WASEDA UNIV.
HRI

Emotional control of emotion expression humanoid robot WE-4RII

Workshop on Building Humanoid Heads

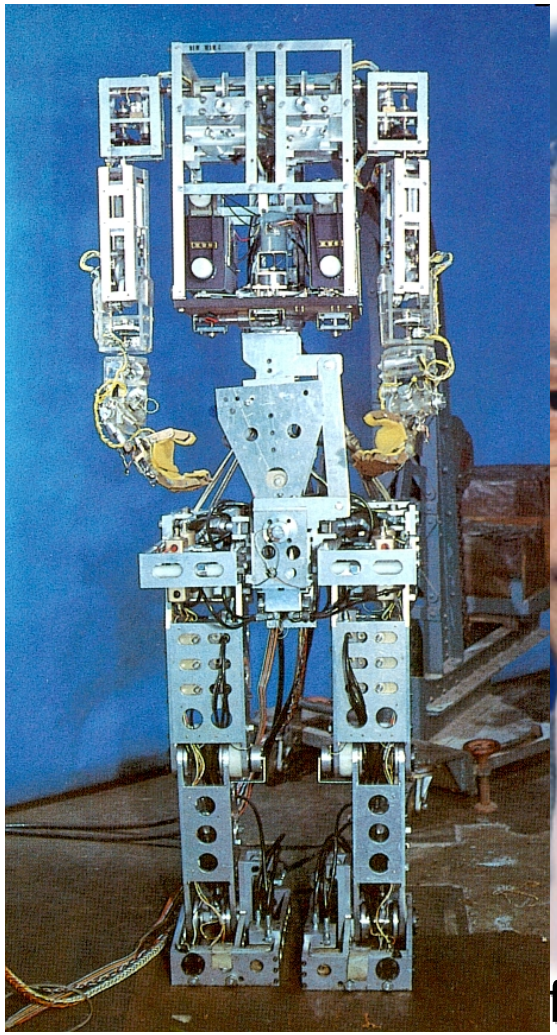
IEEE-RAS/RSJ International Conference on Humanoid Robots
(Humanoids 2004)

Double Tree Guest Suites Santa Monica, Los Angeles, CA, USA

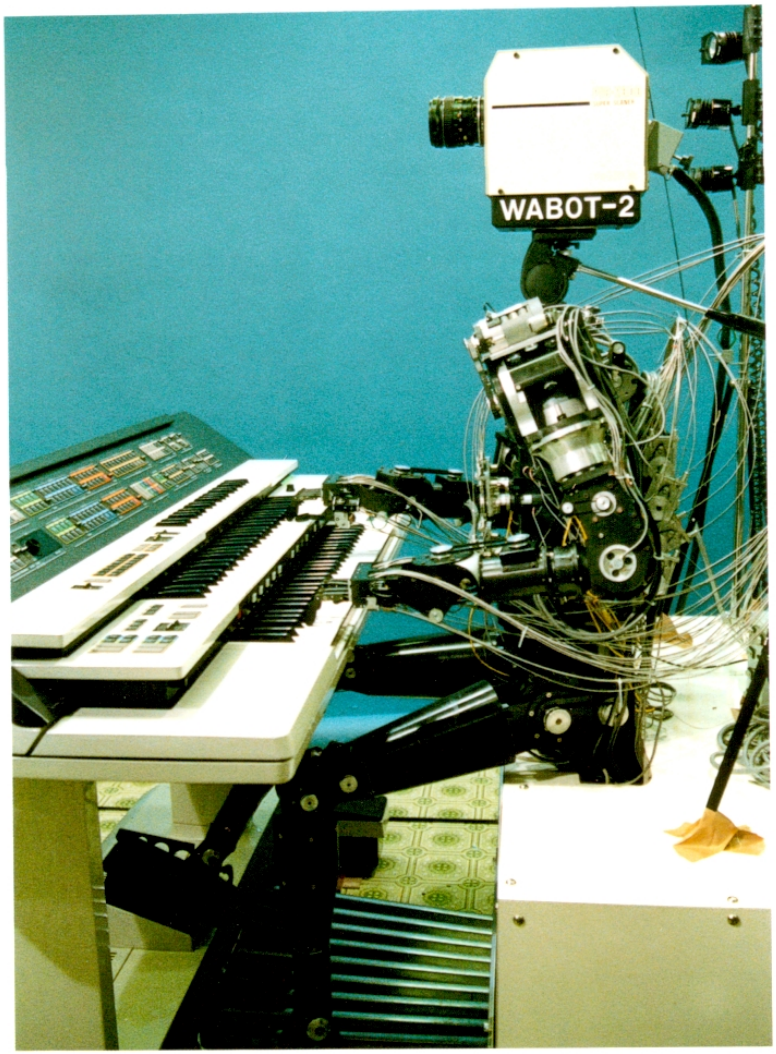
Wednesday, November 10, 2004

Atsuo Takanishi and Hiroyasu Miwa
Dept. of Mech. Eng./Humanoid Robotics Institute, Waseda University

Waseda's Achievements
ed by the late Prof. Ichiro Kato



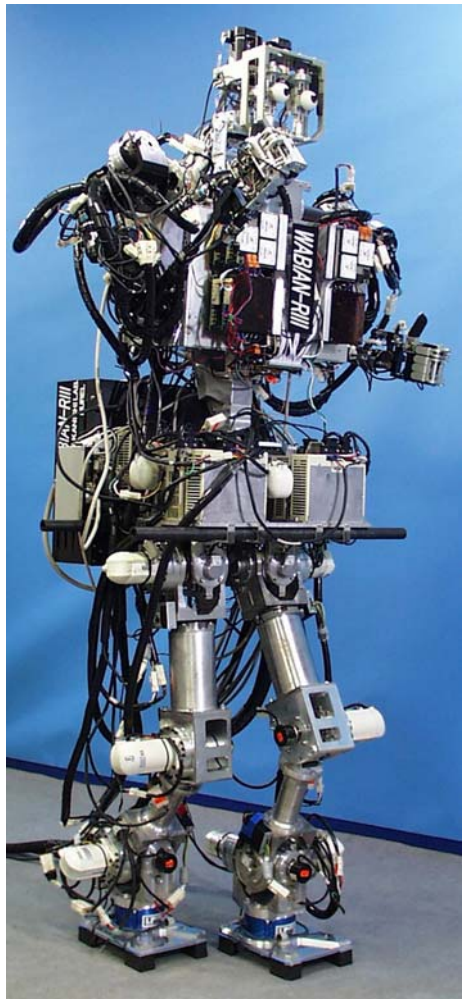
f. Ichiro K
(1926-1994)



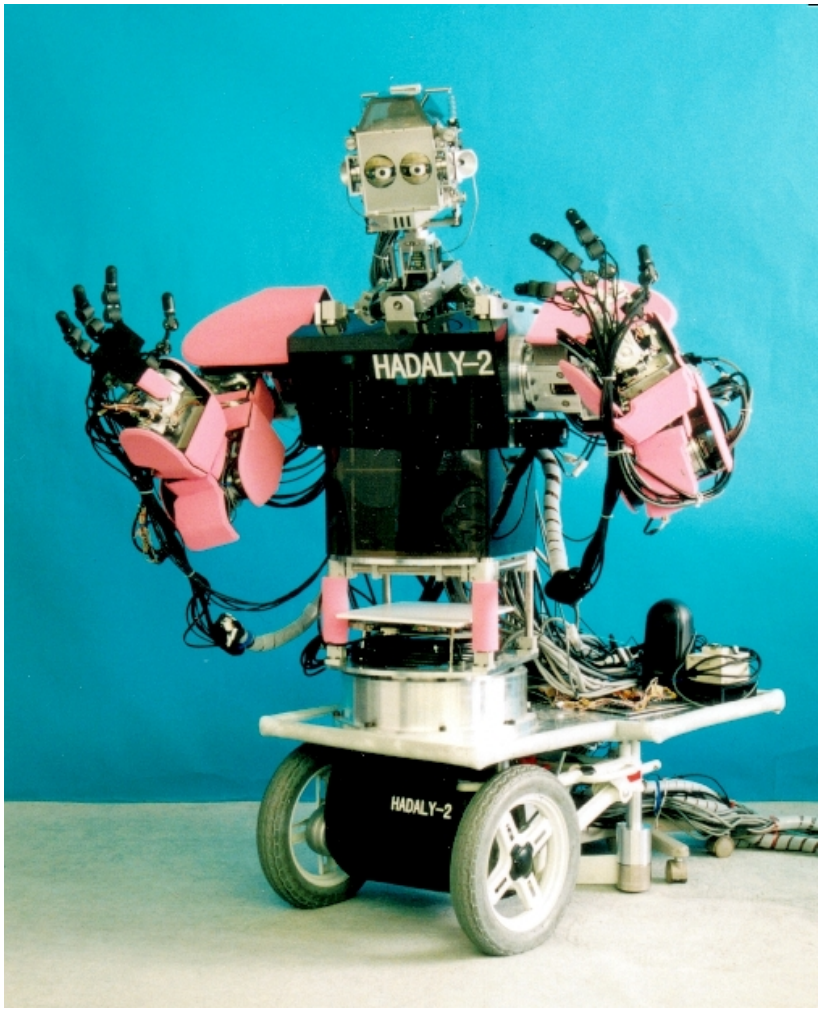
WABOT-1 (1973)

WABOT-2 (1984)

Waseda Robots After Prof. Ichiro Kato: WABIAN and Hadaly-2



WABAIN (1997)



Hadaly-2 (1997)

About Humanoid Robotics Institute, Waseda Univ.

WASEDA UNIV. HRI

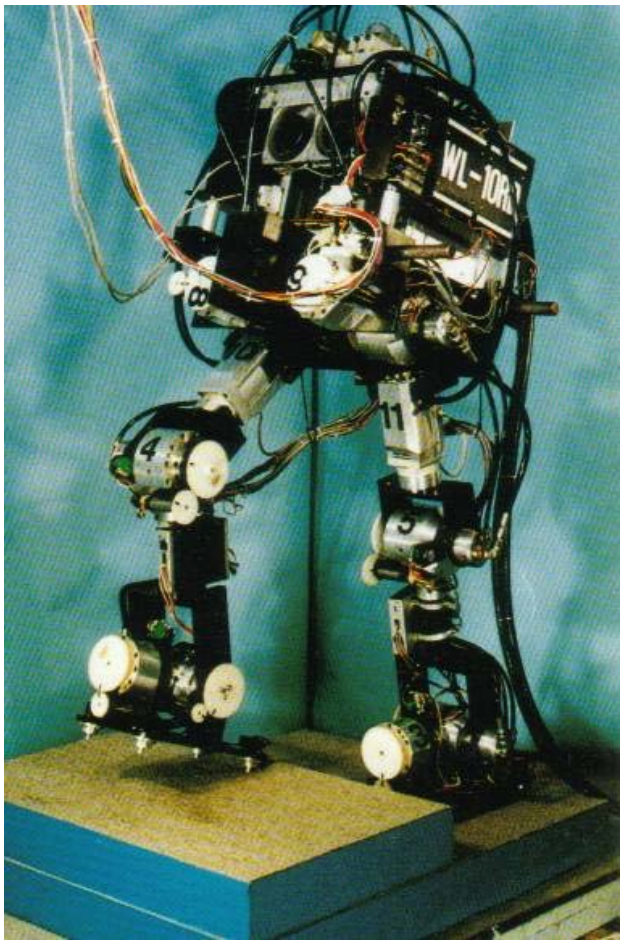
- Established in April, 2000
- 9 Fulltime Professors and 10 Visiting Professors/Researchers including from Overseas
- More than 60 graduate students and post-doc researchers (More than 100 including undergraduates)
- More than 30 ongoing projects
- Organizing Humanoid Consortium
- Supported by: METI, NEDO, MEST, Gifu Pref., TMSUK, SANYO, SONY, HITACHI, NTT, NTT DoCoMo, OKINO, OSADA, ZMP, Fukuoka Pref., Fukuoka City, Niigata Pref.
- RoboCasa: SSSA-Waseda Joint Laboratory (2003/4/1)
- Center of Excellence in the 21st Century in Robotics (2003/7) Show!
- Super COE on Advanced Science and Medical Care (2004/7)

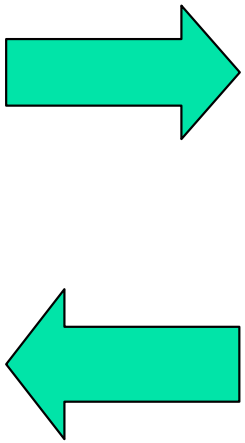
Why Humanoid Robots?

- To Build Human Model to Understand Human from Robotics View Point: *"Robotic Human Science"*
- To Make Robotics as One of the Social Technologies based on the Human Model to Support Elderly Dominated Society and to Support Education, Etc.
- Grand Challenge for Roboticists: A human is considered to be an excellent robot both in motional functionality and in intelligential functionality.

Co-Creative Researches Between Biped and Leg Prostheses Research Group at Kato Lab.

WASEDA UNIV.
HRI





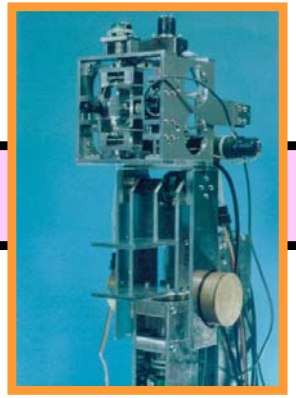
WL-10RD (1984-85)

WLP-8RII (1987)

WASEDA UNIV.
HRI

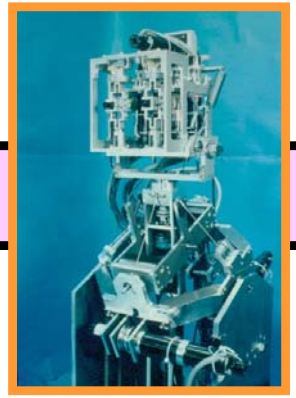
Previous Studies

WE-2 (1995)



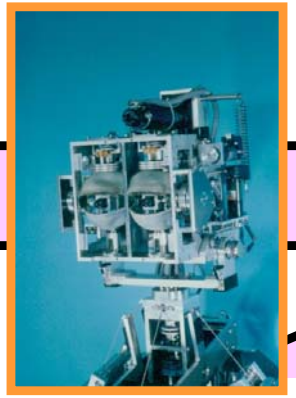
Motion Perception

WE-3 (1996)



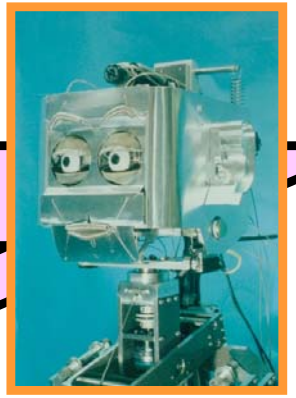
Depth Perception

WE-3R (1997)



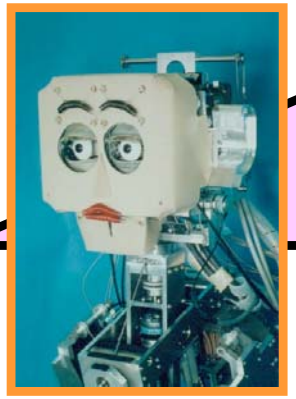
Light Perception

WE-3RII (1998)



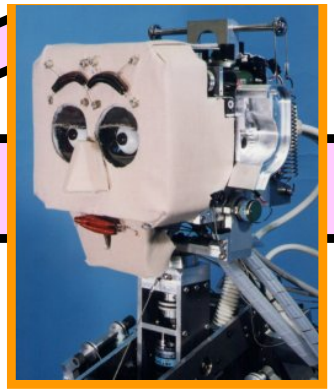
Facial Expression

WE-3RIII (1999)



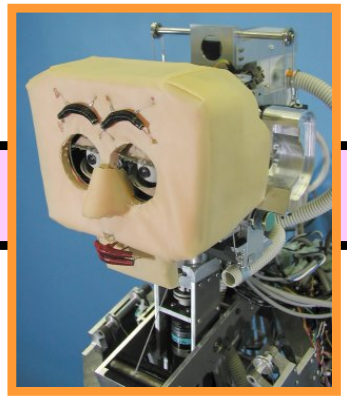
Tactile and Audition

WE-3RIV (2000)



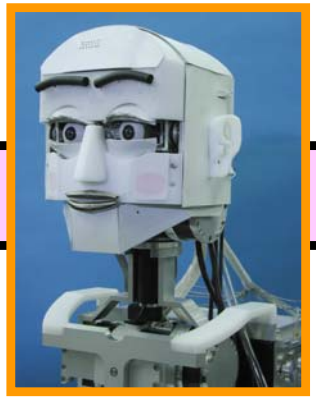
Olfaction

WE-3RV (2001)



Facial Color

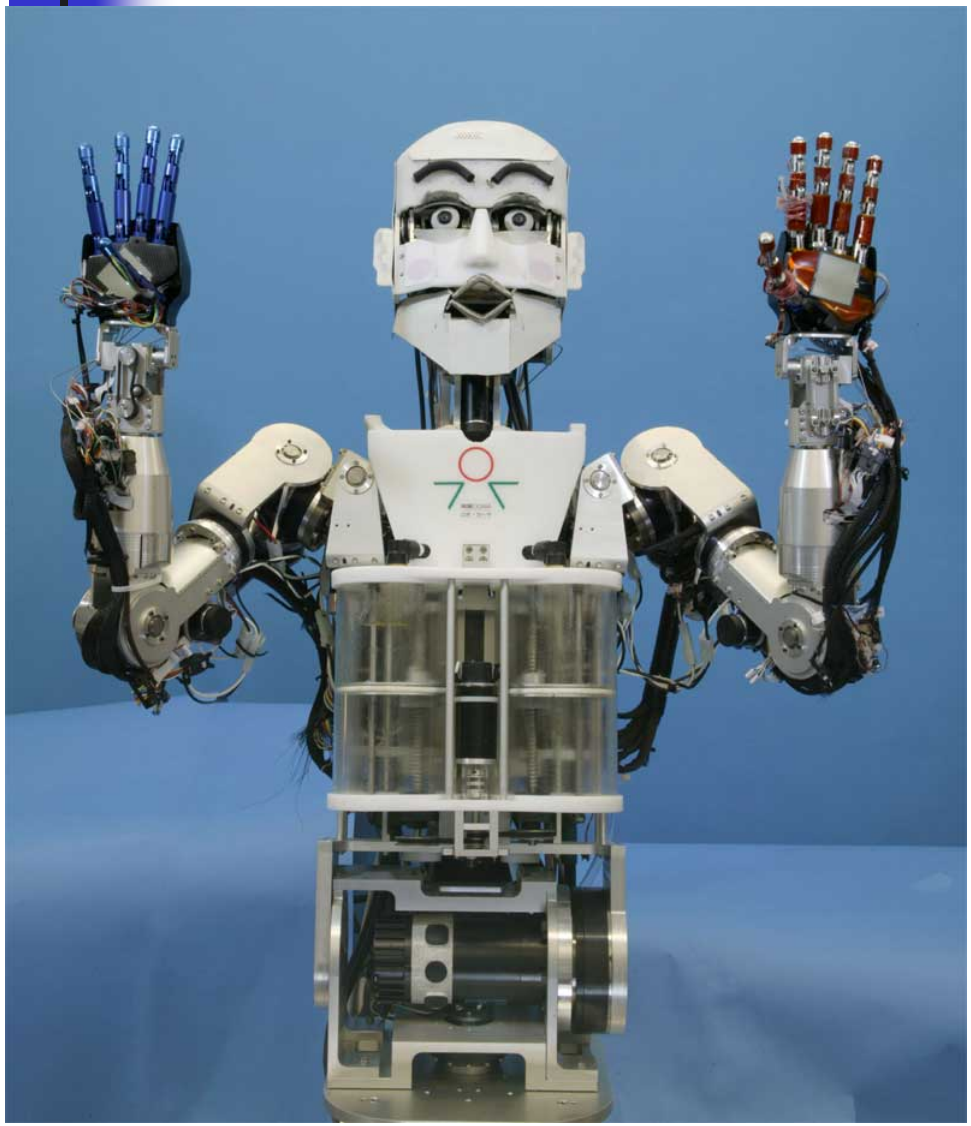
WE-4 (2002)



New Model

Emotion Expression Humanoid **EYE-Chan**: WE-4RII for Modeling Human Mind

WASEDA UNIV. HRI

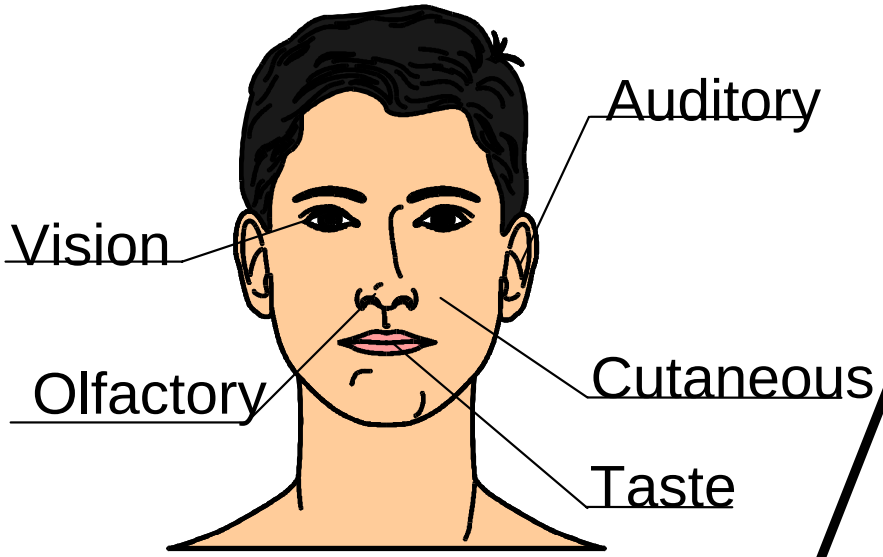


Part	DOF
Neck	4
Eyes	3
Eyelids	6
Eyebrows	8
Lips	4
Jaw	1
Lung	1
Waist	2
Arms	18
Hand	12
Total	59

Importance of the Head Part for Human-Robot Communication

WASEDA UNIV. HRI

Information Input



The five senses exist on the head.

Information Output

Language : 35%
Facial expression etc : 65%

From Book "Non-Verbal Communication"

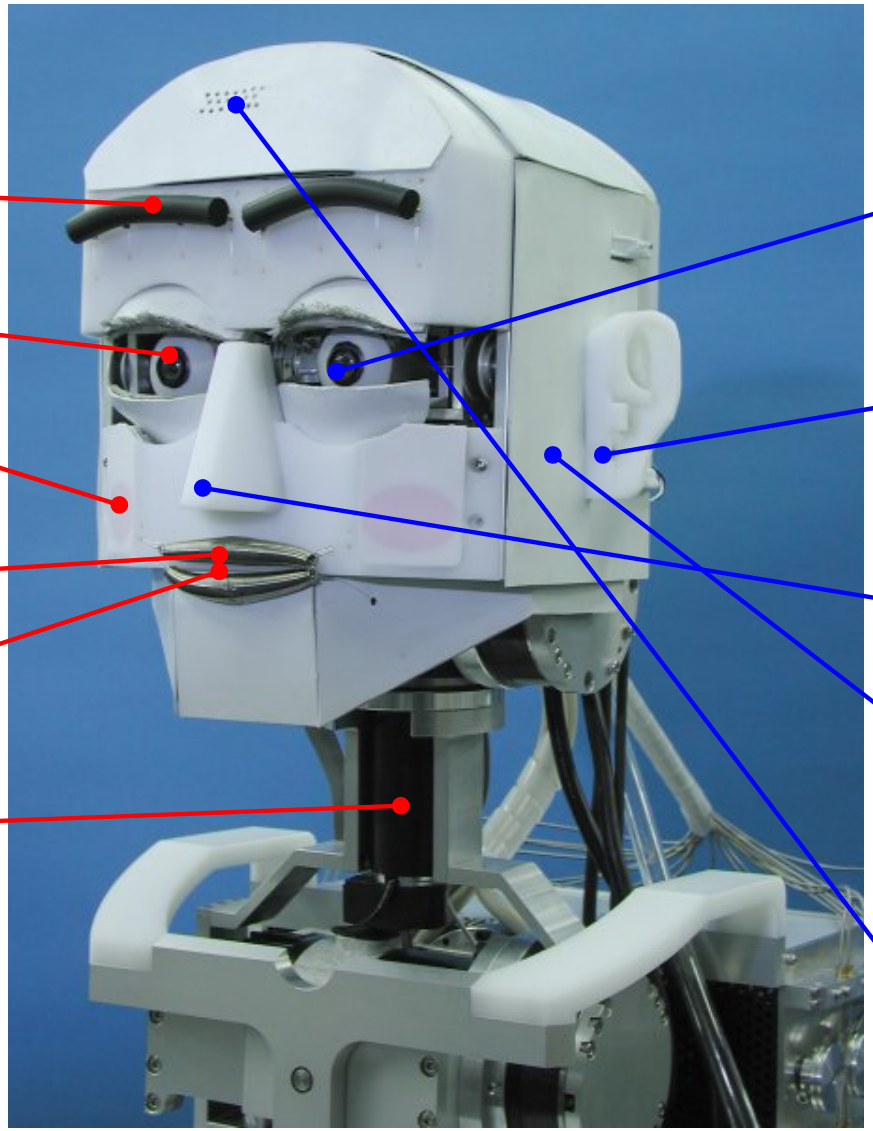
Many information is acquired not only from sense of language but also from gaze or facial expressions in conversation.

WE-4 (Waseda Eye No.4)

WASEDA UNIV. HRI

Expressions

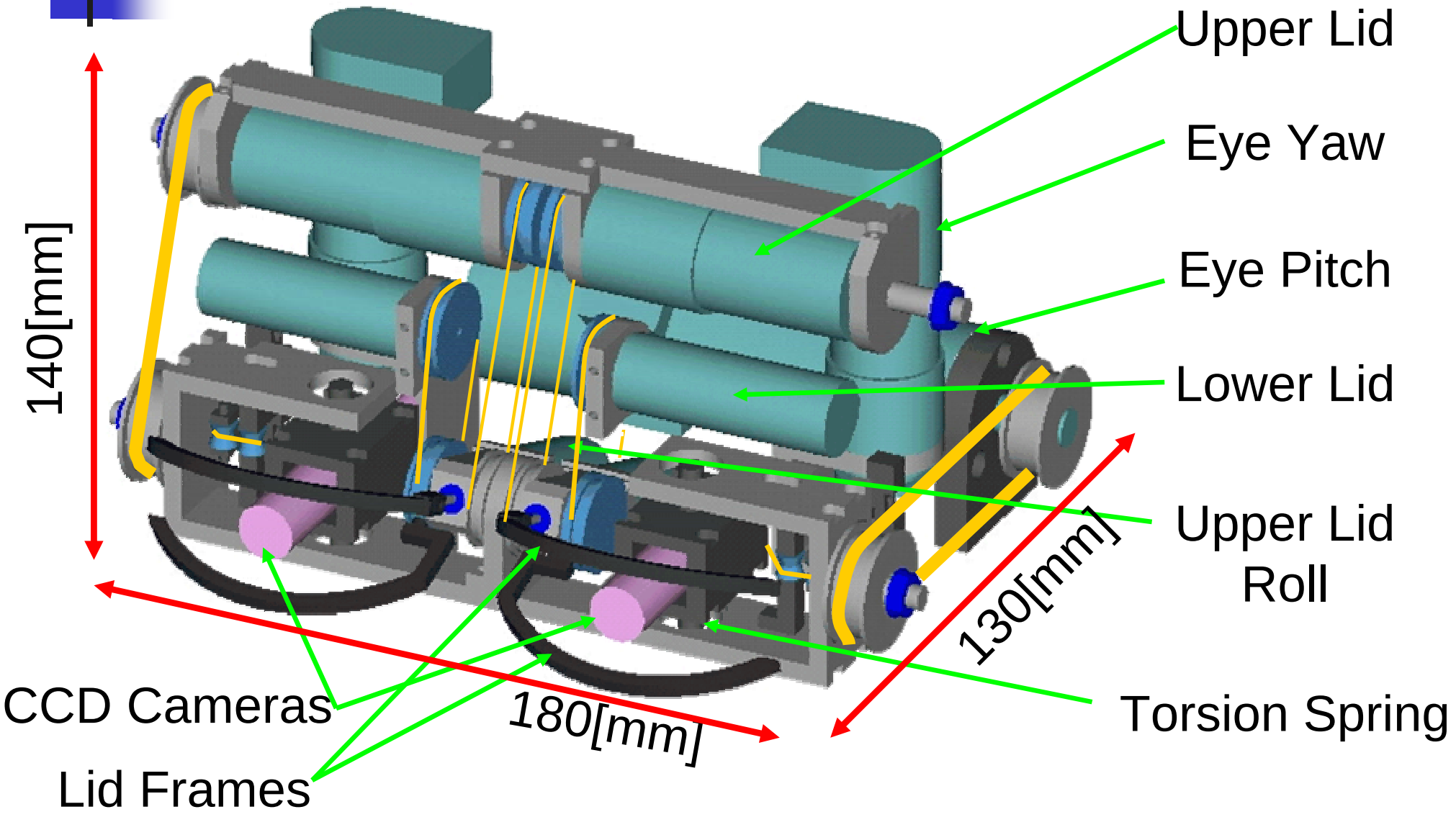
- Eyebrows
- Eyelids
- Facial Color
- Lips
- Voice
- Neck
- Waist
- Lung(Breath)



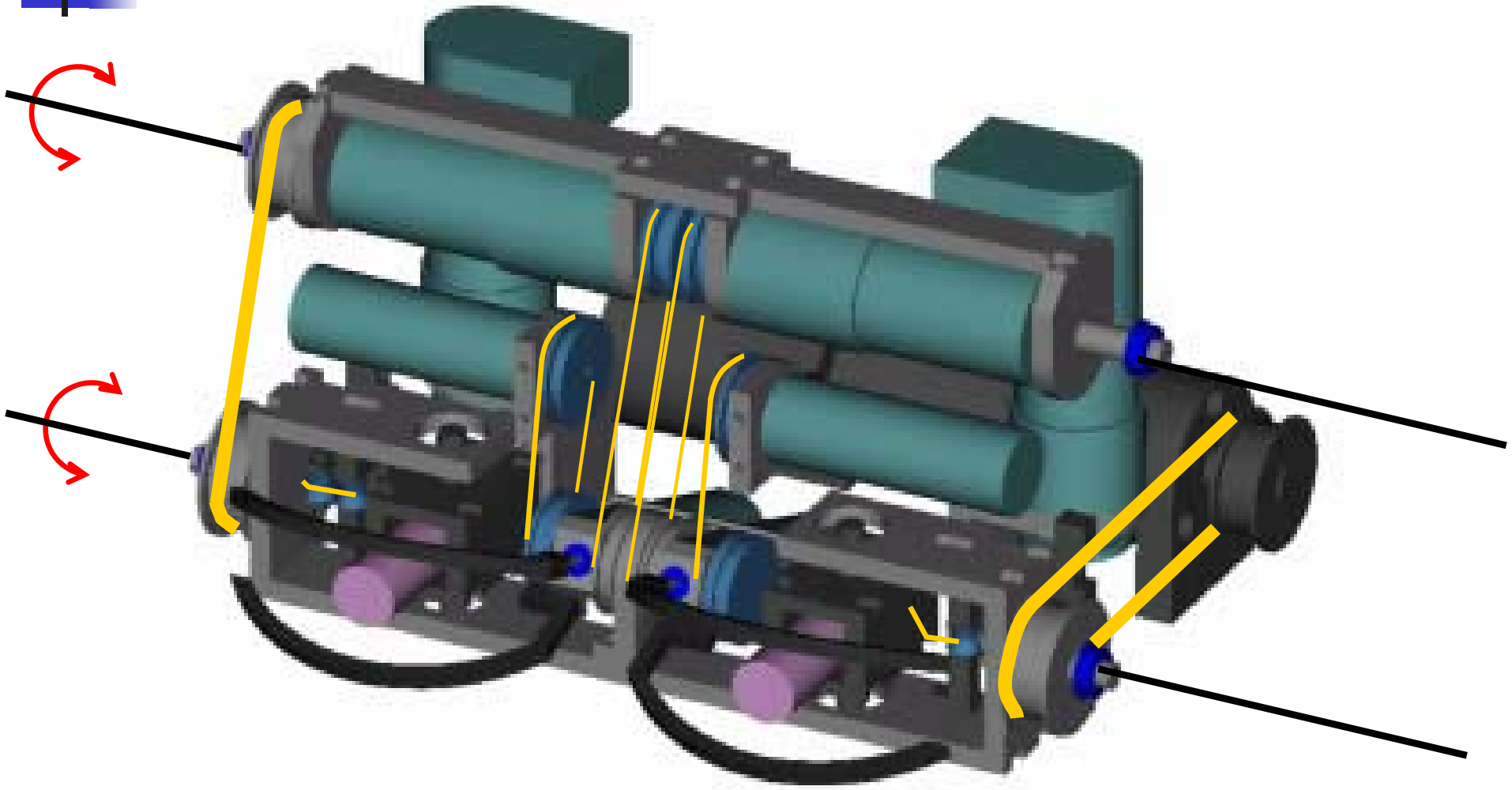
Sensors

- Visual (CCD Camera)
- Auditory (Microphone)
- Olfactory (Gas Sensor)
- Tactile (FSR)
- Temperature (Thermistor)

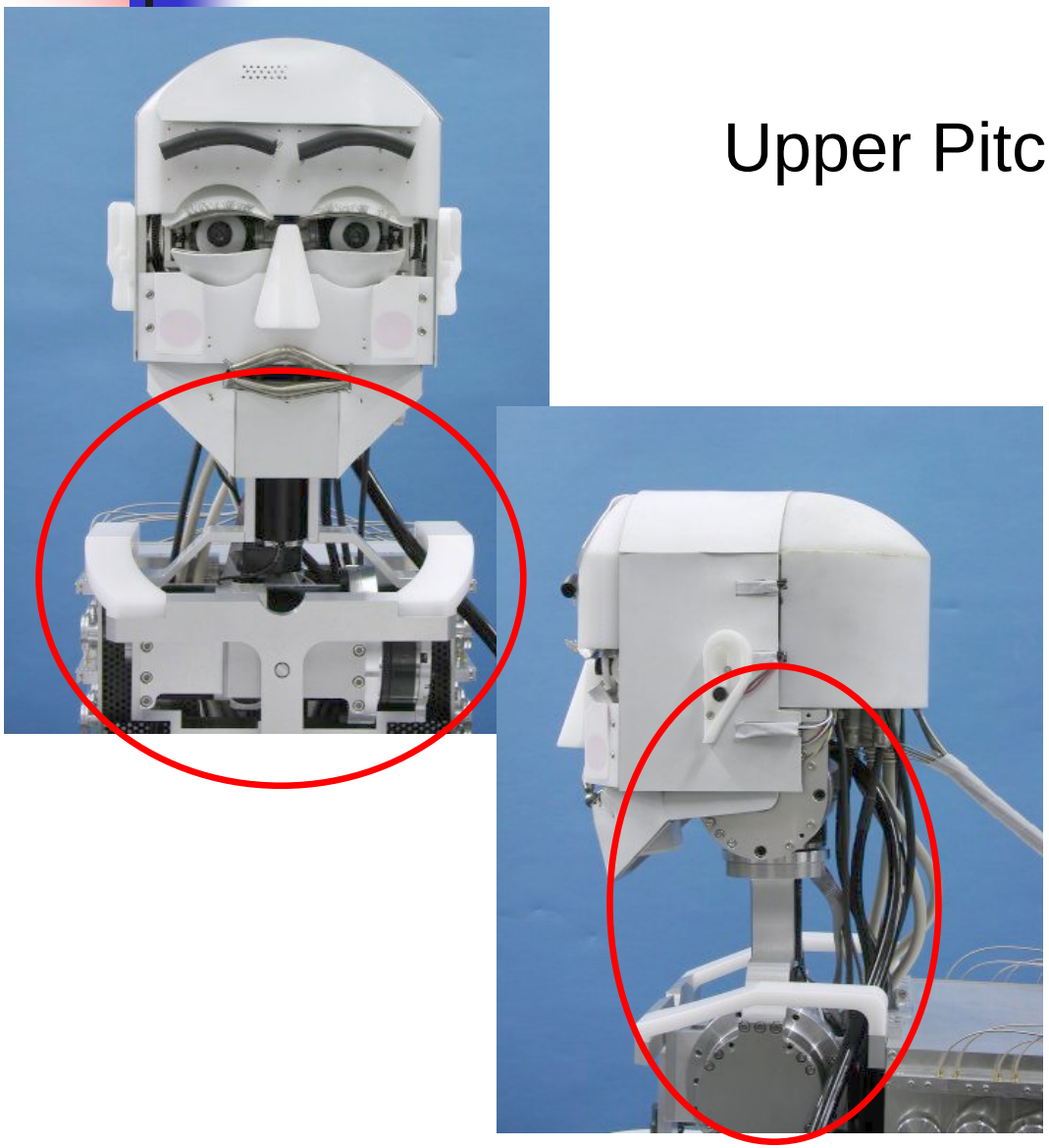
Eye Unit


Upper Lid
Eye Yaw
Eye Pitch
Lower Lid
Upper Lid Roll
Torsion Spring
140[mm]
180[mm]
130[mm]
CCD Cameras
Lid Frames

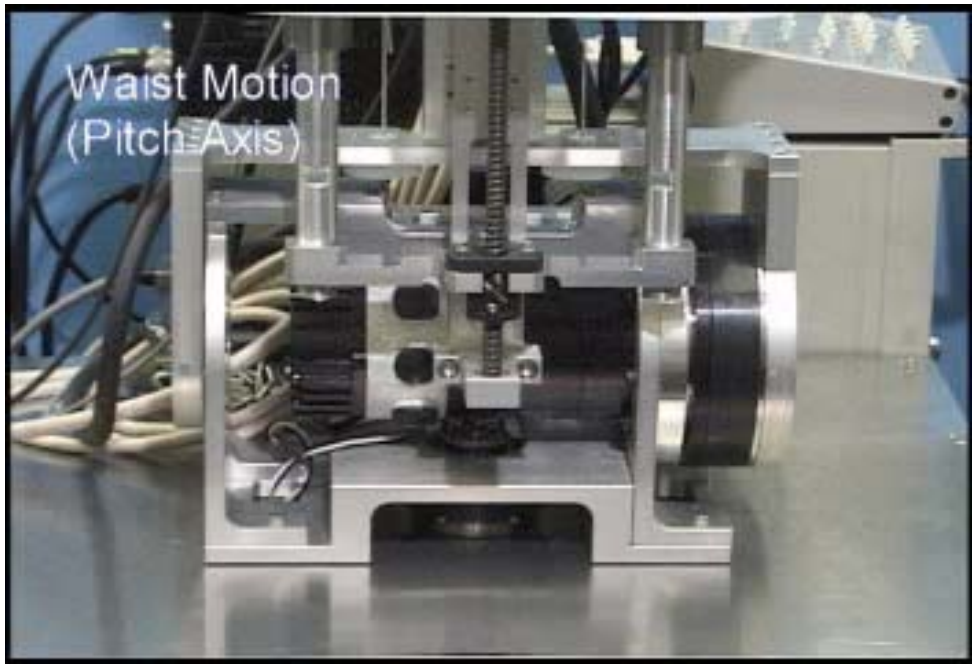
Eye Unit Motion

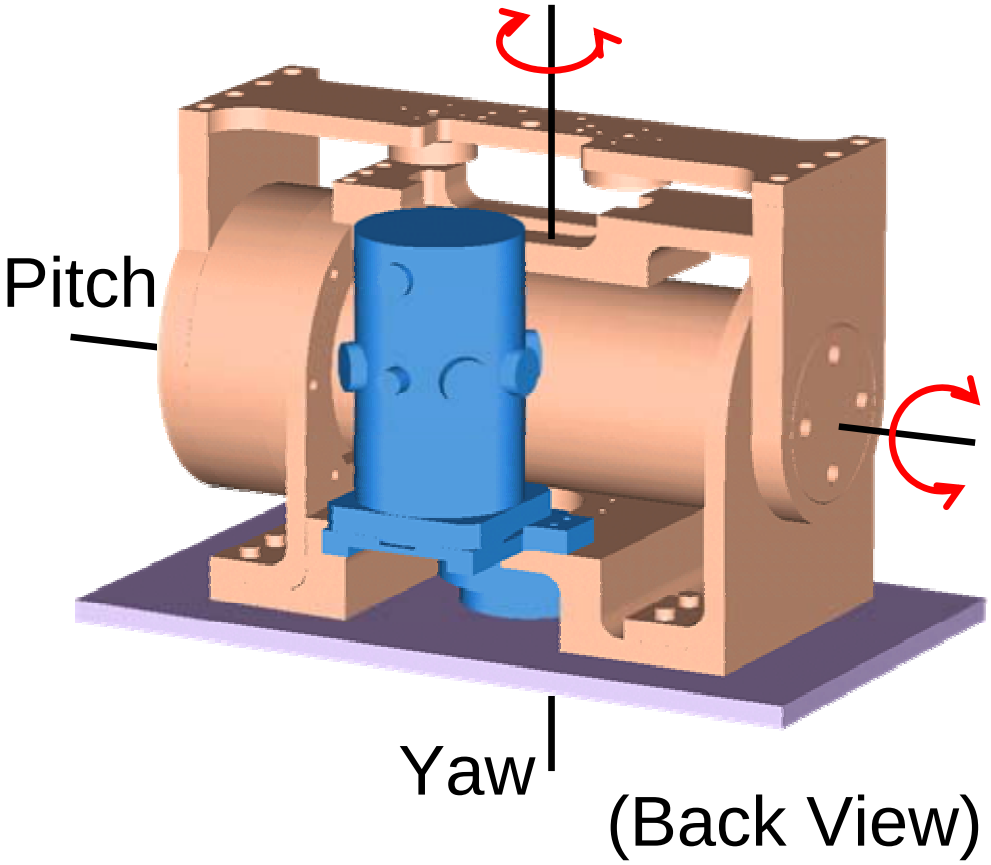


Neck Mechanism

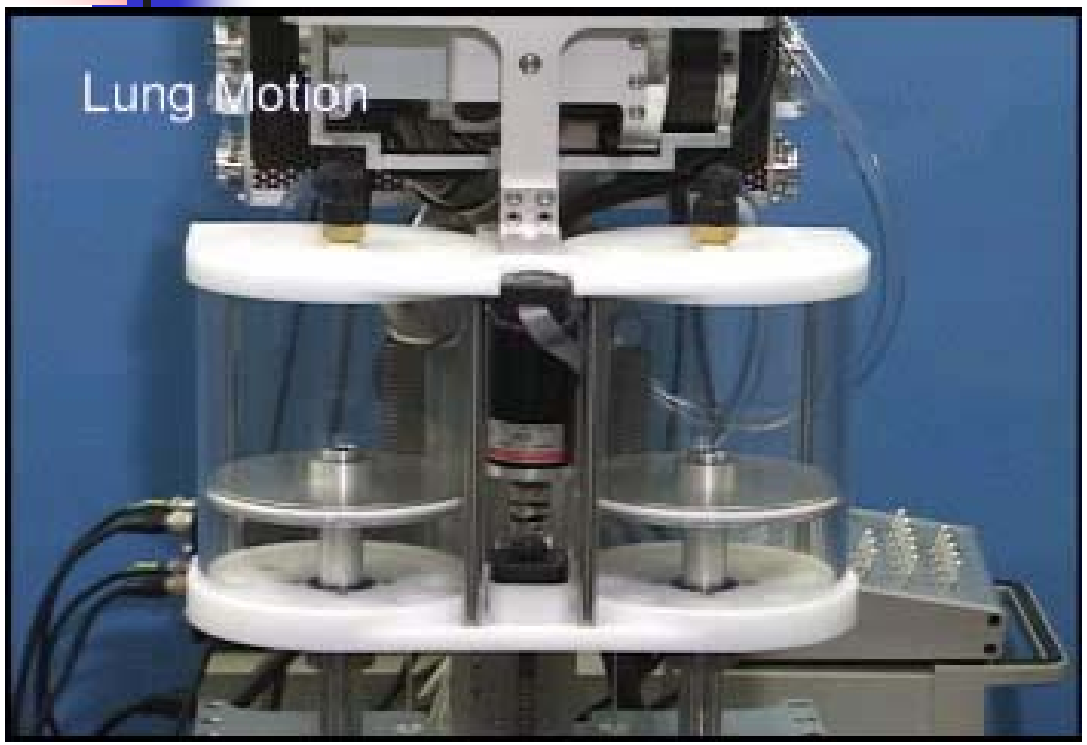


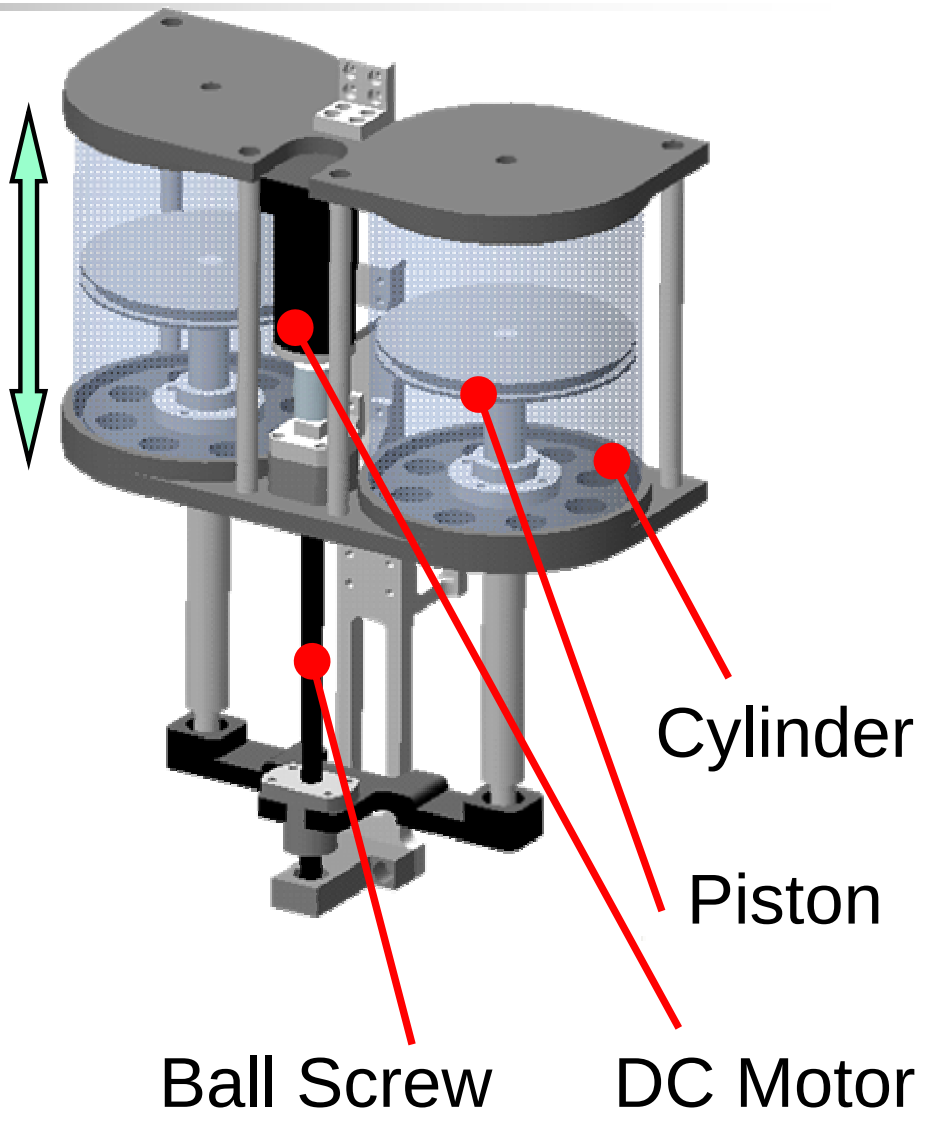
Waist Mechanism





Lungs

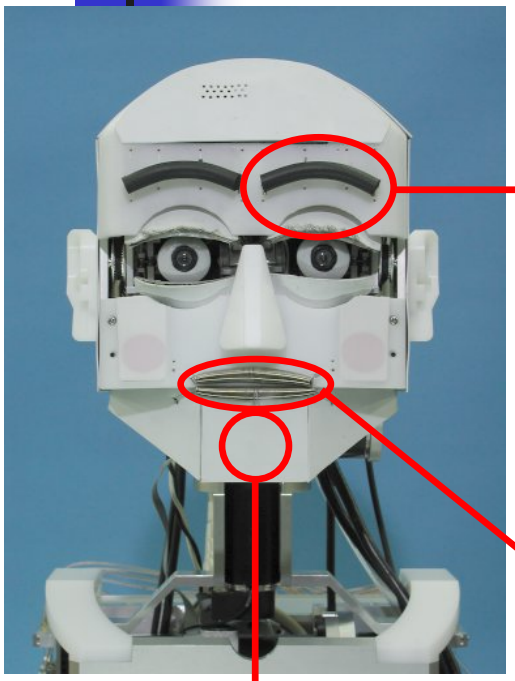


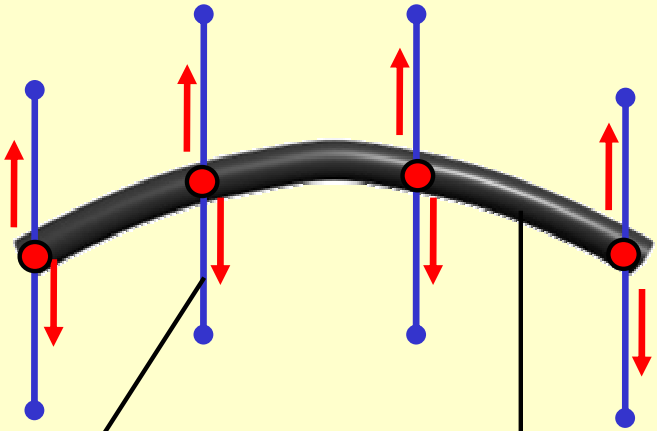


Specification
Volume: 3.2×10^{-3} [m^3]
Stroke : 140 [mm]

WASEDA UNIV.
HRI

Eyebrows and Lips

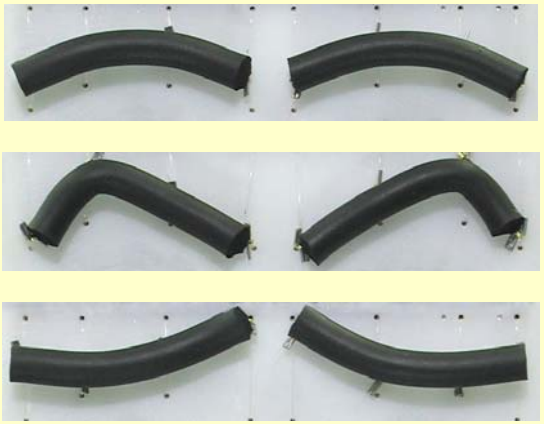




Clear Wire
(for fishing)

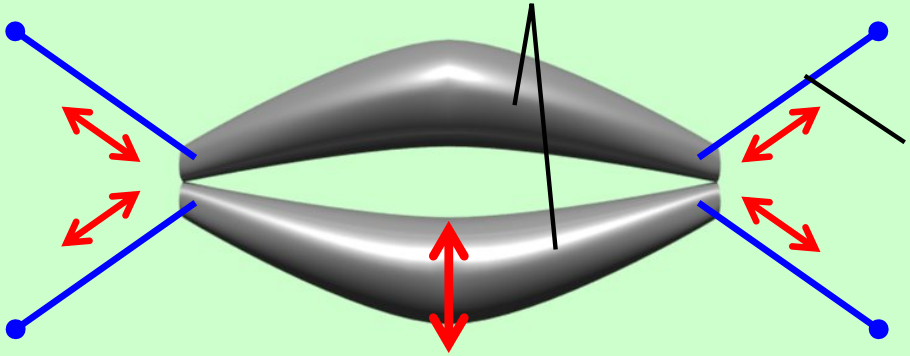
Eyebrows
made by Sponge

Various Shapes



Speaker (1[W])
for Emotional Voice

Spindle Shaped Springs for Lips

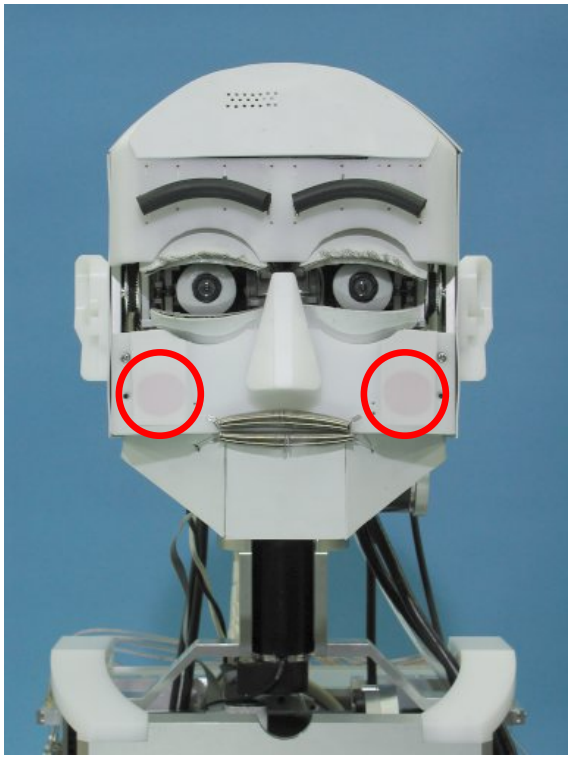


Clear Wire
(for fishing)

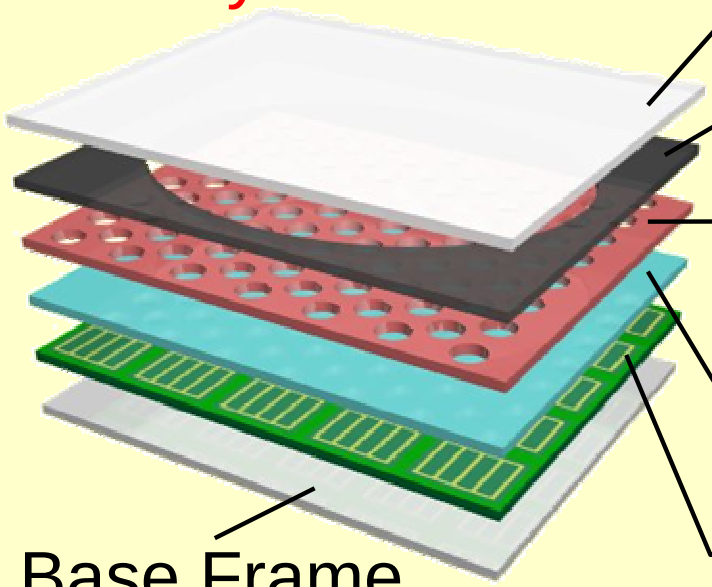
Open/Close by Jaw Motion

WASEDA UNIV.
HRI

Robot Skin



6 Layered Skin



Plastic Skin

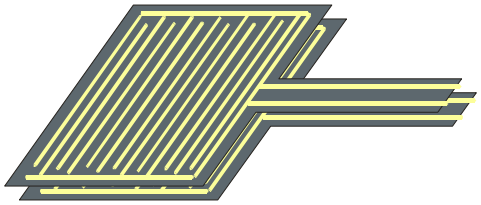
Film for Mask

Red EL Sheet
with ϕ 1[mm] Holes

Blue EL Sheet

FSR

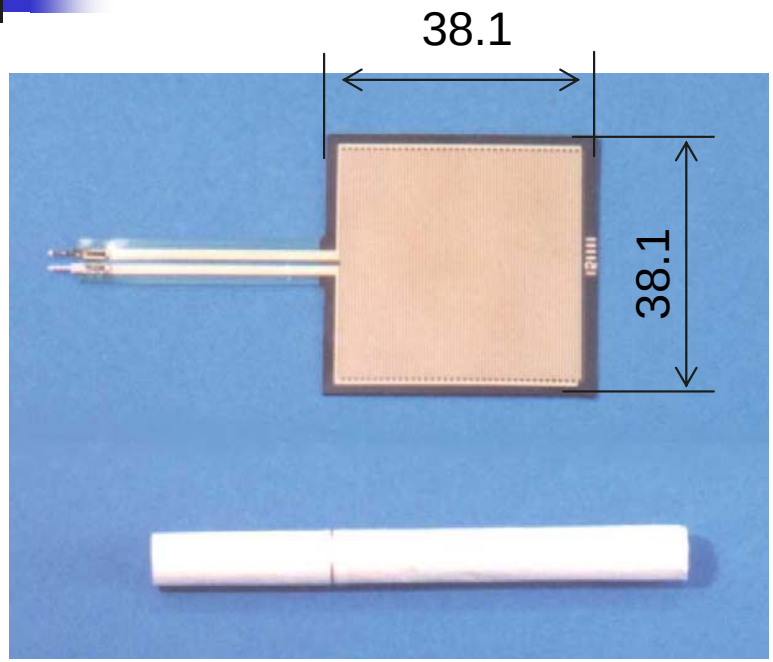
Base Frame



Double Layered FSR

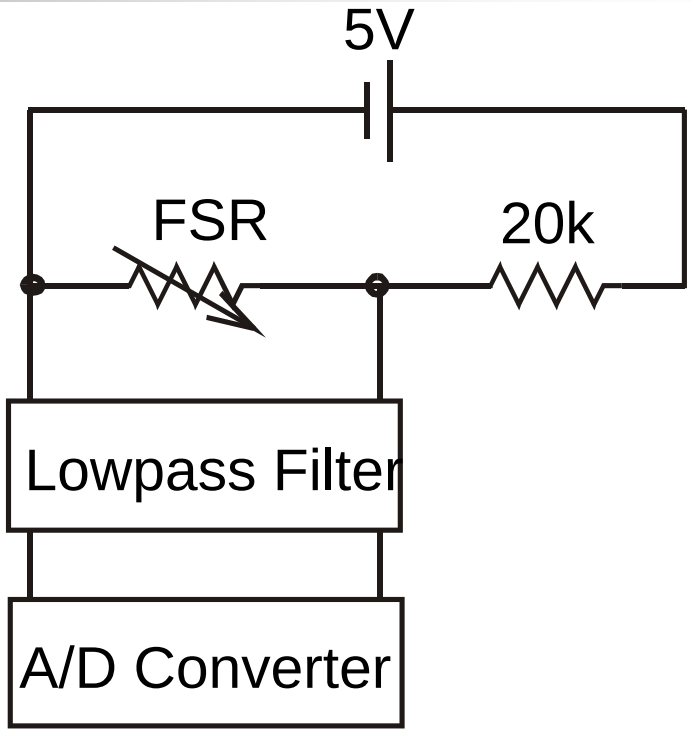
Hit
Stroke
Push

FSR (Force Sensing Resistor)



(thickness : 0.46)

Photo of FSR

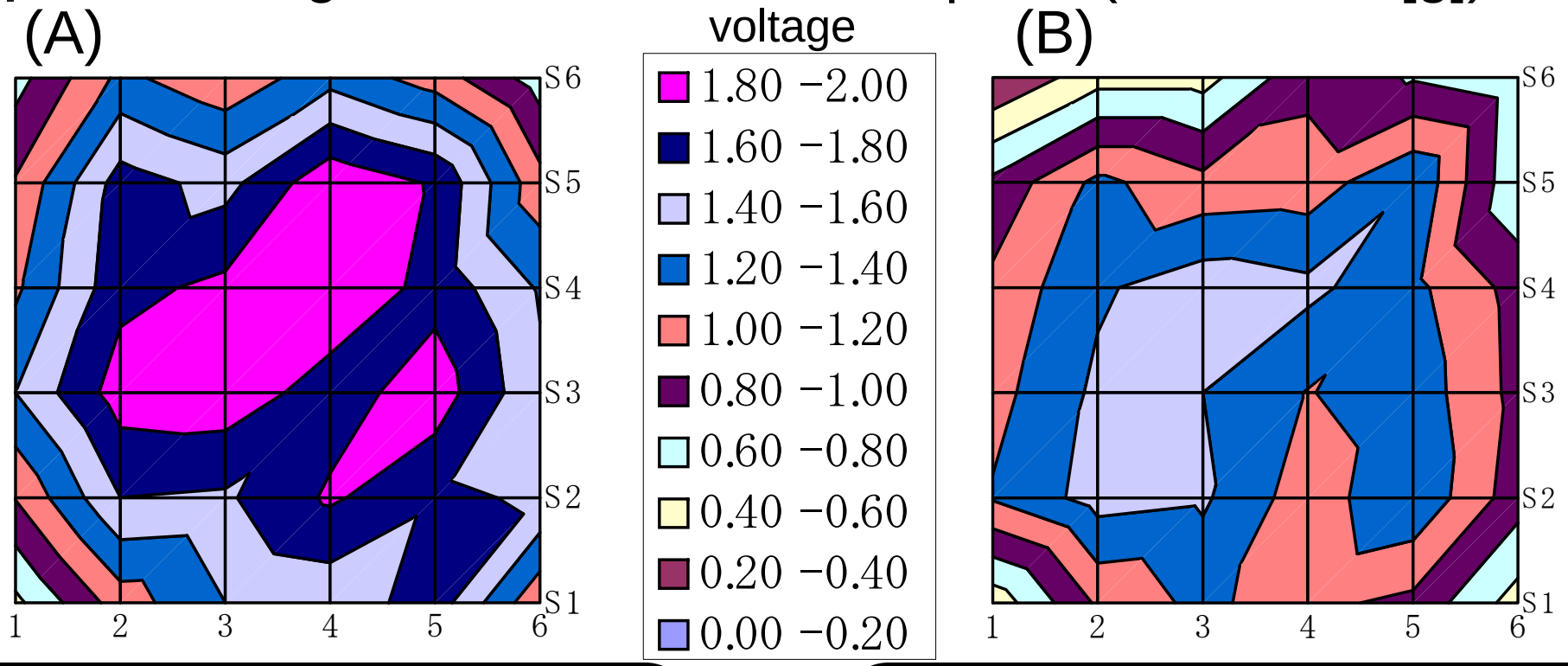


Interface Circuit

FSR is able to detect even very weak forces, and is a thin and light device.

Characteristics of FSR

Loading Position and FSR Output (Load : 20 [g])



The outputs of FSR changes if the loading position changes. And each FSR has different characteristics.

To recognize ‘stroke’, we calculate the correlation coefficient between the double layered FSR outputs.

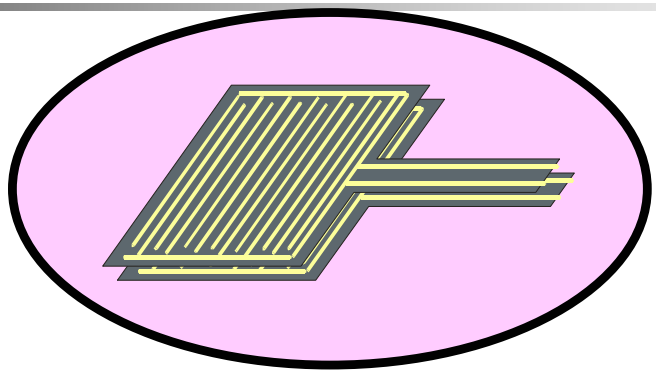
Perception of ‘stroke’

‘push’

Changes of the force

If the output of upper FSR increases, the output of lower FSR also increases.

High correlativity



double layered FSR

‘stroke’

Changes of the loading position

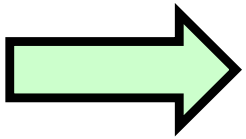
The output of upper FSR increases, and the output of lower FSR decreases.

Low correlativity

Perception of ‘hit’ and ‘push’

The present output is over the threshold.

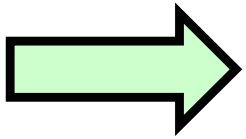
The ratio between the past output and the present output is more than a certain value from time series data.



‘hit’

WE-3RIII doesn’t recognize ‘stroke’ and ‘hit’.

WE-3RIII senses the force.



‘push’

Correlation Coefficients by Different Touching Manners

WASEDA UNIV. HRI

$$r_{ul} = \frac{\sum_{i=1}^{n} u_i l_i - n\bar{u}\bar{l}}{\sqrt{\left(\sum_{i=1}^{n} u_i^{\,2} - n\bar{u}^{2}\right)\left(\sum_{i=1}^{n} l_i^{\,2} - n\bar{l}^{2}\right)}}$$

r_{ul}:correlation coefficient between u and l l

u_i: output of upper FSR

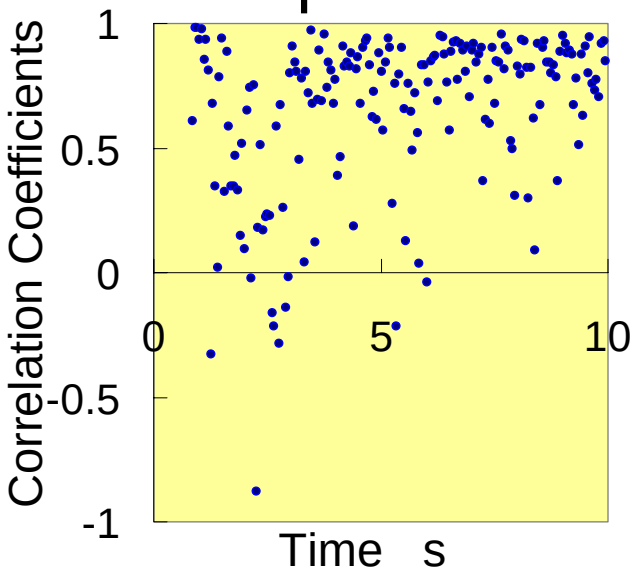
l_i: output of lower FSR

u: average of u

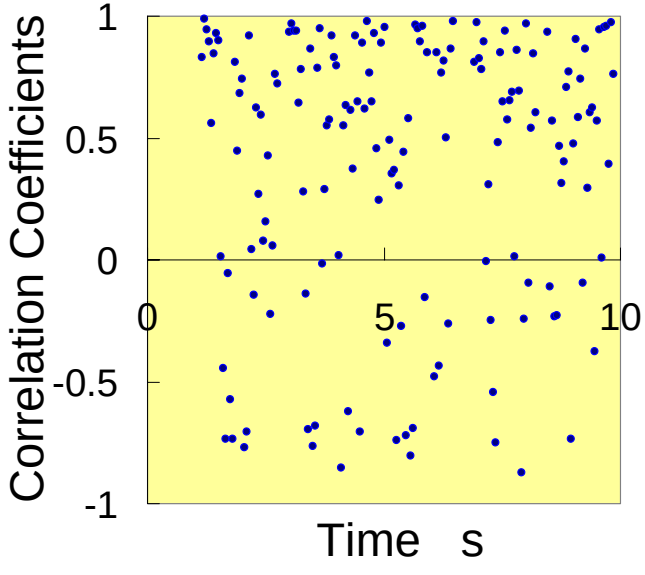
l: average of l

n: number of data

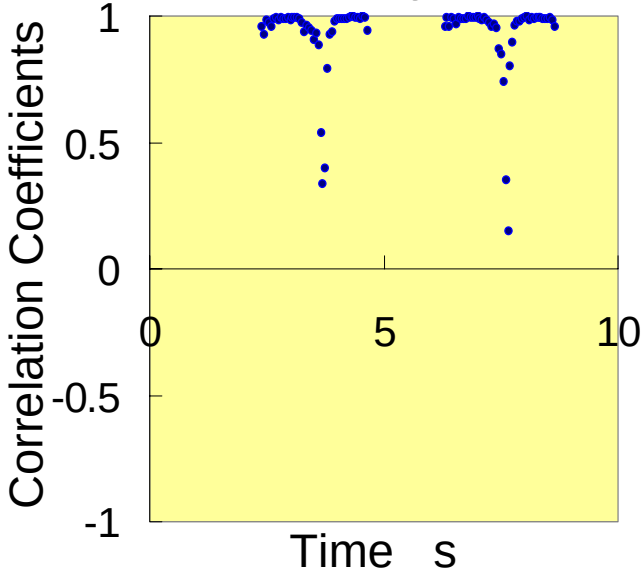
‘push’



‘stroke’



‘hit’



Visual Sensation

Left Camera Right Camera

Robot Vision

Capturing Conditions

Resolution: 320 x 240 [pixels]

Frame Rate: 30 [fps]

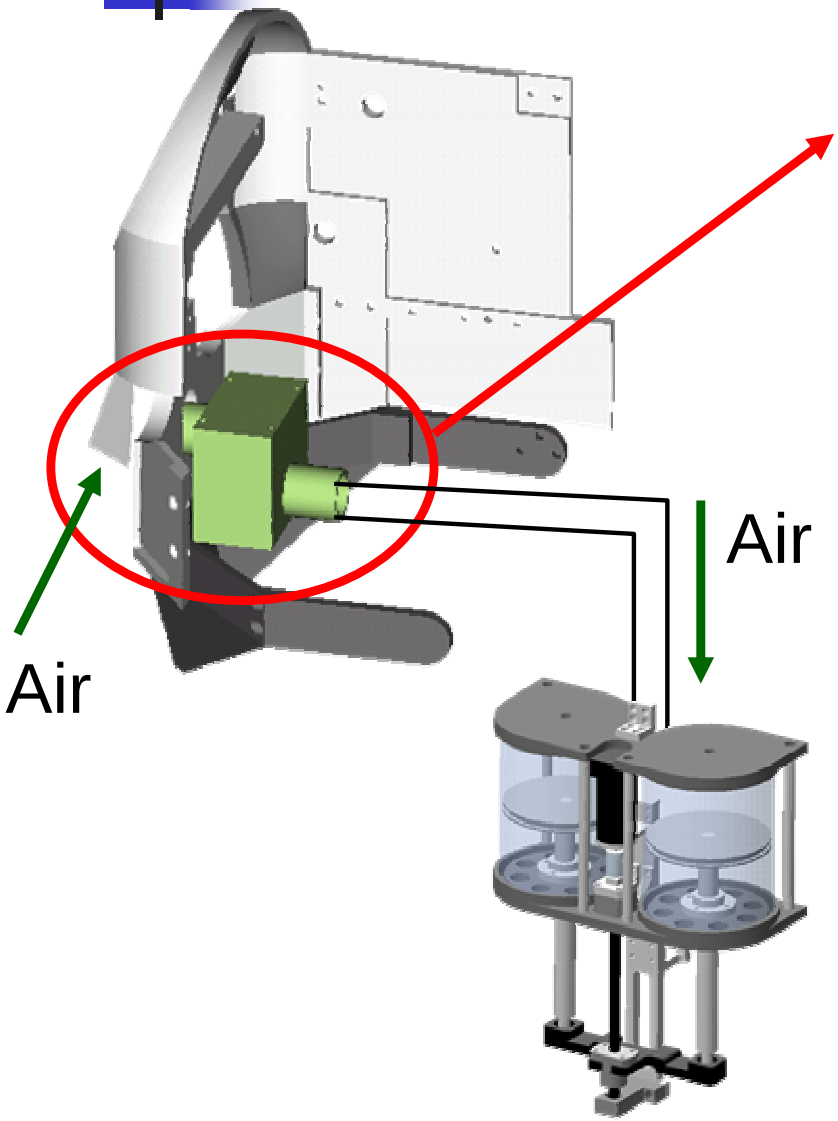
Image Processing

Target Color

Target Position

Target Area

Olfactory Sensor



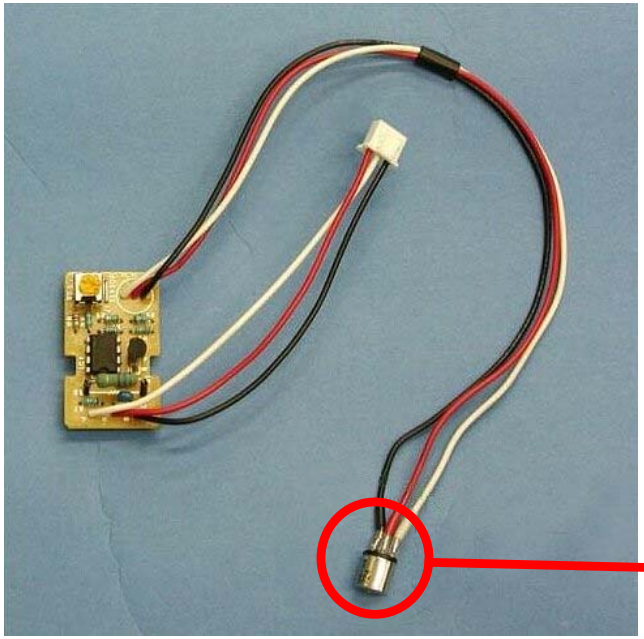
Semiconductor Gas Sensor

SB-19: Inflammable Gas

SB-30: Solvent

SB-E32: Alcohol

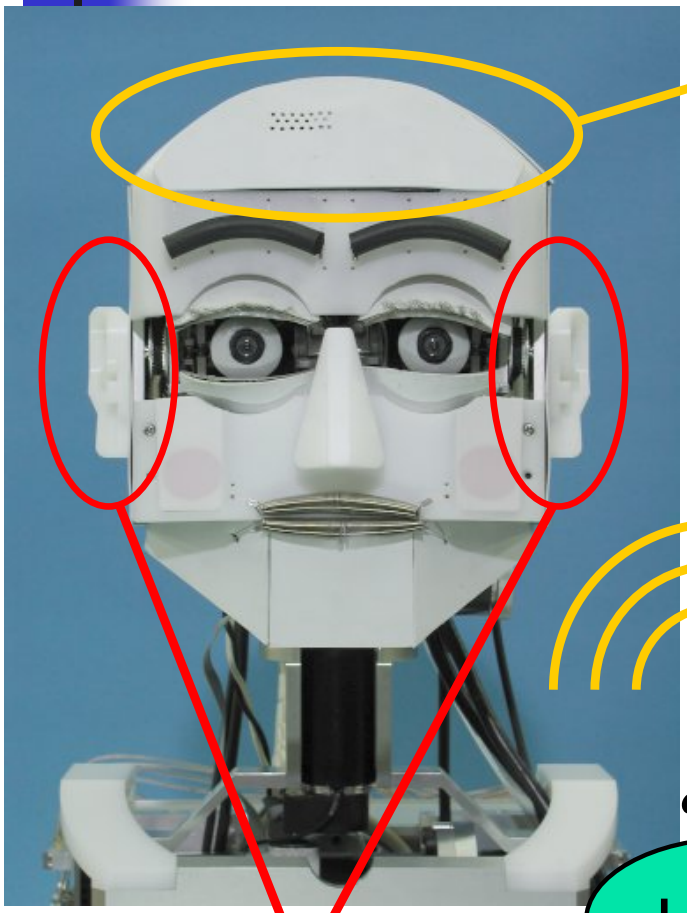
SB-AQ1A: the Whole



Alcohol
Ammonia
Cigarette

Temperature Sensation
Auditory Sensation

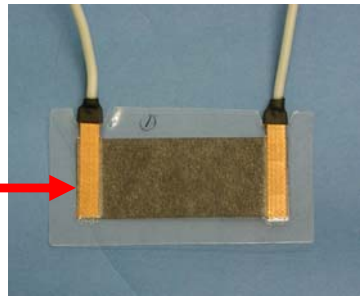
WASEDA UNIV. HRI



Thermistor with Heater

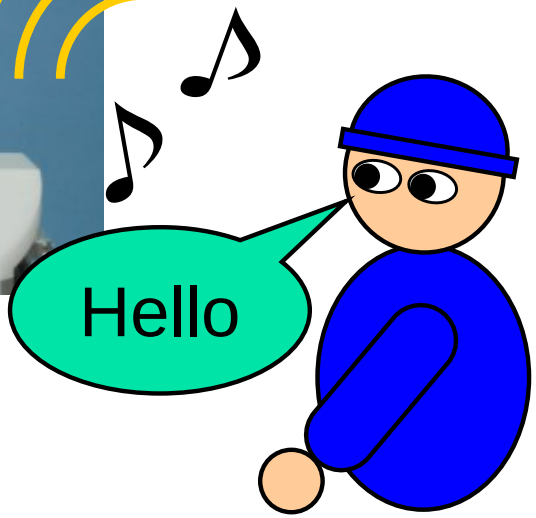
Thermistor

Heat Sheet



Cool
Hot

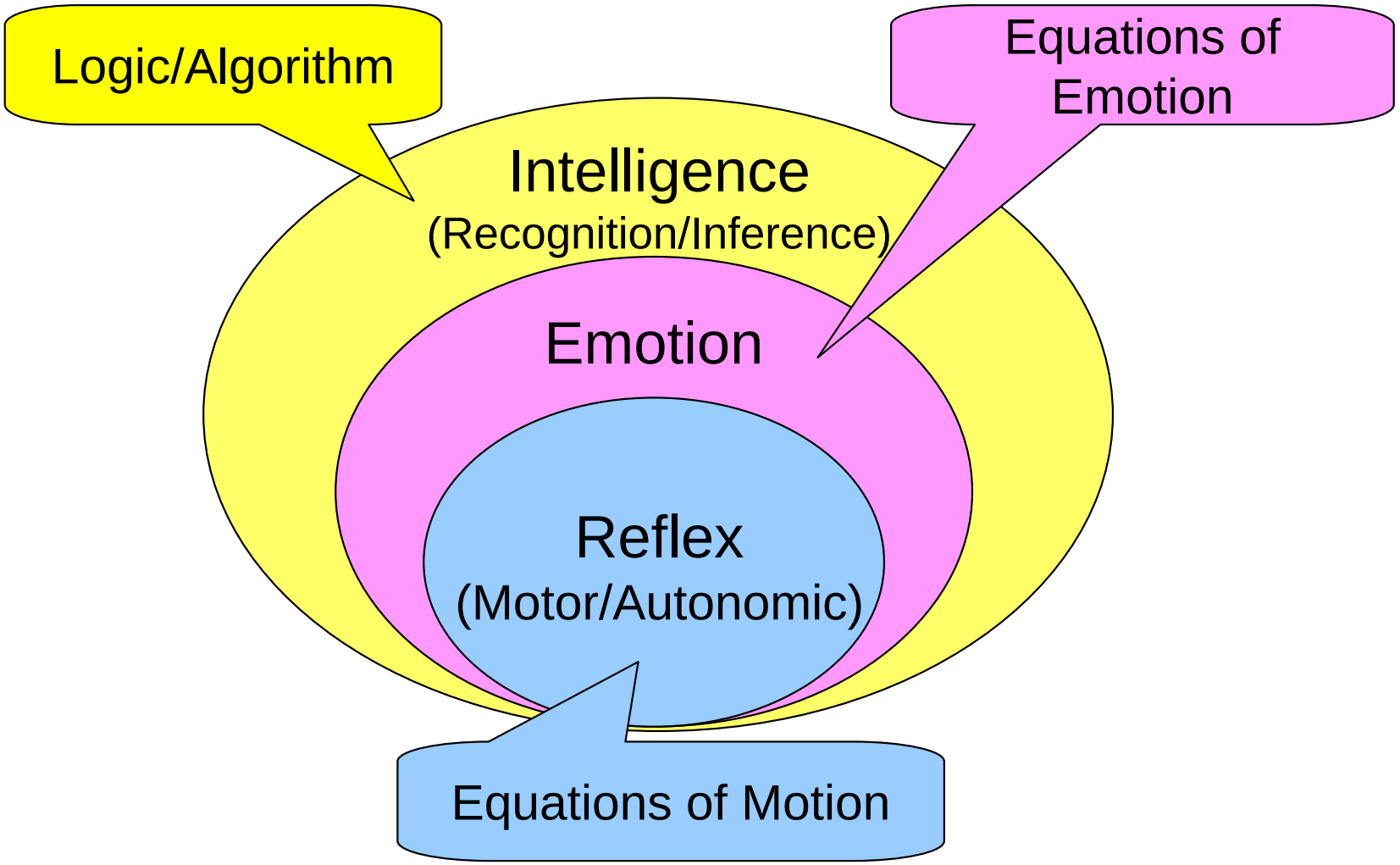
Microphone in the Ears



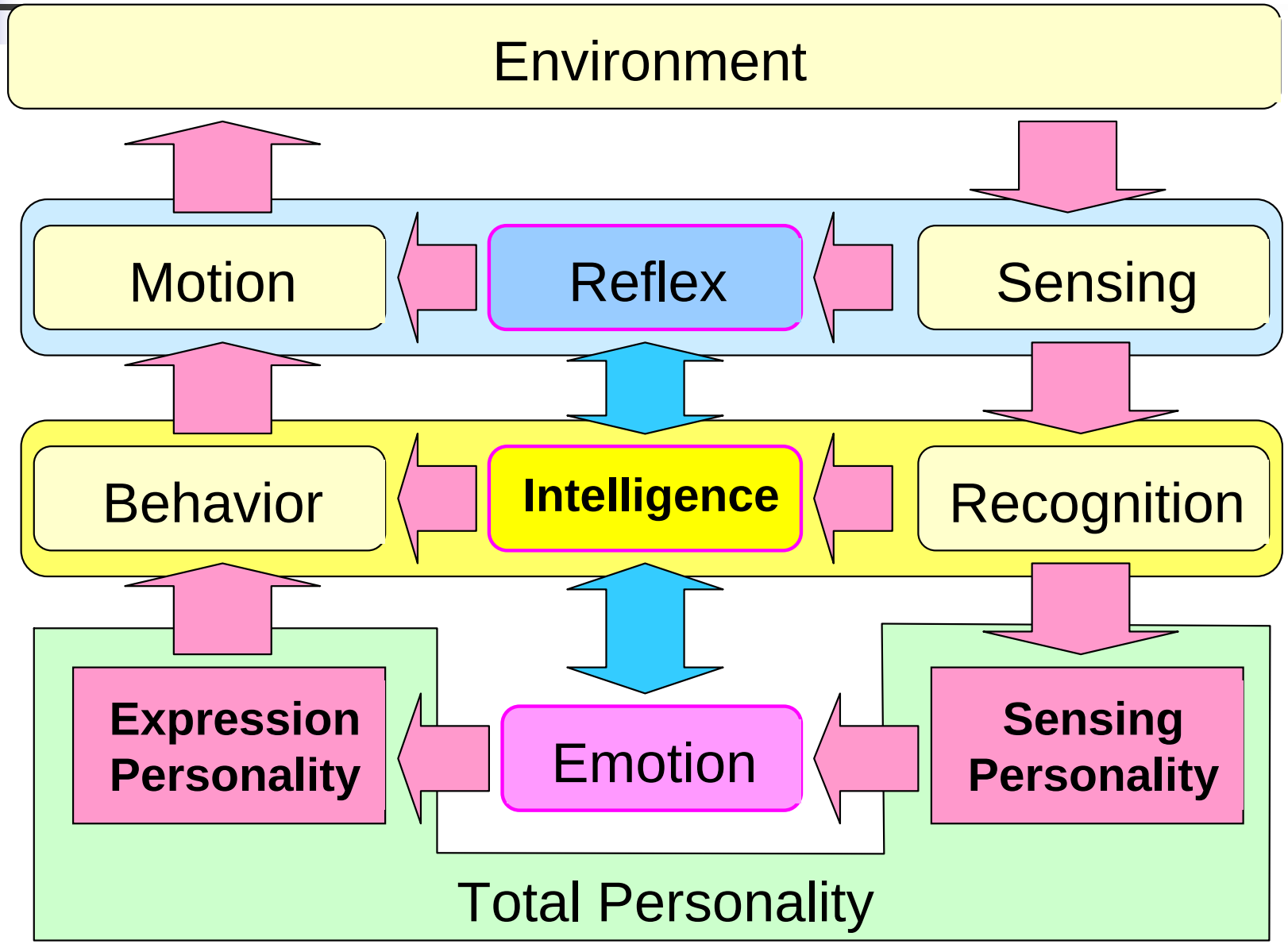
Sound Pressure Phase Difference

Sound Localization

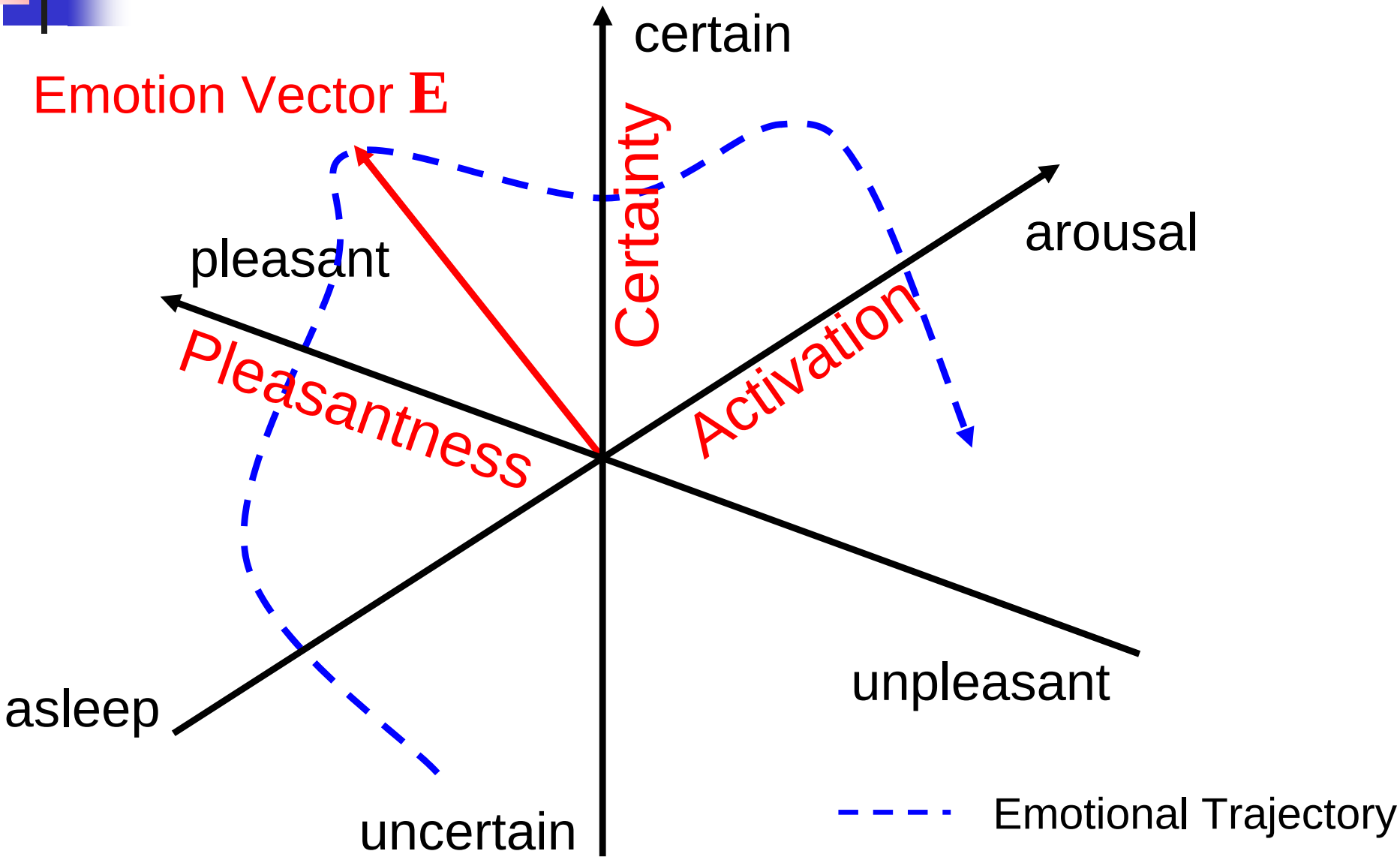
3 Level Structure of Human's CNS



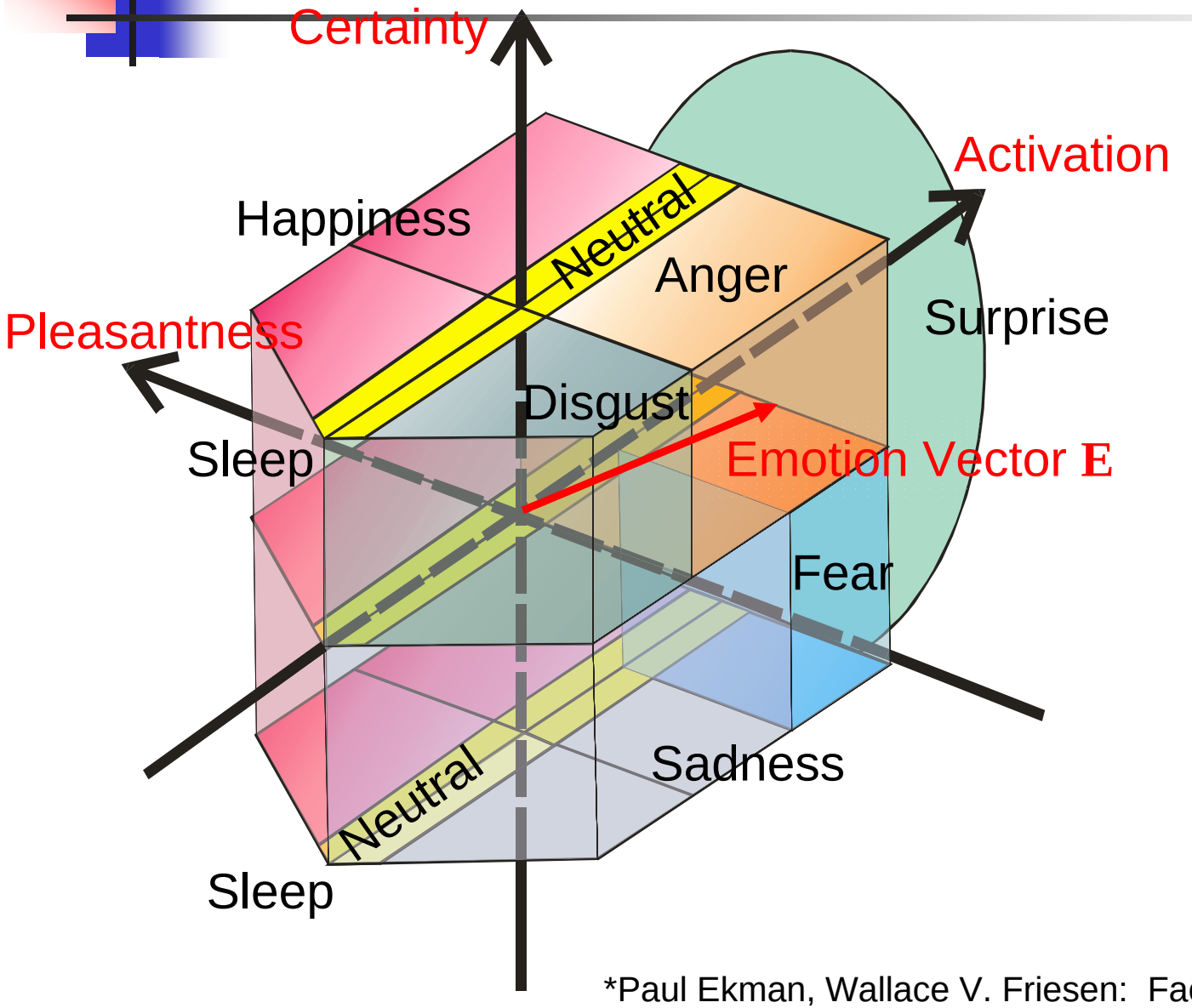
Control System and Personality



Definition of 3D Mental Space and Mental Vector



Emotion Mapping

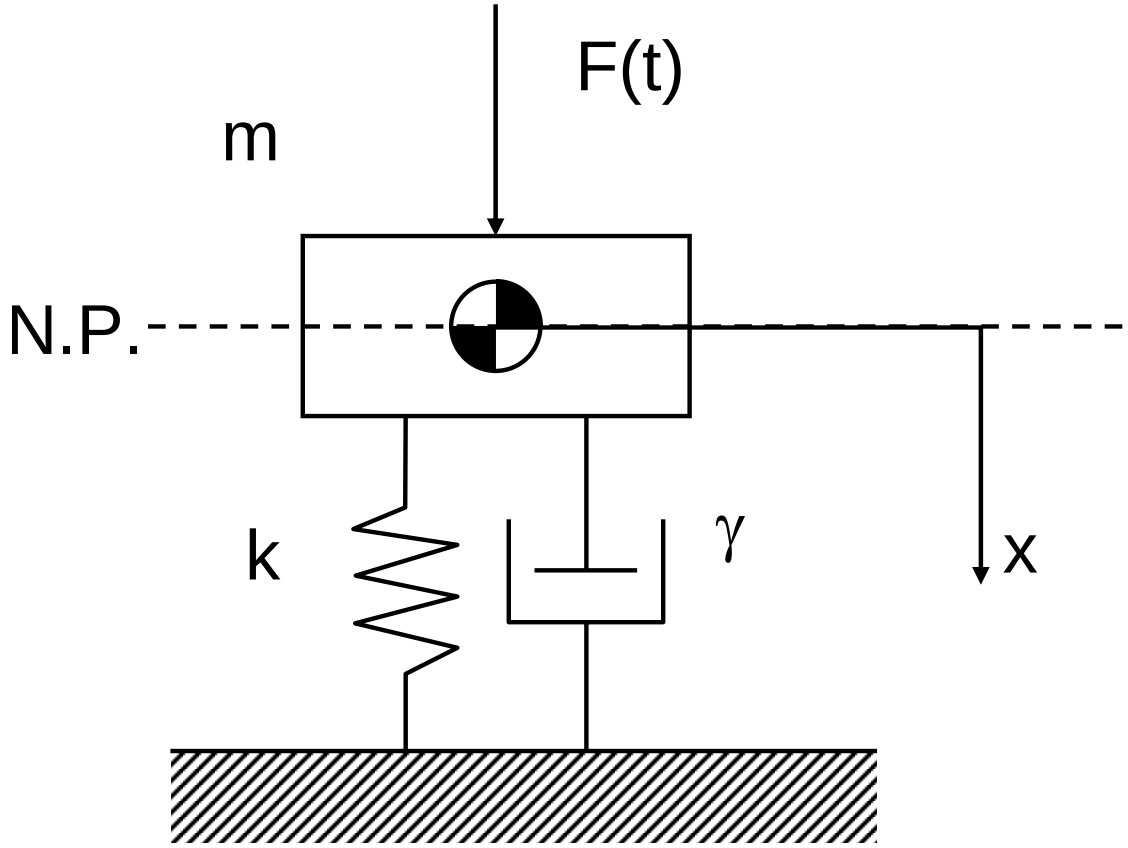


Emotion Matrix

$$E_m = \begin{bmatrix} E_{m\_Neutral} \\ E_{m\_Surprise} \\ E_{m\_Happiness} \\ E_{m\_Sadness} \\ E_{m\_Anger} \\ E_{m\_Fear} \\ E_{m\_Disgust} \end{bmatrix}$$

*Paul Ekman, Wallace V. Friesen: Facial Action Coding System (1978)

Analogy with Equation of Motion



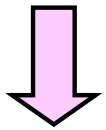
Equation of Motion

$$m\ddot{x} + \gamma\dot{x} + kx = F(t)$$

$$\begin{cases} \zeta = \dfrac{\gamma}{2\sqrt{mk}} \\ \omega_n = \sqrt{\dfrac{k}{m}} \end{cases}$$

Equations of Emotion

Equation of Motion $m\ddot{x} + \gamma \dot{x} + k\,x = F(t)$



Equations of Emotion

$$M\ddot{E} + \Gamma\dot{E} + KE = F_{EA}$$

$\mathbf{E}$: Emotion Vector, $\mathbf{F_{EA}}$: Emotional Appraisal

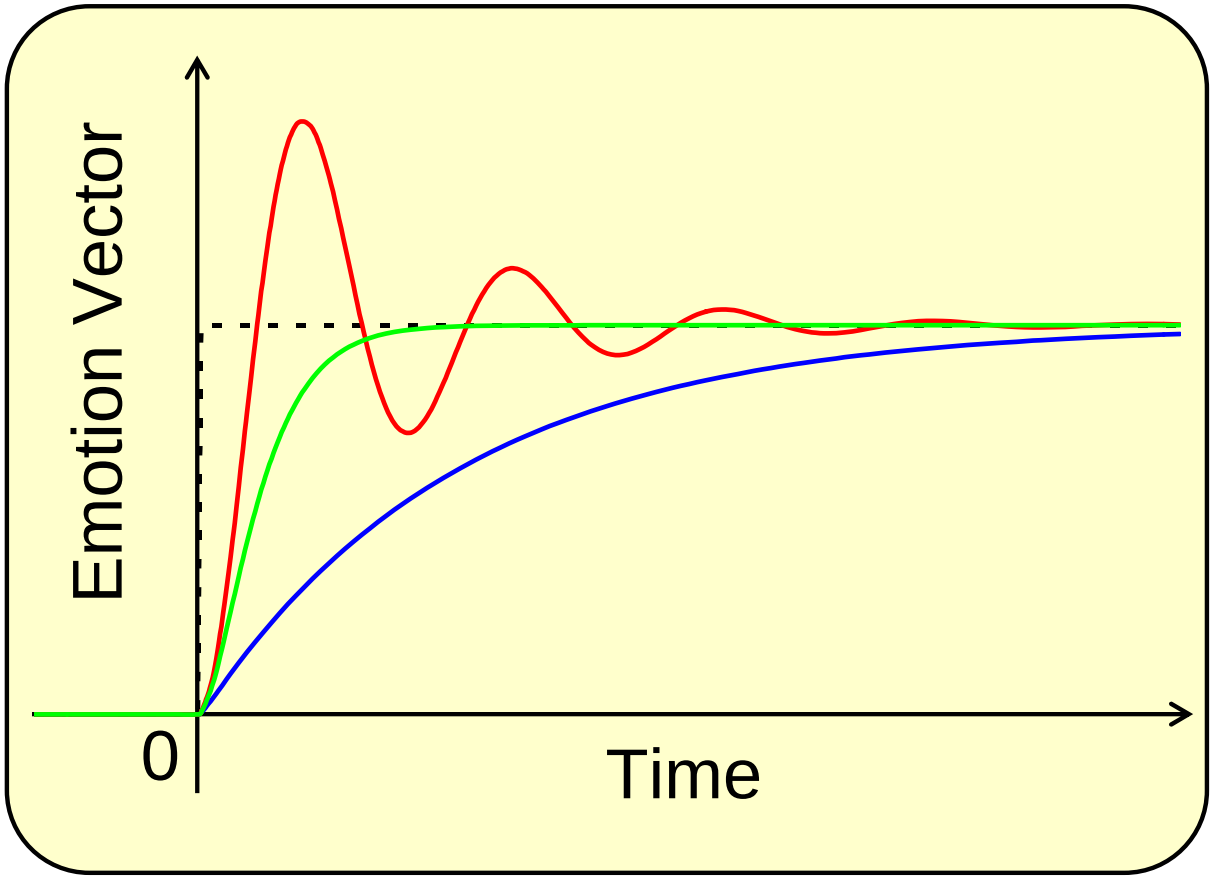
Emotional Coefficient Matrix

$\mathbf{M}$: Emotional Inertia Matrix

Γ : Emotional Viscosity Matrix

$\mathbf{K}$: Emotional Elasticity Matrix

Mental Dynamics



Emotional Attenuation Coefficient:

$$\zeta_i = \frac{\gamma_i^*}{2\sqrt{m_i^* k_i^*}}$$

Emotional Natural Angular Frequency:

$$\det\left|K - \omega_{ni}^2 M\right| = 0$$

$$\omega_{ni} = \sqrt{\frac{k_i^*}{m_i^*}}$$

$$m_i^* = \phi_i^T M \phi_i \qquad \gamma_i^* = \phi_i^T \Gamma \phi_i$$

$$k_i^* = \phi_i^T K \phi_i \qquad \phi_i : Eigenvector$$

Sensing Personality

The Sensing Personality determines how a stimulus sensed in the environment works in the robot's mental state.

Sensing Personality

$$P_S = f_{PS}(S_t, I_t)$$

$$S_t = (S_{Vt}, S_{At}, S_{Tt}, S_{Ht}, S_{Ot})$$

$$P_S = (P_{SP}, P_{SA}, P_{SC})$$

Stimuli

S_{Vt}: Visual Sensation
S_{At}: Auditory Sensation
S_{Tt}: Tactile Sensation
S_{Ht}: Heat Sensation
S_{Ot}: Olfactory Sensation
I_t : Internal Stimuli

Emotional Appraisal: Reaction to the mental state

$$F_{EA} = f_{EA}(P_S)$$

F_{EA} : *Emotional Apprisal*

WASEDA UNIV.
HRI

Sensing Personality Table

Stimulus	Sensation	Δ a	Δ p	Δ c
Visual	Loose Sight of the Target	-	-	-
	Discover the Target	+	0	+
	Dazzling Light	+	-	0
	Target is Near	+	-	0
Tactile	Pushed	+	0	0
	Pushed Strongly	+	-	0
	Stroked	+	+	0
	Hit	+	-	0
Auditory	Loud Sound	+	0	0
Temperature	Heat	0	-	0
Olfactory	Alcohol	-	+	0
	Ammonia	+	-	0
	Cigarette Smoke	+	-	0
	No Sense	-	→0*	0
No Stimulus		-	→0*	0

* "→0" means to converge at "0"

Expression Personality

$$\begin{bmatrix} E_o \end{bmatrix} = \begin{bmatrix} \text{Expression} \\ \text{Personality} \\ \text{Matrix} \end{bmatrix} \begin{bmatrix} E_i \end{bmatrix}$$

E_i: Input Emotion, E_o: Output Emotion

$$\begin{bmatrix} Eo_{\text{Neutral}} \\ Eo_{\text{Surprised}} \\ Eo_{\text{Happiness}} \\ Eo_{\text{Sadness}} \\ Eo_{\text{Anger}} \\ Eo_{\text{Fear}} \\ Eo_{\text{Disgust}} \end{bmatrix} = \begin{bmatrix} 1 & & & & & & 0 \\ & 1 & & & & & \\ & & 1 & & & & \\ & & & 1 & & & \\ & & & & 1 & & \\ 0 & & & & & 1 & \\ & & & & & & 1 \end{bmatrix} \begin{bmatrix} Ei_{\text{Neutral}} \\ Ei_{\text{Surprised}} \\ Ei_{\text{Happiness}} \\ Ei_{\text{Sadness}} \\ Ei_{\text{Anger}} \\ Ei_{\text{Fear}} \\ Ei_{\text{Disgust}} \end{bmatrix}$$

Expression Personality Matrix

High Extroversion

$$\begin{bmatrix} 1.0 & & & & & 0 \\ & 1.0 & & & & \\ & & 1.5 & & & \\ & & & 0.8 & & \\ & & & & 1.0 & \\ 0 & & & & & 0.8 \\ & & & & & & 0.8 \end{bmatrix}$$

High Agreeableness

$$\begin{bmatrix} 1.0 & & & & & 0 \\ & 1.0 & & & & \\ & & 2.0 & & & \\ & & & 0.8 & & \\ & & & & 0.5 & \\ 0 & & & & & 1.0 \\ & & & & & & 0.5 \end{bmatrix}$$

High Openness

$$\begin{bmatrix} 1.0 & & & & & 0 \\ & 1.0 & & & & \\ & & 1.0 & & & \\ & & & 1.0 & & \\ & & & & 1.0 & \\ 0 & & & & & 1.0 \\ & & & & & & 1.0 \end{bmatrix}$$

Low Extroversion

$$\begin{bmatrix} 1.0 & & & & & 0 \\ & 0.5 & & & & \\ & & 0.5 & & & \\ & & & 1.5 & & \\ & & & & 0.5 & \\ 0 & & & & & 1.5 \\ & & & & & & 0.5 \end{bmatrix}$$

Low Agreeableness

$$\begin{bmatrix} 1.0 & & & & & 0 \\ & 1.5 & & & & \\ & & 0.5 & & & \\ & & & 1.0 & & \\ & & & & 2.0 & \\ 0 & & & & & 1.0 \\ & & & & & & 2.0 \end{bmatrix}$$

Low Openness

$$\begin{bmatrix} 1.2 & & & & & 0 \\ & 1.2 & & & & \\ & & 1.2 & & & \\ & & & 1.2 & & \\ & & & & 1.2 & \\ 0 & & & & & 1.2 \\ & & & & & & 1.2 \end{bmatrix}$$

Expression Personality Matrix

Hide one's Emotion	Express one's Emotion	No Anger	Always Happiness
$\begin{bmatrix} 0.5 & & & & & & \\ & 0.5 & & & & & \\ & & 0.5 & & & & \\ & & & 0.5 & & & \\ & & & & 0.5 & & \\ & & & & & 0.5 & \\ & & & & & & 0.5 \end{bmatrix}$	$\begin{bmatrix} 2 & & & & & & \\ & 2 & & & & & \\ & & 2 & & & & \\ & & & 2 & & & \\ & & & & 2 & & \\ & & & & & 2 & \\ & & & & & & 2 \end{bmatrix}$	$\begin{bmatrix} 1 & & & & & & \\ & 1 & & & & & \\ & & 1 & & & & \\ & & & 0 & & & \\ & & & & 1 & & \\ & & & & & 1 & \\ & & & & & & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$

Experiment of Equations of Emotion 1

WASEDA UNIV. HRI

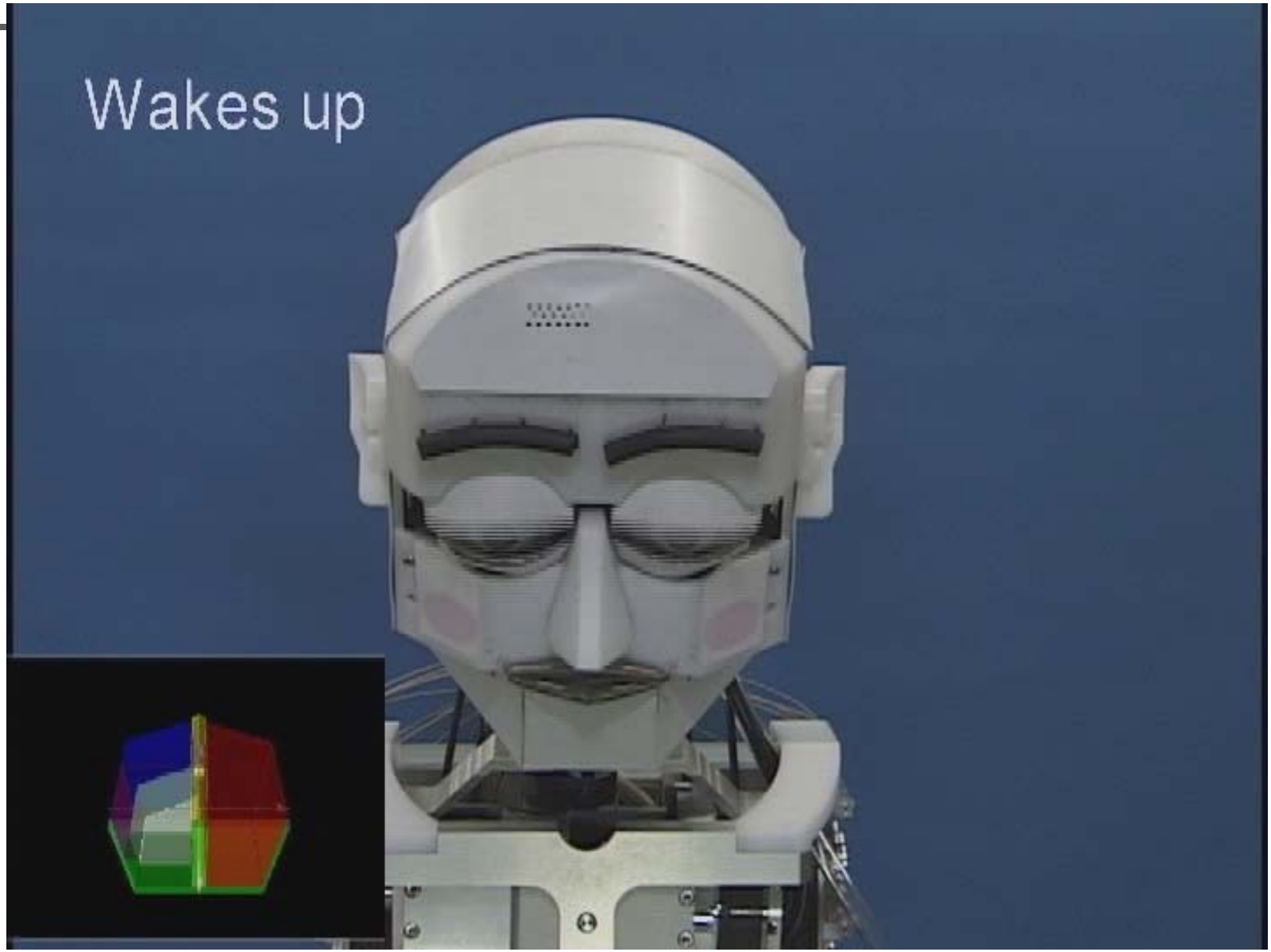
Experimental Conditions:

$\mathbf{M} = 1.0\ \mathbf{E_I}$

$\Gamma = 1.5\ \mathbf{E_I}$

$\mathbf{K} = 0.5\ \mathbf{E_I}$

$\mathbf{E_I}$: Identity Matrix



Experiment of Equations of Emotion 2

WASEDA UNIV. HRI

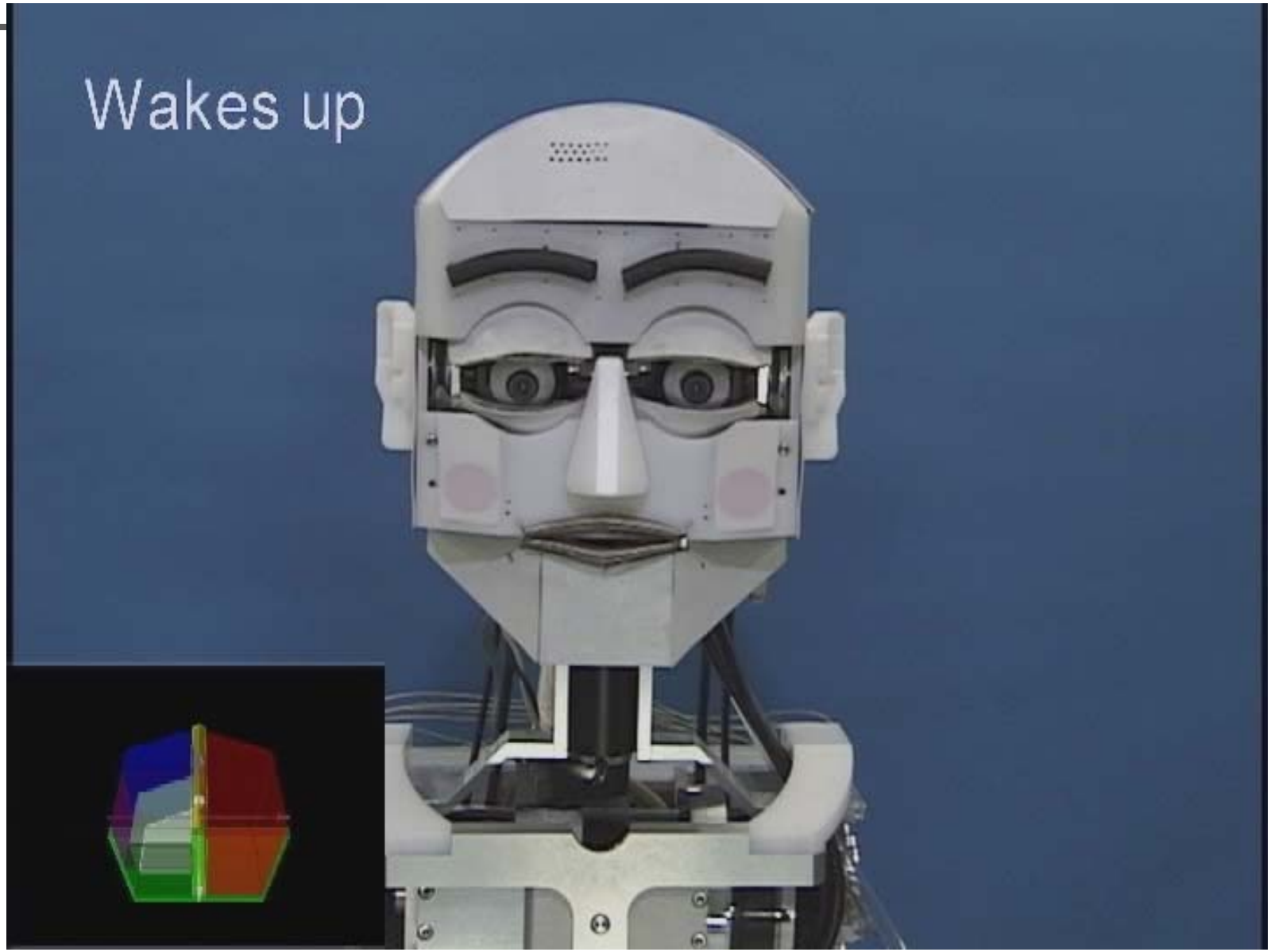
Experimental Conditions:

$\mathbf{M} = 1.0\ \mathbf{E_I}$

$\Gamma = 0.5\ \mathbf{E_I}$

$\mathbf{K} = 1.5\ \mathbf{E_I}$

$\mathbf{E_I}$: Identity Matrix



Demos of EYE-Chan Done in RoboCasa

WASEDA UNIV. HRI

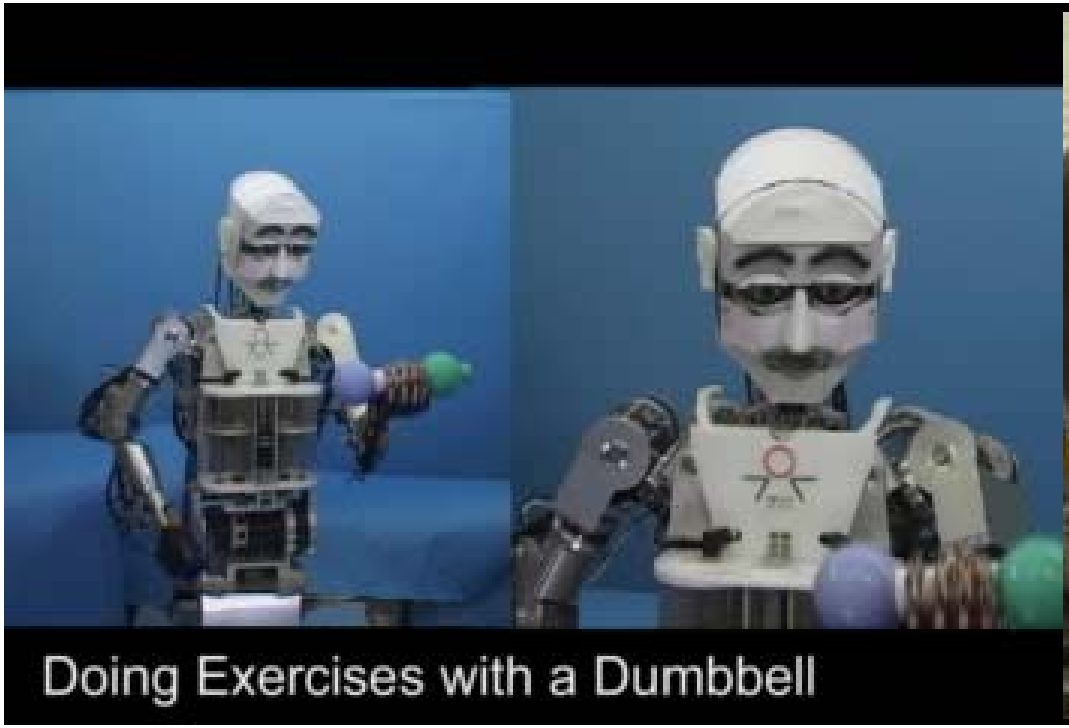
Basic Emotions

Start ALL

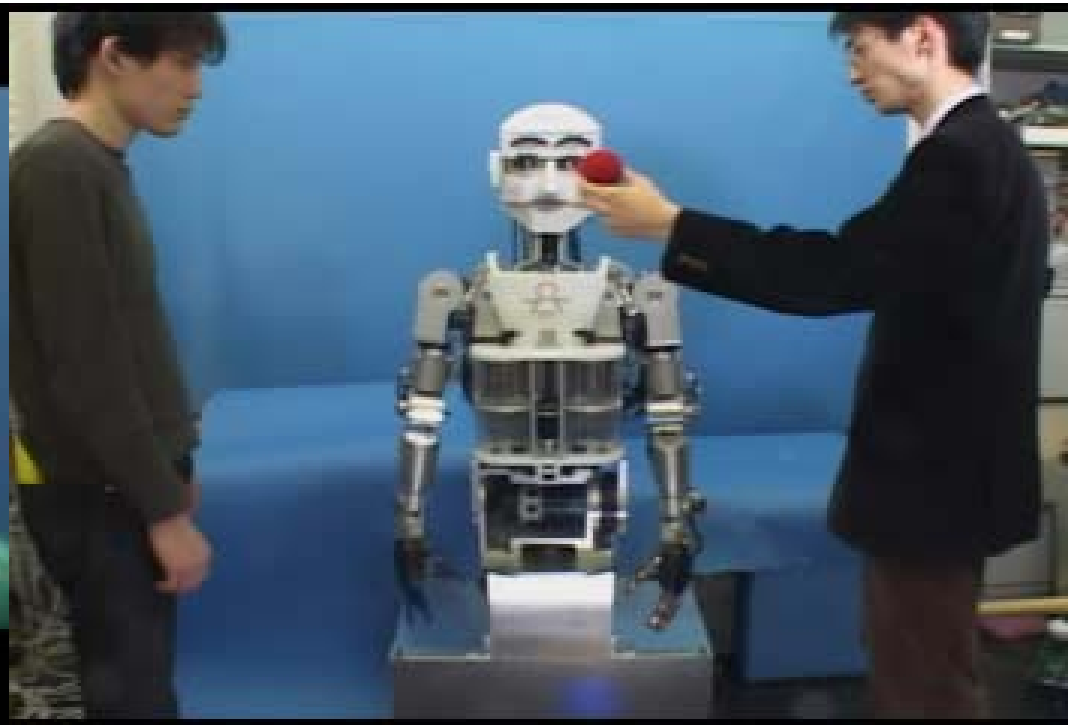
Implementation of Need to EYE-Chan's Mind

WASEDA UNIV.
HRI

Additional Demos



More Behaviors



Addition of Consciousness