

A Quantitative Test for the Robustness of Grasplless Manipulation

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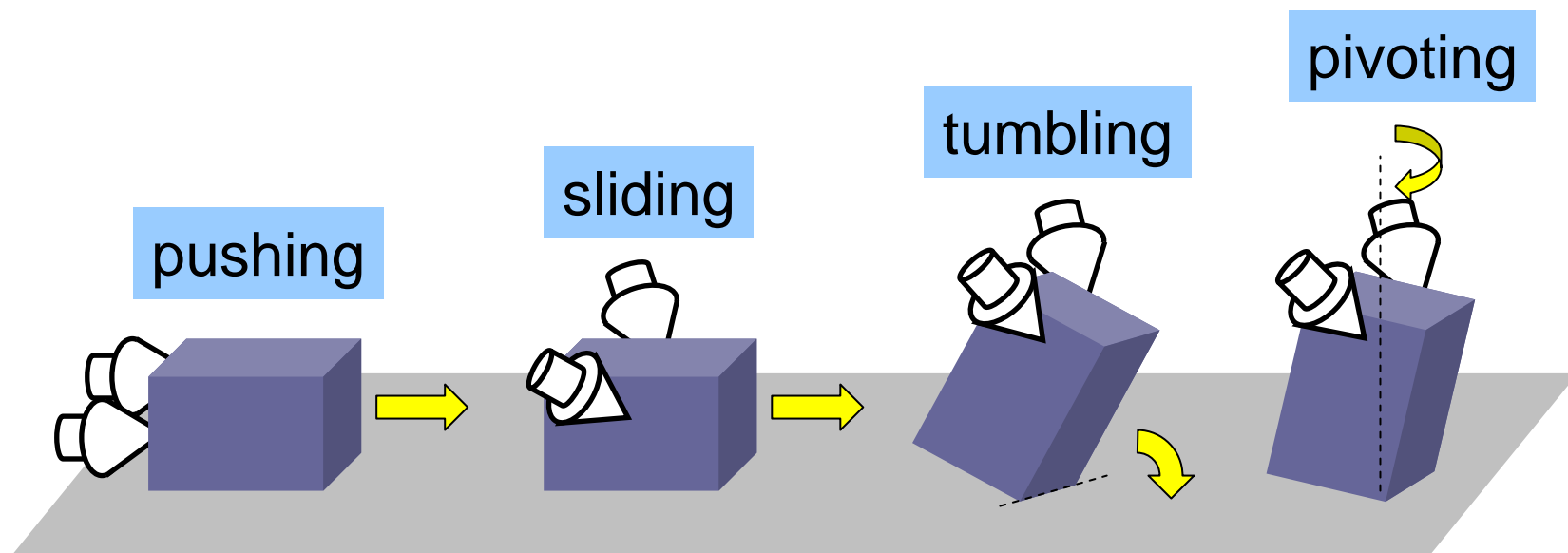
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Orlando, USA
May 17

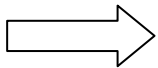
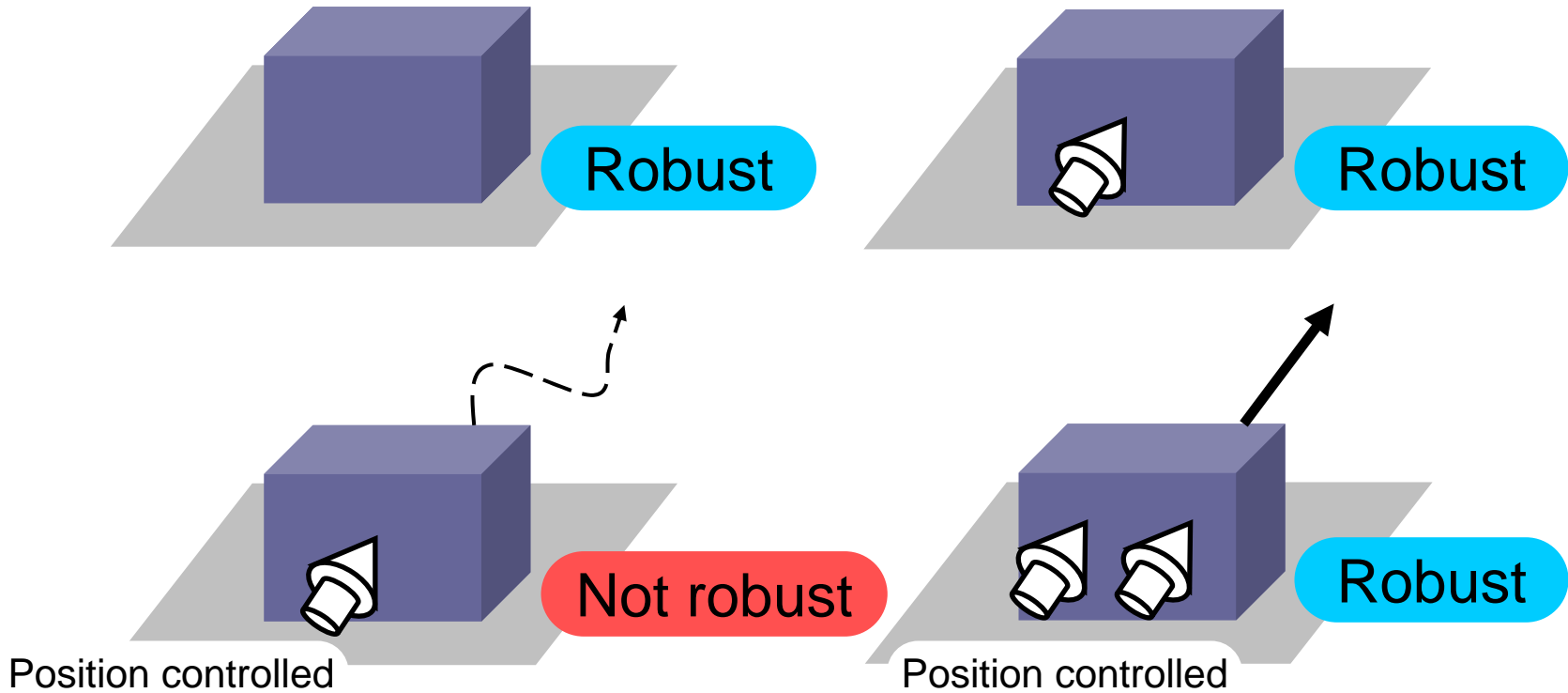
1. Introduction

Graspless manipulation

- Non-grasping
- Objects are in contact with the environment



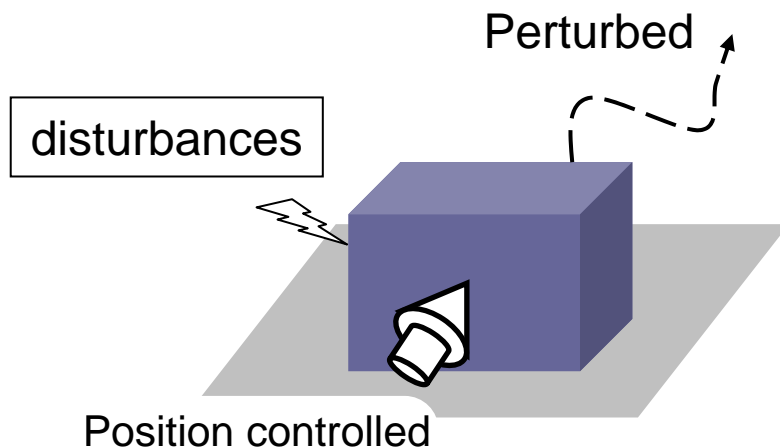
Robustness against External Disturbances



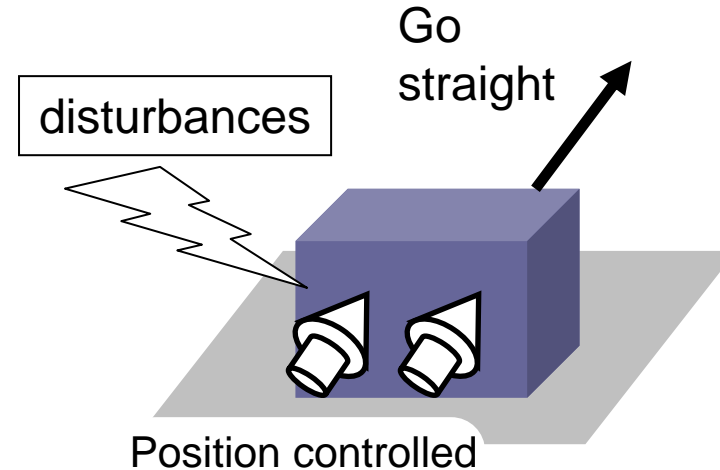
For grasplless manipulation,
we need to evaluate the robustness

Definition of “Robustness measure of manipulation”

How much the manipulated object can resist external disturbances without changing its motion
[Maeda 02 ICRA]



Robustness = 0

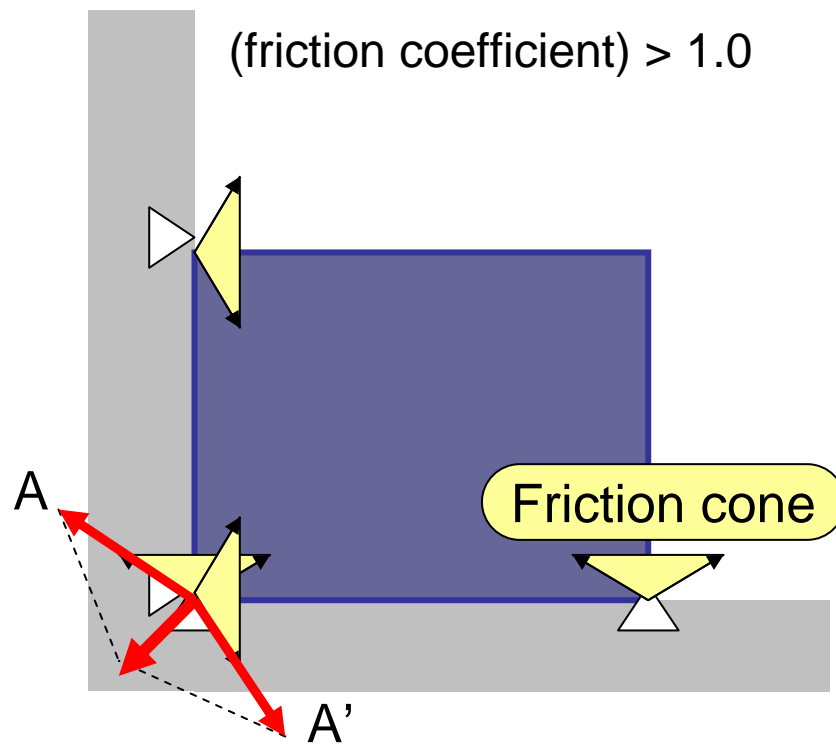


Robustness > 0

Overestimated robustness measures in some cases

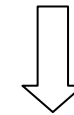
[Maeda 02 ICRA]

<Case: A cuboid on a corner>



assumption

Arbitrary contact forces are feasible in each friction cone



Infinite robustness value

We cannot move the object on a corner !!

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]

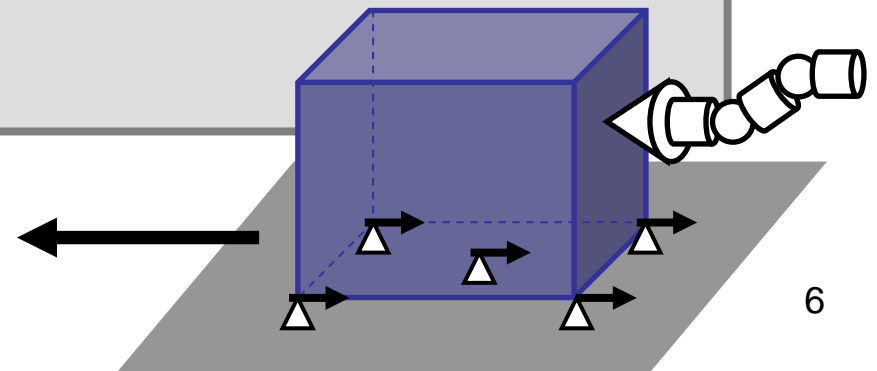
Our approach

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

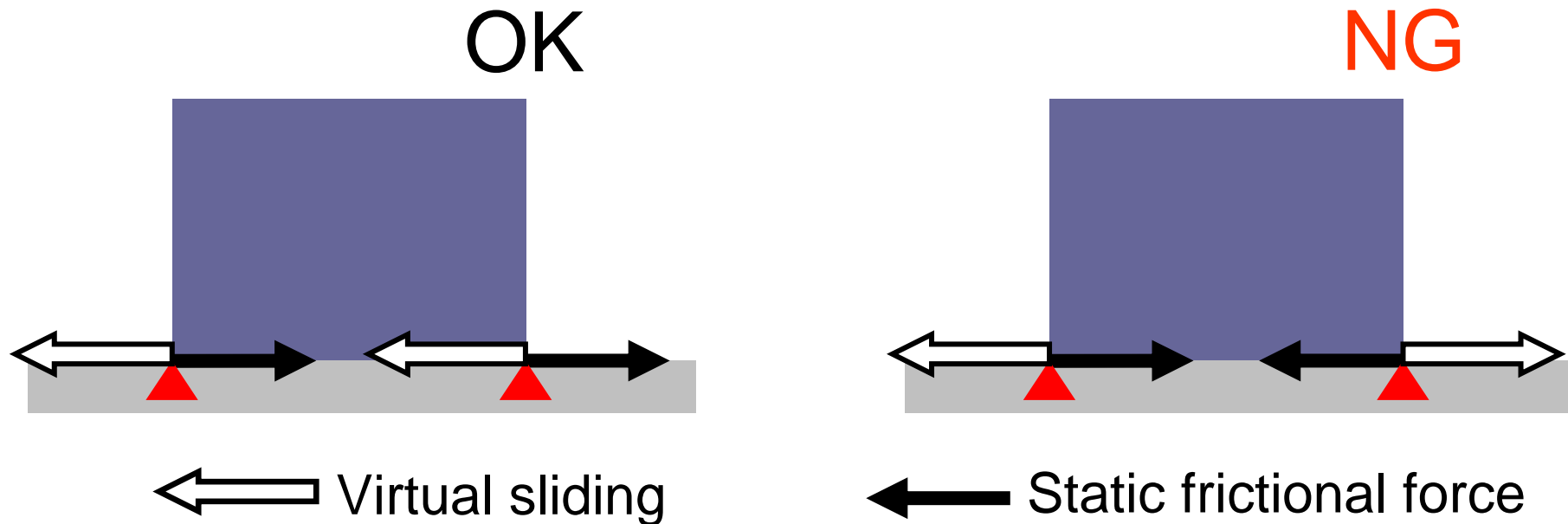
2. Mechanical Model

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

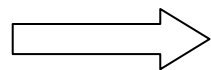
Constraint on static friction [Omata 01]

The diagram illustrates the relationship between various matrices and velocities in a constraint equation. It features the following elements:

- Selection matrix B** : A red circle around the letter B , with a red line pointing to a red-bordered box labeled "Selection matrix".
- Wrench matrix W^T** : A green circle around the letter W with a superscript T , with a green line pointing to the label "Wrench matrix".
- Jacobian matrix J** : A green circle around the letter J , with a green line pointing to the label "Jacobian matrix".
- Virtual object velocity V** : A green circle around the letter V , with a green line pointing to the label "Virtual object velocity".
- Virtual joint velocity $\dot{\theta}$** : A green circle around the letter $\dot{\theta}$, with a green line pointing to the label "Virtual joint velocity".
- Tangent Vectors T** : A green circle around the letter T , with a green line pointing to the label "Tangent Vectors".
- Virtual sliding velocity \dot{Y}** : A green circle around the letter \dot{Y} , with a green line pointing to the label "Virtual sliding velocity".

The equation is represented as: $B \begin{bmatrix} W^T & J \end{bmatrix} \begin{bmatrix} V \\ -\dot{\theta} \end{bmatrix} = T \dot{Y}$

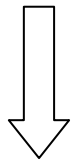
Virtual sliding velocity (\dot{Y}) is constrained



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

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

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

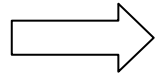
Equilibrium equation

Normalization in 6-dimensions

We solve the minimax optimization problem

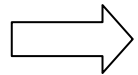
Difficulties

- Constraints on static friction is nonlinear

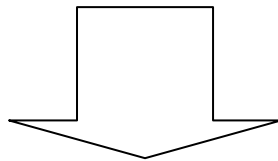


We divide the problem into subproblems based on the sign of the elements of virtual sliding.

- Arbitrary directions in 6-dimensional force/moment space



Approximation by considering only some typical directions

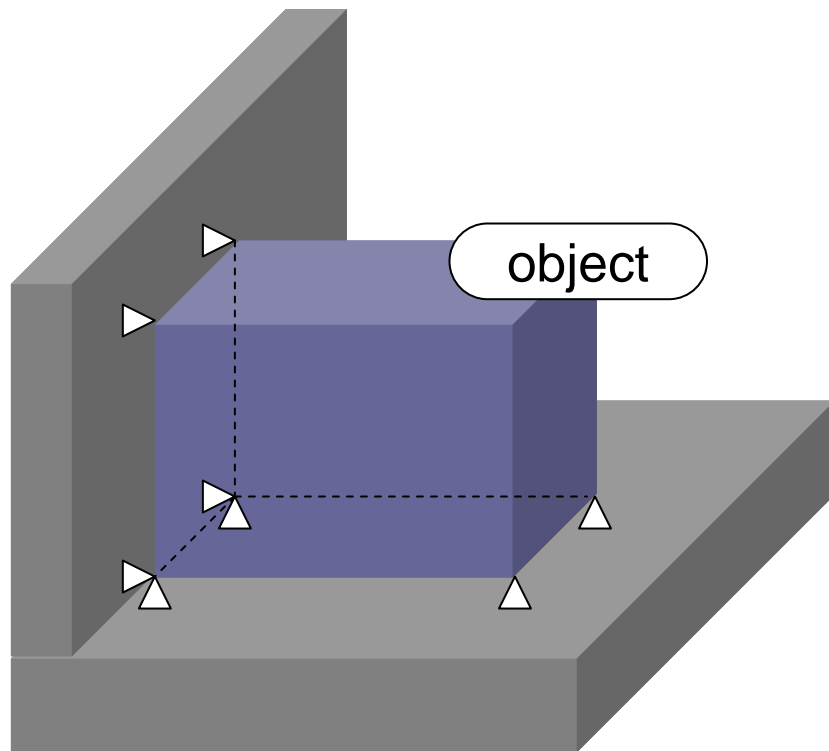


We solve a series of the linear programming problems to obtain the approximate value of the robustness.

4. Numerical examples

(on Celeron 2.4GHz PC)

<Example: An object on a corner>

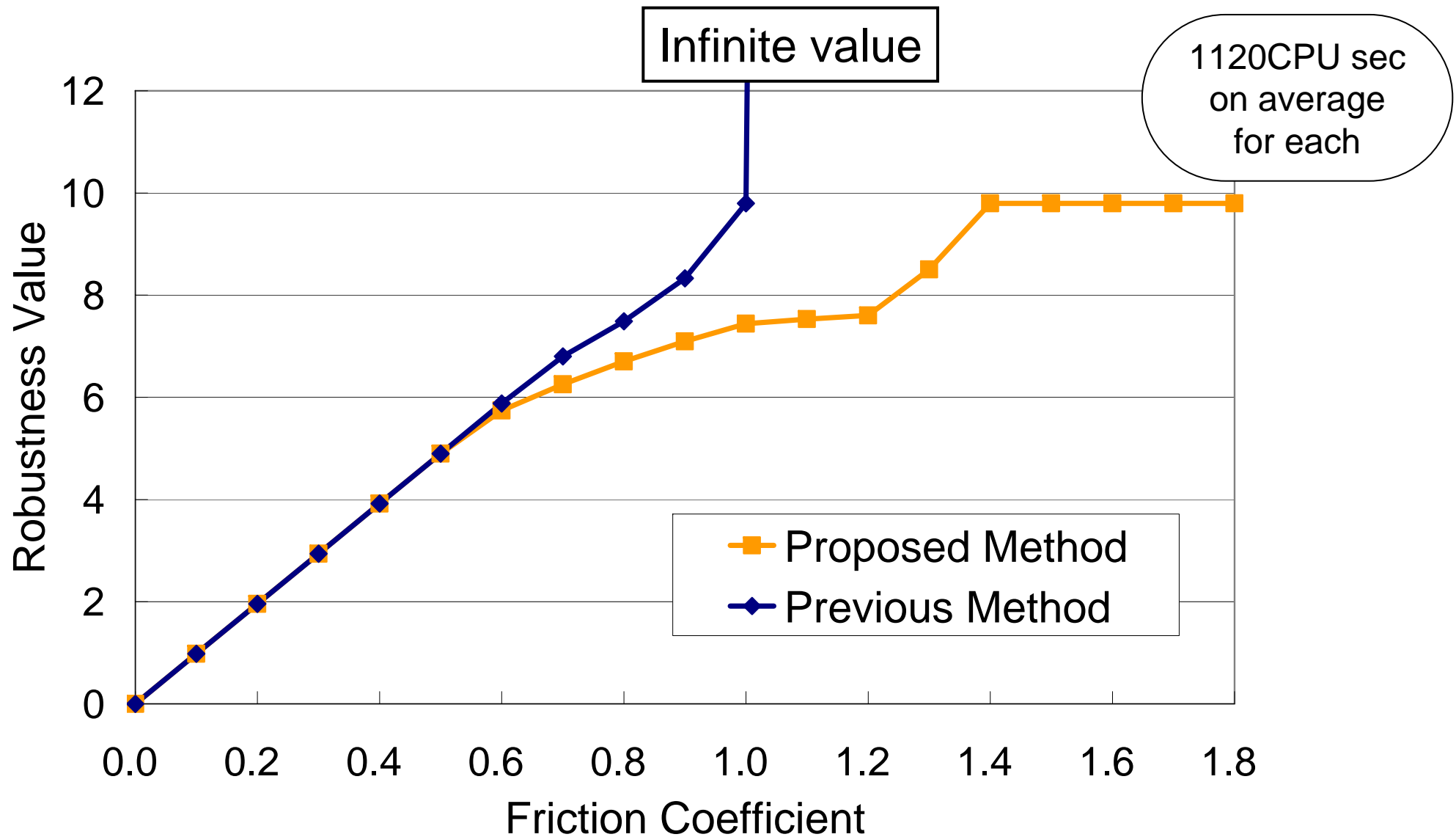


- Object
 - Size : 2x2x2
 - Mass : 1
- Gravitational acceleration : 9.8

Previous method [Maeda 02]

→ **Unreasonable result**

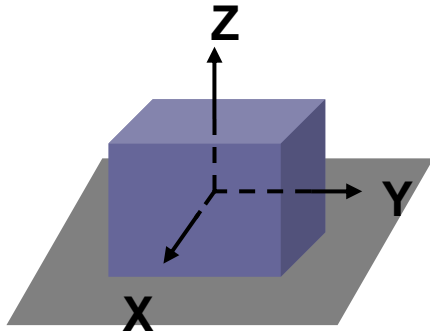
because of not excluding some impossible contact forces



Our proposed method can evaluate the robustness more accurately than previous method.

<Example: Pushing a cuboid>

Friction coefficient : 0.3
Object size : 2x2x1

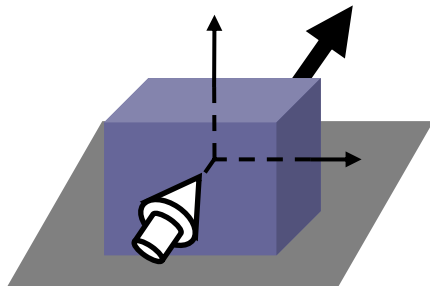


[Stationary with no robot fingers]

(Robustness value) = 2.94

68CPU sec

Equal to the maximum static frictional forces
($1 \times 9.8 \times 0.3 = 2.94$)

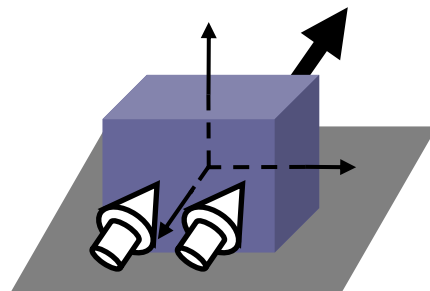


[One-point pushing
with position-controlled robot finger]

(Robustness value) = 0

36CPU sec

Infinitesimal external disturbances can perturb the motion



[Two-point pushing
with position-controlled robot fingers]

(Robustness value) = 0.88

113CPU sec

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