COE Postdoctoral and Doctoral Researchers Technical Presentation

CPG-Based Rhythmic Manipulation for a Multi-Fingered Hand

Robotics Lab.

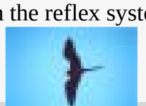
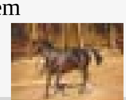
Yuichi Kurita

Background

- Robot hand manipulation
  - Model based analysis
  - Difficult to manipulate unknown objects
- Human hand manipulation
  - Stably grasp and dextrously manipulate unknown objects
  - Sophisticated motion planning
  - Sensory feedback from peripheral sensations

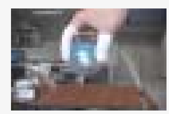
Biological motion control

- Neural and reflex systems control the musculo-skeletal system
- Neural rhythm generator
  - Network of neural oscillators (CPG)
  - Breathing, walking, fluttering, etc.
  - Exists in the spinal cord
  - Generate various patterns based on the feedback from the reflex system

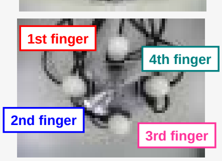
CPG-based control

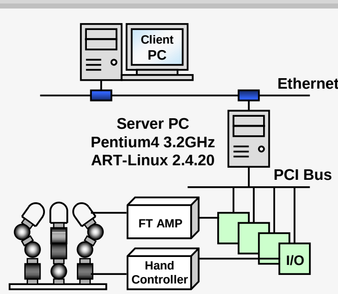
- Walking robots
  - Adaptive walking by the CPG-based control in a variety of environments (Kimura2003)
- Human's rhythmic manipulation
  - Rhythmic finger motions have been observed when a person attains proficiency (Taguchi2002)



CPG-Based rhythmic manipulation for a multi-fingered hand

Multi-fingered hand system



- 4 fingers
- 3 DOF for each finger
- Elastic fingertips
- 6-axes force-torque sensors

Neural oscillator model

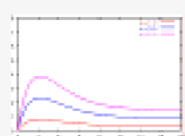
$$\gamma\,\dot{u}_i = -u_i - \beta\,v_i + \sum_{j=1}^{n} w_{ij} y_j + u_0 + S_i$$

$$\gamma'\,\dot{v}_i = -v_i + y_i$$

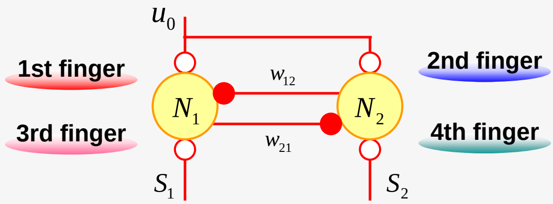
$$y_i = f(u_i) \qquad f(u_i) = \max(0, u_i)$$

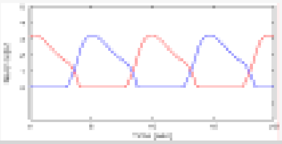
Matsuoka (1987)

- u_i, v_i : Internal states
- y_i : Neural output
- u_0 : External input
- w_{ij} : Connection weight
- S_i : Feedback
- γ, γ' : Time constant
- β : Adaptation Coefficient



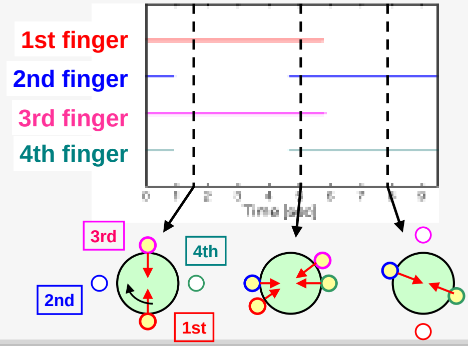
CPG model



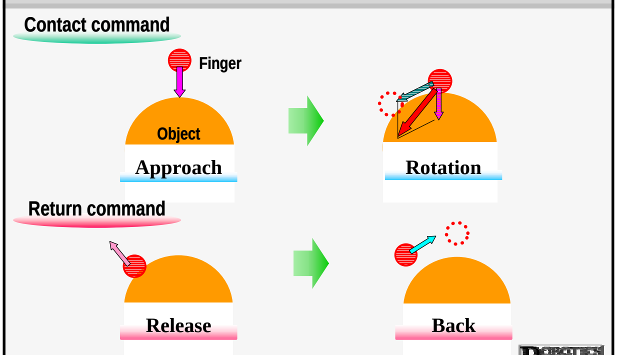


$u_0 = 10.0$ $\gamma = 1.0$
$w_{ij} = 1.8$ $\gamma' = 9.0$
$\beta = 6.0$

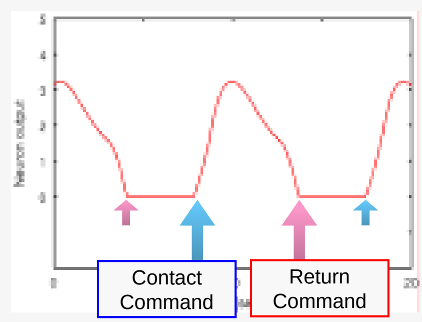
Contact pattern



Motion commands for the manipulation



Issues of the motion commands based on the neural output



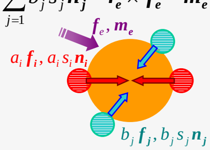
Force control of the fingers

Equilibrium condition of moment

$$\sum_{i=1}^{N_f} a_i \boldsymbol{r_i} \times \boldsymbol{f_i} = -\sum_{i=1}^{N_f} a_i s_i \boldsymbol{n_i} - \sum_{j=1}^{N_f} b_j \boldsymbol{r_j} \times \boldsymbol{f_j} - \sum_{j=1}^{N_f} b_j s_j \boldsymbol{n_j} - \boldsymbol{r_e} \times \boldsymbol{f_e} - \boldsymbol{m_e}$$

Equilibrium condition of force

$$\sum_{i=1}^{N_f} a_i \boldsymbol{f_i} = -\sum_{j=1}^{N_f} b_j \boldsymbol{f_j} - \boldsymbol{f_e}$$



Friction condition

$$\boldsymbol{n_i} \cdot \boldsymbol{f_i} \geq \frac{1}{\sqrt{1+\mu^2}} \| \boldsymbol{f_i} \|$$

$\boldsymbol{f_i}, \boldsymbol{m_i}, \boldsymbol{n_i}, \boldsymbol{r_i}$:Force, moment, contact vector, and vector
s_i :moment size μ :friction coefficient
a_i :1 when the finger is grasping finger, 0 when the finger is manipulation finger
b_i :0 when the finger is grasping finger, 1 when the finger is manipulation finger

Angular velocity of the object

Finger velocity to move the object

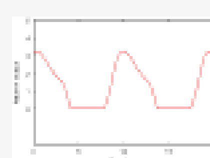
$$\begin{bmatrix} \boldsymbol{v_1} \\ \vdots \\ \boldsymbol{v_i} \\ \vdots \\ \boldsymbol{v_{N_f}} \end{bmatrix} = \begin{bmatrix} \boldsymbol{E}_{3\times3} & -\boldsymbol{r_1} \\ \vdots & \vdots \\ \boldsymbol{E}_{3\times3} & -\boldsymbol{r_i} \\ \vdots & \vdots \\ \boldsymbol{E}_{3\times3} & -\boldsymbol{r_{N_f}} \end{bmatrix} \begin{bmatrix} \boldsymbol{v_o} \\ \boldsymbol{w_o} \end{bmatrix}$$

$\boldsymbol{E}_{3\times3}$:3x3 unit matrix
$\boldsymbol{v_o}, \boldsymbol{w_o}$:desired object velocity
$\boldsymbol{v_i}$:velocity of the finger

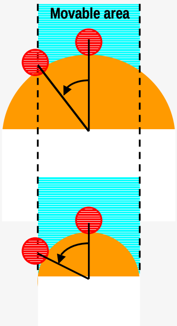
Desired object velocity

$$w_{oz} = k_w y_g$$

w_{oz} :angular velocity of the object along z-axis
k_w :conversion coefficient
y_g :neural output of the grasping finger



Effect of the object size on the manipulation



- Rotatable angle of the object changes depending on the object size and the movable area of the finger
- Movable area is determined by the mechanical configuration of the finger

Joint margin feedback to the neurons

- Relocation of the fingers can be performed when the finger moves to the movable limit

Joint margin feedback

Joint margin of the j-th joint of the i-th finger

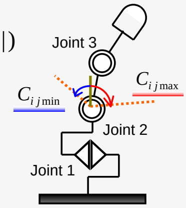
$$m_{ij} = \min(|C_{ij\min} - \theta_{ij}|, |C_{ij\max} - \theta_{ij}|)$$

Finger joint margin of the i-th finger

$$n_i = \min(m_{i1}, m_{i2}, \cdots, m_{iN_j})$$

Feedback to the neurons

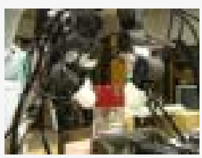
$$S_1 = k_s \min(n_1, n_3)$$
$$S_2 = k_s \min(n_2, n_4)$$

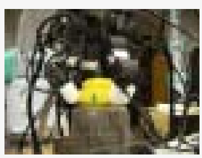


$C_{ij\max}, C_{ij\min}$: Maximum and minimum limit of the joint
N_j : Number of the joint N_f : Number of the finger
k_s : Feedback gain

Experiment

- Experimental setup
  - Rotation of a cylindrical cap
  - Diameter: 50, 60, 75[mm]
  - 2-neuron CPG model

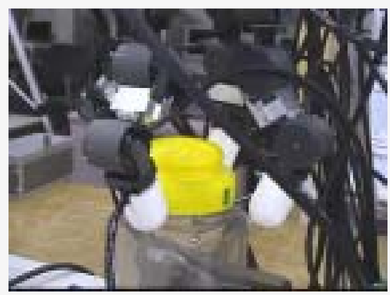




Movable limit of the joint

$C_{i1\min} = -\pi/9$ $C_{i2\min} = -\pi/2$ $C_{i3\min} = 0$
$C_{i1\max} = \pi/9$ $C_{i2\max} = 4\pi/9$ $C_{i3\max} = \pi/2$
[rad]

Experimental scene

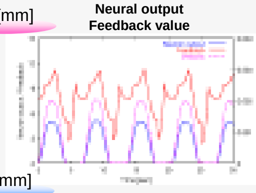


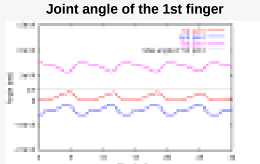
Results

50[mm]

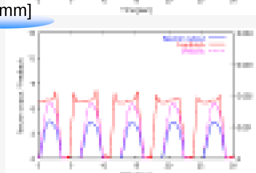
Neural output
Feedback value

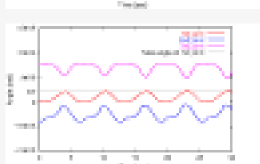
Joint angle of the 1st finger



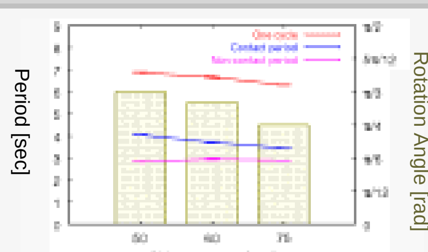


75[mm]





Motion cycle



Adaptive manipulation according to the object size

Conclusion

- CPG-based manipulation using a four-fingered hand system
  - CPG model using two neurons
    - Grasping and rotation using facing two fingers
  - Joint margin feedback
    - Issue of the motion commands depending on the object size
  - Experiment using a hand system
    - Four-fingered hand system
    - Adaptive change of the issuing cycle
- Future work
  - Determination method of the CPG parameters
  - Connecting the CPG directly to the actuators