Constraint-Based Motion Planning*

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FRAMEWORK

We present a novel framework for motion planning of rigid and articulated robots in complex, dynamic, 3D environments. This research is inspired by constrained dynamics in physically-based modeling. We transform the motion planning problem into a dynamical system simulation by treating each robot as a rigid body or a collection of rigid bodies moving under the influence of all types of constraint forces. These may include constraints to enforce joint connectivity and angle limits for articulated robots, constraints to enforce a spatial relationship between multiple collaborative robots, constraints to avoid obstacles and self-collision, or constraints to have the robot follow an estimated path, such as one computed from a generalized Voronoi diagram.

The solution to the motion planning problem is the collection of configurations of the dynamical system that satisfy all geometric and mechanical constraints. They can be computed by using various constraint solving techniques, such as optimization, local iteration, symbolic algebraic solvers, etc. Furthermore, this algorithmic framework can be extended to handle robots and environments that deform over time governed by the law of physics. Our constraint-based planning framework has the following characteristics:

- It can handle both static environments and dynamic scenes with moving obstacles.
- It is applicable to both rigid and articulated robots of arbitrarily high degrees of freedom, as well as multiple collaborative agents.
- It allows various types of geometric constraints.
- It runs in real time for modestly complex environments.

CONSTRAINTS

Constraints are used to both enforce relationships between the objects in the scene, and also to guide the robots' behavior with heuristics that will help solve the planning task. We classify the constraints in our system into two basic types.

Hard Constraints

These are constraints that must be maintained at every step of the simulation to ensure a valid path. In our implementation they are solved using Gauss-Siedel iterative relaxation. Example hard constraints include: object non-penetration, articulated robot joint connectivity, and articulated robot joint angle limits.

Soft Constraints

These constraints allow the user to impose heuristics that will guide the robot to its planning solution. They are implemented in our work using penalty forces. Example soft constraints include: goal attraction, obstacle repulsion, and following a precomputed estimated path.

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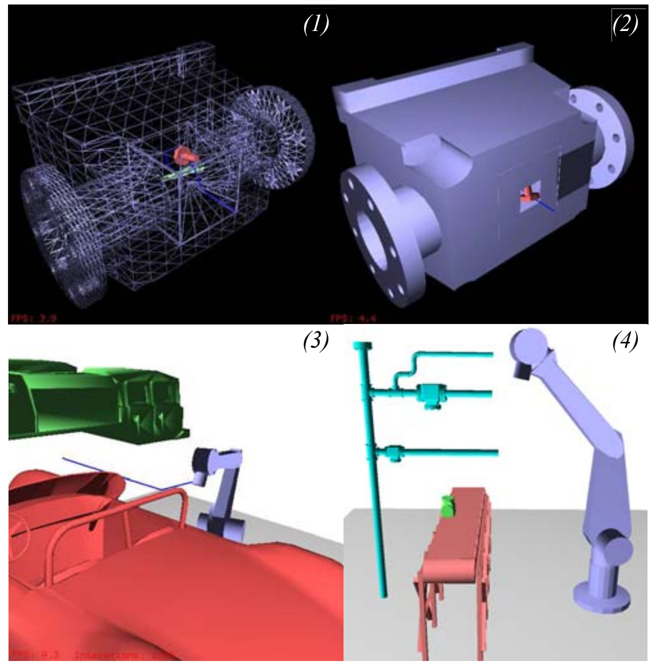
EXAMPLE SCENES



Figures 1 & 2 Maintainability Study: Two robots, a nut and a bolt, maneuver in a pump assembly until the bolt is extracted.
Figure 3 Auto Painting:An an articulated robot arm with 6 joints follows a path along the car body without colliding with obstacles.
Figure 4 Assembly: The articulated robot reaches for a moving part on a conveyer belt while avoiding a moving pipe structure.

FUTURE WORK

Future extensions include (a) inclusion of additional constraints, such as maintaining line of sight contact or other complex geometric relationships, dynamic and non-holonomic constraints; (b) extension to flexible geometry that deforms over time due to contact; (c) incorporation of direction human interaction & control.

RELATED PUBLICATIONS

- M. Garber and M. Lin. Constraint-Based Motion Planning Using Vornoi Diagrams. To appear in *Proc. of WAFR'*2002.
- M. Foskey, M. Garber, M. Lin, and D. Manocha. A Voronoi-Based Hybrid Motion Planner., 2001. *Proc. IEEE/RSJ International Conf. on Intelligent Robots and Systems*
- K. Hoff, T. Culver, J. Keyser, M. Lin, and D. Manocha. Interactive Motion Planning Using Hardware-Accelerated Computation of Generalized Voronoi Diagrams. *Proc. of IEEE International Conference on Robotics and Automation*, 2000.