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Optimal Path Planning using Equilateral Spaces Oriented Visibility Graph Method

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ABSTRACT

Path planning has been an important aspect in the development of autonomous cars in which path planning is used to find a collision-free path for the car to traverse from a starting point Sp to a target point Tp. The main criteria for a good path planning algorithm include the capability of producing the shortest path with a low computation time. Low computation time makes the autonomous car able to re-plan a new collision-free path to avoid accident. However, the main problem with most path planning methods is their computation time increases as the number of obstacles in the environment increases. In this paper, an algorithm based on visibility graph (VG) is proposed. In the proposed algorithm, which is called Equilateral Space Oriented Visibility Graph (ESOVG), the number of obstacles considered for path planning is reduced by introducing a space in which the obstacles lie. This means the obstacles located outside the space are ignored for path planning. From simulation, the proposed algorithm has an improvement rate of up to 90% when compared to VG. This makes the algorithm is suitable to be applied in real-time and will greatly accelerate the development of autonomous cars in the near future.

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1. INTRODUCTION

Path planning has been an emerging trend research nowadays to cater the needs of autonomous systems. Without path planning, autonomous cars could not be materialized. Currently, there are many path planning algorithms that have been developed based on methods such as Voronoi diagram (VD) [1], [2], cell decomposition (CD) [3], [4], genetic algorithm (GA) [5], [6] and visibility graph (VG), to name a few. A path planning algorithm's performance is normally measured based on three criteria which include the computation time, path optimality and completeness.

Basically, the main constraint that affects the computation time of path planning is the number of obstacles contained in a configuration space (C-space). In C-space size of the autonomous car is reduced to a point and the size of obstacle is enlarge based on the size of autonomous car [7]. The higher the number of obstacles in C-space, the higher the computation time to find a collision-free path.

An optimal path can be defined as the shortest path generated by a path planning algorithm among all the produced path commencing from the starting point Sp to the end point Tp [2], [8-11]. A path planning algorithm holds the completeness criterion if it is able to produce a path if one exists.

There are several types of path planning such as combinatorial and bio-inspired. Each of them has their benefits and drawbacks in satisfying the above-mentioned criteria.

VG is a complete algorithm and capable of producing a path with the shortest distance but its drawback is the computation time increases when the number of obstacles in C-spaces increases [9], [10], [12]. VD, on the other hand, uses equidistant techniques to discover a path for which an optimal path cannot be accomplished although it has relatively lower computation time and the algorithm is complete [2], [13].

CD divides the C-spaces into cells which are discrete and non-overlapping. A path is then produced through a cell that is not occupied by the obstacle. The drawback of this method is that it cannot produce optimal path albeit it has a lower computation time. CD is complete where it finds a path if one exists.

The bio-inspired type gets motivation from nature. An application of operators is used in the Genetic algorithm (GA) to emulate natural selection process. The disadvantage of GA is that there are possibilities of not finding the solution in narrow environments as the local minima conditions may occur. Conversely, GA works in parallel and thus, uses less computation time. It is meta-heuristics and hence, does not guarantee the shortest distance[5], [6], [14].

As VG is capable of producing the shortest path and complete, in this paper, an algorithm based on VG is proposed and the simulation is performed using MATLAB to evaluate the performance of the proposed algorithm.

2. PATH PLANNING ALGORITHM

The proposed algorithm, called Equilateral Space Oriented Visibility Graph (ESOVG), is depicted in Figure 1. The idea of the algorithm is to reduce the number of obstacles used when planning a path, which will in turn, lessen the computation time.

The algorithm starts with creating a base line, which connects the starting point Sp and target point Tp. The opening angle ρ is then set to nominal value of 20º. After that, a mid-point between Sp and Tp is identified. This is followed by creating a mid-line which is perpendicular to the base line and intersecting the mid-point. Then, a pair of imaginary lines, which emerge from Sp towards the mid-line with an opening angle of ρ are created. Similarly, another pair of imaginary lines emerging from Tp towards the mid-line are drawn. Both pairs of lines should intersect the points denoted by C_1 and C_2. The equilateral space, shown in darker colour, which is formed by four imaginary lines is illustrated in Figure 2.

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Algorithm:  ESOVG
1:          Create a base line connecting starting point Sp and target point Tp
2:          Set the nominal opening angle ρ to 20º
3:          Identify a mid-point on the base line between Sp and Tp
4:          Create a mid-line passing through the mid-point and perpendicular to the base line
5:          From each Sp and Tp, create a pair of imaginary lines with an opening angle of ρ towards the mid line.
6:          Create an equilateral space from the enclosed area by the four imaginary lines drawn in step 5
7:          Identify the obstacles, O located in the equilateral space
8:          Identify nodes list of the obstacle in step 7
9:          Construct a cost matrix based on the nodes list
10:         Find the shortest path from Sp to Tp using Dijkstra's algorithm
11:         If no path is found within the equilateral space, go to step 2 and increase ρ by 5º.
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Figure 1. The proposed algorithm

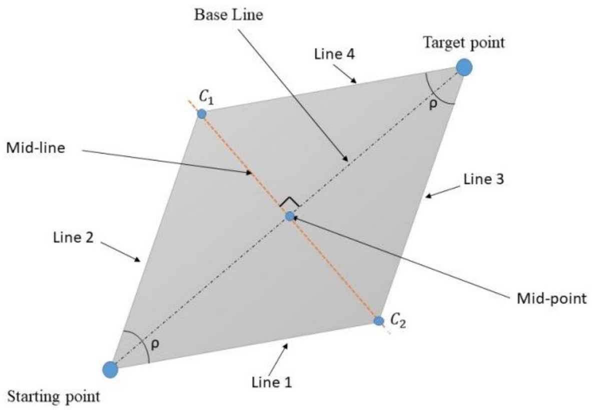

Figure 2. The equilateral space

In this algorithm, the size of the generated equilateral space depends on the opening angle ρ. The nominal angle is set at 20° so that the path planning can be performed with a low computation time as the number of obstacles contained in the area is small. However, if a path is not found in the space, the angle is then increased by 5º until one is found.

Figures 3(a)-Figure 3(d) show the simulation of ESOVG using ρ = 20º, 30º, 40º and 50°, respectively. The figures show 100 obstacles present in the C-spaces but only a few obstacles (shown in green) are being considered by ESOVG for path planning as they are fully or partially contained in the equilateral space (enclosed by the solid lines). On the other hand, the obstacles shown in white are ignored as they are totally outside the space. Notice that the smaller the opening angle ρ, the lesser the number of obstacles are taken into account. The computation time and path length for each ρ are shown in Table 1.

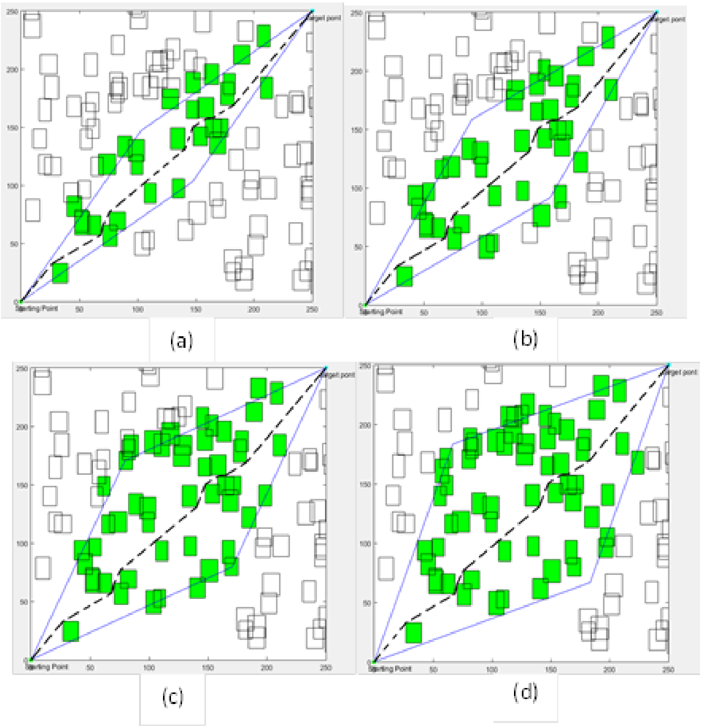

Figure 3. Simulation of path planning using ESOVG, (a) ρ=20°, (b) ρ=30°, (c) ρ=40°, (d) ρ=50°

Table 1. Computation time and path length using different values of ρ

ρ	Computation time (s)	Path length (unit)
20º	0.4389	645.675
30º	0.7145	645.675
40º	1.5478	645.675
50°	2.3856	645.675

The piecewise linear segments shown in dashed line are the resulting path of ESOVG. From Table 1, it is observed that as ρ is enlarged, the computation time increases. This is due to the fact that the number of obstacles contained in the equilateral space is increased by enlarging ρ. However, the path lengths are identical with different ρ. Thus, it is important to decide the value of ρ that can produce an optimal path while minimizing the computation time.

3. SIMULATION RESULTS

The efficiency of the algorithm can be observed through a simulation with different number of obstacles, i.e. between 15 and 150. These numbers of obstacles represent different density of the obstacles in a C-space. To see the effect of the opening angle ρ, three different values are applied which are 20°, 30º and

40°. Table 2 shows the comparison of computation time to search the collision-free paths by ESOVG with different number of obstacles and opening angles ρ. When ρ is 20º and with 15 obstacles in the search space, the computation time to find a path is 0.0679s. As ρ is enlarged to 30° and 40°, the computation times are 0.0955s and 0.1251s, respectively.

When the number of obstacles is increased to 120, the computation time at ρ=20° is 0.6156s. With the same number of obstacles, at ρ=30° and ρ=40°, the computation times are 1.0248s and 2.1233s respectively. With the number of obstacles of 150 in the C-space, at ρ = 20°, 30° and 40°, the computation times are 1.0334s, 1.6662s and 3.0275s, respectively. The simulation result shows that when ρ is small, which results in small equilateral space and a low number of obstacles, the computation time is lower. The trend of the computation times of the simulation is depicted in Figure 4.

The performance of the proposed algorithm is evaluated by comparing it with the conventional VG method. Table 3 shows the comparison of computation time and path length between the conventional VG and ESOVG with ρ=20°.

Table 2. Comparison of computation times with different values of ρ and obstacles

Number of obstacles	Computation time(s) at ρ=20°	Computation time(s) at ρ=30°	Computation time(s) at ρ=40°
15	0.0679	0.0955	0.1251
30	0.1311	0.1808	0.2753
45	0.1599	0.1992	0.3683
60	0.2439	0.2903	0.5371
75	0.3541	0.4602	0.8798
90	0.3880	0.5607	1.2418
105	0.4545	0.7324	1.5761
120	0.6156	1.0248	2.1233
150	1.0334	1.6662	3.0275

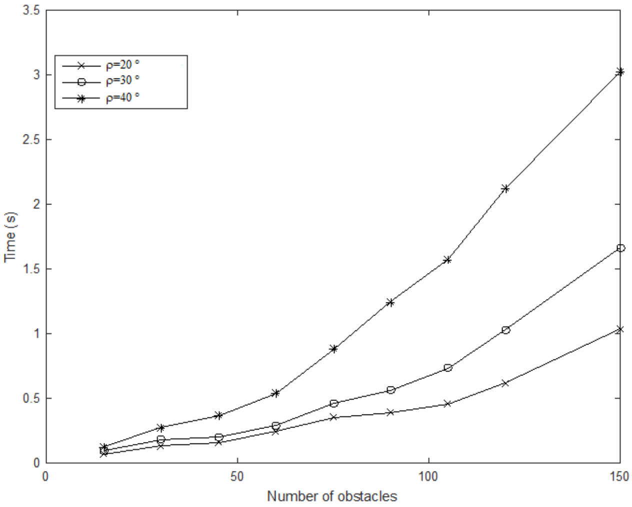

Figure 4. Simulation results of ESOVG with different ρ values and different numbers of obstacles

Table 3. Performance comparison between conventional VG and ESOVG

	Conventional VG		ESOVG with ρ=20°		
No of obstacles	Computation time (s)	Path length (unit)	Computation time (s)	Path length (unit)	Improvement rate (%)
15	0.1862	520.1343	0.0679	520.1343	63.5
30	0.6523	520.1342	0.1311	520.1343	79.9
45	1.4568	627.4492	0.1599	627.4492	89.0
60	2.2357	631.0024	0.2439	631.0024	89.0
75	3.2087	645.6750	0.3541	645.6750	89.0
90	4.4143	645.6750	0.3880	645.6750	91.2
105	6.0465	645.6750	0.4545	645.6750	92.5
120	7.3873	750.2258	0.6156	750.2258	92.0
150	11.8671	910.8723	1.0334	910.8723	91.3

When the number of obstacles is 15, the computation time for finding a path by conventional VG is 0.1862s, and by ESOVG is 0.0679s. ESOVG improves the computation time by up to 63.5 %. When the number of the obstacle is increased to 75, the computation time of conventional VG is 3.2087s while the ESOVG's is 0.3541s, which reduces the VG computation time by 89 %. With 150 obstacles in the environment, the computation time by conventional VG and ESOVG are 11.8671s and 1.0334s respectively. The improvement recorded by ESOVG is 91.3 %.

Figure 5 clearly shows the trends of computation times of conventional VG and ESOVG. The trend indicates that when the number of obstacles escalates, the computation time of conventional VG increases exponentially, whereas ESOVG has computation time that rises almost linearly.

In terms of path length, from Table 3, it can be seen that both VG and ESOVG produce path with identical lengths. This proves that while ESOVG reduces the computation time, it maintains the optimality of the resulting path in terms of length.

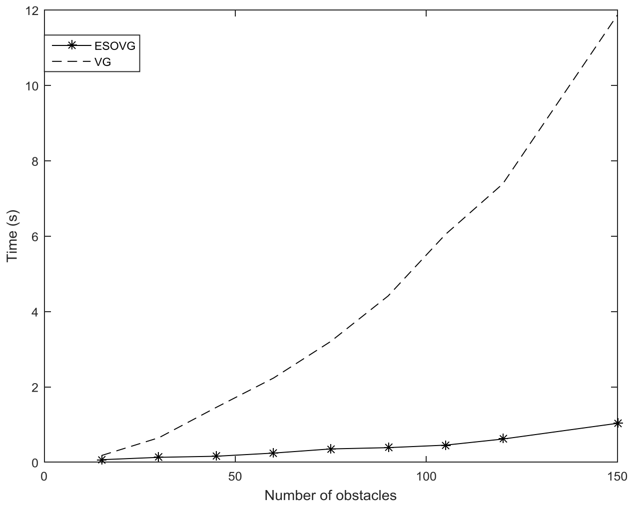

Figure 5. Comparison VG and Equilateral spaces VG

4. CONCLUSION

Equilateral Spaces Oriented Visibility Graph (ESOVG) algorithm has been proposed in this paper to overcome a high computation time in conventional VG. ESOVG creates an equilateral space using four imaginary lines to reduce the considered number of obstacles when planning a collision-free path. In ESOVG, the size of the equilateral space is determined by the opening angle ρ. The nominal value of ρ is set to 20° and if a collision-free path could not be found in the space, it will be increased gradually until a path is found in the space. ESOVG has been compared with the conventional VG in terms of computation time and path length. It was found that ESOVG was able to improve the computation time drastically in comparison with the conventional VG while the optimality of the path length was maintained. In the future ESOVG could be tested in a dynamic environment which has moving and pop-up obstacles. If ESOVG were success in dynamic environment, it could be applied in autonomous car, in which a lower computation time is necessary in order to be applied in real time.

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REFERENCES

[1] X. Chen and X. Chen, *"The UAV dynamic path planning algorithm researched based on Voronoi diagram,"* in 2014 26th Chinese Control and Decision Conference (CCDC), 2014, no. 61074159, pp. 1069–1071.
[2] C. Peng, X. Lu, J. Dai, and L. Yin, "Research of Path Planning Method Based On the Improved Voronoi Diagram," 2013, pp. 2940–2944.
[3] M. Kloetzer, "Optimizing Cell Decomposition Path Planning for Mobile Robots using Different Metrics," *IEEE*,

pp. 565–570, 2015.
[4] D. H. Kim *et al.*, “Path Tracking Control Coverage of a Mining Robot Based on Exhaustive Path Planning with Exact Cell Decomposition,” 2014, pp. 730–735.
[5] S. Ainasser, A. Imam, H. Bennaceur, and A. Imam, “An efficient Genetic Algorithm for the Global Robot Path Planning Problem,” pp. 97–102, 2016.
[6] Z. Yongnian, Z. Lifang, and L. Yongping, “An Improved Genetic Algorithm for Mobile Robotic Path Planning,” 2012.
[7] L. Lulu and A. Elnagar, “A comparative study between visibility-based roadmap path planning algorithms,” *Intell. Robot. Syst. 2005.(IROS*, 2005.
[8] M. S. Ganeshmurthy and G. . Suresh, “Path Planning Algorithm for Autonomous Mobile Robot in Dynamic Environment,” 2015, vol. 15, pp. 1–6.
[9] T. Nguyet, N. Duy-Tung, V. Duc-Lung, and T. Nguyen-Vu, “Global Path Planning for Autonomous Robots using Modified Visibilitygraph,” *IEEE*, vol. 13, pp. 317–321, 2013.
[10] T. T. Nhu Nguyet, T. Van Hoai, and N. A. Thi, “Some advanced techniques in reducing time for path planning based on visibility graph,” 2011, pp. 190–194.
[11] B. Siciliano, L. Sciavicco, L. Villani, and G. Oriolo, *Robotics Modelling Planning and Control*. Springer, 2009.
[12] M. Yingchong, Z. Gang, and P. Wilfrid, “Cooperative path planning for mobile robots based on visibility graph,” 2013, pp. 4915–4920.
[13] R. Gonzalez, C. Mahulea, and M. Kloetzer, “A Matlab-based Interactive Simulator for Teaching Mobile Robotics,” pp. 1–20, Sep. 2014.
[14] N. Achour, *“Mobile Robots Path Planning using Genetic Algorithms,”* ICAS 2011 Seventh Int. Conf. Auton. Auton. Syst., no. c, pp. 111–115, 2011.

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