ARTICLE IN PRESS
ARTINT:2834

Artificial Intelligence ••• (••••) •••–•••

Contents lists available at ScienceDirect

Artificial Intelligence

www.elsevier.com/locate/artint

Geometric backtracking for combined task and motion planning in robotic systems ☆

Julien Bidot, Lars Karlsson, Fabien Lagriffoul, Alessandro Saffiotti *

Centre for Applied Autonomous Sensor Systems, Örebro University, Sweden

ARTICLE INFO

Article history:
Received in revised form 10 February 2015
Accepted 21 March 2015
Available online xxxx

Keywords:
Combined task and motion planning
Task planning
Action planning
Path planning
Robotics
Geometric reasoning
Hybrid reasoning
Robot manipulation

ABSTRACT

Planners for real robotic systems should not only reason about abstract actions, but also about aspects related to physical execution such as kinematics and geometry. We present an approach to hybrid task and motion planning, in which state-based forward-chaining task planning is tightly coupled with motion planning and other forms of geometric reasoning. Our approach is centered around the problem of *geometric backtracking* that arises in hybrid task and motion planning: in order to satisfy the geometric preconditions of the current action, a planner may need to reconsider geometric choices, such as grasps and poses, that were made for previous actions. Geometric backtracking is a necessary condition for completeness, but it may lead to a dramatic computational explosion due to the large size of the space of geometric states. We explore two avenues to deal with this issue: the use of heuristics based on different geometric conditions to guide the search, and the use of geometric constraints to prune the search space. We empirically evaluate these different approaches, and demonstrate that they improve the performance of hybrid task and motion planning. We demonstrate our hybrid planning approach in two domains: a real, humanoid robotic platform, the DLR Justin robot, performing object manipulation tasks; and a simulated autonomous forklift operating in a warehouse.

1. Introduction

Planning for robotic systems requires the combined use of several kinds of reasoning, in particular causal reasoning and geometric reasoning. This paper addresses how to combine these forms of reasoning. Consider the following example. The humanoid robot Justin (Fig. 1) is given the task to put two cups on the red tray. Justin is equipped with a task planner, and the planner generates a plan consisting of four actions: *pick up first cup, put down first cup on tray, pick up second cup, put down second cup on tray.* This plan is then put to execution: Justin selects the first action, calls a motion planner to find a suitable collision-free motion path, follows it, and then goes to the next action. Unfortunately, when executing the first put-down action, the motion planner decides to put the cup at the center of the tray. When Justin tries to put down the second cup, it finds no valid path because there is no sufficiently large free space left on the tray. Plan execution fails. What is worse, recovering from this failure might be impractical, since it involves undoing previous actions to redo them differently — said differently, it involves backtracking in the physical world.

☆ Note from the Editors-in-Chief: although a guest editor of the special issue of which this article forms a part, Alessandro Saffiotti played no part in the reviewing process for this paper.

* Corresponding author.
E-mail address: asaffio@aass.oru.se (A. Saffiotti).

http://dx.doi.org/10.1016/j.artint.2015.03.005

Please cite this article in press as: J. Bidot et al., Geometric backtracking for combined task and motion planning in robotic systems, Artificial Intelligence (2015), http://dx.doi.org/10.1016/j.artint.2015.03.005

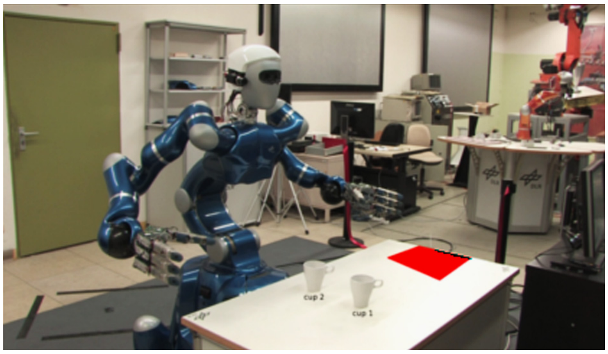

Fig. 1. The robot Justin at DLR, about to manipulate two cups. The red tray is at the far end of the table. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The reason for this failure was that the task planner did not take geometry into account. If it had, it might have detected that the plan could fail depending on the placement of the first cup. Even better, it might have been able to select, at planning time, a position for the first cup which left enough space for the second cup. Abstracting from the geometric details is customary in AI planning, but it may lead to problems such as the one above when planning the actions of a robotic system. This paper describes a hybrid planner that reasons both at the task level and at the geometric level.

1.1. Experimental platforms

Throughout this paper, we use *Rollin' Justin*, or simply Justin, as our main test-bed. The robot Justin has been developed at the institute of Robotics and Mechatronics at the German Aerospace Center (DLR) in Oberpfaffenhofen. This is one of the most advanced humanoid research robots, equipped with two arms with four-fingered hands, a head with stereo vision, and a base with four wheels mounted on extensible legs. The upper body of Justin has 43 degrees of freedom (DOF): 7 for each arm, 12 for each hand, 3 for the torso and two for the neck [1]. Like other complex robotic systems, Justin was until recently dedicated to performing only tasks involving pre-specified objects and action sequences, at least at an abstract level. The work reported in this paper originated in the European FP7-project GeRT,[1] aimed among other things at providing Justin with general task planning capabilities. Not surprisingly, one of our first findings when trying to apply existing AI planning techniques to a complex platform such as Justin, was that task planning and motion planning cannot be done independently, lest the robot find itself in situations such as the one in the vignette above. Combining task and motion planning is a challenging issue, and it is the object of growing interest in the AI and the robotics fields — see next section.

Justin is an excellent platform to study the intricacies of combining task and motion planning. However, the approach presented in this paper is not limited to table-top manipulation, and it may be applied to more mundane domains such as transportation and logistics. Consider a warehouse where an autonomous forklift truck controlled by an automated planner must move pallets around. Space and kinematic constraints must be taken into account carefully at planning time: if not, the truck may encounter execution failures similar to the ones above, and may have to perform unnecessary back and forth maneuvers to recover from these. For example, suppose that the truck is to move two pallets to a shipping area. If the shipping area can only fit two pallets and is close to walls, it is crucial that the pose of the first pallet is chosen such that (i) there is enough space left for the second pallet and (ii) the forklift can reach the pose for undocking to the second pallet. In this paper, we apply our hybrid planner to a warehouse domain, and we show how it deals with problems like the one above. Our warehouse testbed is simulated, but it is inspired by a real-world industrial scenario. Fig. 2 shows an image from this scenario involving an autonomous Linde forklift equipped with computing and sensing resources.

1.2. Contributions

In this paper, we present a combined task–motion planning system which combines search on the task planning level with search on the motion planning level. The key idea is to use two levels of backtracking: action backtracking to reconsider *what* actions to perform, and geometric backtracking to reconsider *how to* perform those actions on the geometric level. Through this combined search, we can address the problem in the opening scenario by finding at planning time a better pose for the first object when we detect that there is insufficient space to place the second one. The combined task–motion search space may grow extremely large, so we study several ways to manage this complexity.

[1] See http://www.gert-project.eu.

Please cite this article in press as: J. Bidot et al., Geometric backtracking for combined task and motion planning in robotic systems, Artificial Intelligence (2015), http://dx.doi.org/10.1016/j.artint.2015.03.005