Toggle Space Exploration

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1 Introduction

The motion planning problem considers an environment, robot, and start and goal point and finds a valid path. There are no known algorithms to efficiently solve this problem, making it computationally intractable [1]. Existing algorithms are very computationally expensive, or do not explore the environment. The aim of this project is to design an algorithm that efficiently finds a feasible solution, despite the complexity, doing so by decreasing the computation time while also exploring the space.

2 Prior Work

The main algorithms this project draws on are Probabilistic Road Map (PRM) [2] and Lazy PRM [3]. PRM is an algorithmic method for motion planning problems that does this by sampling points from the configuration space. Then, the validity of each sampled point is checked. The free points are then connected with edges, with each edge being validated and removed if it is not valid. This process is repeated until a stopping condition is met. This results in a valid road map, which is used to determine whether or not there exists a valid path. Edge validation is the most computationally demanding step, requiring hundreds of validity checks, or more, depending on the edge and environment.

Lazy PRM is an optimized variant of PRM that aims to reduce the computational complexity of PRM. Similarly to PRM, Lazy PRM samples points from the configuration space and checks the validity of each point. Again, like PRM, the free points are connected using edges, however, the edges are not validated immediately. These steps are repeated until a path is found between the start and goal position. Only once a path is found are the edges validated. If an invalid edge is found while validating the path, the edge is removed, and the process is repeated until a stopping condition is met. This algorithm typically has a lower complexity relative to PRM because it waits to validate edges that will probably not be used in the final solution.

3 Method

The Toggle Space Exploration (SET) algorithm follows a similar pattern to Lazy PRM but has some significant differences that allow it to explore the space, while still being close in complexity. One important adaptation of SET is using the Power Diagram. The Power Diagram is a version of the Voronoi Diagram, that approximates the influence regions of weighted points, considering both their spatial location and associated weights. Once a point is sampled, the power diagram is used to push the point to a less explored area in the configuration space. The validity is checked, similar to Lazy PRM. However, once the validity is checked, an n-dimensional sphere (n being the dimension of the configuration space) is expanded around the point. This sphere is expanded using the Annuli Expansion method.

Annuli Expansion begins by creating an annulus around a given point. Then, multiple samples are taken within the annulus, and if all samples' validity matches with the validity of the original given point, then the current annulus is kept and a new annulus is expanded around the last. This process is repeated until a stopping condition is met or a sample of the opposite validity is found, in which case the current annulus where the sample was found is removed and the sphere's outer annulus is the annulus created before the current annulus.

After the sphere is created, the free points already in the road map are then connected using either one-hop or two-hop edges. A one-hop edge connects free points whose corresponding spheres overlap using a straight edge. This edge is believed to be free and thus not validated. A two-hop edge shoots a ray from a point and if the ray hits the surface of a sphere whose validity is also free, one edge is added between the original point and the surface of the sphere, and another edge is added between the surface of the sphere and the sphere's corresponding center. The first edge can be validated, while the second edge is already believed to be free.

After each repetition of these steps, there is a query performed to see if a path exists. If there exists a path, similar to Lazy PRM, the path is validated. If the path is valid, or a stopping condition is met, then the algorithm stops. However, if the path is not valid, then, given the point that was invalid, the edge that the point was one will be invalidated and removed. Also, if the point lies inside of a sphere, the sphere will be re-expanded, with the maximum radius being the distance between the point and the center of the sphere. Once this process is completed, the end result is a road map with spheres of both free and obstacle validity, that should be able to approximate the space.

4 Results and Conclusions

The environment used for these experiments contains three large blocks of equal size, two of which are on the bottom, spread apart, and one on the top in between. This causes there to be one path from end to end. The width of these blocks varies, where the wider the block, the narrower the passage. However, the wider the block, the more likely it is to be found and identified.

The experiments were carried out using these variables: environment obstacle width (ranging from 1 to 6 relative to the environment which is 20 by 20), number of samples within a free annulus (using the values 15, 10, 6, and 3), and whether or not the two-hop edge was validated. The dependent variable used is the total number of collision detection calls.

The results showed that the thinner the width of the obstacle, the more annuli samples needed and two-hop edges result in more collision detection calls, regardless of whether the edges are validated. The results also concluded that SET does not really outperform Lazy PRM in the case of single queries.

5 Future Work

As a result of the above experiments, we believe that SET will perform better than Lazy PRM when using multiple queries, as SET explores the space and is able to give a good representation of the space, especially when compared to Lazy PRM. Thus, our future work will be looking into SET with multiple queries.

References

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[1] [2] [3]