sharp turns and mobile robot has to adjust its acceleration to follow the trajectory. The variation in the magnitude of acceleration put time delay in reaching the target.

6. Conclusion

This research work demonstrated the performance analysis of various path planning techniques based on a range of parameters such as path minimization problem, obstacle free path, computation load and smoother trajectory. Various simulation based trial had been tested to check the reliability of the path planning techniques and it is experimentally verified that A* algorithm emerges out to be better technique for path planning as shown in Table. 5, 6, 7 and 8. While A* is also suffer from one major drawback of high number of sharp turns which is removed by B Spline methods. While implementing the A* with B Spline method the trajectory become smoother which result in reducing the time lag by 9.87% w.r.t conventional A* as shown in Table.9 and Figure.1.

Table 9. Time based analysis on the trajectory generated with conventional A* and A* + B Spline method

Trials	Time taken by the mobile robot to reach the destination	
	A*	**A* + B Spline method**
Trial #1	5.23 second	4.33 second
Trial #2	21.45 second	19.96 second
Trial #3	34.72second	31.04 second
Averaging	20.46 second	18.44 second
Improvement	**9.87% lesser time taken with A* + B Spline method**	

The future scope is the implementation of A* with other non-heuristic approach such a Particle Swarm Optimization, Rapid Exploring Random Tree, Ant Colony Optimization, etc. to make A* algorithm more time- efficient with smoother trajectories.

Conflicts of interest

The authors declare no conflicts of interest.

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