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Simulation of Deformation in Robotics

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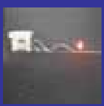
Robots vs Creatures

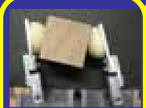
Robots
- rigid material
- rigid motors

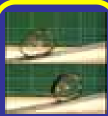
Creatures
- soft material
- soft muscles

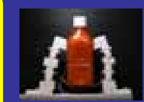
Can **soft robots** be?

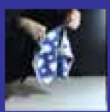
Soft Robots in our lab.

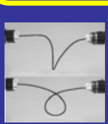

Flexible arm control

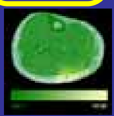

Soft-fingered manipulation


Crawling and jumping soft robots


Loosely coupled joint

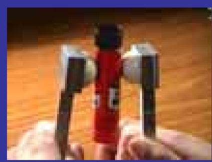

Cloth unfolding

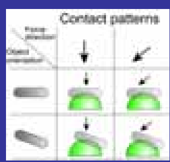

Linear object manipulation

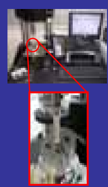

Non-uniform biological object modeling

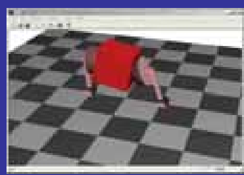

Belt object modeling

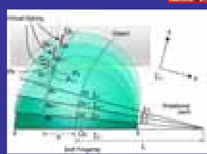
Soft-fingered Manipulation











Background

Humans exhibit outstanding dexterity

What's the sources of dexterity
- **brain-nerve system**
- **binocular eyes**
- **tactile receptors**
- **else?**

Robots vs Humans

Delay in signal transmission	**< 1 ms**	**30 – 50 ms**
Rate in vision	**up to 1,000 Hz**	**30 Hz**

Why humans can manipulate objects despite of such poor performance?

Human Finger Structure

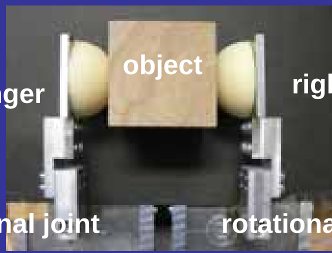
Human finger
- soft fingertip
- hard fingernail on the reverse side

Differs from animals

Does this structure contribute to dexterity?

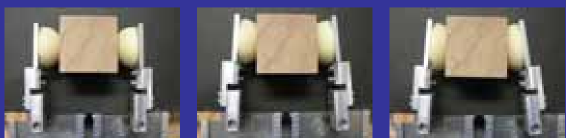
Observations (1/3)

Ability of a pair of 1-DOF fingers with hemispherical soft tips and hard back plates



Observations (2/3)

move two fingertips inward

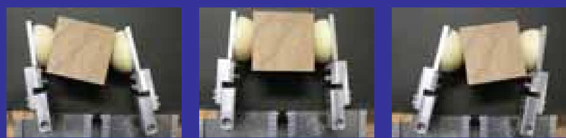


small deformation (grasping force) → large deformation (grasping force)

Can control grasping force

Observations (3/3)

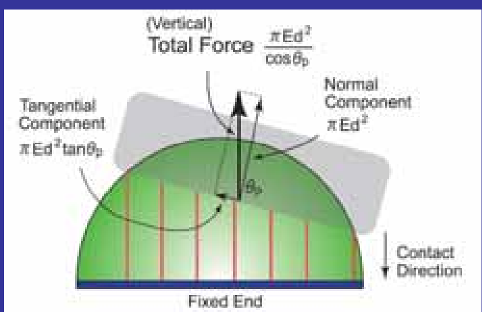
rotate two fingertips in the same direction



Can control object posture

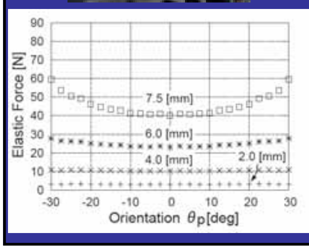
Modeling

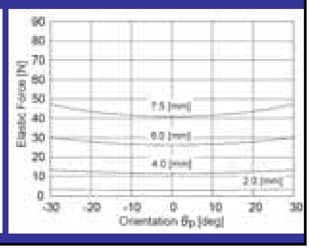
Parallel distributed model



Model verification

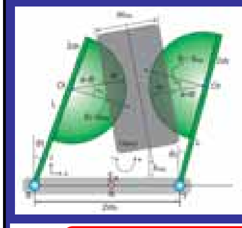
parallel model





Experiment

Simulation



dynamic simulation based on Lagrange formulation

kinetic and potential energies

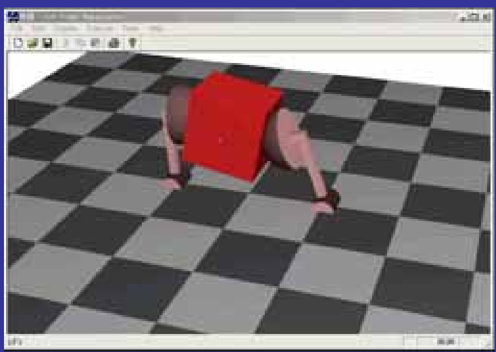
object

left fingertip right fingertip

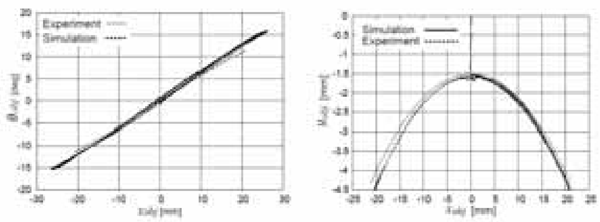
$$T = \frac{1}{2}m_{\mathrm{obj}}(\dot{x}_{\mathrm{obj}}^2 + \dot{y}_{\mathrm{obj}}^2) + \frac{1}{2}I_{\mathrm{obj}}\dot{\theta}_{\mathrm{obj}}^2 + \frac{1}{2}I_{\mathrm{finger}}\dot{\theta}_1^2 + \frac{1}{2}I_{\mathrm{finger}}\dot{\theta}_2^2$$

$$U = U_{\mathrm{parallel}}(d_{n1}, d_{t1}, \theta_1 - \theta_{\mathrm{obj}}) + U_{\mathrm{parallel}}(d_{n2}, d_{t2}, \theta_2 + \theta_{\mathrm{obj}}) + m_{\mathrm{obj}}\, g\, y_{\mathrm{obj}}$$

Simulation



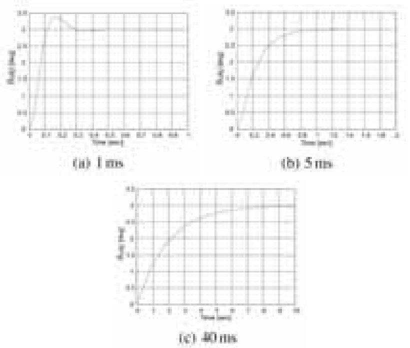
Comparison



(a) orientation (b) position

simulation vs experiment

Simulation with Time Delay



(a) 1 ms (b) 5 ms

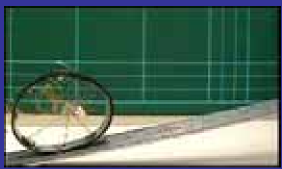
(c) 40 ms

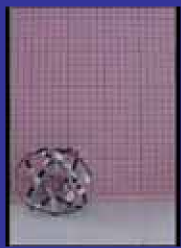
Summary

- Model of soft finger
- Simple as possible
- Force depends on relative angle
- Model can describe this dependency
- Simulation with time delay

We can manipule objects by soft fingers despite of time delay in signal transmission

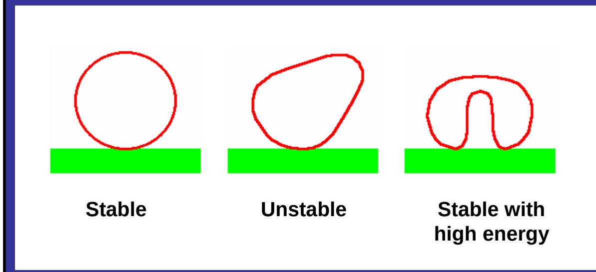
Crawling and Jumping Soft Robots





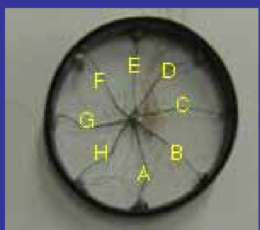
Principle

Charge/Discharge of Potential Energy



Circular Robot (2D motion)

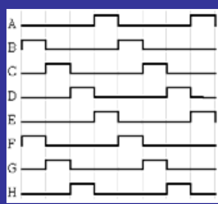
8 SMA coils for crawling
Toki corp. BMX-100



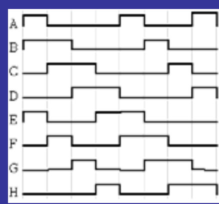
diameter 40mm weight 3g

Control

Open loop PWM control of SMA coils

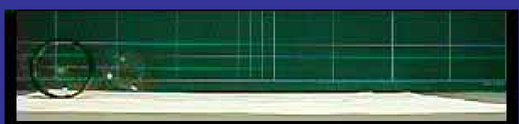


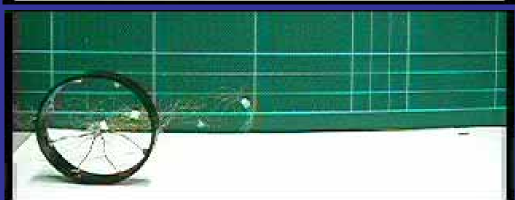
crawling



hill-climbing

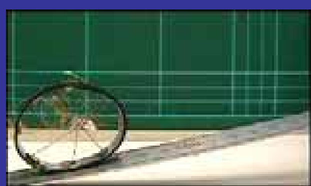
Crawling





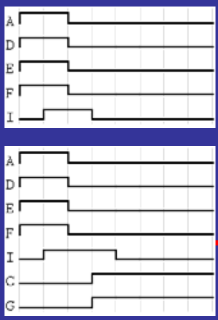
25mm/s (65% of diameter per second)

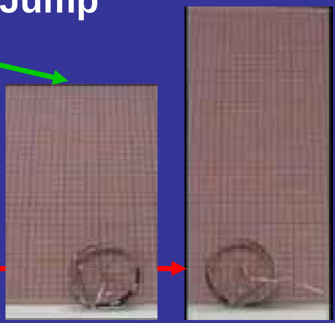
Slope Climbing



20 degrees

Jump

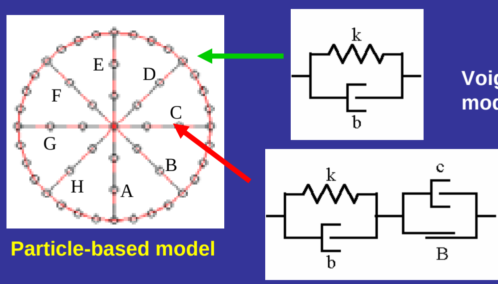




90mm

300mm
(3 times diameter)

Simulation model

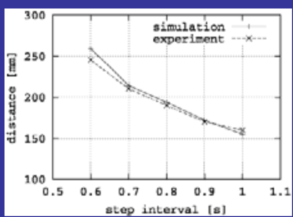


Voigt model

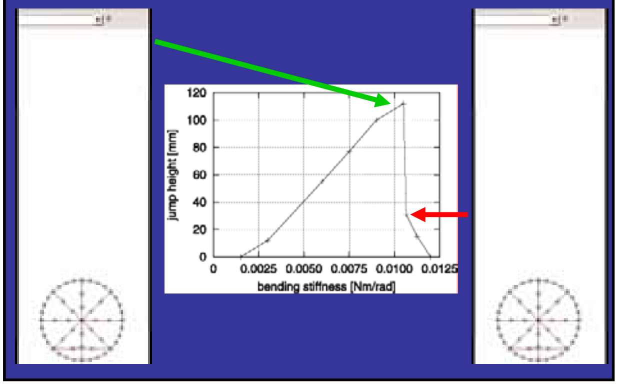
Particle-based model

three-element model with slider

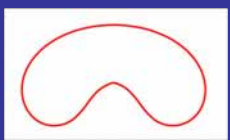
Simulation results



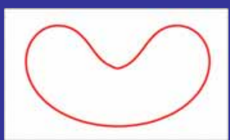
Simulation results



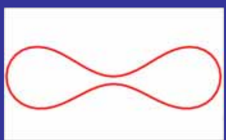
Initial shapes with same energy



(a) Cap shape



(b) Cup shape

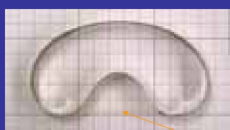


(c) Peanut shape

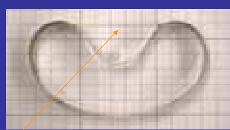
(d) Dish shape

$16.0 \times 10^{-2}\mathrm{Nm}$

Initial shapes with same energy

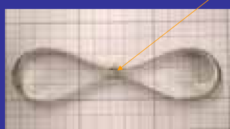


(a) Cap shape

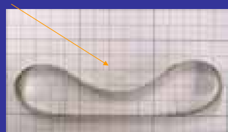


(b) Cup shape

thread



(c) Peanut shape

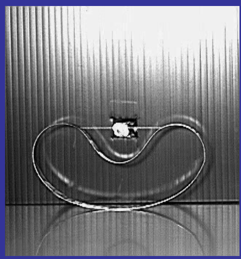


(d) Dish shape

$16.0 \times 10^{-2}\mathrm{Nm}$

Experiments (1/2)

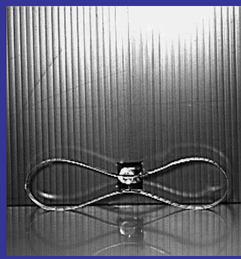
(a) Cap shape



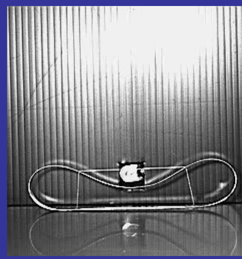
(b) Cup shape

frame rate: 1 KHz

Experiments (2/2)



(c) Peanut shape



(d) Dish shape

frame rate: 1 KHz

Effect of initial shapes

(a) Cap (b) Cup (c) Peanut (d) Dish

Simulation

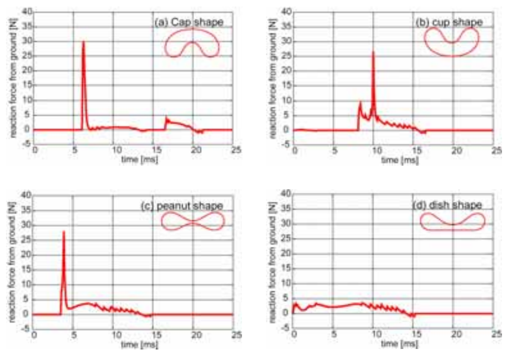
(b) Cup shape

(d) Dish shape

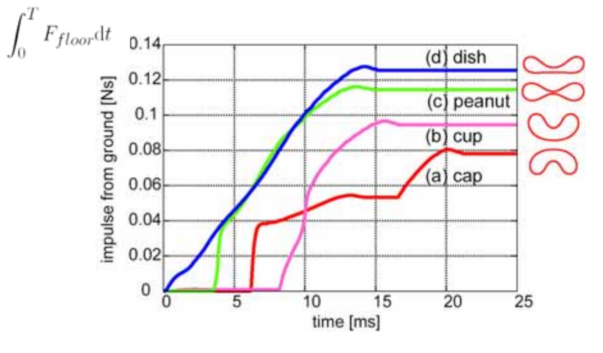
Jumping heights

	experiment [mm]	simulation[mm]
(a) cap	480	457
(b) cup	670	669
(c) peanut	970	980
(d) dish	1180	1171

Reaction force



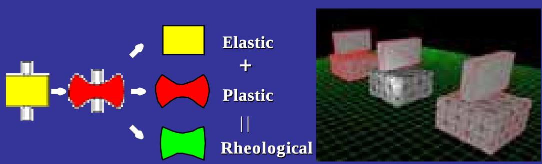
Impulse



Summary

- Circular robot (2D) jump
  three times its diameter
- Simulation
  particle-based modeling works well
- Spherical robot (3D) jump
  twice its diameter
- Jumping height depends on initial shapes
- "Dish shape"
  small force but long contact time
  large impulse, higher jump

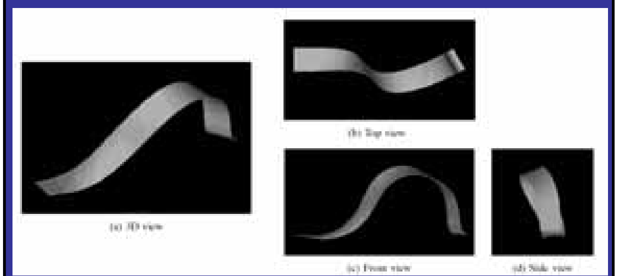
Modeling of Rheological Deformation



Applications:

⌘ Robot grasping;
⌘ Surgical simulation;
⌘ Food engineering;

Modeling of Belt Object Deformation



Simulation of deformation in Robotics

- General models often do not apply
- Simple models with other simulations
- Experimental verification is essential

Thank you for your attention