Motion Planning

Department of Computer Science University of North Carolina at Chapel Hill February 2004

Highlights

- **Motion planning using hardware accelerated Voronoi computation.**
- **Motion planning in dynamic environments.**
- **Constraint-based planning.**

The Challenge

Motion planning is a classical problem in robotics, with applications to solid modeling, molecular modeling, computer animation, and many other areas. The problem can be posed as follows: Given a complex environment and a movable object, which we refer to as the robot, find a collision-free path for the robot from one specified position to another. Some example problems would be to plan how to move a piano through a cluttered room, to plan a path for an animated character, or find a way to remove a component of a complex engine. In general, the motion planning problem is extremely difficult to solve. In complex planning scenarios, a robot with a complicated shape may have to move and twist through a maze of very tight passages. In our work we have considered both rigid and articulated robots, moving in two and three dimensions.

The Approach

Our main approach to motion planning has been to use a method of *hardware-accelerated Voronoi computation* to gain geometric information that we can use to solve the planning problem. The Voronoi computation takes all of the edges, vertices, and polygons from the obstacles in the scene and generates proximity information at a large uniform sampling of locations in the environment. Thus, given a dense sampling of points in the scene, we know for each sample the closest obstacle and the distance to it. Intuitively, we get from the Voronoi computation information that tells us which parts of the environment are close to obstacles and which are not. Since we can compute this global geometric information quickly using graphics hardware, we have explored ways that it can be used to solve tough motion planning problems faster then previously possible.

Planning in Dynamic Environments

For a two-dimensional scene, the discrete Voronoi diagram can be computed many times a second. We exploited this ability to allow motion planning in the presence of moving obstacles. In each cycle, a new Voronoi diagram is generated, and information from the distance buffer is used to generate simulated forces that push the robot away from the obstacles. To draw the robot towards the goal, suitable points are chosen from the Voronoi graph to serve as sub goals. Since many 3D problems, like moving furniture through a house, can be expressed as 2D planning situations, this approach has many useful applications.

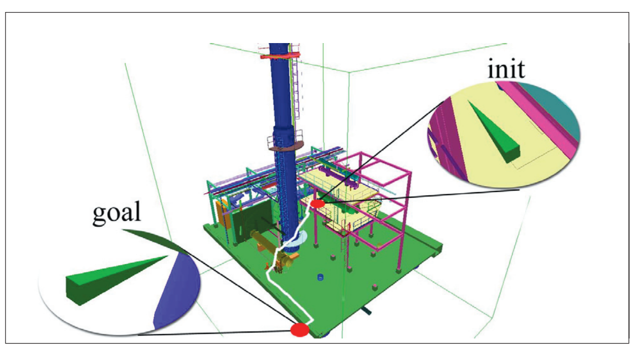
Voronoi-Biased Sampling

The key to the standard randomized planning approaches, like the PRM planner mentioned above, is that configurations of the robot are generated at random, sampling the space of possible robot poses. This technique has been found to work well for a wide variety of scenarios, but its performance degrades considerably when the robot must pass through a narrow passage of some sort to reach the goal. In these cases very many samples must be generated to produce a sufficient number lying in the narrow passage.

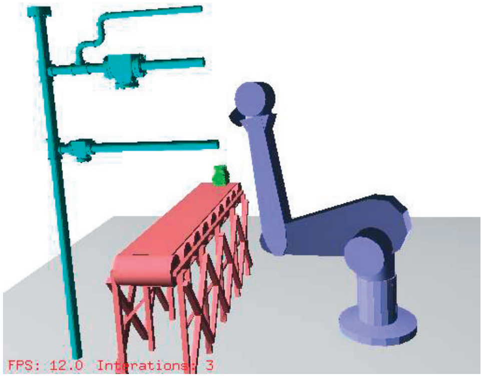
To ameliorate this problem, we first generated the Voronoi graph of the scene, and then biased our choice of samples to place the robot near the Voronoi graph. This tended to increase the proportion of samples that are ultimately usable. Samples chosen in this way are less likely to place the robot in collision than ones chosen uniformly. Furthermore, samples are not wastefully scattered across large open spaces but are concentrated near the Voronoi graph. This approach has resulted in a speedup of as much as an order of magnitude over an unbiased random approach.

vPlan

vPlan is a planner for free flying rigid and articulated robots in static 3D environments. In this approach, we attempt to maximize our use of the geometric information provided by the discrete Voronoi diagram while retaining the flexibility of some classical planning methods. From the proximity and distance information that we get from the Voronoi diagram, we can construct the Voronoi graph. This is a graph of edges that are equidistant from obstacles in the scene. By performing a graph search on the Voronoi graph, we



A wedge shaped robot navigates a complex crane environment with 128,000 polygons.



The robot arm must access a part on the moving conveyer belt, while avoiding a piping structure. The moving obstruction causes the robot to reactively modify its path to avoid collision.

find an estimated path for the robot. This estimated path tells us how to move the robot from the starting position to the goal position through maximally clear areas of the scene. But it does not tell us how to orient the robot as it follows the path, which is a major component of the planning problem whenever the robot has a complicated shape and is large compared to the environment. To align the robot along the estimated path, we orient the robot by aligning its major axis along the tangent direction of the path. This has worked well for robots with elongated shapes.

We perform a post-processing step in which the estimated path is checked for collision of the robot with the environment. Segments of the path where the robot collides are removed and are replaced by paths generated using a standard local planning technique from a PRM Planner (Probabilistic Roadmap Planner). The advantage of our technique over just using the PRM planner is that the Voronoi computation allows us to solve much of the planning problem very quickly, so that we can restrict our use of the PRM planner to a small neighborhood around an invalid segment. In this way, we use our geometric information to concentrate random sampling only in the areas in which it is needed, greatly reducing the total number of samples generated. From this we have observed speedups of more than an order of magnitude in some scenarios, as compared to the pure PRM method.

Constraint-Based Motion Planning

We recently developed a novel framework for motion planning of rigid and articulated robots in complex, dynamic, 3D environments. It is based on transforming the motion planning problem into the simulation of a dynamical system. Motion of each rigid robot is subject to the influence of virtual forces induced by all types of geometric constraints. These may include constraints to enforce joint angle limit and connectivity constraints for articulated robots, constraints to enforce a spatial relationship between multiple collaborative robots, or constraints to have the robot follow an estimated path to perform certain tasks in a sequence. The resulting algorithm uses all contributing forces to move the robot along the estimated path, while avoiding collision with obstacles and enforcing joint and positional constraints. Our algorithm works well in dynamic environments with moving obstacles and is applicable to challenging planning scenarios where multiple robots must move simultaneously to achieve a collision free path. We demonstrate its effectiveness on parts removal, automated car painting, and assembly line planning.

Project Members

Ming C. Lin, professor
Dinesh Manocha, professor
Mark Foskey, adjunct reseach assistant professor
Maxim Garber, graduate student

Past Project Members

Timothy Culver, Kenny Hoff, John Keyser, Charles Pisula

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Selected Publications

Garber, M., and M. Lin. "Constraint-Based Motion Planning for Virtual Prototyping," *Proc. ACM Symposium on Solid Modeling and Applications*, 2002.

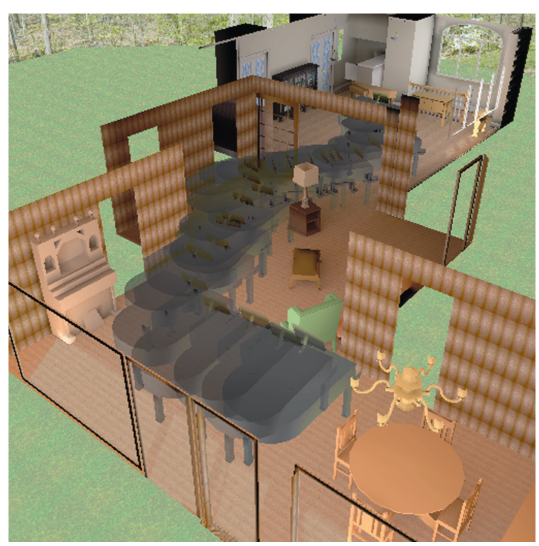
Foskey, M., M. Garber, M. Lin, and D. Manocha. "A Voronoi-Based Hybrid Motion Planner," *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2001.

Hoff III, K. E., T. Culver, J. Keyser, M. Lin, and D. Manocha. "Interactive Motion Planning Using Hardware-Accelerated Computation of Generalized Voronoi Diagrams," *Proc. IEEE International Conference on Robotics and Automation*, 2000, 2931–2937.

Pisula, C., K. Hoff III, M. Lin, and D. Manocha. "Randomized Path Planning for a Rigid Body Based on Hardware Accelerated Voronoi Sampling," *Proc. Fourth International Workshop on Algorithmic Foundations of Robotics*, 2000, SA31–SA44.

Related Work

- gamma.cs.unc.edu/PIVOT/
- gamma.cs.unc.edu/voronoi/



A piano avoids moving furniture as it navigates through a cluttered house.