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R&D Project

Exploiting contact constraints in robotic manipulation tasks

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I, the undersigned below, declare that this work has not previously been submitted to this or any other university and that it is, unless otherwise stated, entirely my own work.

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Abstract

Your abstract

Acknowledgements

Thanks to ....

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1 Introduction

In the field of industrial robotics, achieving high levels of accuracy, precision, and repeatability in free space motion is a critical requirement. To meet this requirement, robots must be designed to be stiff and avoid contacts along their trajectories. One approach to achieving a high degree of stiffness is to use lightweight materials such as carbon fiber. However, the production of carbon fiber is expensive, leading some companies to opt for cheaper and heavier robot manipulators to reduce manufacturing costs. While this approach may reduce costs, it also results in increased energy consumption as the robot must expend more energy to maintain its joints and links in mid-air.

During motion planning, robot manipulators commonly treat contact surfaces as obstacles rather than opportunities. This approach contrasts with the behavior of humans, who often rest their wrists on a table while writing on paper. By exploiting contact surfaces, robots can achieve selective improvements in accuracy and precision compared to writing on paper with their wrists in mid-air. Furthermore, utilizing contact surfaces can help reduce energy consumption.

To enable robots to imitate this behavior, two adaptations of control software are required: Dynamics and partial constraint. Contact handling requires not only the kinematics of the robot but also its dynamics. There are existing dynamic solvers that can be used to solve the robot's equations of motion. To fully exploit the contact surface, the specification of partial constraints must be introduced. The acceleration-constrained hybrid dynamics algorithm (ACHDA) limits the ability to handle the partial constraint of an end-effector. ACHDA can handle partial motion specifications in some direction and leave them determined by nature. Since nature determines part of the motion, the solver provides higher energy efficiency, passive adaptation, and desire constraints that do not require explicit control. Shakhimardanov has demonstrated the potential for extending constraints to arbitrary links [1]. However, this extension has not yet been incorporated into any software library. This means that while the theoretical framework for extending constraints to arbitrary links has been established, it has not yet been implemented in practice

In this research and development project, we will address three case studies to demonstrate a robot that exploits environmental constraints: Grasping an object by sliding along its surface, performing a writing task, and resting robot manipulation. The first case study aims to establish the required infrastructure for task execution through a proof-of-concept task. The second case study aims to implement the extension of the Vereshchagin solver in daily tasks to investigate whether exploiting contact surfaces can improve the accuracy and precision of robot motion. The third case study aims to evaluate whether resting some of the joints on a supporting surface can lead to higher energy efficiency.

The content of this research and development report is presented as follows. (Add after the meeting when the overall structure is fixed)

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State of the Art

2.1 Robot dynamic

1. Forward Dynamic (FD)
2. Inverse Dynamic (ID)
3. Hybrid Dynamic (HD)

2.2 Dynamic solver

The follwing algorithms are some common solvers to solve the dynamic problem in robotics.

2.2.1 Articulated Body Algorithm (ABA)

The Articulated Body Algorithm (ABA) solver is a direct method used to compute the dynamics and motion of articulated bodies, such as robots or human bodies. This solver models the dynamics of each body in the system using a hierarchical approach, taking into account the interactions between the bodies and the forces acting upon them. The ABA solver is used to solve a forward dynamics problem, where accelerations are calculated from input torques.

2.2.2 Recursive Newton-Euler algorithm (RNEA)

The Recursive Newton-Euler Algorithm (RNEA) is a recursive approach to solving the inverse dynamics problem, which involves calculating joint-space torques from joint-space accelerations for each body in a system. This algorithm takes into account the relationships between the bodies and the forces acting upon them.

2.2.3 Acceleration-constrained hybrid dynamics algorithm (ACHDA)

The Articulated-Body Hybrid Dynamics Algorithm (ACHDA) is capable of computing three types of dynamics: inverse dynamics, forward dynamics, and hybrid dynamics. In inverse dynamics, the solver calculates joint torques from Cartesian acceleration constraints. In forward dynamics, the solver takes feed-forward joint torques as input and computes Cartesian accelerations. In hybrid dynamics, the solver combines both of the above methods. Additionally, as a byproduct, it can also take external forces as input and compute joint accelerations.

2.3 Controller

2.3.1 Proportional-integral-derivative (PID) controllers

2.3.2 Fuzzy logic algorithm

2.3.3 Impedance controllers

2.4 Full/whole body task based controll

2.4.1 iTaSC

2.4.2 Stack of tasks

2.5 Existing application of exploting surface in robot manipulation

2.6 Limitations of previous work

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Problem Statement

Many robots today are heavy, energy-consuming, and costly to manufacture. During motion planning, contact surfaces are often treated as obstacles, resulting in the robot's joints remaining in mid-air. This approach can lead to wasted energy as the robot must expend energy to maintain its joints and links in such a pose. Additionally, existing dynamic solvers do not handle partial constraint conditions. In this R&D project, we will explore an approach that addresses the dynamics of this situation. By considering contact surfaces as opportunities rather than obstacles, we aim to develop a more energy-efficient and cost-effective solution for robotic motion planning.

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Popov-Vereshchagin hybrid dynamic solver for partial constraint control

5

Solution

5.1 Proposed algorithm

5.2 Implementation details

6

Evaluation anf results

In this RnD, two experiements are being conducted with respected to two use cases: (1) Grasp object by sliding motion along surface and (2) Perform writing task. In this chapter, the methodology will be divided according to use cases.

6.1 Use case 1 - Grasp object by sliding motion along surface

The aim of this case study is to grasp the object successfully by sliding the robot manipulator along a contact surface. Assume that the object pose is known, only the object to be grasped is on the table , no obstacle and the contact surface is known. The manipulator should first approach the contact surface, for example, a table with the target object placed on it. When the manipulator is above the contact surface, it moves toward the surface until establishing contact. By activly monitoring the velocity along linear Z axis v_{lin_z}in world frame. If the absolute value of v_{lin_z} for 10 samples is less than a threshold value. The contact between a surface and the robot manipulator is being established. After contact is established, the manipulator slides along the linear x direction for 10 cm $d_x = 0.1$ until it reaches a grasping region. Finally, the end-effector performs a grasping motion.

6.1.1 Setup

- Kinova® Gen3 Ultra lightweight robot maniputlator is attached to a table
- The motion will starts at a fixed starting pose $q = 6.28318, 0.261895, 3.14159, 4.01417, 0, 0.959856, 1.57079$ in radian

6.1.2 Experimental Design

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6.2 Use case 2 - Perform writing task

The aim is to draw a line on the paper with a wrist joint contacting the writing surface like human writing. Before starting the manipulation task, the gripper firmly grasps the pen or marker. The manipulator should first approach the contact surface, for example, a table with the target object placed on it. When the manipulator is above the contact surface, it moves toward the surface until establishing contact. Once contact is established, the manipulator draws a line according to a predefined motion specification. The evaluation will be a trajectory comparison in terms of position or velocity with and without contact between the robot and the support surface

6.2.1 Setup

6.2.2 Experimental Design

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7 Conclusions

7.1 Contributions

7.2 Lessons learned

7.3 Future work

A
Coordinate transformation for force and motion vectors

p.22 from featherstone

B

Plucker coordinate for spatial vectors

C
Cross product operators

D

Parameters

References

[1] A. Shakhimardanov, "Composable robot motion stack," Ph.D. dissertation, 2015.