A Quantitative Test for the Robustness of Graspless Manipulation

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ICRA 2006
Orlando, USA
May 17
1. Introduction

Graspless manipulation

- Non-grasping
- Objects are in contact with the environment
Robustness against External Disturbances

For graspless manipulation, we need to evaluate the robustness.
Definition of “Robustness measure of manipulation”

How much the manipulated object can resist external disturbances without changing its motion [Maeda 02 ICRA]
Overestimated robustness measures in some cases

[Maeda 02 ICRA]

<CASE: A cuboid on a corner>

We cannot move the object on a corner!!

(friction coefficient) > 1.0

Arbitrary contact forces are feasible in each friction cone

Infinite resultant force

(2D schematic view)
Objective

A new quantitative test for the robustness of graspless manipulation

- More accurate than our previous method [Meada 02]

Our approach

We consider the constraints on static friction originally derived by [Omata 00, 01] for power grasps
2. Mechanical Model

Assumptions

- Rigid bodies
- Stationary or in quasi-static manipulation
- Coulomb friction
- Approximation of all the contact by finite-point contacts
- Approximation of friction cone by polyhedral convex cone
- Position- or force-controlled robots
- Infinite servo-stiffness for position-controlled robots
Relationship between virtual sliding and static frictional force [Omata 00, 01]

Consider a combination of virtual slidings

Exclude impossible frictional forces
Constraint on static friction [Omata 01]

Virtual sliding velocity (\(\dot{\mathbf{Y}}\)) is constrained

Static frictional forces are also constrained.
3. Robustness measure

How much the manipulated object can resist external disturbances without changing its motion.

The value of the robustness, $z$

$$z = \min_{Q_{\text{dist}}} \max_k \left\| Q_{\text{known}} + WCk \right\|_R$$

subject to

$$\begin{cases} T^T Ck \in \mathcal{F} \\ A(N^T Ck - f_n) = 0 \\ Q_{\text{dist}} + Q_{\text{known}} + WCk = 0 \\ \|Q_{\text{dist}}\|_R = 1 \\ k \geq 0. \end{cases}$$

Constraints on static friction
Constraints on contacts with force-controlled robot fingers
Equilibrium equation
Normalization in 6-dimensions

We solve the minimax optimization problem.
Difficulties

• Constraints on static friction is nonlinear
  We divide the problem into subproblems based on the sign of the elements of virtual sliding.

• Arbitrary directions in 6-dimensional force/moment space
  Approximation by considering only some typical directions

We solve a series of the linear programming problems to obtain the approximate value of the robustness.
4. Numerical examples

(On Celeron 2.4GHz PC)

<Example: An object on a corner>

- Object
  - Size: 2x2x2
  - Mass: 1
  - Gravitational acceleration: 9.8

Previous method [Maeda 02]

Unreasonable result

because of not excluding some impossible contact forces
Our proposed method can evaluate the robustness more accurately than previous method.
<Example: Pushing a cuboid>

Stationary with no robot fingers

(Robustness value) = 2.94
Equal to the maximum static frictional forces
(1x9.8x0.3 = 2.94)

One-point pushing with position-controlled robot finger

(Robustness value) = 0
Infinitesimal external disturbances can perturb the motion

Two-point pushing with position-controlled robot fingers

(Robustness value) = 0.88

These calculation results match the real-world phenomena
5. Conclusion

Summary

A new quantitative test for the robustness of quasi-static graspless manipulation for rigid bodies with Coulomb friction

• Consideration of constraints on static frictional force originally derived by Omata and Nagata [Omata 00, 01]
• More accurate evaluation than our previous work [Maeda 02]

Future work

• Reduction of the computation time
• Application to manipulation planning