



Physically-based Motion Planning

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The Challenge

Motion planning encompasses a vast area of research which has received considerable attention for several decades. It has a wide variety of applications; including robot motion control, autonomous vehicle navigation, virtual prototyping, medical procedure simulation, and character animation. Motion planning research attempts to solve the problem of how to find a collision-free path for a robot through an environment with obstacles. The primary challenge of motion planning is that its complexity is exponential in the number of degrees of freedom of the problem. For instance, a complete solution would be intractably difficult for an agent with a large number of joints or a completely deformable agent. And, in many cases, these solutions do not account for the dynamics of the agent that governs its motion. Our goal is to provide a practical solution for planning of these high complexity robots while also generating realistic motion.

Approach

We propose a novel method called Physically-based Motion Planning (PMP). The idea motivating PMP is that it is not always necessary or even desirable to search and explore the space of all possible robot configurations, the configuration space. Instead, in many realistic scenarios it is sufficient to guide a robot through the environment while allowing it to locally adjust and adapt to the obstacles around it. The local adjustments only depend on the equations governing the agent's motion, so PMP is applicable to a wide variety of agents, from snake-like robots to deformable tubes and vehicles.

The core of PMP consists of an iterative simulation and integration loop and a set of motion equations and biasing forces (See Figure 1). By applying virtual constraint forces to the agent, its motion can be influenced or encouraged

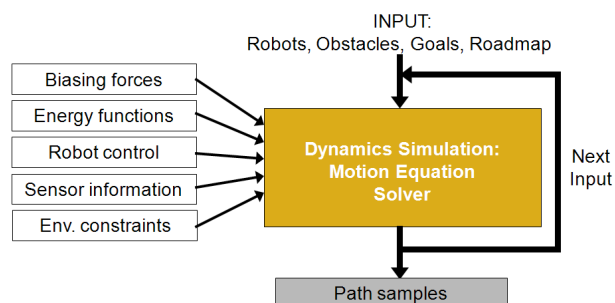


Figure 1: Physically-based Motion Planning system architecture. Inputs including artificial biasing forces, the environment, and the agent state are used to generate the next configuration for the agent.

Highlights

- **Dynamic simulation allows simple changes to behavior of planner and agent; from goal attraction, obstacle avoidance, or inaccuracies in sensing.**
- **Generates motion which satisfies kinematic, dynamics, and mechanical constraints on the agent and its motion.**
- **Coherence greatly reduces total planning time in complex environments.**

toward the goal. These biasing forces can also be used to locally avoid obstacles while also accommodating for noisy input or sensor information. Other bias may include all valid agent configurations biased by other governing constraint equations, as well as the agent's previous configurations. This approach greatly improves planning performance by avoiding an expensive search through a very high-dimensional configuration space. Additional performance gains can be achieved by exploiting the temporal coherence of the robots. For instance, joints in an articulated body can be held constant, or rigidified, when they contribute little to the global motion. In this way, we reduce the dimensionality of the problem, which also helps to improve performance. Since all motion is described with motion equations, the resulting path obeys any kinematic, dynamic, or mechanical constraints necessary for the agent.

Results

We tested our algorithm on a number of benchmarks. In each case, a highly articulated robot in a serial linkage must navigate through an environment. The goal of the planning is for the end effector to reach a certain position in the workspace. The base links of the robot, including the thin rigid bodies are shown and described in Figure 2 and Figure 3. Our method achieves significant performance improvement upto 1-2 orders of magnitude, as observed in the benchmarks shown.

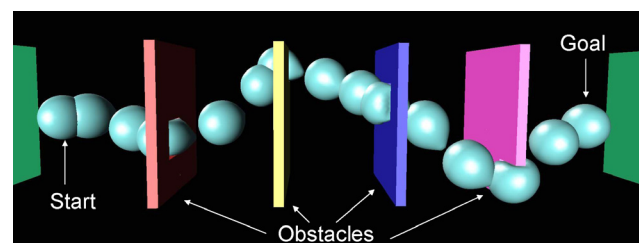


Figure 2: Planning results for a deforming sphere navigating through a series of walls. The sphere has over 5,000 surface elements.

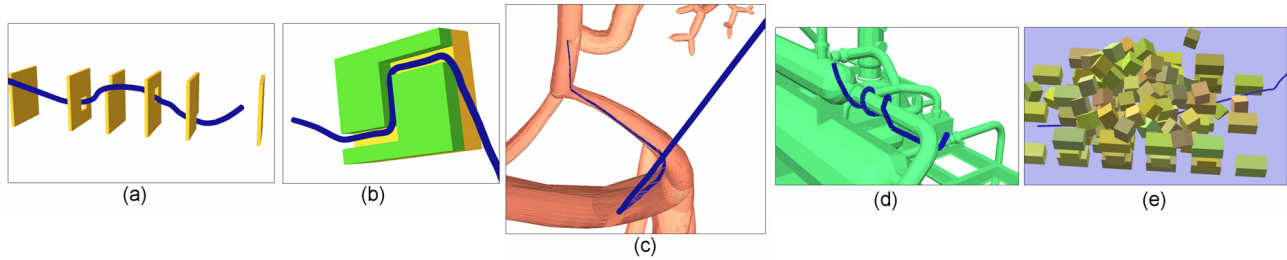


Figure 3: Highly articulated bodies in various benchmarks. (a) Serial Walls (300 DoF), (b) Tunnel (600 DoF), (c) Catheterization (2,500 DoF), (d) Pipes (2,000 DoF), (e) Search and rescue among debris (2,000 DoF)

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Selected Publications

R. Gayle, S. Redon, A. Sud, M.C. Lin, and D. Manocha. “Efficient Motion Planning of Highly Articulated Chains using Physics-based Sampling,” *Proc. of International Conference on Robotics and Automation (ICRA)*, 2007.

R. Gayle, M.C. Lin, and D. Manocha. “Adaptive Dynamics with Efficient Contact Handling for Articulated Robots,” *Proc. of Robotics: Science and Systems*, 2006.

R. Gayle, W. Segars, M.C. Lin, and D. Manocha. “Path Planning for Deformable Robots in Complex Environments,” *Proc. of Robotics: Science and Systems*, 2005.

R. Gayle, M.C. Lin, and D. Manocha. “Constraint-Based Motion Planning of Deformable Robots,” *Proc. of International Conference on Robotics and Automation (ICRA)*, 2005.