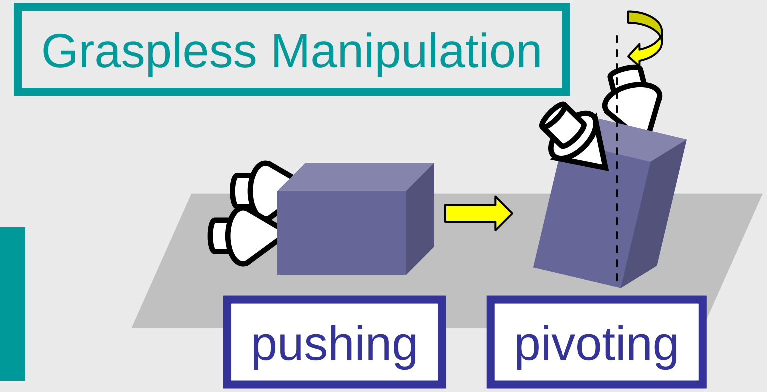
Joint Torque Optimization for Grasp/Graspless Manipulation

○MAKITA, Satoshi, NAKAMURA, Shinobu, MAEDA, Yusuke

(Yokohama National University, JAPAN)

ISHF2007
Jun 14-16
Lisbon, PORTUGAL

1. Introduction



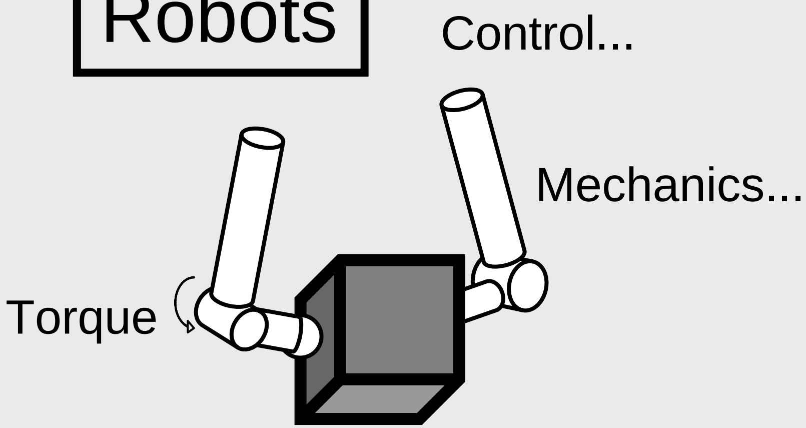
Dexterous Manipulation

- Using both *grasping* and *graspless manipulation*
- Adapting various circumstances

Humans

Flexibly! Dexterously!

Robots



Realize human-like dexterity of robots...

Our study

Optimization Method of Joint Torques of Robots for Grasp/Graspless Manipulation

(Algorithm applicable to both grasping and graspless manipulation)

Previous Work

- Joint Torque Optimization for Power Grasps [Omata 2001, 2002]

Omata's method is based on rigid-body statics (Considering a constraint on static friction)
[Omata and Nagata 2000, Omata 2001]

However... ⇓

We can obtain no solutions in some cases because the constraint is too restrictive.

⇓

We derived a modified constraint on static friction
[Maeda and Makita 2006]

Objective

Constructing an improved procedure for joint torque optimization

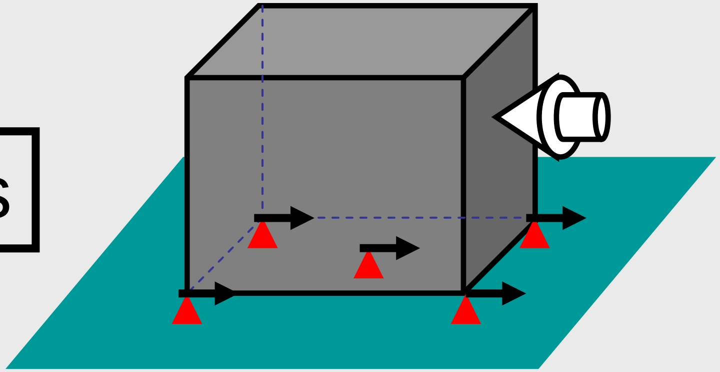
- Based on the new constraint on static friction
- Applicable to both grasping and graspless manipulation

- Approach
  - Apply the new constraint to Omata's method
  - Modify the objective function of the optimization

2. Mechanical Model

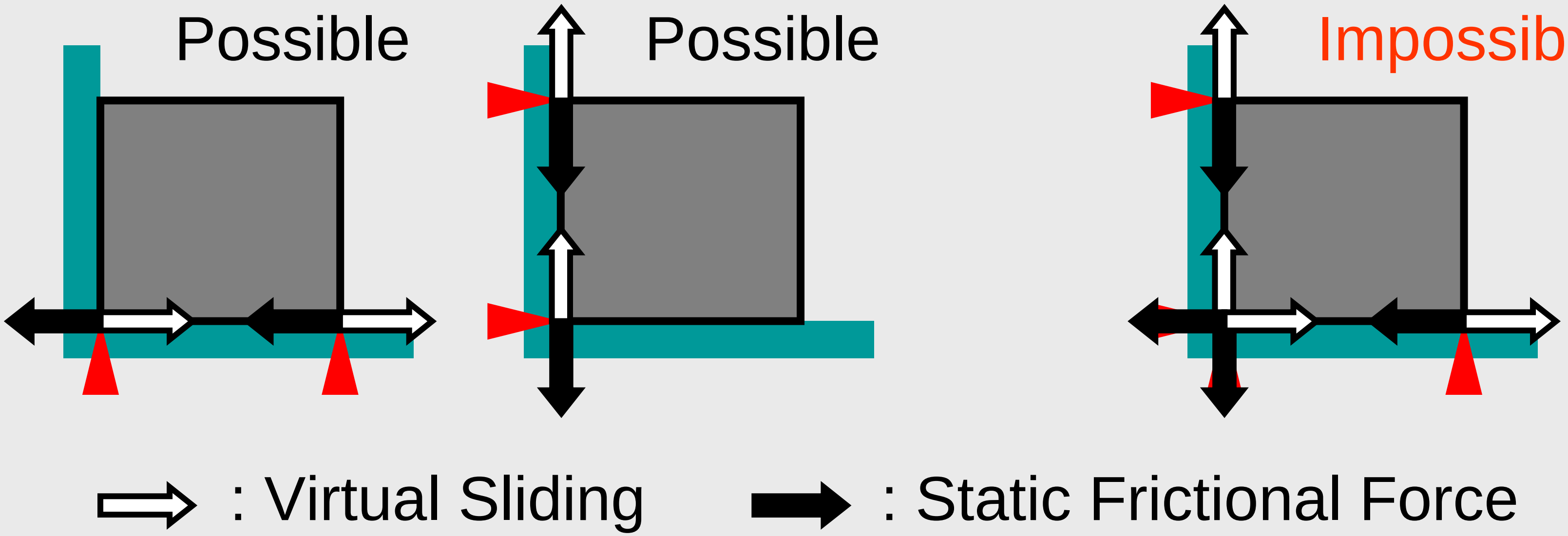
- Assumptions
  - – Rigid bodies
  - – Approximation of all the contacts by finite point contacts
  - – Approximation of friction cone by polyhedral convex cone
  - – Coulomb friction

Indeterminacy of contact forces



Constraint on static friction [Omata and Nagata 2000, Omata 2001]

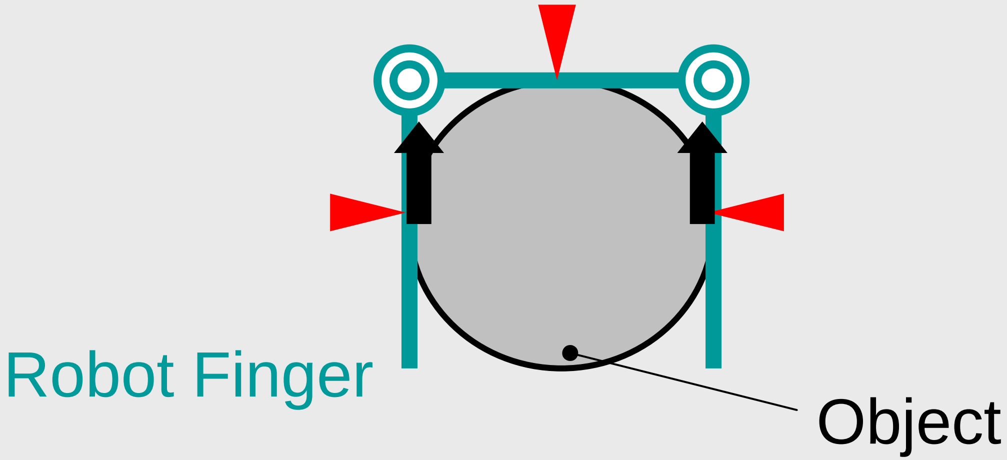
Virtual sliding causes static frictional force



Exclude infeasible combinations of virtual sliding

⇨ **Estimate possible indeterminate contact force**

Paradoxical Result



All the combinations of virtual sliding are excluded by Omata's constraint

Too restrictive!!

Modified Constraint on Virtual Sliding [Maeda and Makita 2006]

Apply the constraint on virtual sliding
to only selected contact points

$$B\left[W^{T} \; J\right]\begin{bmatrix} V \\ -\dot{\theta} \end{bmatrix} = T\dot{Y}$$

Virtual Object Velocity

Wrench Matrix

Tangent Vectors

Jacobian Matrix

Virtual Sliding Velocity

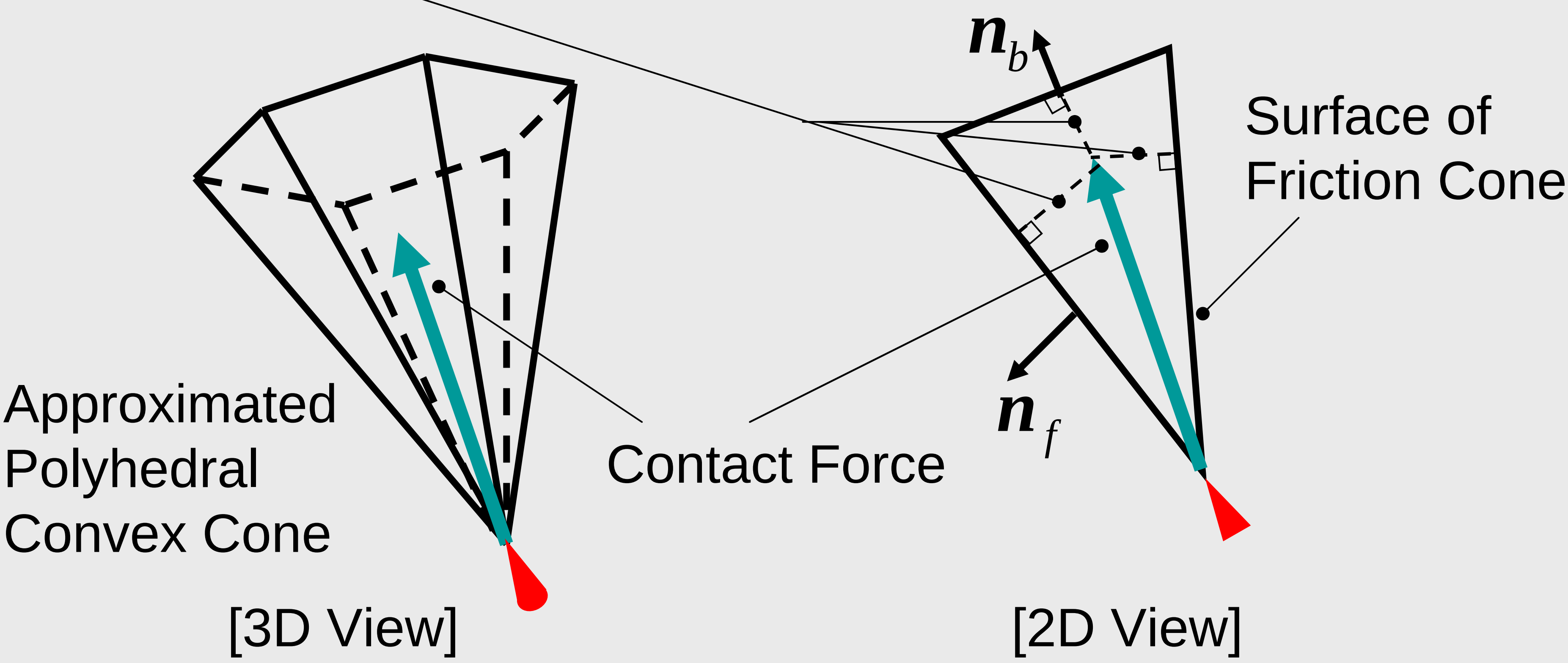
Selection Matrix

Virtual joint Velocity

Estimating contact forces -> Optimal Joint Torques

3. Optimization Algorithm

The margin between contact force and friction cone



Maximizing the margin for contact firmness

Objective Function

Maximizing the minimum margin in the WORST case [Omata 2001, 2002]

⇓

The margin might be always zero in not a few cases (Because of unbounded indeterminate contact forces)

⇓

We modified the objective function
-> maximizing the margin in BEST case

Maximizing the minimum margin e in the best case

$$\max e$$

$$\text{subject to } \begin{cases} \boldsymbol{A}^T \boldsymbol{f} = \boldsymbol{\omega} \\ \boldsymbol{T}^T (\boldsymbol{I}_3 - \boldsymbol{B}) \boldsymbol{f} = \boldsymbol{0} \\ \boldsymbol{S}\boldsymbol{T}^T \boldsymbol{f} \le \boldsymbol{0} \\ e\boldsymbol{1} - \boldsymbol{N}_f^T \boldsymbol{f} \le \boldsymbol{0} \\ e\boldsymbol{1} - \boldsymbol{N}_b^T \boldsymbol{f} \le x\boldsymbol{1} \\ \boldsymbol{\tau}_{\min} \le \boldsymbol{\tau} \le \boldsymbol{\tau}_{\max} \end{cases}$$

Equilibrium of the object

No friction on un-selected contact points

Constraint on static friction

The margin between contact forces and friction cone

Limitation of joint torques

Another Objective Function

Minimizing joint Torques

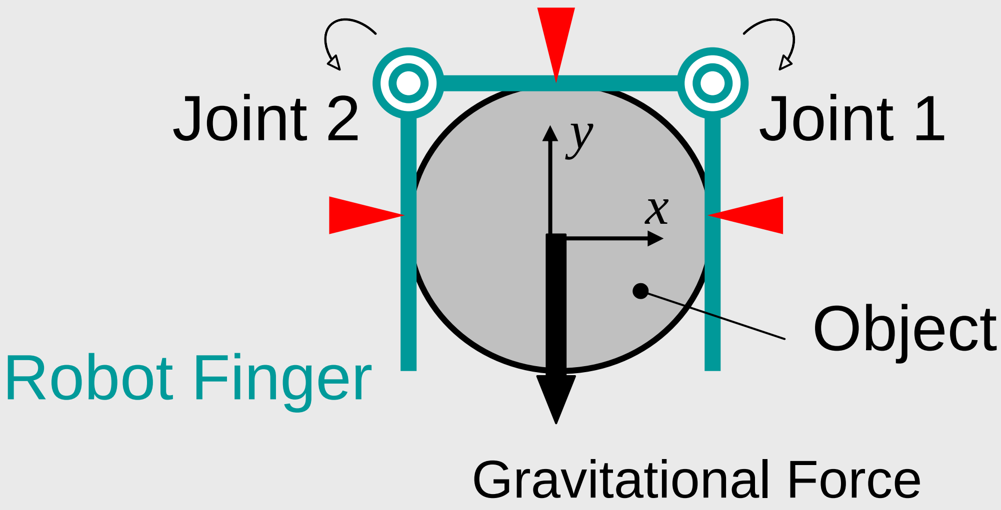
For less energy and less internal force

$$\min \tau_{\max}$$

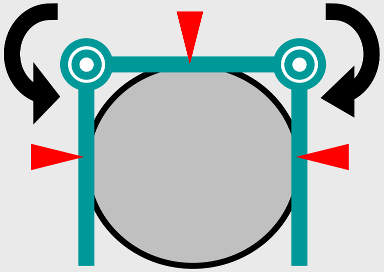
$$\text{subject to} \begin{cases} \boldsymbol{A}^T \boldsymbol{f} = \boldsymbol{\omega} \\ \boldsymbol{T}^T \left(\boldsymbol{I}_3 - \boldsymbol{B} \right) \boldsymbol{f} = \boldsymbol{0} \\ \boldsymbol{S}\boldsymbol{T}^T \boldsymbol{f} \le \boldsymbol{0} \\ e\boldsymbol{1} - \boldsymbol{N}_f^T \boldsymbol{f} \le \boldsymbol{0} \\ e\boldsymbol{1} - \boldsymbol{N}_b^T \boldsymbol{f} \le x\boldsymbol{1} \\ -\tau_{\max} \boldsymbol{1} \le \boldsymbol{\tau} \le \tau_{\max} \boldsymbol{1} \end{cases}$$

4. Numerical Examples

A case where we can obtain no solution by Omata's algorithm

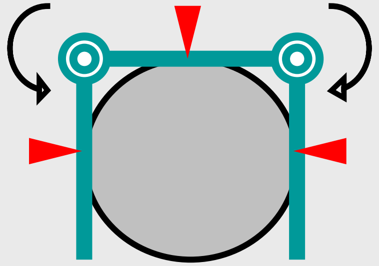


- Assumptions
  - External disturbance $\omega_{\mathrm{ext}} = [0.0 \quad -1.0 \quad 0.0]^T$
  - Frictional coefficient: 0.5
  - Approximated friction cone with 8 edges
  - The origin at the center of the object
  - The limitation of joint torques: $-2.0 \le \tau \le 2.0$



Algorithm 1
Maximizing the margin e

$e = 4.25, \quad \boldsymbol{\tau} = [-2.00, 2.00]^T$



Algorithm 2
Minimizing joint torque τ

$e = 0.1$ (constant), $\boldsymbol{\tau} = [-0.14, 0.14]^T$

We can calculate optimal joint torques successfully

5. Conclusions

- **An optimization algorithm of joint torques**
  - Applicable to both grasping and graspless manipulation
  - With modified constraint on virtual sliding
  - Two kinds of objective functions available

Future Work

- Reduction of computation time
- Implementation of human-like skills using our joint torque optimization method