On the Possibility of Excessive Internal Forces on Manipulated Objects in Robotic Contact Tasks

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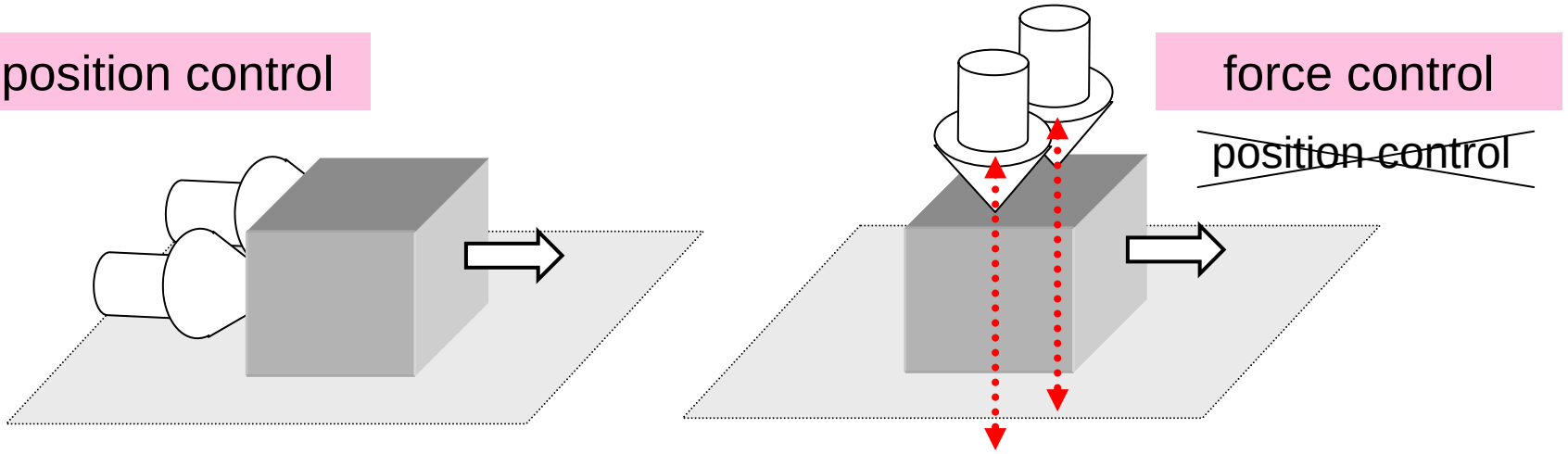
1. Introduction

Robotic Contact Tasks and Excessive Internal Forces

position control

force control

~~position control~~

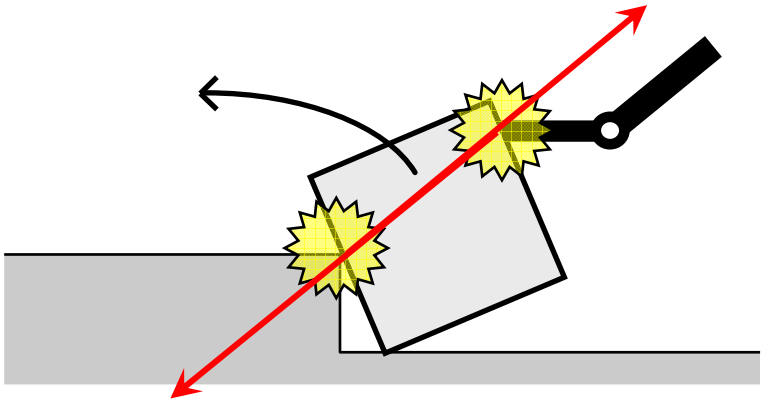


⇨ Prior assessment of the possibility of excessive internal forces is important for robotic contact tasks

c.f. control mode determination [Maeda 03 IROS]

Definition of “Excessive Internal Forces”

When contact forces can be increased unlimitedly without breaking equilibrium, the object cannot escape from infinite (=*excessive*) internal forces.



Related Works

[Asada 85]… bilateral constraints
(→ excessive internal forces in frictionless cases)

[Trinkle 92]…“strong force closure”
(→ Judgment algorithm for frictionless cases)

[Hirai 93]… Judgment algorithm of bilateral constraints by polyhedral convex cones

[Bicchi 94]… Analysis of “internal passive contact force”

[Maeda 96]…Judgment algorithm for *frictional* cases

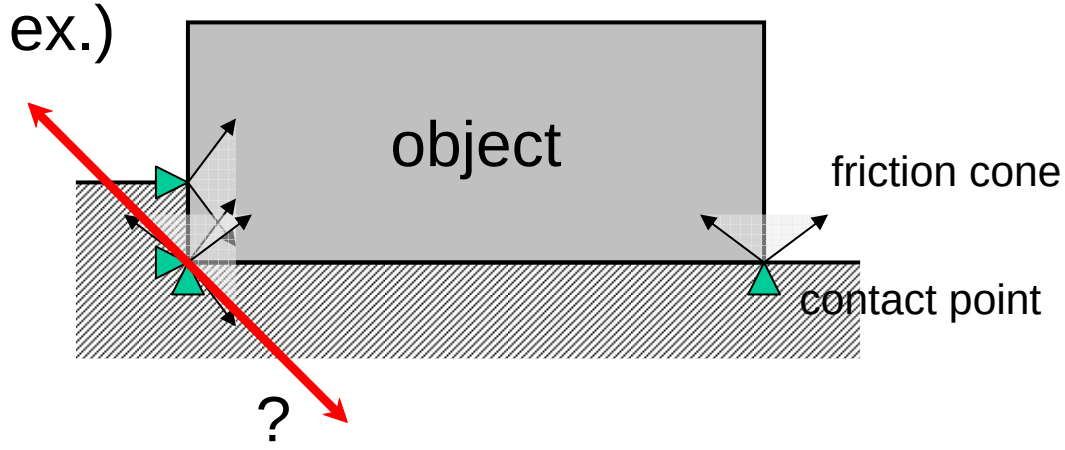
Judgment Algorithm for Frictional Cases [Maeda 96 IROS]

- Judgment on the possibility by linear programming
- It tests only a weak necessary condition

⇩

It sometimes says that there is a danger of excessive internal forces even when they could not be generated

ex.)



⇨ Some combinations of locally feasible contact forces are infeasible

Objective

More accurate judgment algorithm on the possibility of excessive internal forces in robotic contact tasks

- than our previous study [Maeda 96 IROS]
- Under rigid-body statics with Coulomb friction

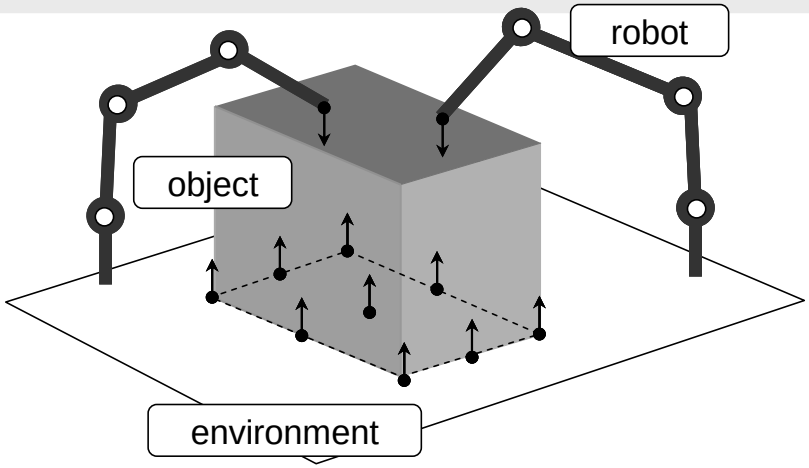
Our Approach

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

2. Mechanical Model

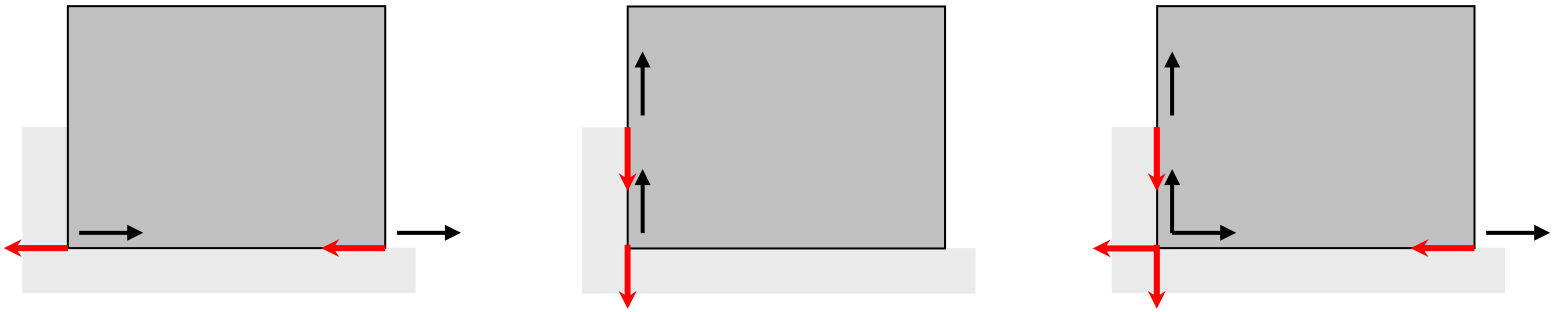
Assumptions

- Rigid bodies
- Point contacts
- Static Coulomb friction
- Position- or force-controlled robots
- Infinite servo-stiffness for position-controlled robots



Relationship between Virtual Object Sliding and Static Friction Forces [Omata 00, 01]

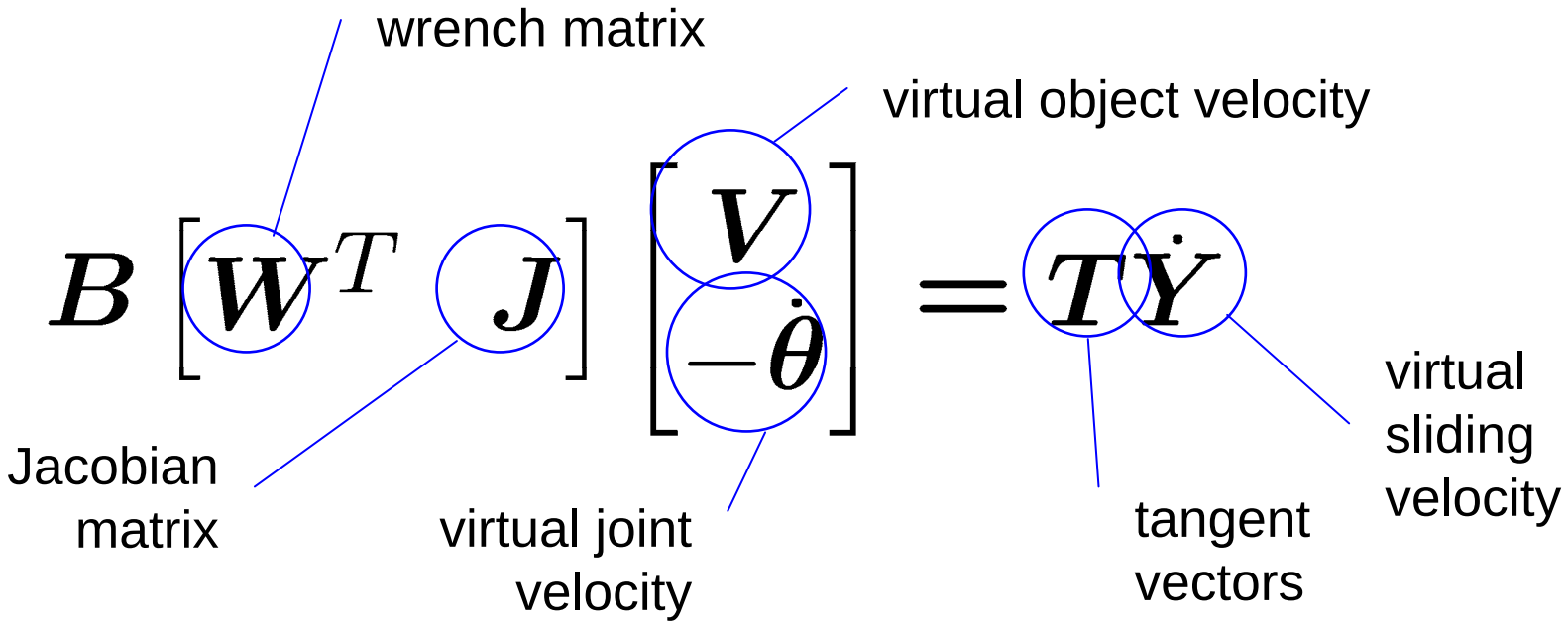
“A combination of friction forces does not exist in the opposite directions of a combination of (virtual) sliding directions incompatible with a rigid body motion.”



OK OK NG

We can obtain constraints on friction forces by investigating constraints on virtual sliding

Constraint on Virtual Sliding [Omata 01]



B : selection matrix

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

⇨ Directions of friction forces are also constrained

3. Judgment Algorithm

How to judge the possibility of excessive internal forces?

- Check the possibility of infinite internal forces under constraints on friction forces
- But, the constraints are complex and nonlinear

⇨ Divide the problem into cases so that the constraints become linear

We can judge the possibility of excessive internal forces by solving a series of linear programming problems

Judgment Procedure

Step 1. Assume a combination of (virtual) sliding/non-sliding contact points.

Step 2. Enumerate all the possible combinations of signs of the elements of the virtual sliding assumed in Step 1.

Step 3. Judge the possibility of excessive internal forces for each combination enumerated in Step 2. If there is a possibility of excessive internal forces, stop. Otherwise, go back to Step 1.

Step 4. If all the combinations have been checked, stop. In this case, there is no possibility of excessive internal forces.

Judgment on the Possibility of Excessive Internal Forces

Judgment by linear programming for each case (Step 3.)

$$\text{maximize } 1^T k$$

$$\text{subject to} \begin{cases} WCk = 0 & \text{Equilibrium condition} \\ J^T ACk = 0 & \text{Constraints on defective contacts} \\ ST^T BCk \geq 0 & \text{Constraints on directions of friction forces} \\ T^T (I_{3M} - B)Ck = 0 & \text{Constraints on non-sliding contacts} \\ k \geq 0 \end{cases}$$

$1^T k \to \infty$ With possibility of excessive internal forces

$1^T k = 0$ Without possibility (in this case)

Computational Complexity

Number of cases:

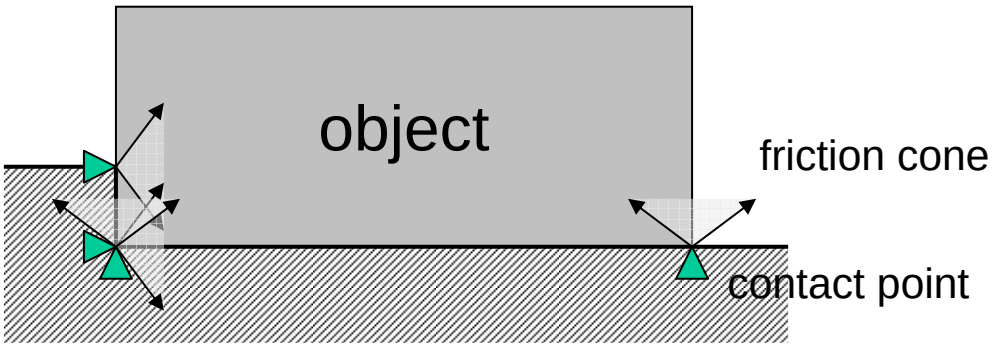
$$\sum_{n=0}^{M} {}_{M}C_{n} 2^{2n} = 5^{M}$$ (M: number of contacts)

⇒ 5^M linear programming problems at most

But, we can omit many of calculations
by using relaxation problems

4. Numerical Examples

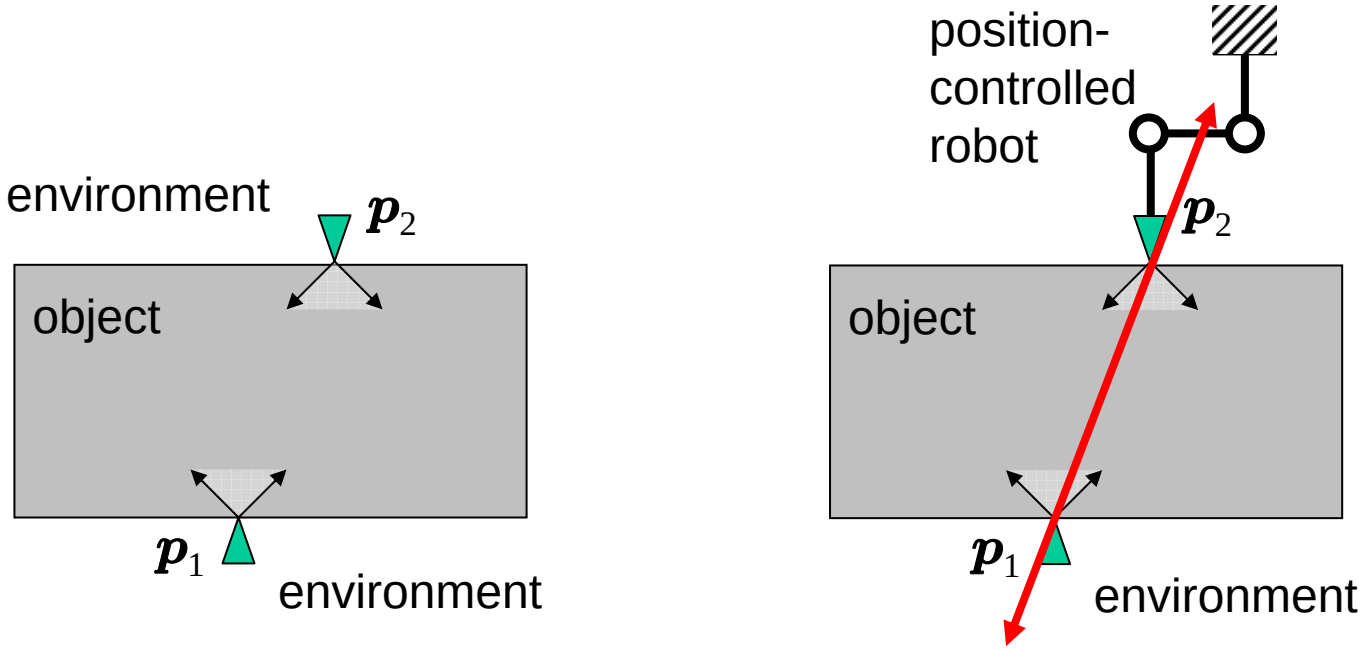
Example: Rectangle on a Corner



$\mu \geq 1.0$

- Our previous method [Maeda 96 IROS]
  ⇨ “With possibility of excessive internal forces”
- Our new method ⇨ “Without possibility”

Example: Pinched Rectangles

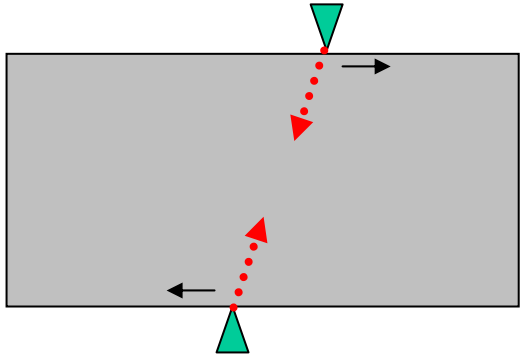


Without possibility of excessive internal forces

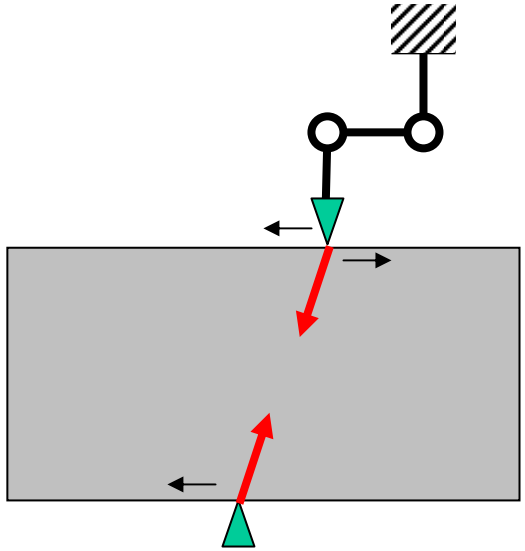
With possibility of excessive internal forces

- Our previous method [Maeda 96 IROS]
  ⇨ “With possibility” for both cases

Constraints on Virtual Sliding and Internal Forces

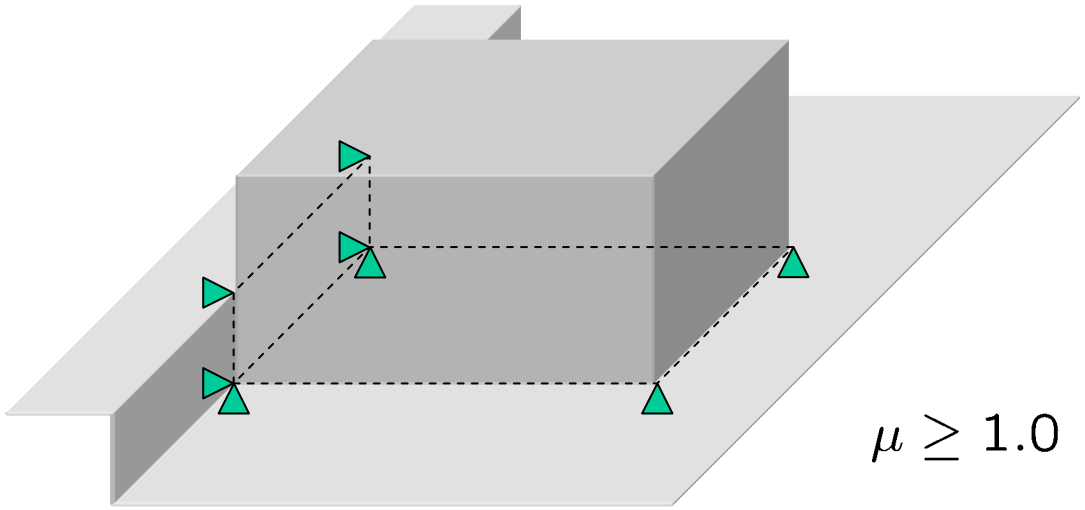


Incompatible virtual sliding



Compatible virtual sliding

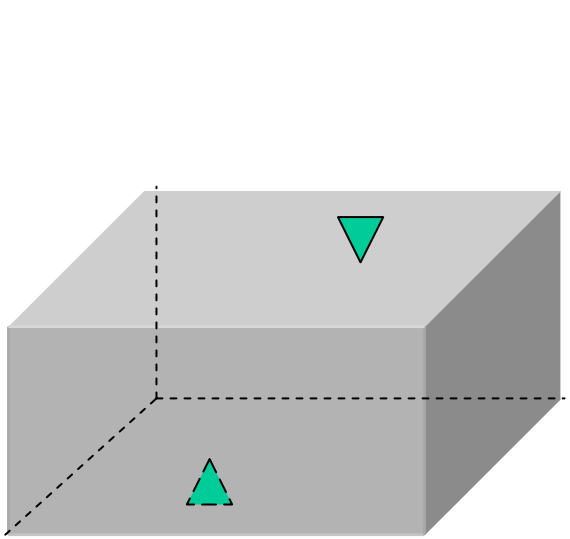
Spatial Cases (1)

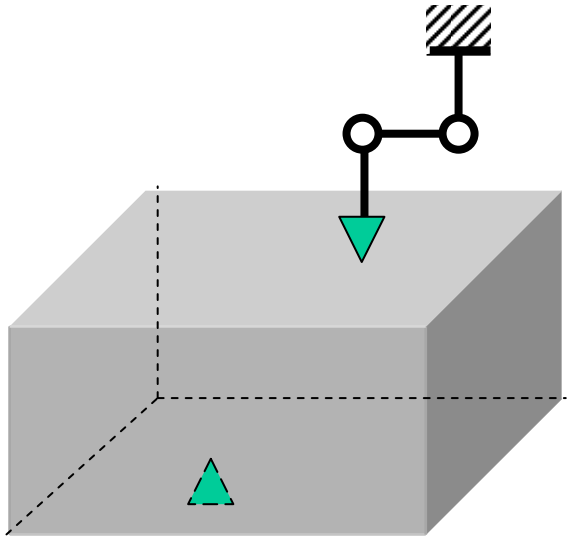


No possibility of excessive internal forces

Computation time : 600 CPU seconds
(Scilab program on Celeron 2.4 GHz)

Spatial Cases (2)





Without possibility of excessive internal forces

With possibility of excessive internal forces

Computation time :
0.08 CPU seconds

Computation time :
0.10 CPU seconds

(Scilab program on Celeron 2.4 GHz)

5. Conclusion

Summary

A new judgment algorithm on the possibility of excessive internal forces in robotic contact tasks for rigid bodies with Coulomb friction.

- Based on the results on power grasps [Omata 00, 01]
- More accurate judgment than our previous method [Maeda 96 IROS]

<Future Work>

- Acceleration of judgment
- Application to manipulation planning