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Mobile Robots Obstacle Avoidance and Shortest Path Planning Using Algorithms – A Review

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Abstract

In mobile robotics, navigation technique is the leading research area. For the navigation system from the last five decades, so many methods are implemented based on the application of the mobile robot in known and unknown terrains. All plans have some advantages and disadvantages. Challenges are highlighted in this paper. The path planning methods of the mobile robot classified by Dijkstra's algorithm, A* algorithm and Modified A*, D* algorithm (Dynamic A* algorithm), Family of D* algorithms (Focussed D* algorithm, Field D*, Hierarchical D* algorithm, Focused Hierarchical D*, Focused D* &Witkowski's algorithm, Modified D* algorithm), Bug2 algorithm, RBVG method, and some classical and heuristic methods. In all research papers focused on the find the shortest path along with weights. The most common advanced techniques are presented here.

Keywords: *mobile robots, obstacle avoidance, Classical methods, and Heuristic methods.*

I. Introduction

Over the past few decades, autonomous robots are used in many applications, that too exploring motion path planning [1], [2], and replanning in a static environment and dynamic environment [3]. Tomas Lozano Perez at al [4] described a collision avoidance algorithm for planning a safe path for a polyhedral object moving among known polyhedral objects in 1979. The algorithm transforms the obstacles to represent the locus of prohibited situations for an arbitrary reference point on the moving object. A Path trajectory [5] of this reference point, which avoids all prohibited areas is free of collisions. Path trajectories are found via looking through a system that indicates, for every vertex in the changed obstacles, which different vertices can become to securely. The present situation of autonomous robots is replaced by humans [6], [7] in all aspects by small to hazard tasks. However, the most critical significant goals in autonomous robots are finding the optimal shortest path planning and collision obstacle avoidance [8], [9]. Many path planning methods have been improved the development of the shortest path planning algorithms, like A*[10], [11], D* or Focused D*[12], [13], [14], Greedy, HierarchicalD*[15],[16], Field D*[17], Witkowski's algorithm[18], Bellman ford, Genetic algorithm[19], TWD* algorithms[20]. For obstacle avoidance [21] using proprioceptive sensors [22] and Exteroceptive sensors [23], [24] to detect surrounding obstacles and work with high accuracy. The main challenges in this area are which expenses are limited? Which points of confinement are considered? And results (robot, joint space, Cartesian space [25], straight line, utilizing focuses with pivots [26], utilizing splines

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[27], and so on. In this review paper, we represented the two primary units used in autonomous robots: shortest path planning algorithms and obstacle avoidance in section II.

II. CLASSIFICATION OF MOTION PATH PLANNING ALGORITHMS:

Dijkstra's algorithm:

Edsger W. Dijkstra et al. [28] invented Dijkstra's Shortest Path First algorithm in 1956. The basic principle of this algorithm is finding out the shortest paths [29] between the nodes. He proposed two fundamental graph-theoretic problems [30], [31]: the minimum weight spanning tree problem and the shortest path problem. It is a viral algorithm in the motion planning area and computer science also. And it is one of the best methods in iteration techniques.

A* algorithm:

Hart et al. [10] introduced the A* algorithm in 1968. Frantisek Duchon et al. [11] proposed the mobile robot with functional and reliable reactive Navigation [32] and SLAM [33], [34] techniques in 2014. He modified and improved the A* algorithm with Rectangular Symmetry Reduction [RSR] [35] and Jump Point Search [JPS] [36]. These modifications are focused primarily on computational time and the path optimality. The main idea of RSR as a pre-processing step identifies and eliminates the symmetries shown in Fig1. Advantages of RSR are low computational demands, and the possibility of combination with the family of star algorithms, the computational time of path planning algorithms can be reduced ten to a hundred times. JPS is the cropping of neighborhood cells in the surroundings of actually evaluated cells. The advantages of JPS are an excellent reproduction of symmetries, and the resultant path is created as a set of points. The disadvantage of JPS cannot search at every angle.

Fig.1. The path between initial node positions to goal node position.

D* Algorithm:

Stentz et al. [12] [13] proposed the D* algorithm in 1994, Inspired by the A* algorithm [10]. It is an informed, incremental search algorithm. This algorithm works in Path planning for unknown, partially known, changing environments. He proposed one more algorithm related to the D* algorithm is Focused D* algorithm; it is an incremental heuristic search algorithm [37] combination of A* algorithm techniques. Both D*, FD* assumptions are the same as Navigation, free space searching in terrain, etc. The D* algorithm operates use as fundamental states like NEW, OPEN, CLOSED, RAISE, and LOWER.

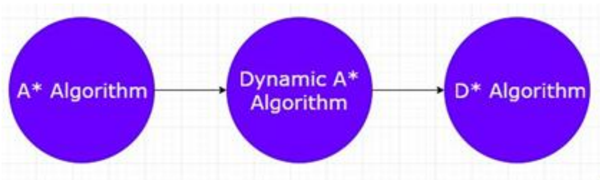

Fig.2.Modification of A* to D* algorithm.

Focused D* and Witkowski's algorithm (WFD*):

Marija Seder and Ivan Petrovi' [15] For Finding the shortest path in the geometrical terrain based

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on the grid map with proved by calculations presented a new path planning and replanning algorithm with a combination of focused D* algorithm [38] and Witkowski'salgorithm[18]. Focused D* algorithm fit for fast replanning in dynamic environments, and Witkowski's algorithm uses a BFS algorithm in a binary obstacle terrain with the cost is directly proportional to distance. It generates optimal paths in the grid map. So they presented the WFD* algorithm inspired by FD* AND Witkowski's algorithms. This algorithm made path optimality is proved for a smooth robot trajectory path in dynamic window obstacle avoidance [39]. They tested this algorithm in two environments. The first one is a known environment; in this environment, FDW* works 12% faster than the FD* algorithm shown in Fig3. The second environment is an unknown environment with randomly placed unknown obstacles. In this environment worked 5% more quickly than the FD* algorithm. Finally, they concluded is WFD* is a little bit faster than the FD* algorithm.

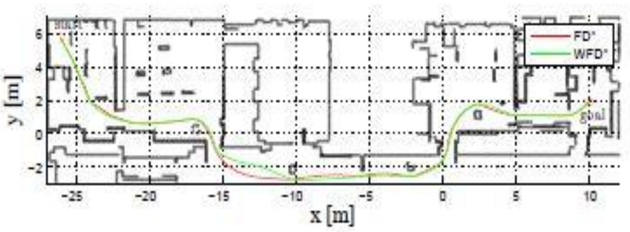

Fig.3.Mobile Robot trajectory followed by FD* path (42.81 m long) and robot's trajectory following the WFD* (42.67 m).

Hierarchical D*(HD*):

Daniel Cagigas et al. [16] developed a Hierarchical D* algorithm, a new hierarchical extension of the D* algorithm for robot path planning is introduced. This algorithm finds out the replanning and saves time and costs to improve the performance of the mobile robot. It allows the online path algorithm for optimality. It decreases the time to travel from the start node to the goal node in this path, divided into terrain vertical and horizontal path planning. The result of the algorithm works compare to the D* algorithm, HD* reduce the 50% of the computational time shown in Fig4.

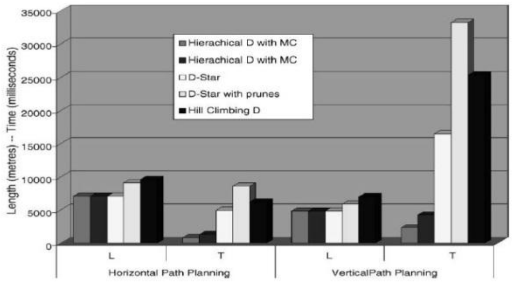

Fig.4. *L* indicates total path cost (length), and *T* indicates full computational time.

Field D*:

Dave Ferguson and Anthony Stentz [17] represented Field D* algorithm inspired by the D* algorithm. This is for interpolation-based planning and replanning algorithm for creating safe paths via an un-certain cost grid. We tested this algorithm in Pioneer robot, Automated E-Gator, Automated ATV, and GDRS XUV solution, which is, on average, 96% as costly as those generated by the D* Lite algorithm. We took 1.7 times as long as solutions. In re-planning, the results are similarly shown in Fig5.

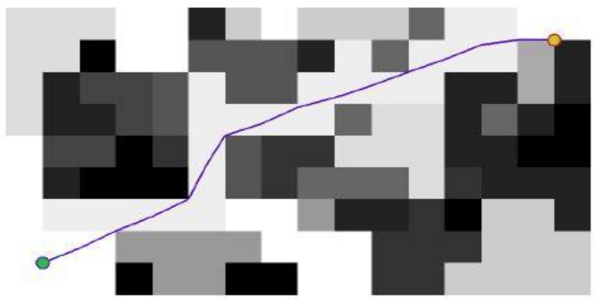

Fig.5. A close-up of a path planned using Field D* showing individual grid cells. Notice that the way is not limited to entering and exiting cells at corner points.

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Focussed Hierarchical D*(FHD*):

Marija Seder, PetarMostarac, and Ivan Petrovic et al. [40] developed the FHD* algorithm, Inspired by the Hierarchical D* (HD*) algorithm. Comparing the HD* algorithm, FHD* algorithm result is maximum optimum of the path, short time for path planning, and replanning. Few modifications made in the HD* algorithm for deriving this FHD* algorithm. These modifications create the bridge nodes for hierarchy creation, reduce the search area for loss of optimality, and reduce the time for replanning operation. It created partial starts and goals between nodes. The result of the FHD* algorithm is reduced the path cost, time, and memory size usage compare with HD*, FD* and D*. SO for replanning FHD* is very fast in a dynamic environment with a quick response shown in Fig 6.

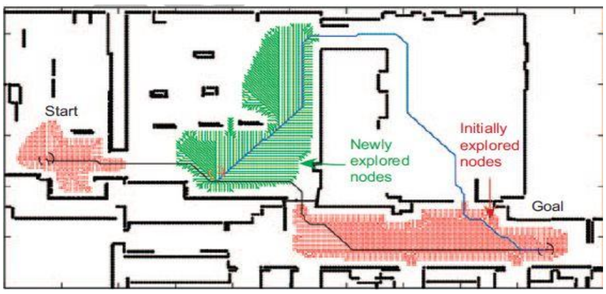

Fig. 6. The area searched by the FHD* algorithm.

Two-way D* algorithm:

MarijaDakulović, Ivan Petrović et al. [20] developed a Two-way D* algorithm, inspired by the Witkowski's algorithm, and they present a novel path planning and replanning algorithm (TWD*). Using this algorithm to find out the optimal paths in weighted occupancy grid maps, and this path is native to the D* algorithm. In this paper, they tested D* and TWD* algorithm using in both forward and backward searches of the graph [41] with eight unknown obstacles (o1 to 08) in different environments [42], [43]. The resultant path by the TWD* algorithm is shorter than the D* algorithm path, approximately 4%, and calculated the number of points between the path, it changes direction. It decreases the 60% lower sum of all path angels shown in Fig7. Based on these results, the TWD* algorithm approximately 20% faster than the D* algorithm.

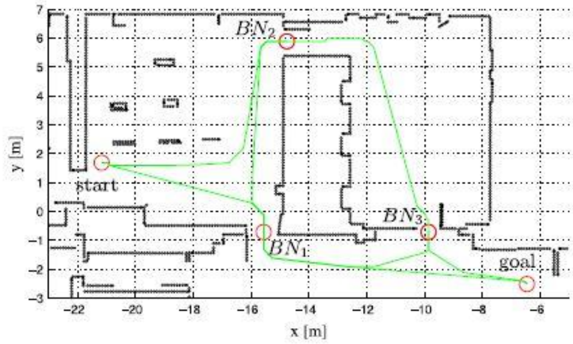

Fig.7.The set of pre-calculated paths between bridge nodes.

D* Lite:

Sven Koenig, Maxim Likhachev et al. [44] implemented the D* Lite algorithm for Fast Replanning for Navigation in Unknown Terrain. This algorithm developed inspired by the D* algorithm only. Both algorithms concept is the same but works differently. D* is a heuristic search method; it means they repeatedly determine the shortest path between the present position of the robot to a goal position in terrain. But the D* Lite algorithm builds on their LPA* (lifelong planning A*), and its most similarity is A*, it minimizes the priority queue to reach the current robot position to goal position in terrain. They concluded D* Lite algorithm is lightly efficient than the D* algorithm. And they suggested to researchers, to adapt this algorithm is useful in many applications of mobile robots.

Complete Coverage D*:

MarijaDakulović, SanjaHorvati, Ivan Petrovi'c et al. [45] developed a Completed Coverage D*

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algorithm inspired by the path transform (PT) algorithm of Zelinsky [46], based on the D* algorithm. CCD* algorithm works robot safety motion and reduction of path length, path search time, and terrain changes in high-resolution occupancy grid map [47]. PT algorithm works using a wavefront algorithm. It produces the cost values between every node up to the end node. These cost values are calculated by the propagation of one node to the remaining all free nodes to the goal node. And D* algorithm works fast planning and replanning paths. They tested this algorithm in a room-cleaning robot with completely known static obstacles and some unknown obstacles with moving continuously in the terrain. The robot starts from position R to goal position, G shown in Fig 8. While robot moving in this path detects any obstacle, it avoids and creates a new complete coverage path from that position to the goal position G. After completed the tests. They concluded that robot trajectory cells' visits slowlydecrease, which means path searching time very fast and short.

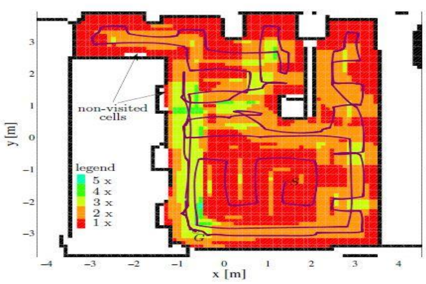

Fig.8.The complete trajectory plan from Start node S to Goal node G with visits of cells during the robot motion.

Genetic algorithm:

IBI Ashiru, Chris Czarnecki et al. [19] performed genetic algorithm real-time motion-planning algorithms for mobile robots to move in uncertain and unstructured terrain. They tested using this algorithm in three environments with and without obstacles. Implemented this algorithm in c++ running in UNIX OS. In the first environment is a single wall obstacle. The robot finds a path between the starting point to the goal point. And second and third environments were randomly positioned obstacles with a resolution of 80*80. Results of the single-wall obstacle environment using fitness function mutation rate is 0.003 and randomly placed obstacles environments mutation rate is up to 0.003 shown in Fig 11. Future work they implemented this method in collision-free path planning in a dynamic environment [48].

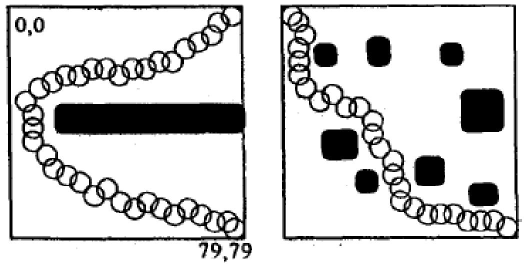

Fig.11. Robot paths from (0, 0) position to the goal position (79, 79)

Fuzzy-GA:

SapamJitu Singh, Sudipta Roy, KhumanthemManglem Singh, and ThongamKhelchandra et al. [49] used a technique of motion planning of robot using Fuzzy Method [50], [51] and Genetic Algorithm [52] along with Three Path concept in a dynamic environment. Using this concept calculated, the two types of solutions first are the distance and angles of obstacles from the robot moving path to endpoint [53]. Second is the moving obstacle velocity and velocity of the moving robot. Finally, they concluded that for dynamic obstacle avoidance Fuzzy-GA algorithm [54], [55], [56], is best and efficient to other hybrid methods shown in Fig12.

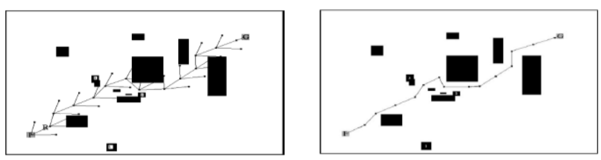

Fig.12. Robot paths from initial position to the goal position

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Table.1.List of motion Path planning algorithms.

S.No	Year	Method
1	1956	E.W Dijkstra [28] - Dijkstra's algorithm Two fundamental graph-theoretical problems.
2	1968	Hart [10] - A* algorithm Path-planning in an unknown environment.
3	1983	Witkowski's [18] - Witkowski's algorithm Parallel do searching and obstacle avoidance.
4	1994	Stentz [12] [13] - D* algorithm Planning in unknowing, partially known, and changing environment.
5	1995	Stentz [38] - Focused D* algorithm Reduced total time for start to goal the same as replanned.
6	1995	Ashiru.I&Czarneckic [19] - Genetic algorithm Optimizing a path planning and replanning for mobile robots in uncertain and Unstructured environments.
7	2005	Sven [44] - Dynamic A* (D* algorithm) Able to replan quickly as they are of the areas change.
8	2005	Daniel Cagigas [16] - Hierarchical D* (Extension of D* algorithm) For improving performance created a pre-calculated path.
9	2007	Ferguson &Stentz [17] - Field D* Interpolation based planning and replanning for creating safe paths in non-uniform cost Grids.
10	2009	Marija& Ivan [15] - WFD* (Focused D* &Witkowski's algorithm) Occupancy 2D grid map generated a new path planning and replanning.
11	2009	Marija Seder [40] - FHD* (Focused Hierarchical D*) Optimization of global paths.
12	2011	Marija& Ivan [20] - TWD* (Two-way D* algorithm) Path planning and replanning for weighted occupancy grid maps.
13	2014	Frantisek [11] - Modified A* algorithm Improvement s in Rectangular Symmetry Reduction and Jump Point Search.
14	2016	C. Saranya [57] - Modified D* algorithm Added distance, terrain slope, and cost function
15	2017	Ji-Hong-Li [58] – RBVG method Using a rubber band visibility graph for finding path planning for underwater vehicles.
16	2019	HaiyanWang,Zhiyu [59] - PSO algorithm (particle swarm optimization algorithm)

III. COMPARISON STUDIES

All hierarchical search algorithms and artificial intelligent algorithms have advantages and disadvantages. Some are suitable in a static environment, and some are dynamic environments in both planning and replanning. Compare all techniques mainly considered path planning time, replanning, and Obstacle Avoidance [60].

Table.2. Comparison of A*, D* and GA-Fuzzy methods

Method	Global Path	Local Path	Obstacles		Time
			Dynamic	Static	
A* Family	Yes	No	No	Yes	High
D* Family	Yes	Yes	Yes	Yes	High
GA-Fuzzy	Yes	Yes	Yes	Yes	Low

IV. CONCLUSION

In this review paper, after a referred lot of articles in the broad area of motion path planning using algorithms, each author method has been clearly explained and classified—this paper organized of each stage from Dijkstra's algorithm to current using methods GA and fuzzy approaches. As per the available data modification, D* algorithms exactly fir for dynamic environment free obstacle

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collision. Later motion path planning technology developed Fuzzy-GA technology used everywhere.

Table 3. Comparison of Initial and replanning of all algorithms

Type of Process	Considerations Points	D*	D* Lite	FD*	HD*	FHD*	CCD*	TWD*	FUZZY-GA
Initial	Grid Cells	200*200	200*200	200*200	200*200	200*200	200*200	200*200	200*200
	Path cells	187	188	187	187	187	185	188	188
	No. of Explored nodes	20500	8500	7405	4568	4015	3856	3000	2760
	No. of iterations	22560	18075	9587	8547	7452	4758	3874	2759
	Planning time[mille sec]	168	192	96	74	63	37	27	16
Replanning	Grid Cells	200*200	200*200	200*200	200*200	200*200	200*200	200*200	200*200
	Path cells	188	189	188	188	188	186	189	187
	No. of Explored nodes	17652	9054	12578	5264	4415	3702	3125	2859
	No. of iterations	22560	18075	9587	8547	7452	4758	3874	2759
	Planning time[milli sec]	183	205	127	91	78	43	35	24

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