Master in Computer Science
University of Pisa

Robotics

Retina-like vision and Eye Movements in Robots

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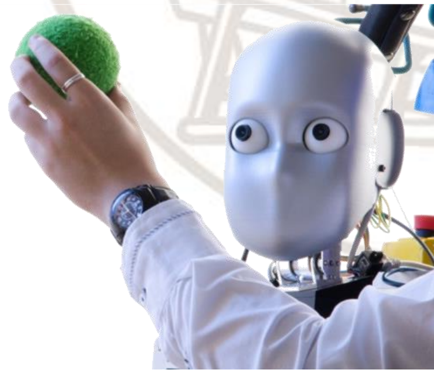

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Basic principles of retina-like vision

Standard image

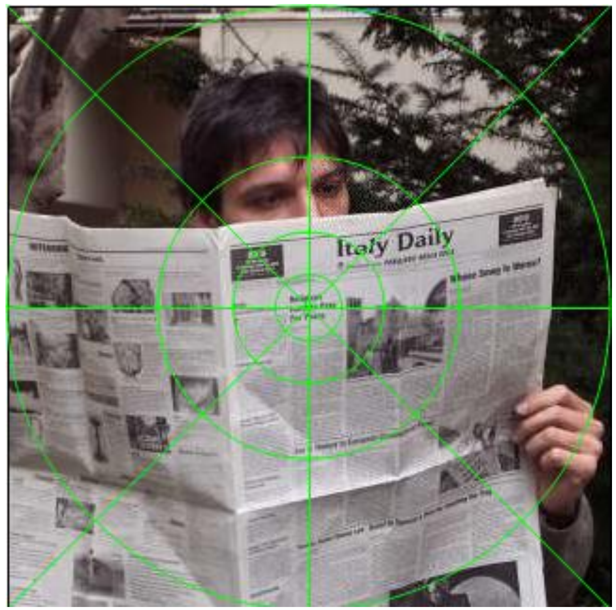
Retina-like image

Log-polar image (magnified to 200% for display)

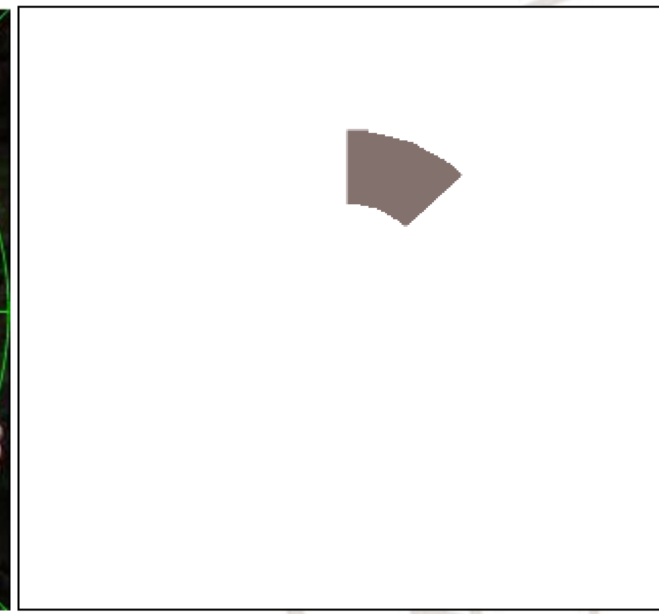
Log-polar projection

Building a retina-like image

Cartesian image

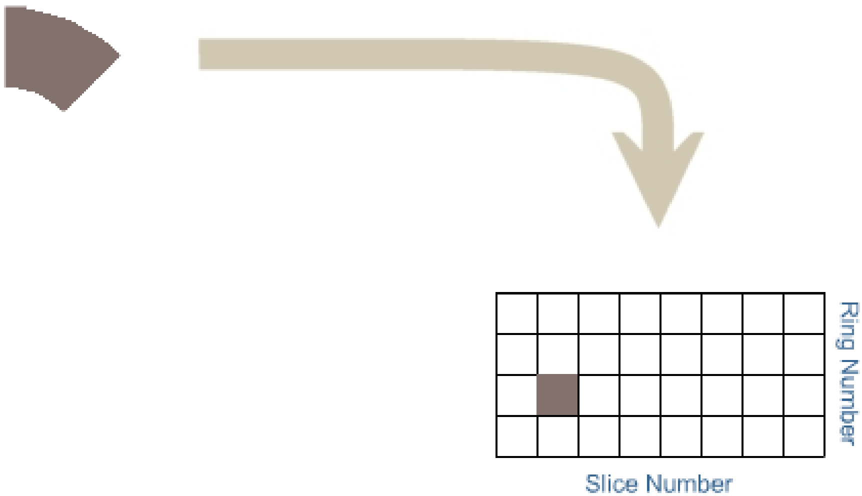


Cutting in circles and slices



Computing the average value in each sector

Building a retina-like image



Copying the average value of a sector in a polar image

Resulting polar image

Cartesian image re-built from the polar image

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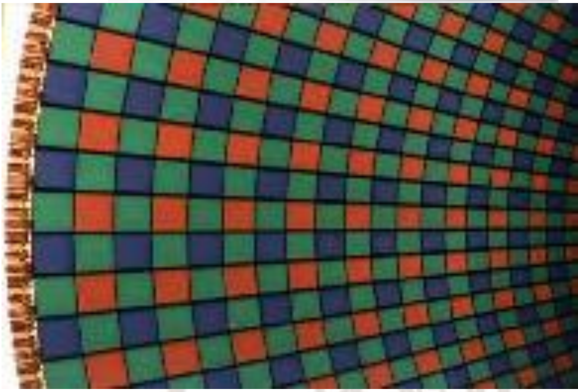
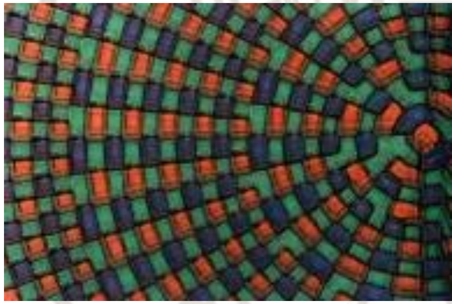
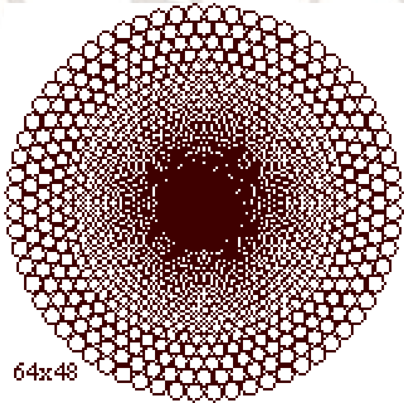
The Retina-like Giotto cameras

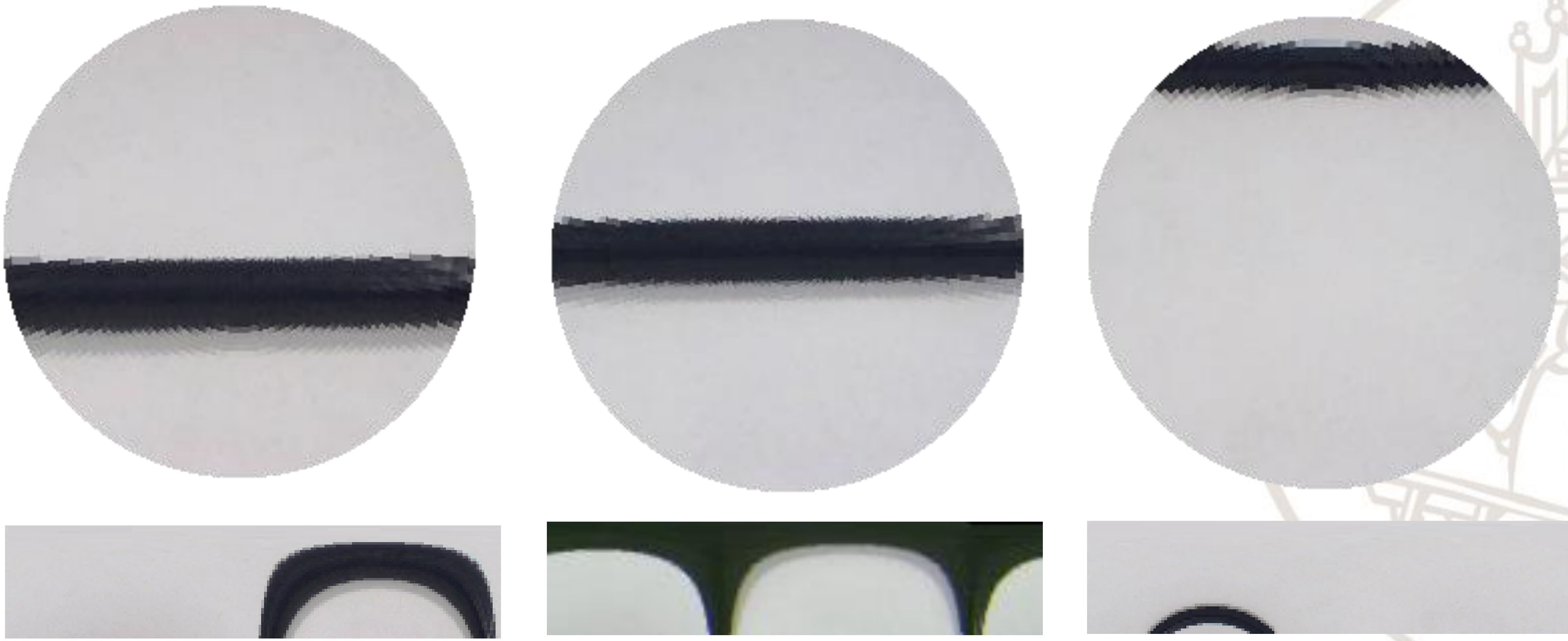




- Technology: 0.35 micrometer CMOS
- Total Pixels: 33193
- Geometry:
    - 110 rings with 252 pixels
    - 42 rings with a number of pixels decreasing toward the center with a "sunflower" arrangement
- Tessellation: pseudo-triangular
- Pixels: direct read-out with logarithmic response
- Size of photosensitive area: 7.1mm diameter
- Constant resolution equivalent: 1090x1090
- On-chip processing: addressing, A/D, output amplifier



An example of pattern translation



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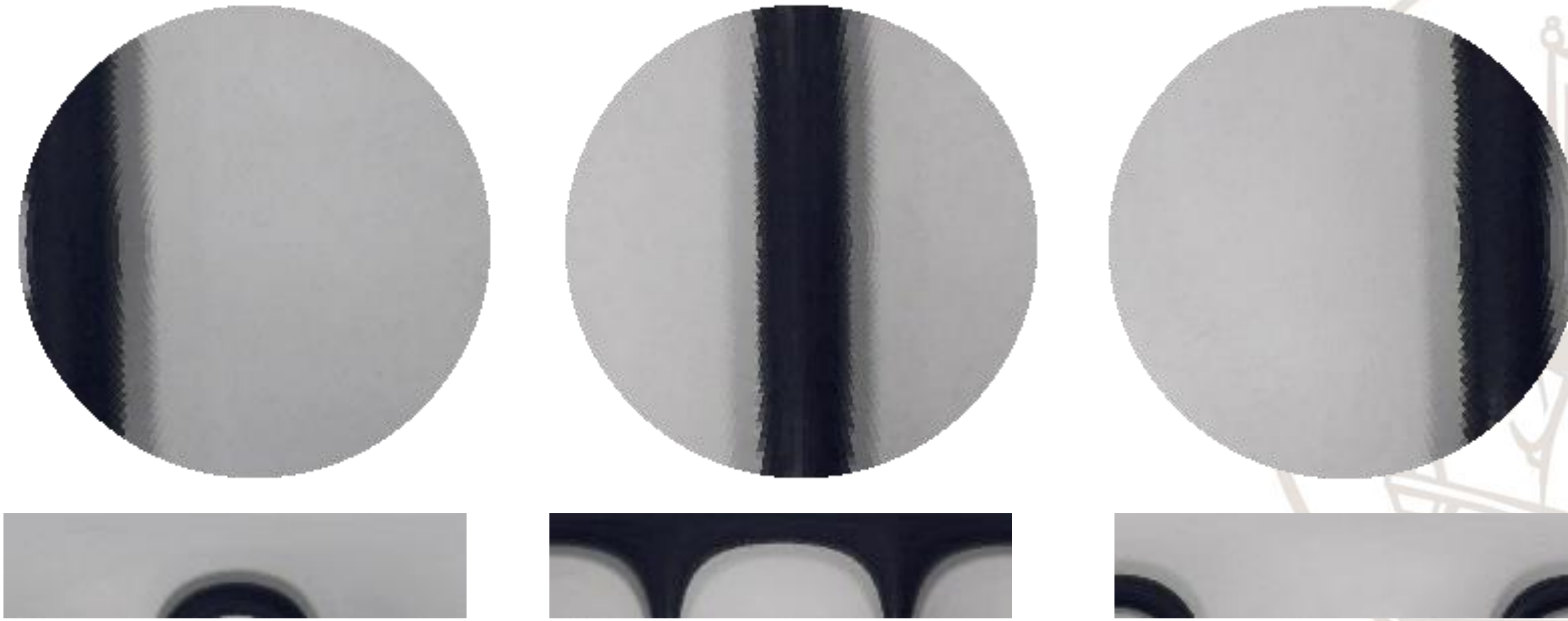
An example of pattern translation



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An example of simulated foveation

Object detection in the periphery

Object foveation

Foveation of a point of interest (edge)

Retina-like vision for visuo-motor co-ordination of a robot head

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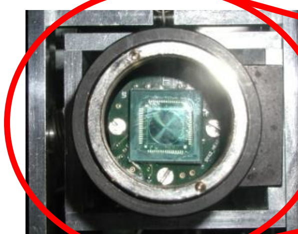
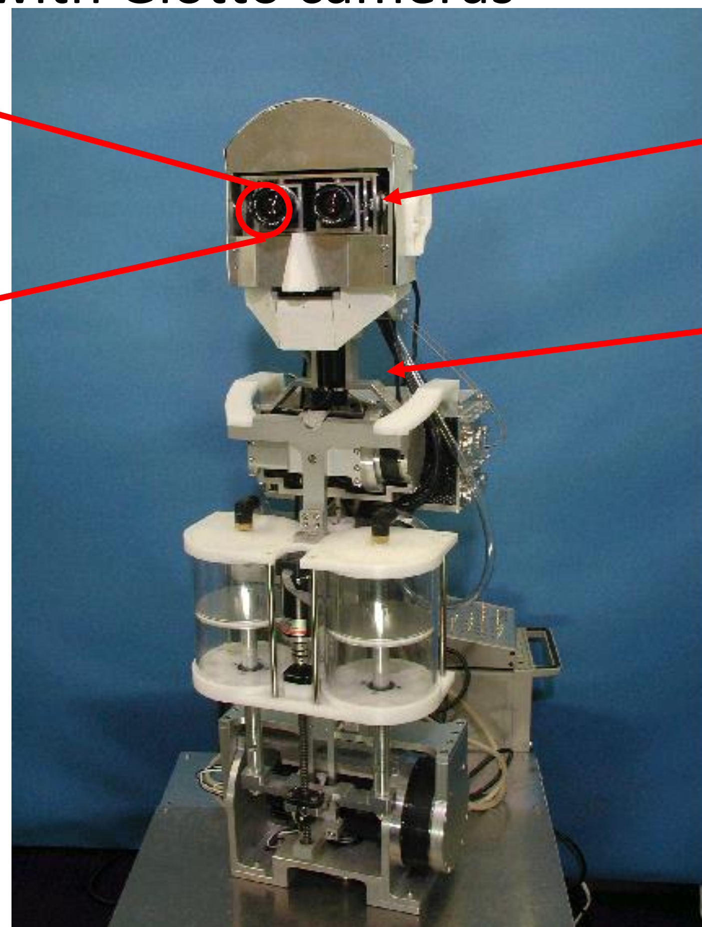
WE-4 robotic head with Giotto cameras



Retina-like Giotto cameras by the University of Genova, Italy



3 dof for eye movements

4 dof for neck movements

WE-4 robotic head by Takanishi Lab, Waseda University, Tokyo, Japan

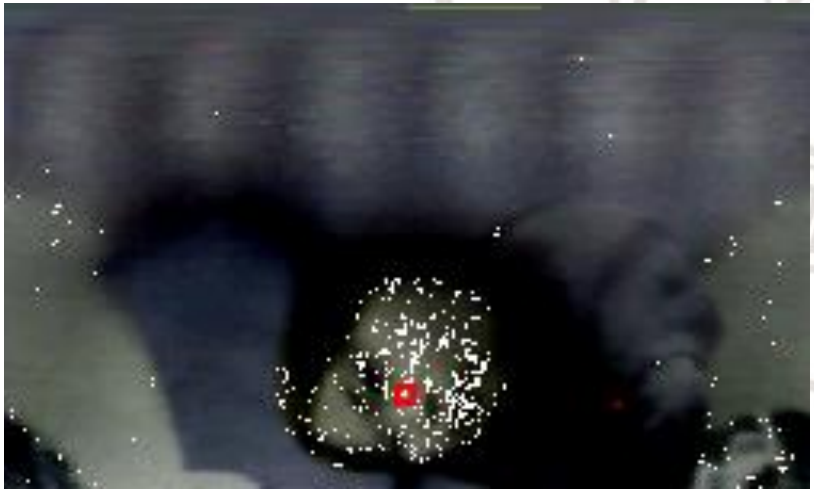
Face detection by hue

Hue = information on the color

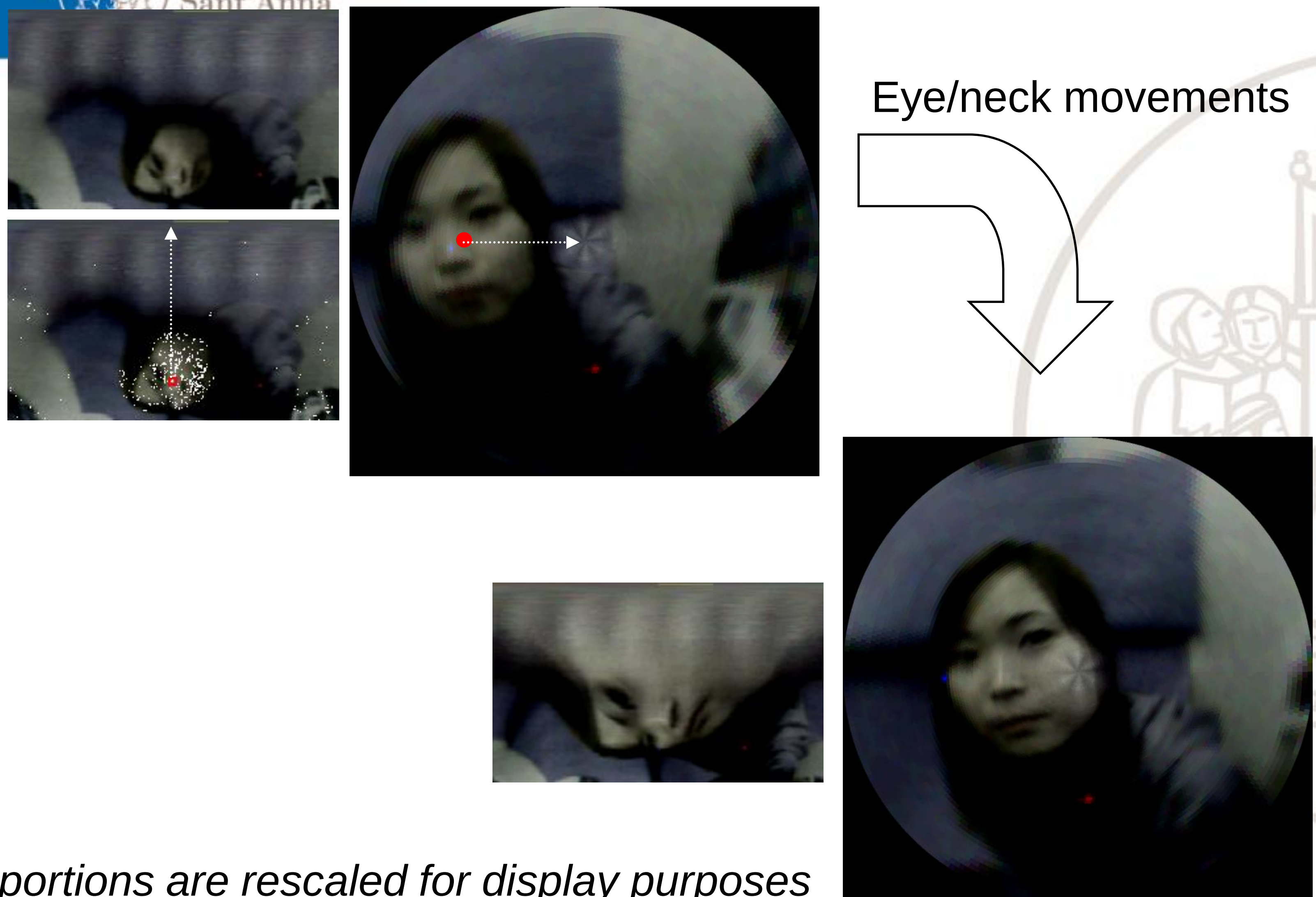
$$\text{Hue} = \cos^{-1}\left(\frac{(R-G)+(R-B)}{2\sqrt{(R-G)^2+(R-B)(G-B)}}\right)$$

if B>G then Hue = 2π - Hue

R, G, B = RED, GREEN, BLUE components, respectively



An example of foveation



Proportions are rescaled for display purposes

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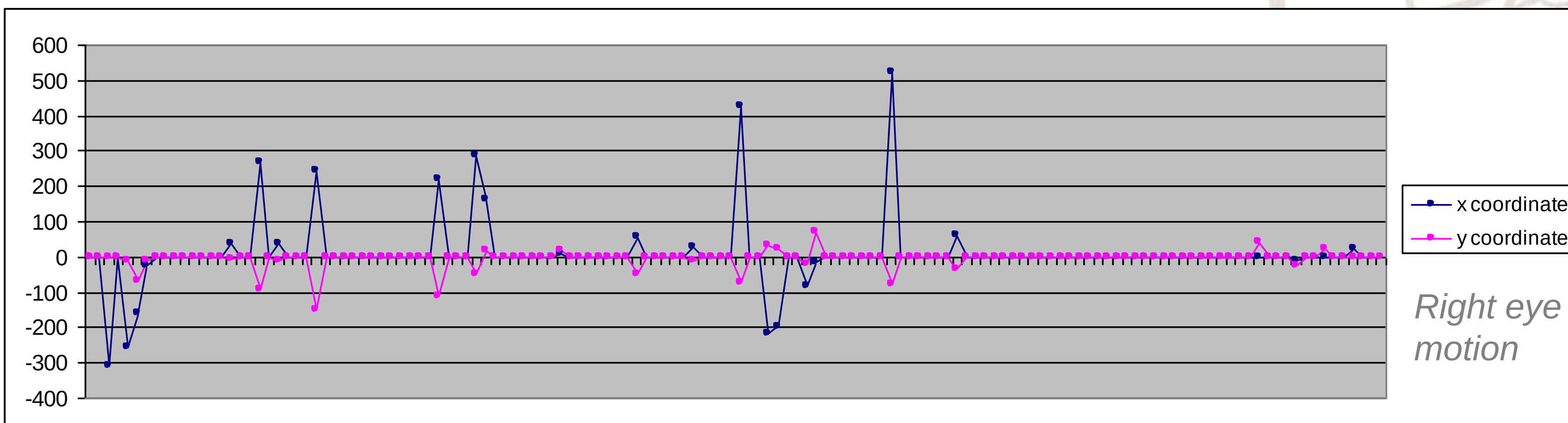
Experimental trials



[Cecilia Laschi, Hiroyasu Miwa, Atsuo Takanishi, Eugenio Guglielmelli, Paolo Dario, 2002]

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Example of design and development of a human-like robotic head

The ARTS humanoid robot head

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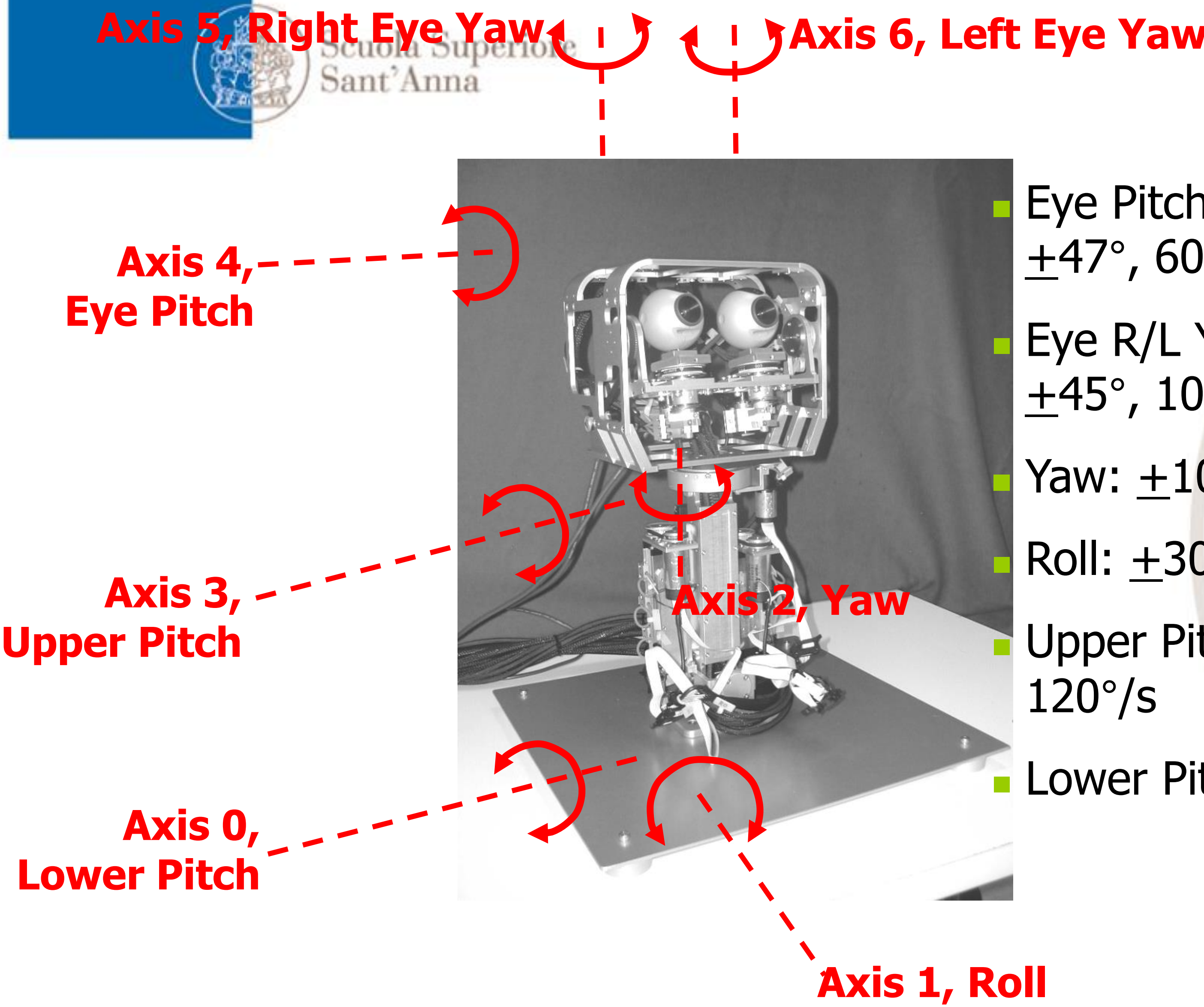
Kinematic structure of the SSSA Robot Head



- Eye Pitch Axis: ±47°, 600°/s
- Eye R/L Yaw Axis: ±45°, 1000°/s
- Yaw: ±100°, 170°/s
- Roll: ±30°, 25°/s
- Upper Pitch: ±30°, 120°/s
- Lower Pitch: ±25°, 20°/s

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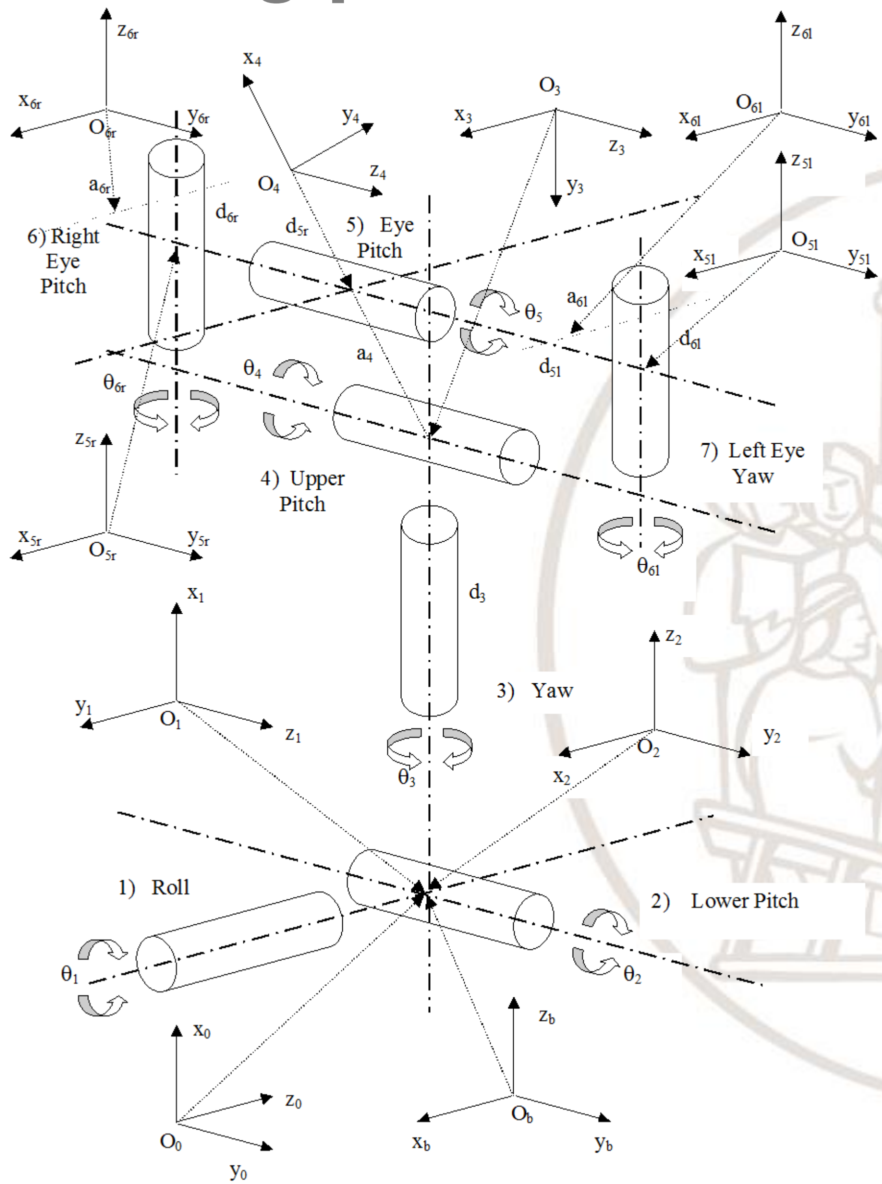
Head kinematic chain and Denavit-Hartenberg parameters

Joint	a_i (mm)	d_i (mm)	α_i (rad)
J1	0	0	$-\pi/2$
J2	0	0	$\pi/2$
J3	0	195	$-\pi/2$
J4	137.5	0	0
$J5_r$	0	-30 ÷ -50	$\pi/2$
$J5_l$	0	30 ÷ 50	$\pi/2$
$J6_l$	a_{6l}	d_{6l}	0
J6r	a_{6r}	d_{6r}	0



Comparison of performances between human and robotic head

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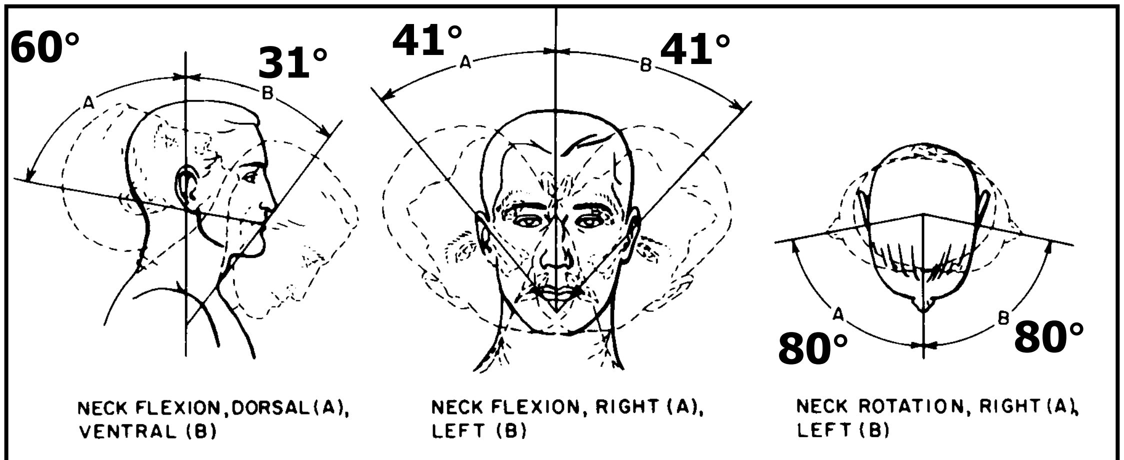
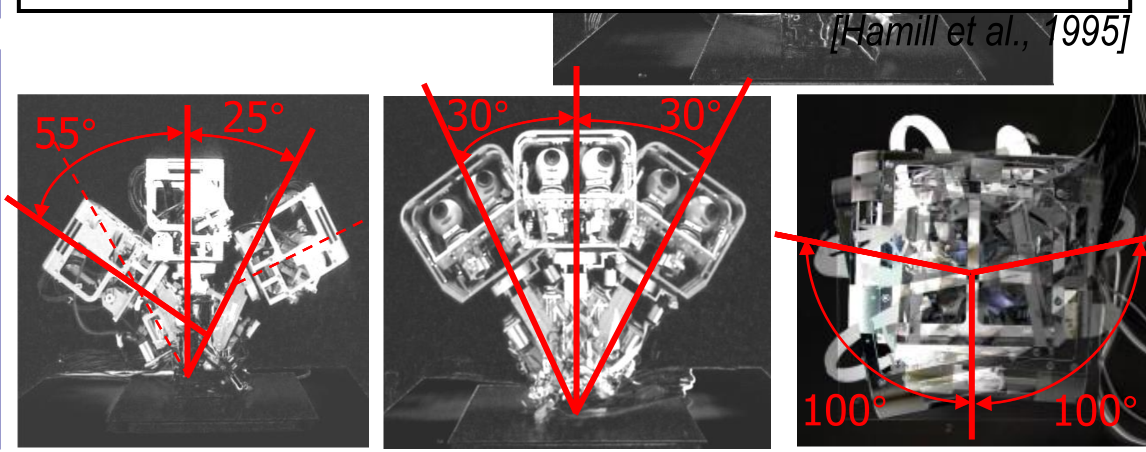
	Neck:	**Eye:**
Human		Pitch: + 60°, 600°/s Yaw: + 30°, 600°/s
Robot		Pitch: + 47°, 600°/s Yaw: + 45°, 1000°/s

[Hamill et al., 1995]

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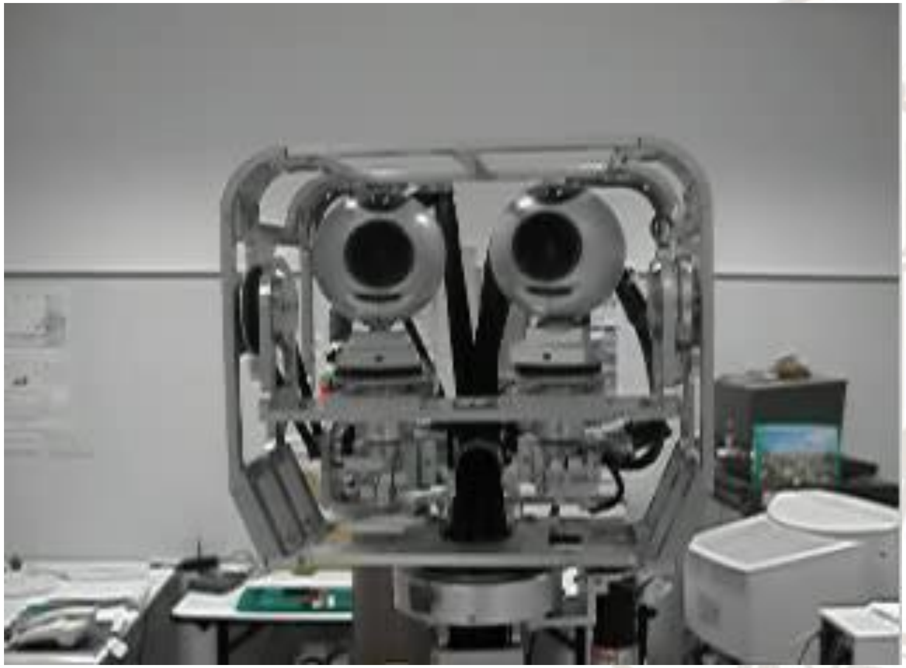
The movements of the 7 dofs of the robotic head

Neck Movements



Saccades, 400°/sec

Example of sensory-motor scheme for a retina-like vision system

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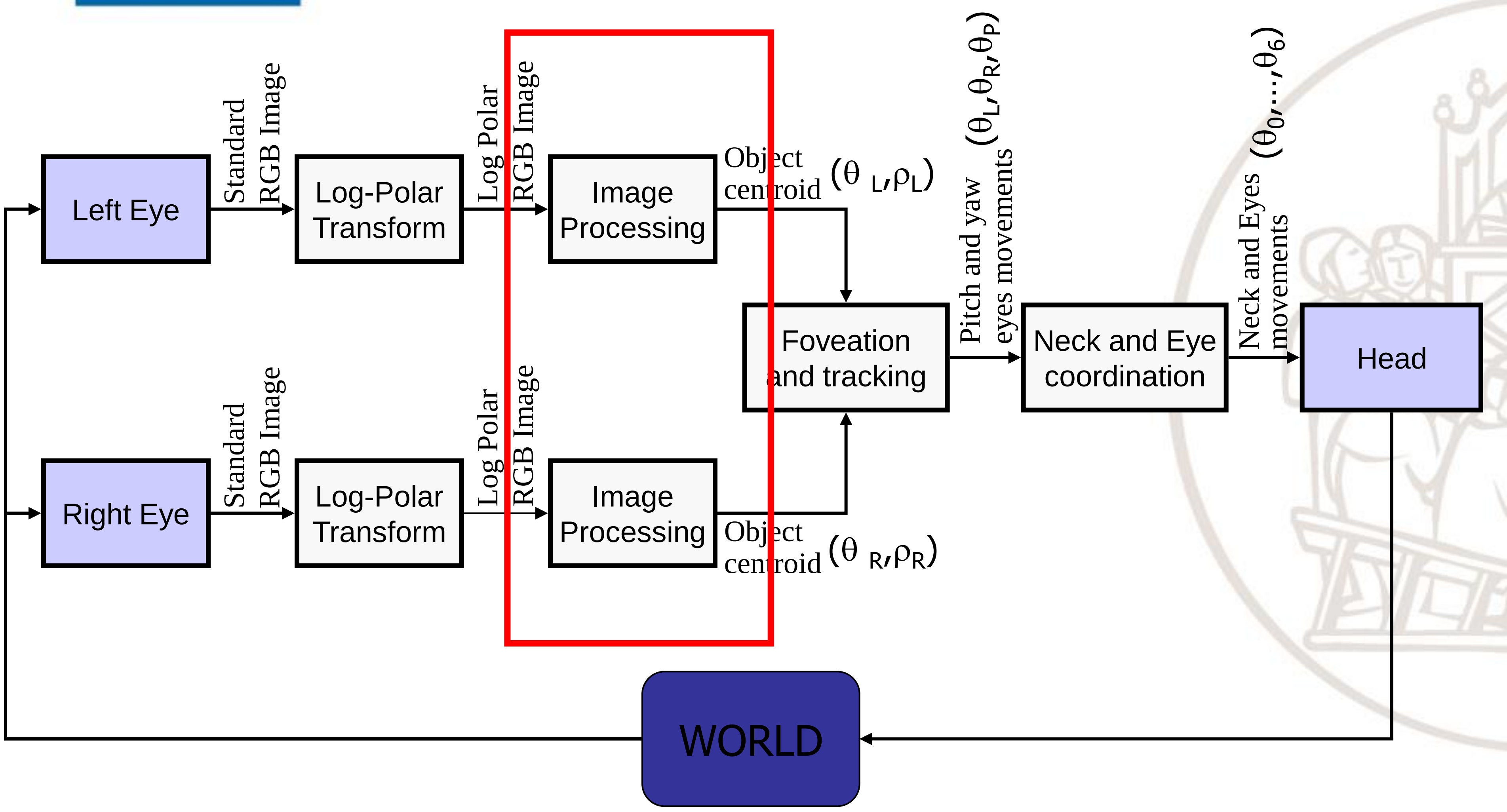

Examples of algorithms developed for retina-like image processing

- Acquiring standard image
- Creating log-polar image from standard image
- Creating retina-like image from log-polar image
- Thresholding of image based on RGB and HUE
- Computation of the centroid of a thresholded area
- Edge detection
- Line detection

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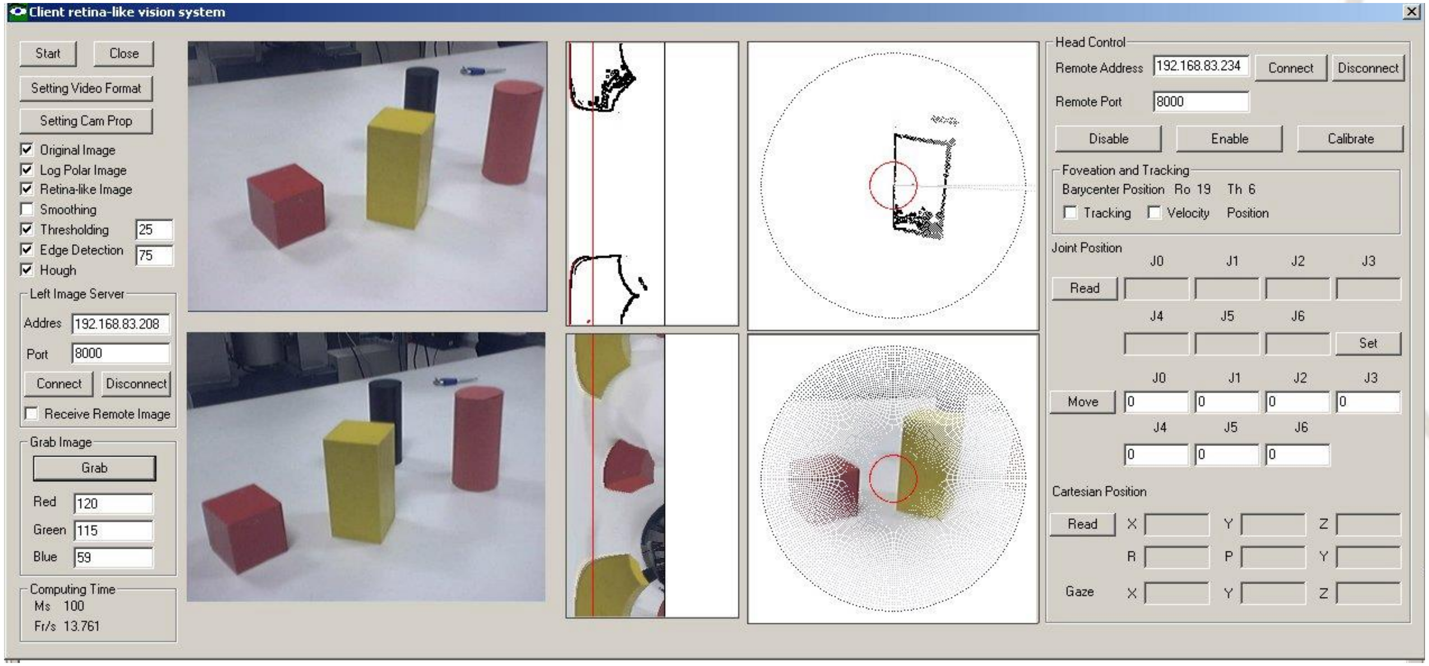
Simulation of retina-like cameras and basic image processing

- Acquiring standard image
- Creating log-polar image from standard image
- Creating retina-like image from log-polar image



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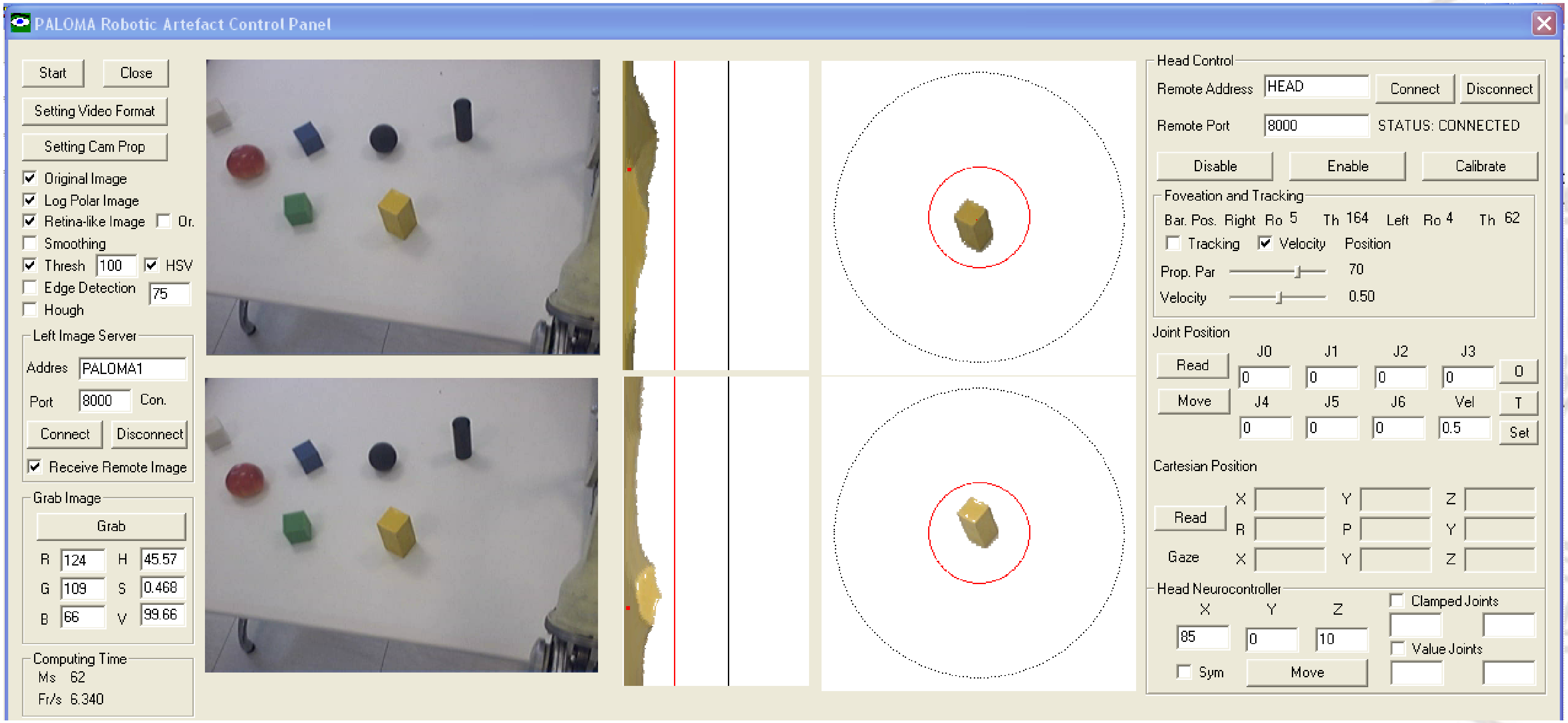
Thresholding of image based on RGB and HUE



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Edge Detection (gradient based method)

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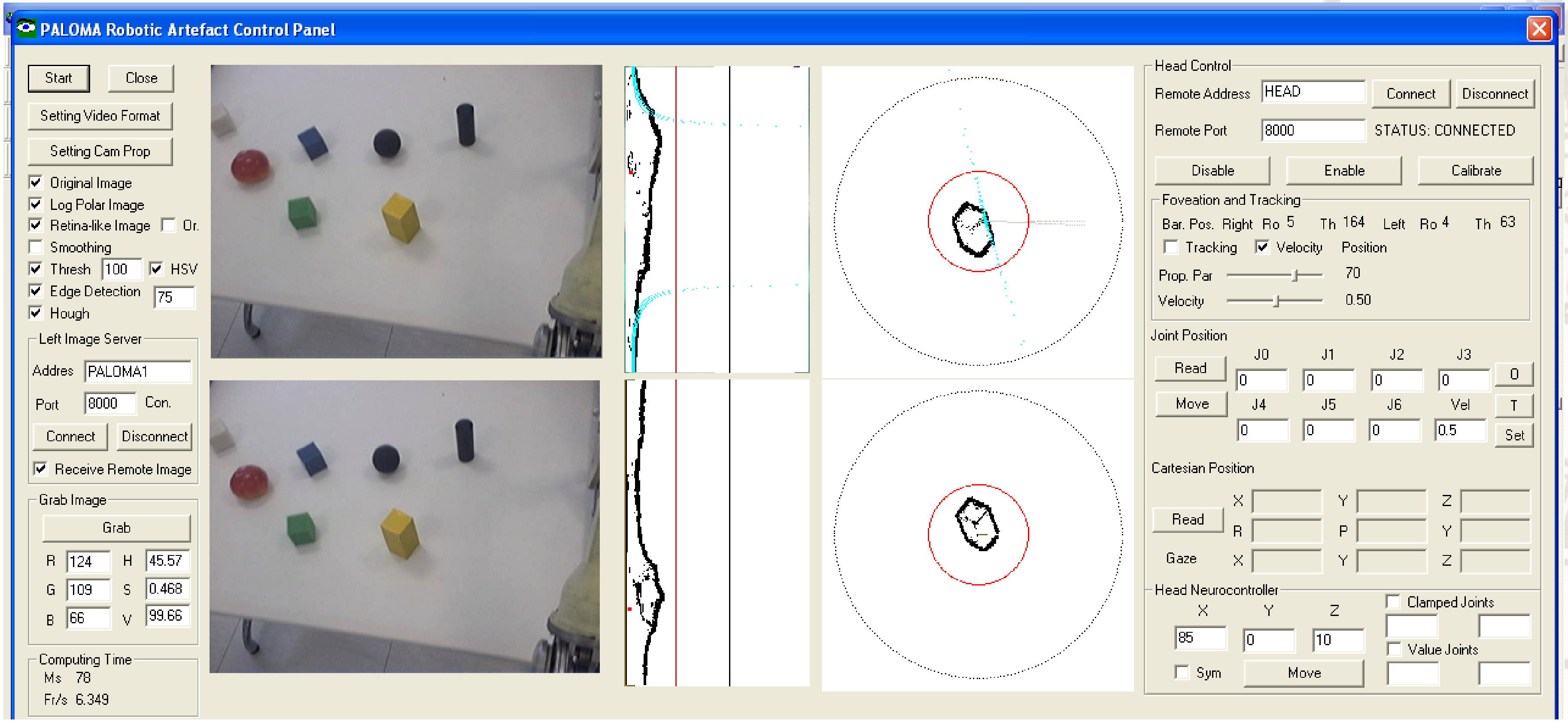
Line detection (Hough method)

- Applied only to pixels belonging to the fovea



Example of sensory-motor scheme for a retina-like vision system

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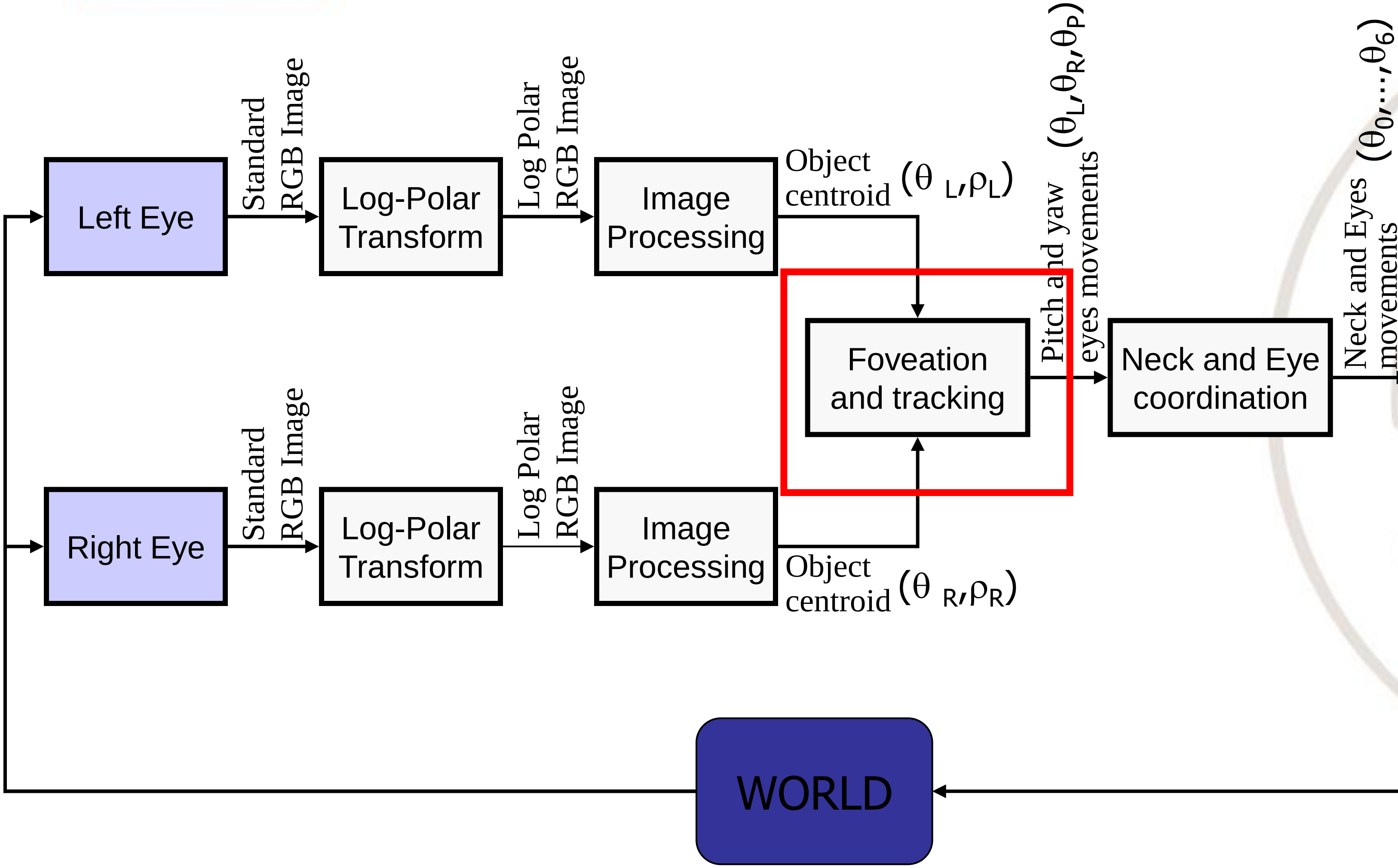
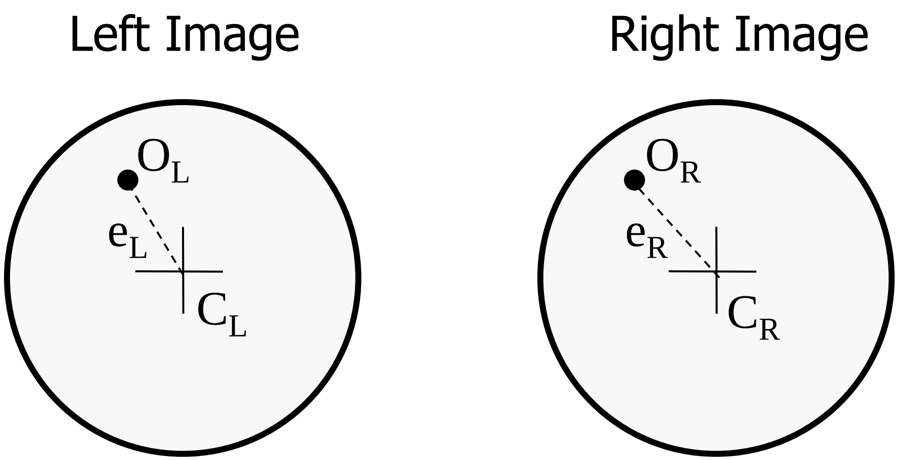


Foveation of the object centroid

Proportional control based on the visual error



$O_L = (\rho_L, \theta_L)$ $\quad$ $O_R = (\rho_R, \theta_R)$

$e_L = \rho_L / M_{ro}$ $\quad$ $e_R = \rho_R / M_{ro}$

M_{ro} is the maximum ρ value (i.e. 152)

Computation of yaw and pitch eye movements

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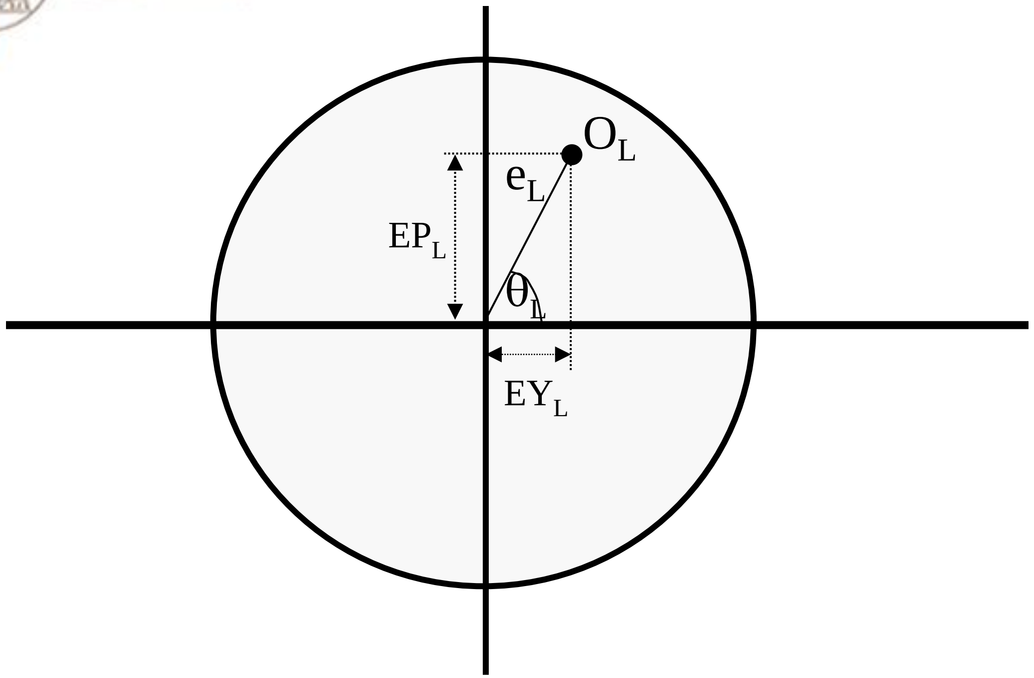


$EY_L = e_L * \cos(\theta_L) * P_L$

$EY_R = e_R * \cos(\theta_R) * P_R$

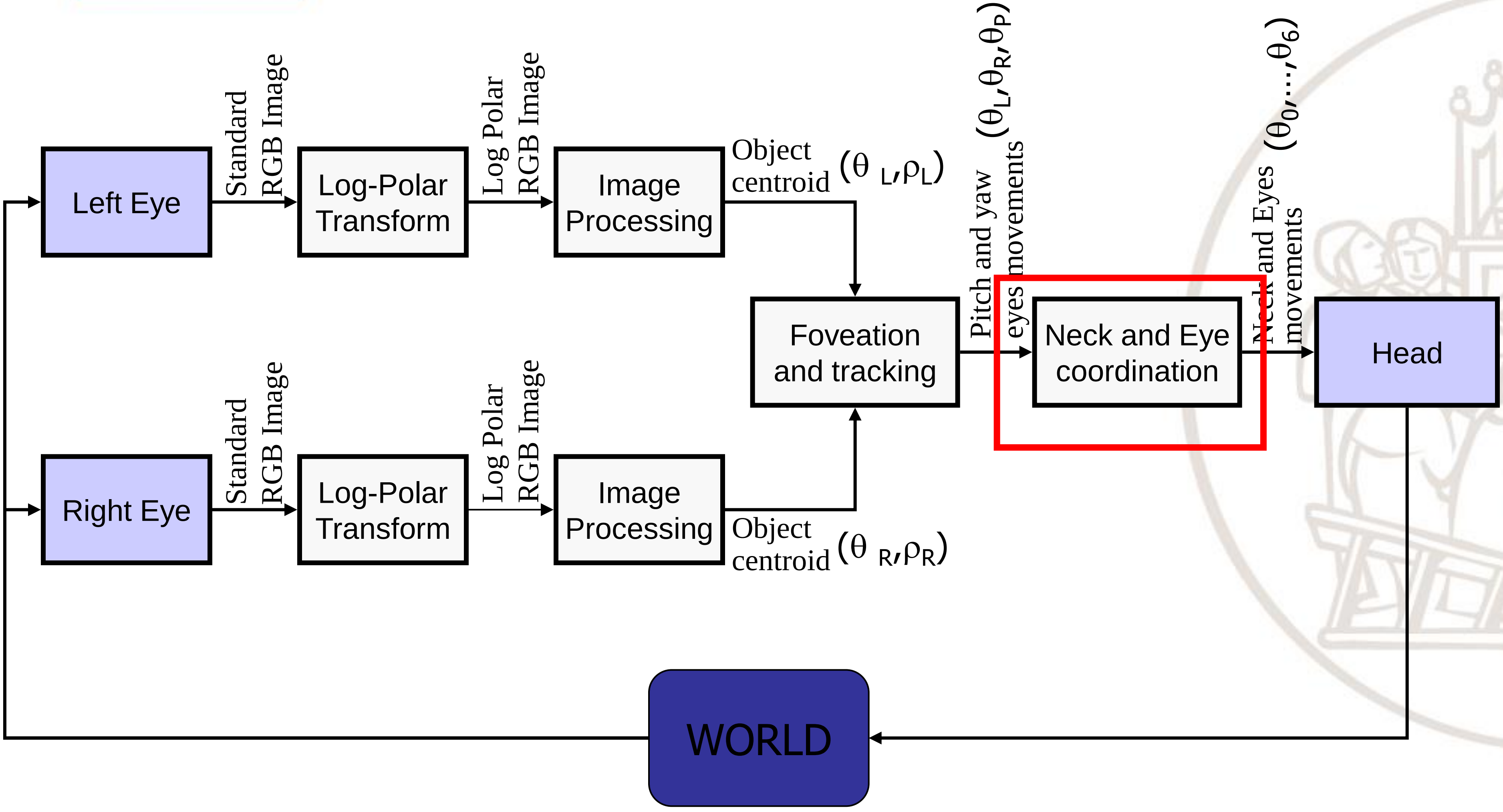
$EP_L = e_L * \sin(\theta_L) * P_L$

$EP_R = e_R * \sin(\theta_R) * P_R$

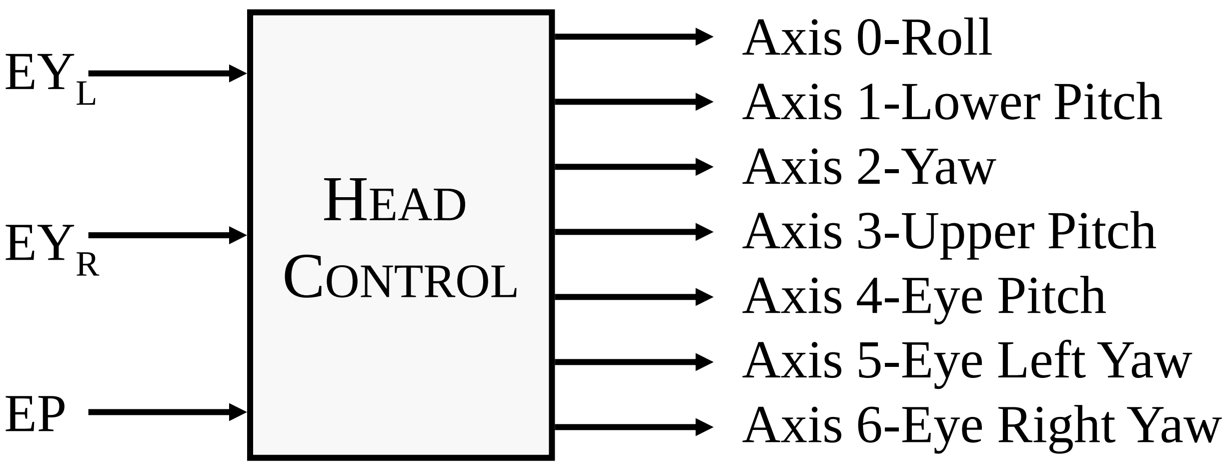
$EP=(EP_L+EP_R)/2$

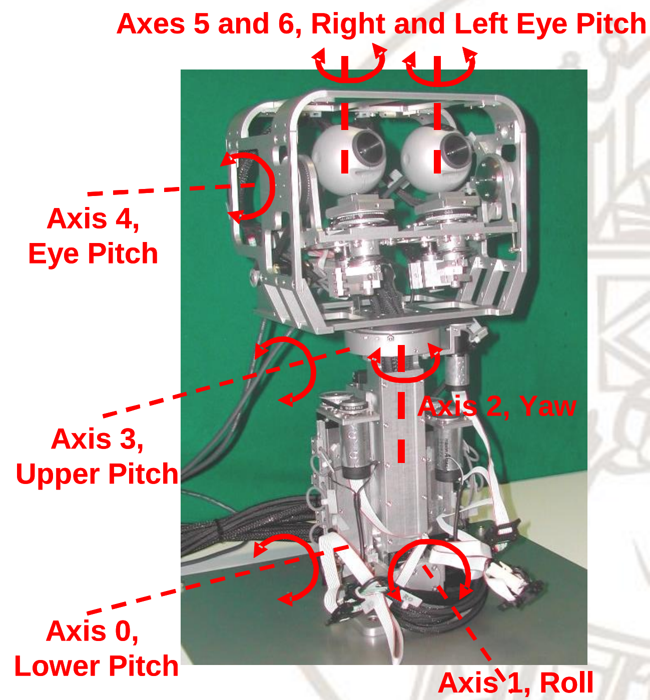
P_L and P_R are the proportional parameters for left and right eye, respectively.

Example of sensory-motor scheme for a retina-like vision system



Eye-neck coordination





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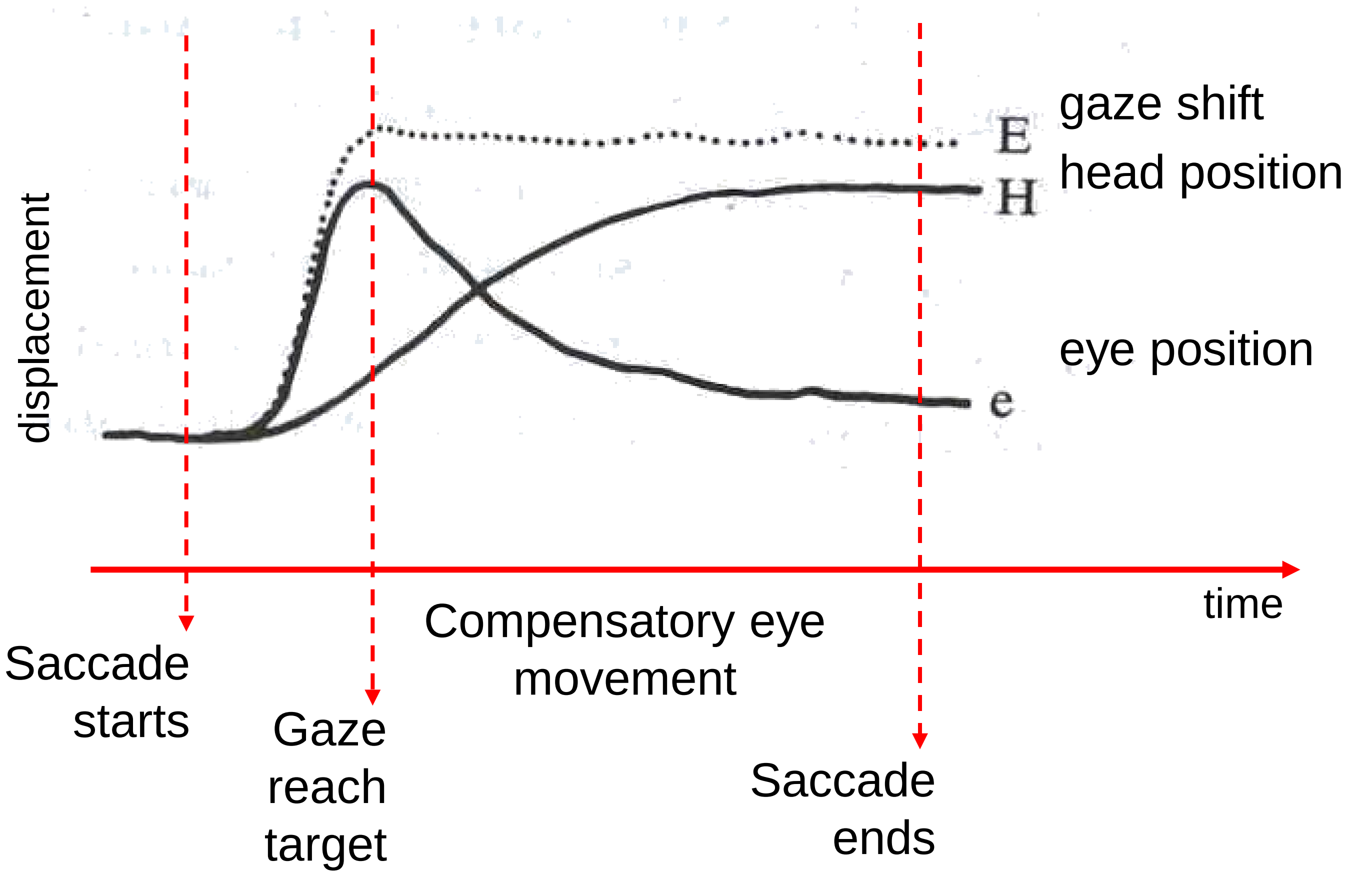
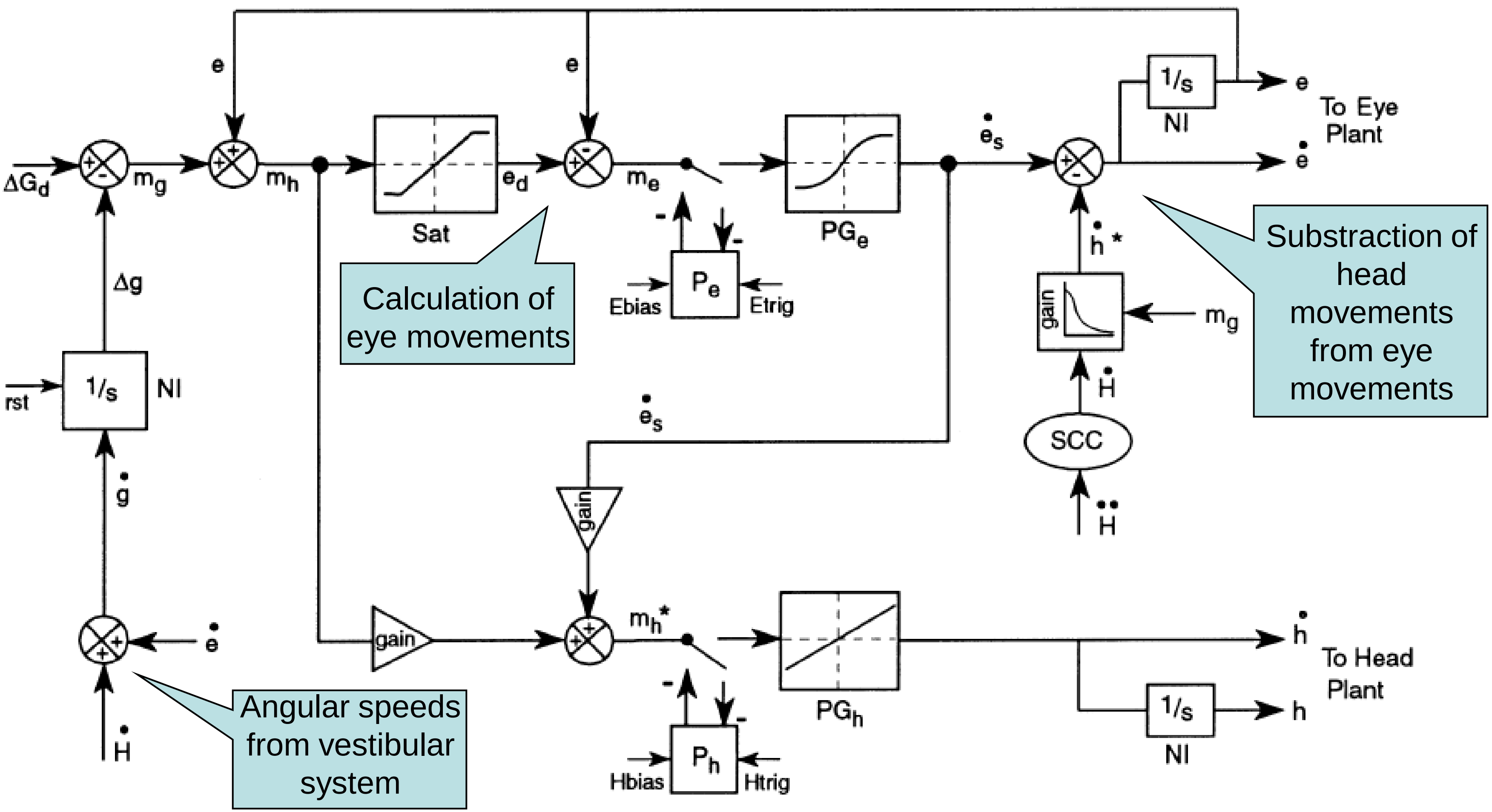
Implementation of a biological model of head-eye coordination

E.S. Maini, G. Teti, C. Laschi, M. Rubino, P. Dario, "Bio-inspired control of eye-head coordination in a robotic anthropomorphic head", *IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics*, Pisa, Italy, February 20-22, 2006

Coordination of eye and head movements in fast gaze shifts



A model of fast gaze shift, coordinating eye and head movements



Goossens H.H. and Van Opstal A.J., “Human eye-head coordination in two dimensions under different sensorimotor conditions”, *Exp. Brain Res.* 1997, Vol. 114, pp. 542–560

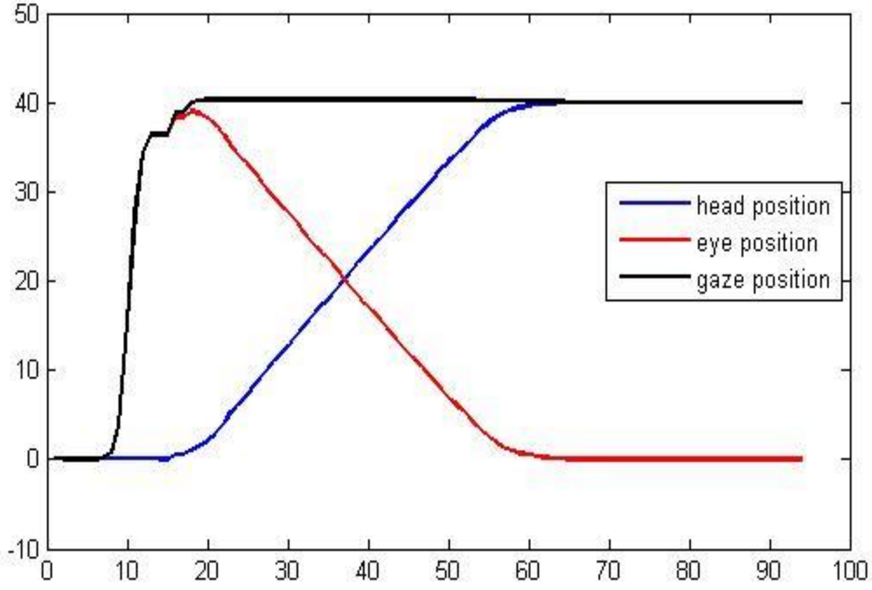
Model of fast gaze shift

The saccade starts and the eye joint moves at his **highest velocity** thus realizing the initial phase of the saccade.

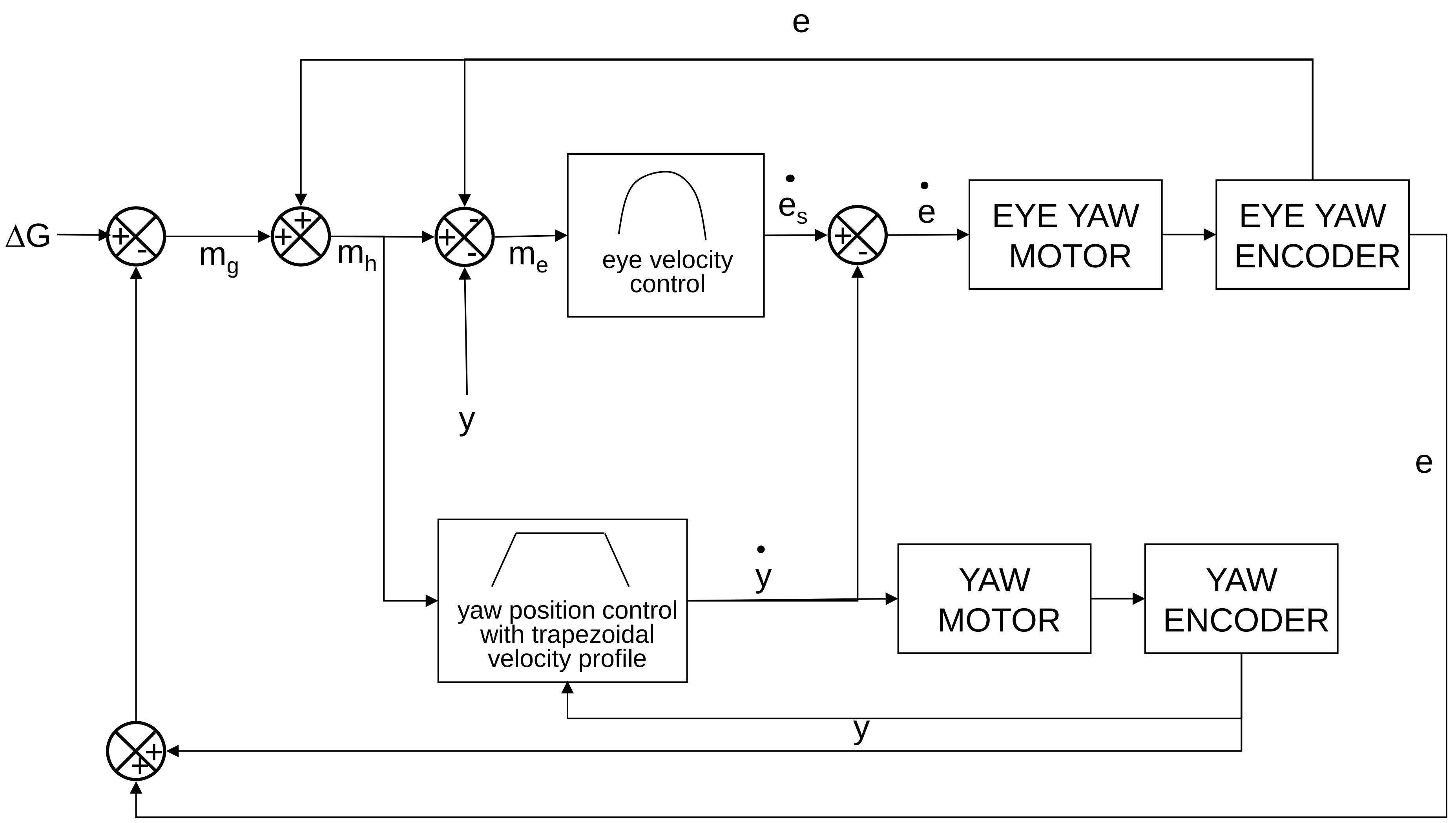
At the same time the head does not move, but it will start moving only after the head delay time is passed.

Given that the speed of the eye is much higher than the speed of the head, the *eye reaches the target position well before the head.*

Time course of head, eye and gaze position of a saccade of 40 degrees



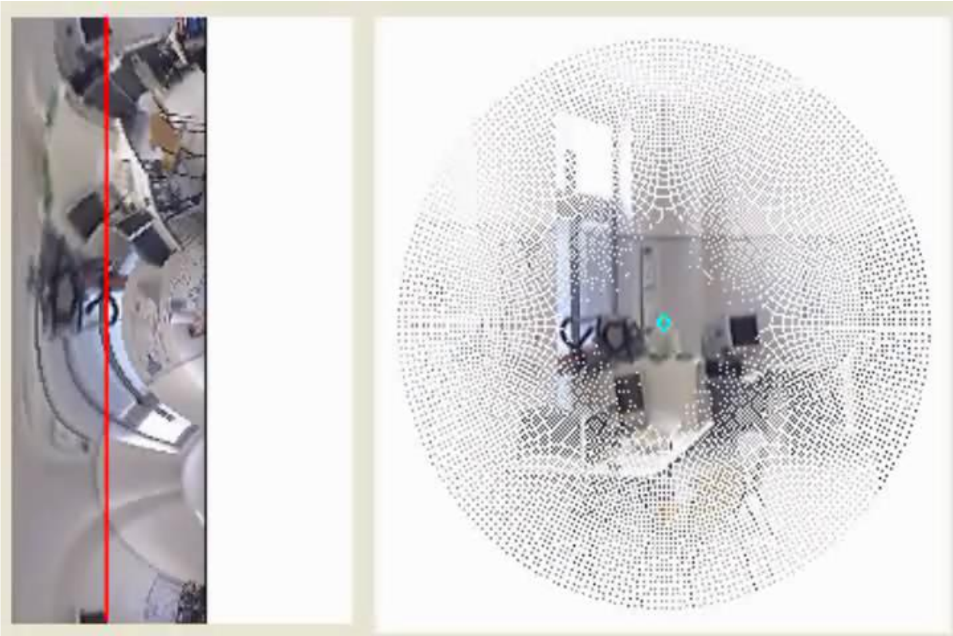
The robotic model for horizontal motion



E.S. Maini, L. Manfredi, C. Laschi, P. Dario, “A bio-inspired velocity control of fast gaze shifts on a robotic anthropomorphic head”, *Autonomous Robots*, Vol.5, 2008, pp.37-58

Robotic implementation: horizontal saccades

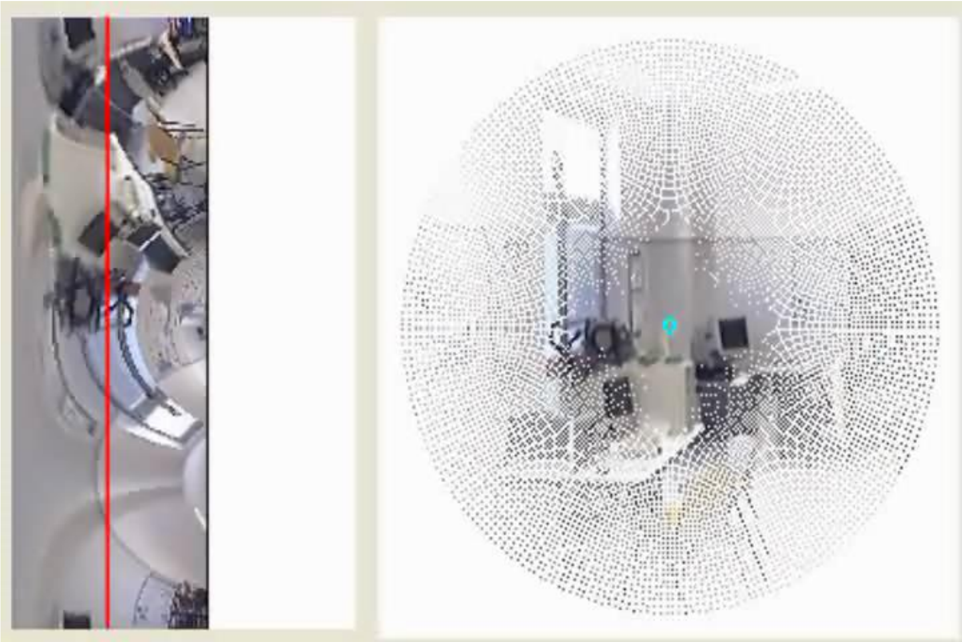
Left eye only



Camera View

E.S. Maini, L. Manfredi, C. Laschi, P. Dario, “A bio-inspired velocity control of fast gaze shifts on a robotic anthropomorphic head”, *Autonomous Robots*, Vol.5, 2008, pp.37-58

Robotic implementation: vertical saccades



Camera View

E.S. Maini, L. Manfredi, C. Laschi, P. Dario, “A bio-inspired velocity control of fast gaze shifts on a robotic anthropomorphic head”, *Autonomous Robots*, Vol.5, 2008, pp.37-58

Experimental Results