Fast Manipulation Path Planning for Humanoid Robots

– 感覚行動統合全身型ヒューマノイド H6 での実現 –

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Abstract—We present an interactive manipulation path planner under development for providing high-level task-based control for humanoid robots. Using a graphical simulation environment, the software is designed to facilitate the automation of object grasping and manipulation tasks. A randomized path planner is used to directly search the free configuration space of the robot for a collision-free manipulation path. Experimental results are shown using a model of the dynamic humanoid "H6" robot in a virtual world.

Key Words: Humanoid Robot, Object Manipulation, Path Planning, Randomized Algorithm

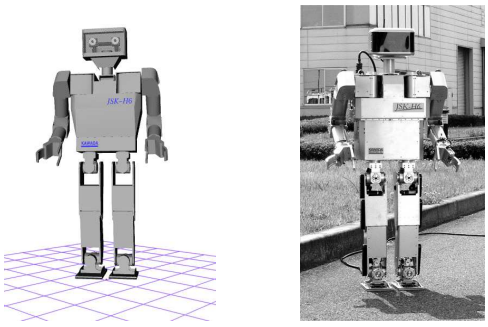

Fig.1 The virtual and real dynamic humanoid 'H6'.

1. Introduction

As the technology and algorithms for real-time 3D vision and tactile sensing improve, humanoid robots will be able to perform tasks that involve complex interactions with the environment (e.g. grasping and manipulating objects). The enabling software for such tasks includes motion planning for obstacle avoidance, and integrating planning with visual and tactile sensing data.

To facilitate the deployment of such software, we are currently developing a graphical simulation environment for the H6 dynamic humanoid robot[1]. The project builds upon a software framework that was originally developed for the high-level control of computer animated characters in 3D virtual environments[2]. The software automatically computes object grasping and manipulation trajectories through a combination of inverse kinematics and randomized path planning. Feasible manipulation trajectories can be computed at interactive rates. We hope that through the use of such interactive simulations, the current and future capabilities of humanoid and other complex robotic systems can be improved.

2. Robot Model and Assumptions

We have based our simulation experiments on an approximate model of the H6 dynamic humanoid robot, including the kinematics and link geometry (see Fig 1). Although the current manipulation planner computes a strictly kinematic path, dynamic models have been used to generate stepping motions[3] and to plan dynamically-stable full-body motions[4].

Environment Model: We assume that the robot has acquired a 3D model of the surrounding environment (e.g. using stereo vision), and has localized itself. The model need not be exact, provided that a reasonable model of sensing error is taken into account by the planner, and that it is possible to obtain visual or tactile feedback while executing the manipulation motion in order to adjust for errors.

Task Specification: The robot is given a high-level task command such as *"move the book to the top shelf"*. The task command is provided explicitly by a human operator (e.g. voice commands), or issued by top-level behavior software. For these experiments, we have focused on tasks that can be accomplished by a single arm, though the planner could potentially be extended to handle tasks which require both arms. Given the target object and new location, the motion planning software will then attempt to compute collision-free arm trajectories to grasp, reposition, and release the object at the new location.

Inverse Kinematics: We assume that an inverse kinematics algorithm is available for computing body configurations from world space frames. Our current inverse kinematics algorithm uses only the arm joints, thus the torso remains fixed during the motion.

3. Manipulation Path Planning

Path planning problems involve searching a system configuration space for a collision-free path connecting a given start and goal configuration[5]. For problems in low dimensions, the configuration space can often be explicitly represented and exact algorithms can be used effectively. For high-dimensional configuration spaces however (such as 6 DOF robot arms), it is typically impractical to explicitly represent the configuration space. Instead, the space is *sampled* in order to discover free configurations (e.g. probabilistic roadmaps[6]). Here, the fundamental challenge lies in devising a practical and efficient sampling strategy.

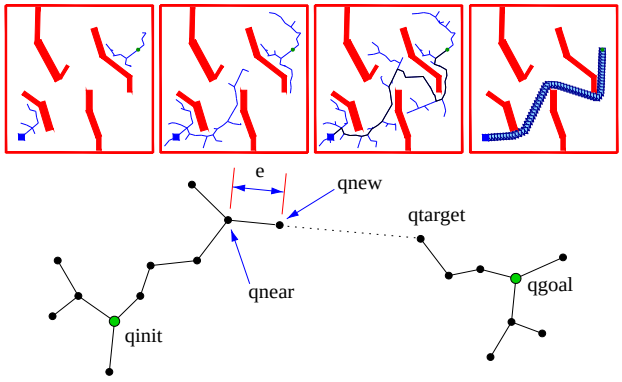

Fig.2 RRT-Connect builds a connection between trees.

We have built our simulations upon a randomized path planner with a sampling heuristic, known as *RRT-Connect*, which has been specifically designed to quickly handle single-query path planning problems without any preprocessing of the configuration space[7]. The planner incrementally builds two Rapidly-Exploring Random Trees (RRTs)[8] of free configurations rooted at the start and the goal (Fig 2). RRTs are biased to expand towards the unexplored regions of the space, and have been shown to ultimately converge toward a uniform distribution over the free configuration space [7].

4. Experiments

We have implemented a prototype path planner that provides an interactive high-level control mechanism for object manipulation tasks. Through a graphical user interface, an operator can click and drag an object to a target location and issue a *move* command. The software will then automatically compute the motions necessary to complete the task. Inverse kinematics is used to compute goal configurations from target reference frames.

Fig 3 shows the humanoid robot H6 repositioning a bottle from the lower shelf to the upper shelf. Each of the motions to reach, grasp, and reposition the bottle were generated using the planner in less than two seconds on average over 100 trials on a 270MHz SGI O2 workstation (see the table below). The arm consists of a 7-DOF kinematic chain.

Task	avg. time(sec)	std
Bottle (reach)	1.15	0.63
Bottle (reposition)	1.87	1.02
Bottle (release)	1.07	0.51
Coffee Pot (reach)	0.92	0.43

5. Discussion

We have given an overview of an experimental interactive path planner for automatically generating manipulation trajectories for humanoid robots. There are many potential uses for such software, with the primary one being a high-level control interface for solving complex object manipulation tasks. By using a graphical simulation environment, sophisticated motion generation algorithms can be efficiently developed and debugged, reducing the costs and safety risks involved in testing software for humanoid robots. Future work includes extending the planner to handle multi-arm tasks, taking into account the arm and

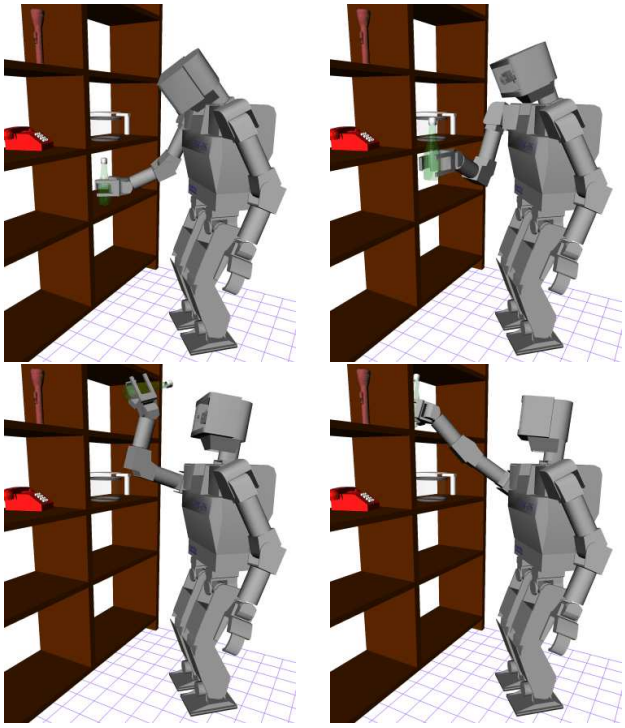

Fig.3 The H6 humanoid robot repositioning a bottle.

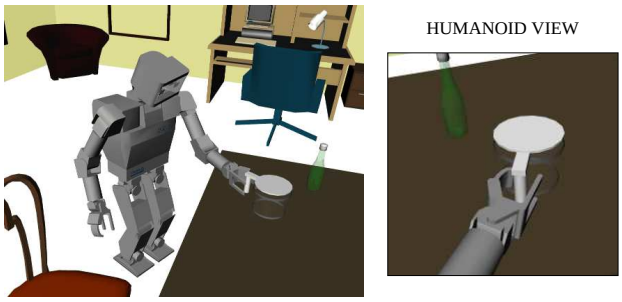

Fig.4 Reaching and grasping a coffee pot.

object dynamics, and integrating visual and tactile feedback into the planning process.

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