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

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

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
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

\[
T = \frac{1}{2} m_{obj} \left( \ddot{x}_{obj} + \dot{y}_{obj} \right)^2 + \frac{1}{2} I_{obj} \dot{\theta}_{obj}^2 + \frac{1}{2} I_{finger1} \dot{\theta}_{1}^2 + \frac{1}{2} I_{finger2} \dot{\theta}_{2}^2
\]

\[
U = U_{paralleld} \left( d_{obj}, d_{1}, \theta_1 - \theta_{obj} \right) + U_{paralleld} \left( d_{obj}, d_{2}, \theta_2 + \theta_{obj} \right) + m_{obj} g \delta_{obj}
\]

**Simulation**

**Comparison**

simulation vs experiment

**Simulation with Time Delay**

**Summary**

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

We can manipulate objects by soft fingers despite of time delay in signal transmission
**Crawling and Jumping Soft Robots**

**Circular Robot (2D motion)**
- 8 SMA coils for crawling
- Diameter 40mm, weight 3g

**Control**
- Open loop PWM control of SMA coils

**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

Simulation results

Simulation results

Initial shapes with same energy

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

Initial shapes with same energy

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

16.0 \times 10^{-2} \text{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

<table>
<thead>
<tr>
<th></th>
<th>experiment [mm]</th>
<th>simulation [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) cap</td>
<td>480</td>
<td>457</td>
</tr>
<tr>
<td>(b) cup</td>
<td>670</td>
<td>669</td>
</tr>
<tr>
<td>(c) peanut</td>
<td>970</td>
<td>980</td>
</tr>
<tr>
<td>(d) dish</td>
<td>1180</td>
<td>1171</td>
</tr>
</tbody>
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Reaction force
Impulse

\[ \int_{t_0}^{t} F_{\text{float}}(t) \, dt \]

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

Elastic + Plastic || Rheological

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