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Dual Arm Manipulation Strategy for Tight Space Manipulation

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With the increase in automation and usage of collaborative robots in both fixed and changing environments, there is a high interest in utilizing dual arm robots to expand the possibilities to manipulate more complex or heavy objects with human-like capabilities. However, planning for dual arm manipulation is more complicated and is even more challenging when done in tight spaces in a changing environment, due to the added constraints that need to be fulfilled and the much-reduced feasible solutions. In this paper, we explore and discuss our current strategies to increase the chance of successfully finding the solutions to the dual arm manipulation planning problems, especially when performed in tight spaces. The problem statement is described, and the experimental simulations are reported and analyzed.

1. Introduction

With the recent advancement in the robotics technology, there is a high interest in implementing dual arm manipulation to replicate and replace human workers without major redesigns of the workspace. In general, dual arm manipulation can be classified into non-coordinated manipulation, where the two arms perform two separate tasks, and coordinated manipulation, where the two arms carry out different functions of the same task. Coordinated manipulation itself can be classified into goal-coordinated manipulation, where the two arms work towards the same goal but do not physically interact with each other, and bimanual manipulation, where the two arms physically interact with the same object [1].

Analyzing non-coordinated dual arm manipulation is essentially similar to analyzing multiple single arms as they do not need to coordinate between each other. On the other hand, analyzing coordinated dual arm manipulation requires additional amounts of both high-level and low-level synchronizations between the two arms. Particularly, planning for bimanual manipulation requires dealing with kinematic closed-chain constraints which considerably amplify the complexity of the problem [2].

To perform motion planning under constraints, the constraints can usually be incorporated into the architecture of the commonly used random sampling-based algorithms [3]. Several numerical techniques that can be used to apply such constraints without altering the core of the sampling-based algorithms include projection, tangent spaces, and atlas [4-7]. However, planning under closed-chain constraints can be seen as a case of the well-known narrow corridor problem, where the solution must find its way through a small area with the probability of being randomly sampled is not just low, but null [8]. One proposed way to circumvent this is through informedly sampling the solution in the subsets of the constraints to increase the probability of randomly generating valid configurations [9-11], which requires complicated and structure-dependent kinematic decomposition and application of closed form analytical inverse kinematics.

In this work, we are trying to tackle the two major challenges in motion planning simultaneously, namely planning for the motion of bimanual manipulation navigating through narrow spaces. Several strategies that we employed in order to increase the chance of successfully finding a solution include: 1) fixing the orientation of the end effectors of the dual arms, 2) goal-oriented sampling in task space, and 3) checking the constraint conditions separately for the two arms. In section 2, we describe the case study that motivates this work. Section 3 describes the approach that we employ to solve the motion planning problem and section 4 reports the simulation results.

2. Problem Description

The particular case study that motivates our work is the process of twist-lock handling in the container industry. While the logistics industry is moving towards a complete automation of the whole procedure of container handling, the process of removing and fixing the twist-locks which secure the shipping containers is still very much manually performed by human. Two major difficulties of automating this process from motion planning point of view is the need to employ dual arm coordinated manipulation to fulfill the task, as well as the tight and narrow spaces for the arms to navigate in between the container and the trailer to access the twist-locks (see Fig. 1 [12]).

Fig 1. Removing and fixing the twist-lock from and to the corner cast of the container is an example of a task requiring coordinated dual arm manipulation navigating through tight spaces.

3. Methodology

As discussed in the introduction section, the probability of finding a solution by simply enforcing the closed-chain constraints onto the random sampling-based planning algorithms is almost zero. Hence, we are employing different strategies in order to increase the chance of successfully finding a solution to this problem.

First of all, knowing that the space that the arms need to navigate through is narrow and tight, we fix the orientation of both arms as there will be low probability anyway that changing the orientation of the arms will result in sampling a valid collision-free configuration, and it will in fact unnecessarily complicate the motion planning. Hence, this helps to increase the chance of successfully and efficiently finding a solution for valid configuration.

Secondly, knowing that the space that the arms need to navigate through is narrow and tight, we thus know that sampling in certain directions in the task space will not result in obtaining a collision-free solution. Hence, the strategy that we employ to increase the chance of getting a valid solution is through a goal-directed sampling in the task space instead of the commonly used joint space. In other words, e.g., if we know that the narrow space is constrained in the z-axis direction by obstacles and the goal is for the arms to navigate out of the tight space in y-axis direction, we direct the sampling of the solutions more in the y-axis direction than in the z- or x- axis direction.

Thirdly, since the solutions are sampled in the task space, we then can check the fulfillment of the constraint conditions of the two arms independently simply using inverse kinematics. In other words, we check whether both arms can reach the sampled task pose as well as whether the arms' configurations are collision-free.

Hence, using these strategies, we first ensure that the samples in the task space are collision-free through the goal-directed sampling. After that, we then further check whether the two arms can reach the sampled pose with valid collision-free configurations.

4. Simulation Results

In this section, we reported the simulation results of the bimanual planning using the approach and strategies that we have described in the methodology section. The dual arms that we use are Universal Robots UR16e, and we perform the simulation tests on Ubuntu 18.04 and ROS Melodic environment. We put in the CAD models of a trailer, container, and twist-locks to represent the obstacles, and command the dual arms to extract the twist-lock from in between the container and trailer. The two arms are positioned as if they are holding the twist-lock together just like how human would do. The tight area in between the container and trailer as well as the tight space in between the container and the dual arms in fact create a complex L-shaped narrow corridor. The features of the twist-locks further increase the complexity to search for solutions. We perform the motion planning tests on three different sets of settings: using three different locations along the trailer having different features and obstructions, three different twist-lock configurations, as well as three different initial positions of the dual arms, to check the robustness of the planning under different circumstances and conditions.

As a comparison, we also test the same sets of motion planning queries on the available MoveIt! OMPL constrained planning, which employs numerical techniques to incorporate constraints into standard random sampling-based algorithms. As expected and discussed previously, it is not able to successfully provide us with a solution even after running the algorithm for a long time, which is another motivation for us to figure out and apply those strategies in order to be able to obtain a solution to the motion planning problem.

Fig. 2 shows the snapshots of the solutions for the three different sets of motion planning queries. The dots show the valid path in the task space in order to successfully extract the twist-lock collision-free from an initial position inside the tight space in between the container and trailer to a goal position outside. As can be seen from the solutions, the resulting path is able to adjust and find different solutions based on the different environmental settings.

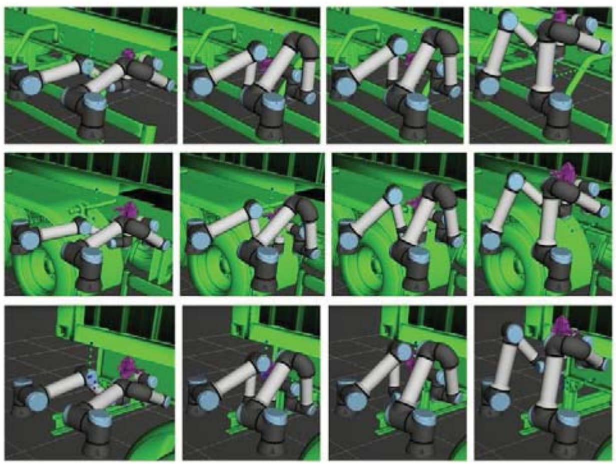

Fig 2. Snapshots of the three different successful motion planning solutions to the three different sets of narrow-corridor environments.

5. Conclusions

In this work, we have reported, discussed, and applied some possible approaches and strategies in order to be able to tackle the two major challenges in the motion planning field simultaneously, namely planning for the motion of bimanual manipulation navigating through narrow tight spaces. The simulation results show that the strategies help to find valid solutions to the complex narrow-corridor motion planning queries that are not able to be solved if using only the conventional constrained sampling-based algorithm.

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