



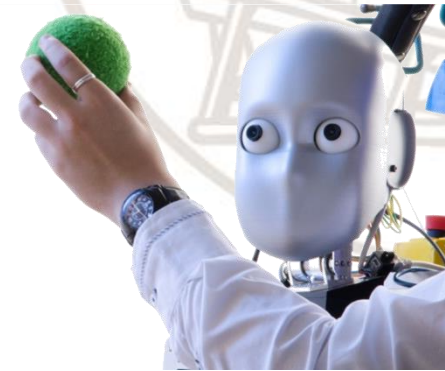
Robotics

Retina-like vision and Eye Movements in Robots

Cecilia Laschi

The BioRobotics Institute

cecilia.laschi@sssup.it





Basic principles of retina-like vision

Standard image



Retina-like image



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



Log-polar projection

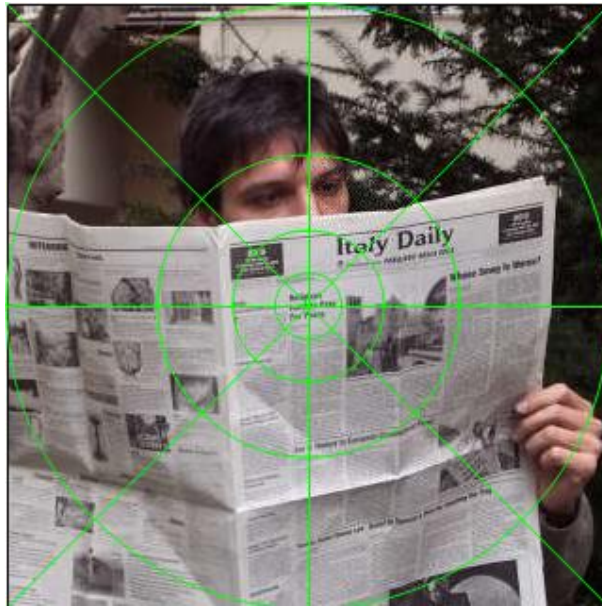




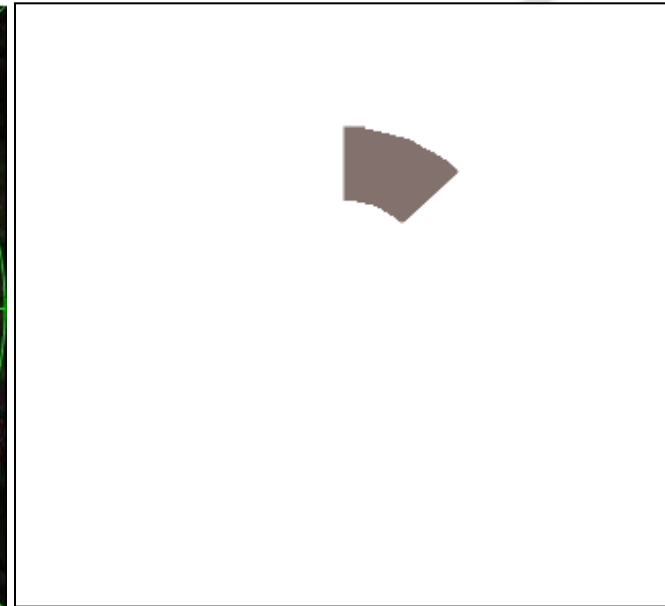
Building a retina-like image



Cartesian image

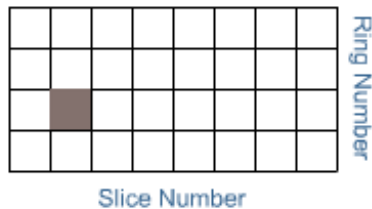


Cutting in circles and
slices



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



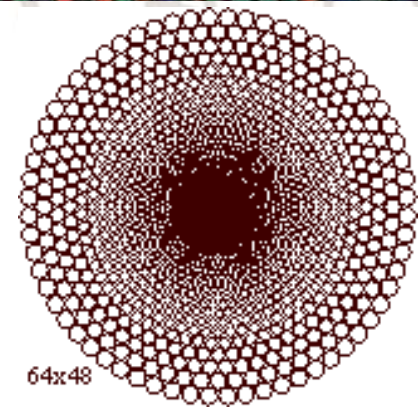
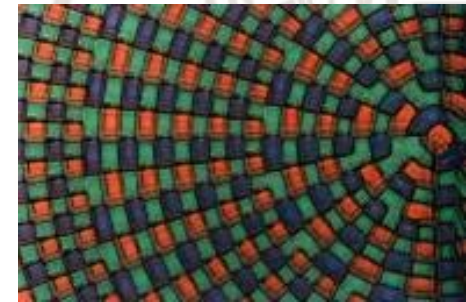
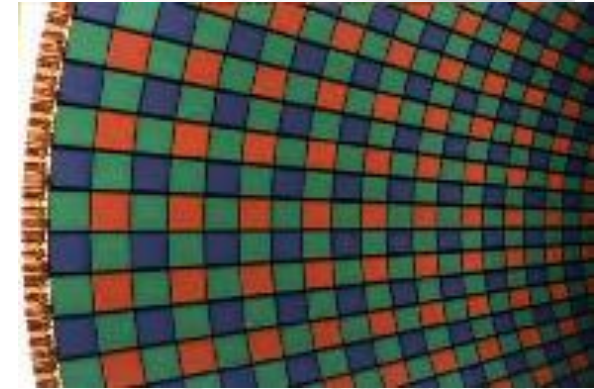
Cartesian image re-built from the polar image



The Retina-like Giotto cameras

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Sant'Anna

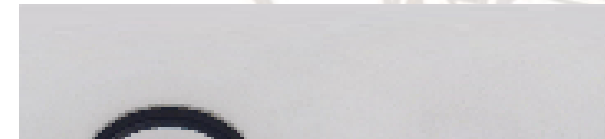
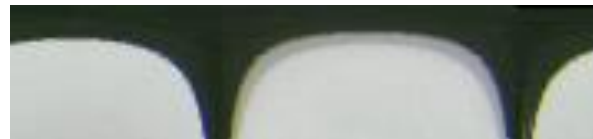
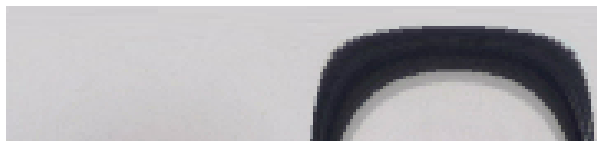
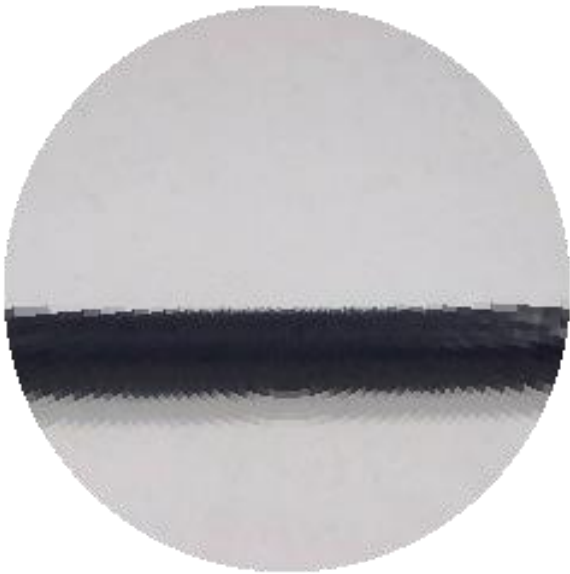
- Technology: 0.35 micrometer CMOS
- Total Pixels: 33193
- Geometry:
 - 110 rings with 252 pixels
 - 42 rings with a number of pixels decreasing toward the center with a "sunflower" arrangement
- Tessellation: pseudo-triangular
- Pixels: direct read-out with logarithmic response
- Size of photosensitive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





An example of pattern translation

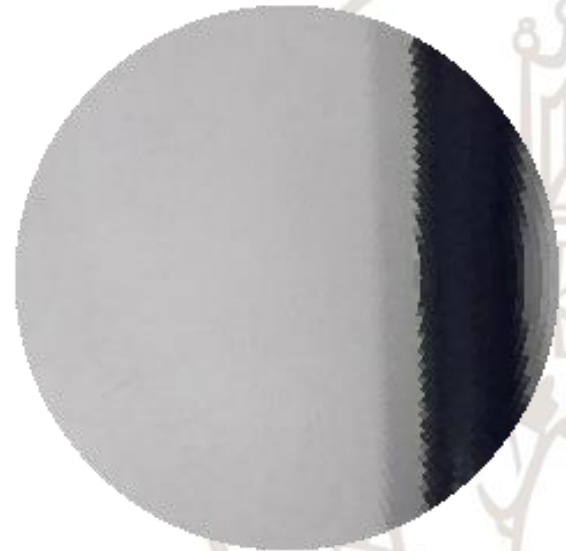
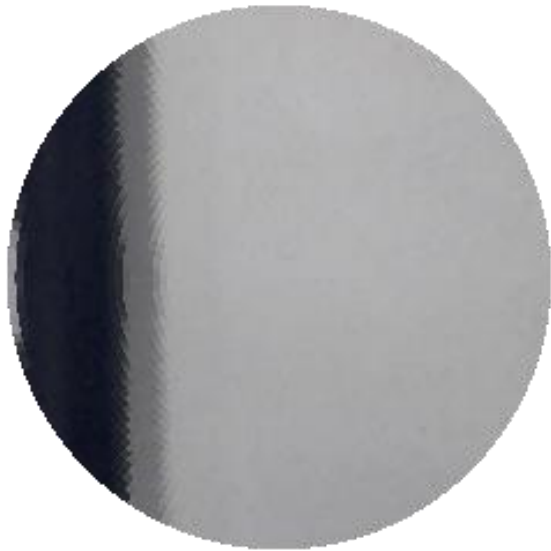
Seuola Superiore
Sant'Anna





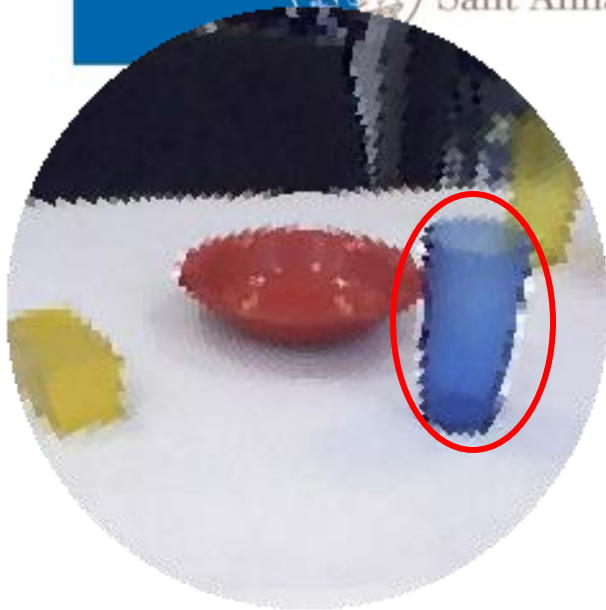
An example of pattern translation

Scuola Superiore
Sant'Anna





An example of simulated foveation



Object detection
in the periphery



Object foveation



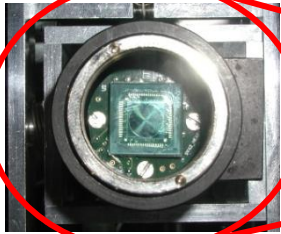
Foveation of a
point of interest
(edge)



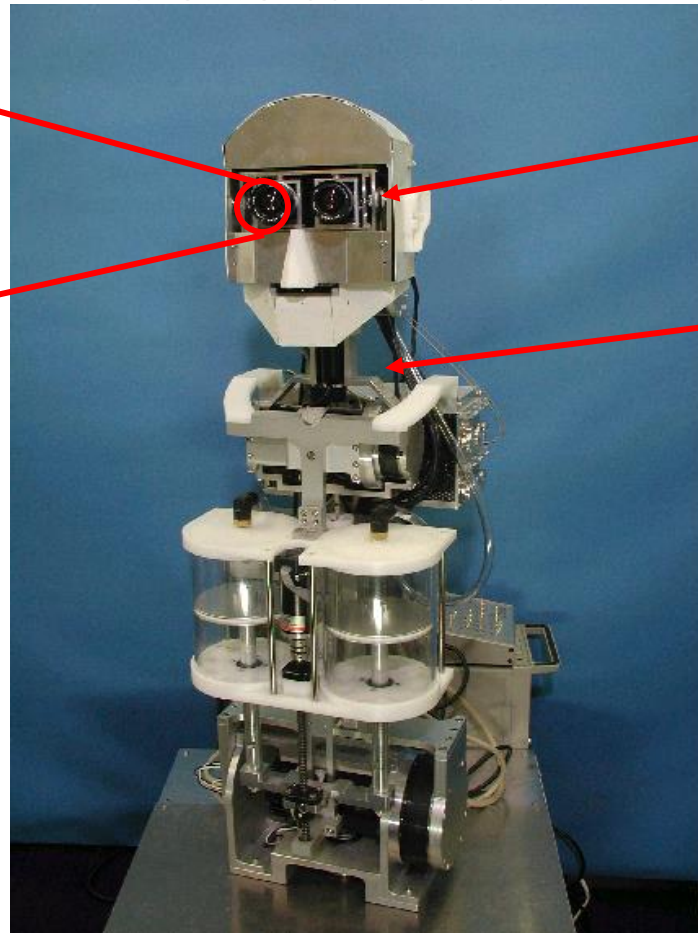
Retina-like vision for visuo-motor coordination of a robot head

Scuola Superiore
Sant'Anna

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

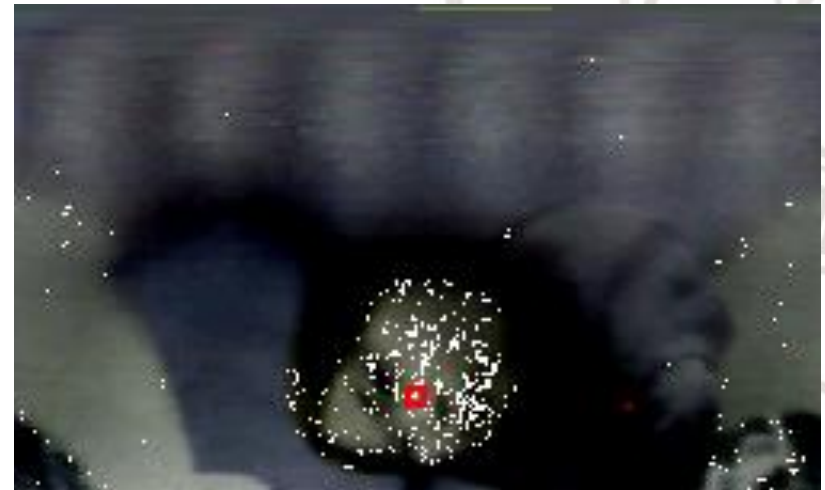
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Sant'Anna

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 $\text{Hue} = 2\pi - \text{Hue}$

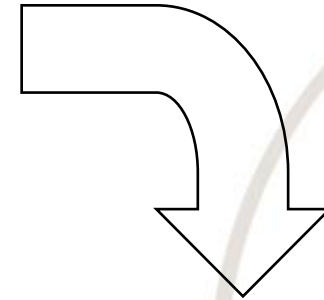
R, G, B = RED, GREEN, BLUE components, respectively



An example of foveation



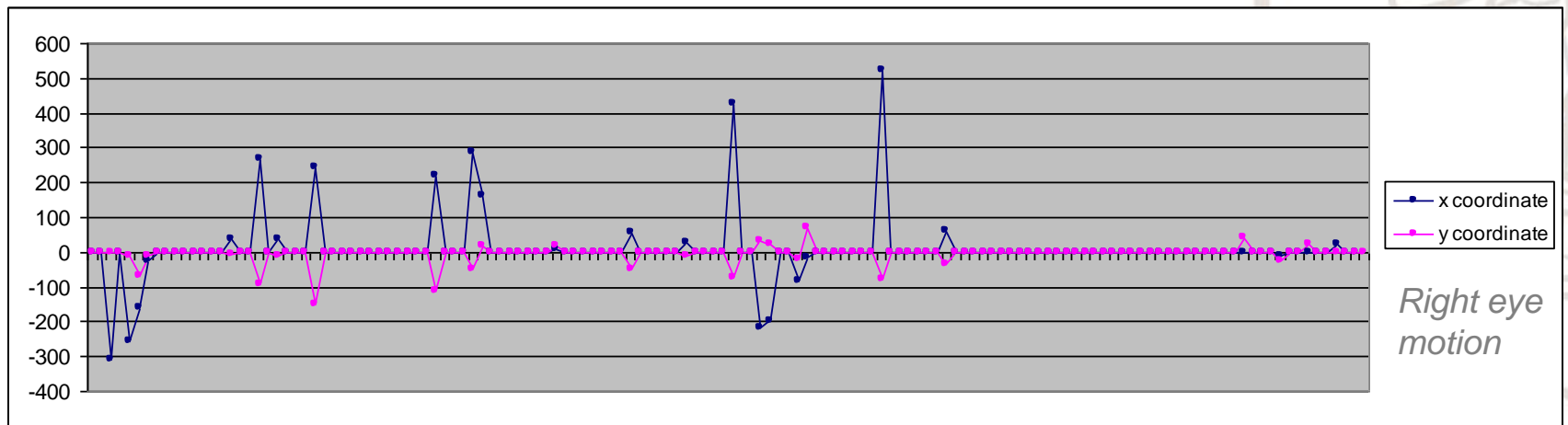
Eye/neck movements



Proportions are rescaled for display purposes



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



Kinematic structure of the SSSA Robot Head

Axis 5, Right Eye Yaw

Axis 6, Left Eye Yaw

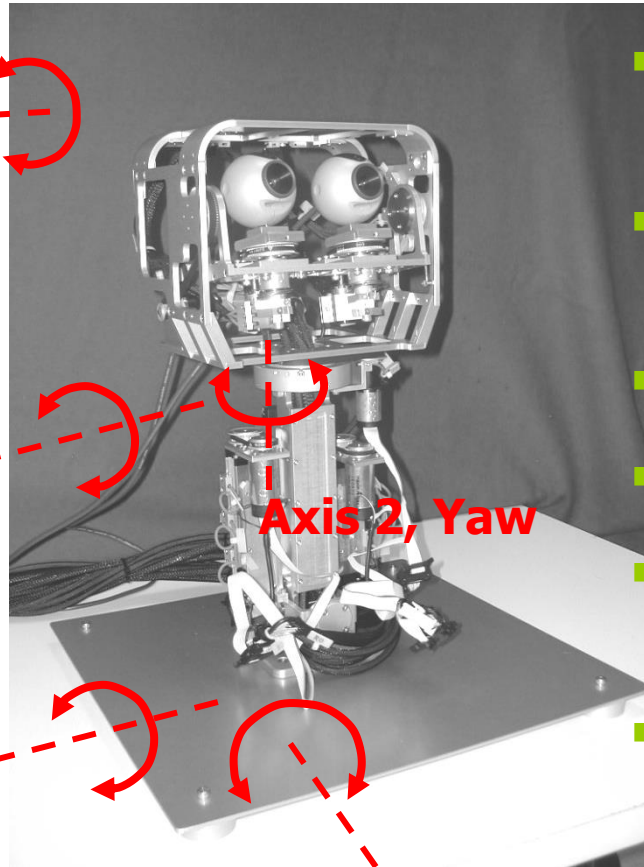
Axis 4,
Eye Pitch

Axis 3,
Upper Pitch

Axis 0,
Lower Pitch

Axis 2, Yaw

Axis 1, Roll



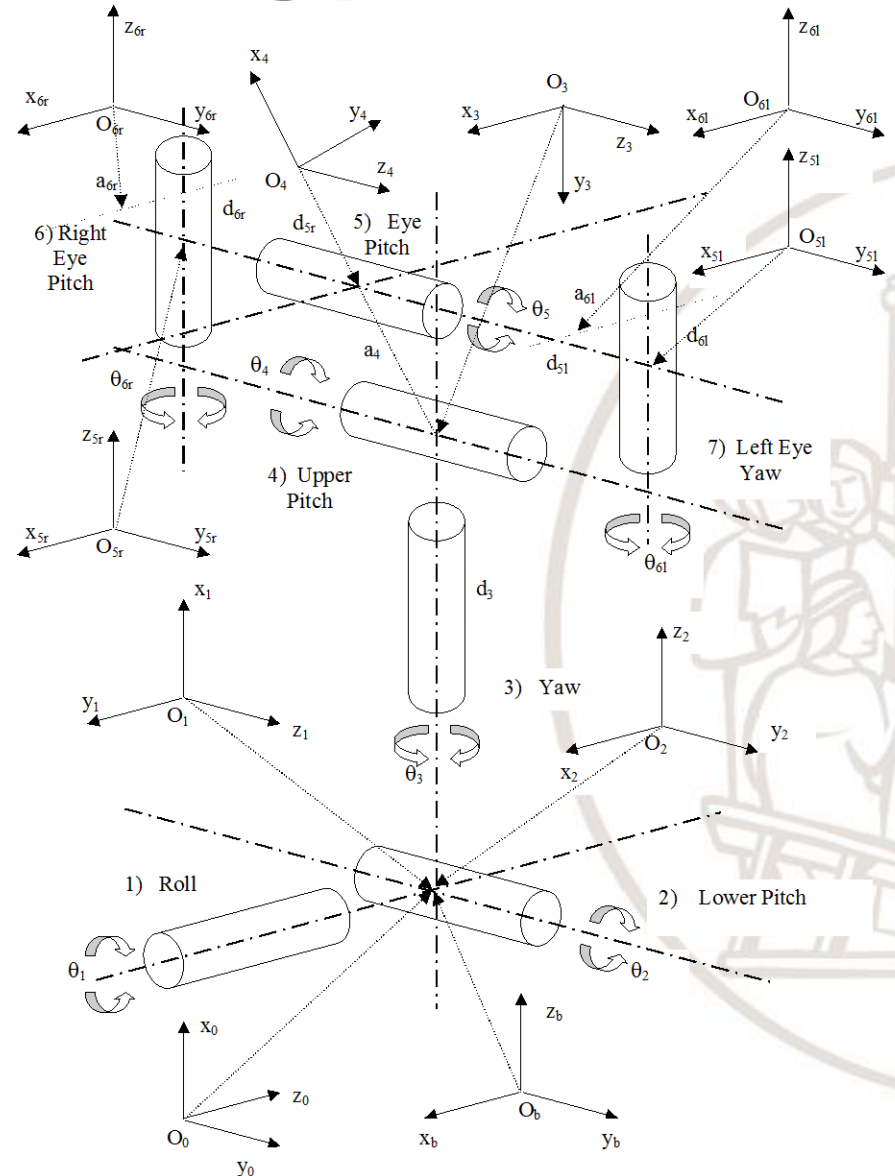
- Eye Pitch Axis: $\pm 47^\circ$, $600^\circ/\text{s}$
- Eye R/L Yaw Axis: $\pm 45^\circ$, $1000^\circ/\text{s}$
- Yaw: $\pm 100^\circ$, $170^\circ/\text{s}$
- Roll: $\pm 30^\circ$, $25^\circ/\text{s}$
- Upper Pitch: $\pm 30^\circ$, $120^\circ/\text{s}$
- Lower Pitch: $\pm 25^\circ$, $20^\circ/\text{s}$



Head kinematic chain and Denavit-Hartenberg parameters

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Sant'Anna

| 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 | $-30 \div -50$ | $\pi/2$ |
| J5 _l | 0 | $30 \div 50$ | $\pi/2$ |
| J6 _l | a_{6l} | d_{6l} | 0 |
| J6 _r | a_{6r} | d_{6r} | 0 |





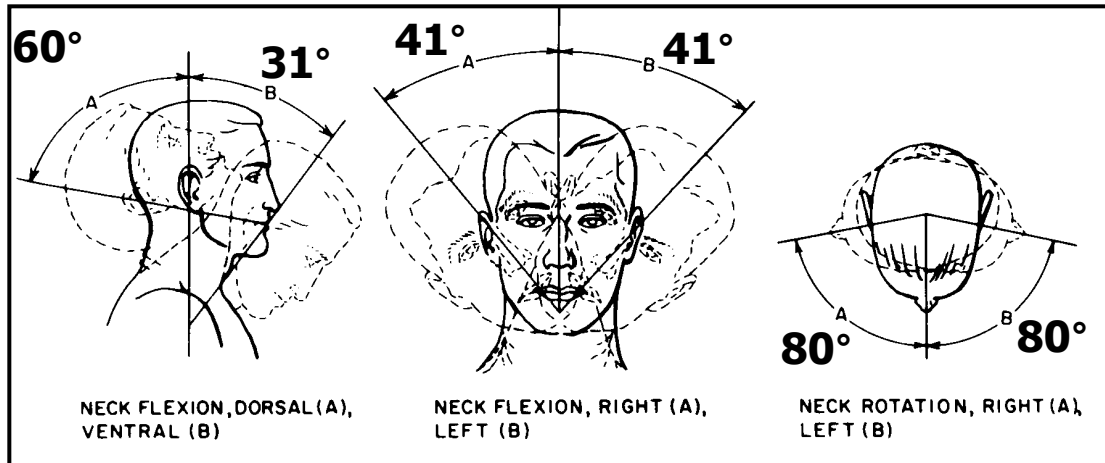
Comparison of performances between human and robotic head

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Neck:

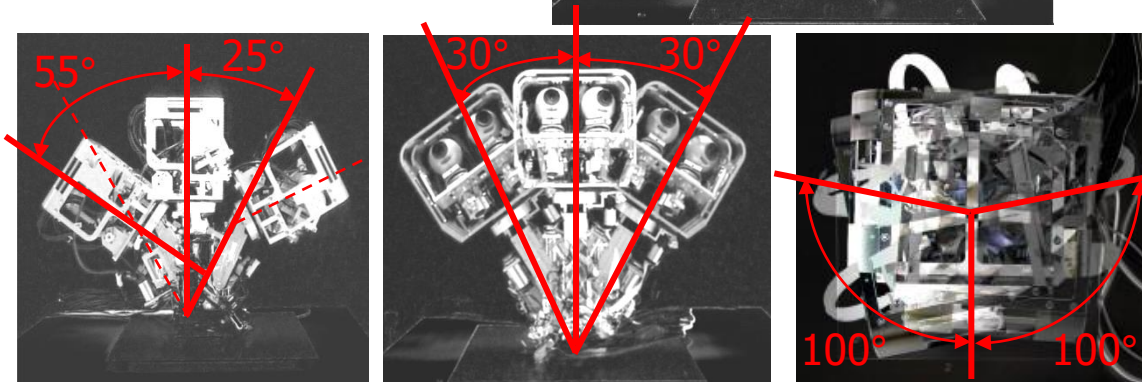
Eye:

Human



[Hamill et al., 1995]

Robot



Pitch: $\pm 60^\circ$, $600^\circ/\text{s}$

Yaw: $\pm 30^\circ$, $600^\circ/\text{s}$

Pitch: $\pm 47^\circ$, $600^\circ/\text{s}$

Yaw: $\pm 45^\circ$, $1000^\circ/\text{s}$

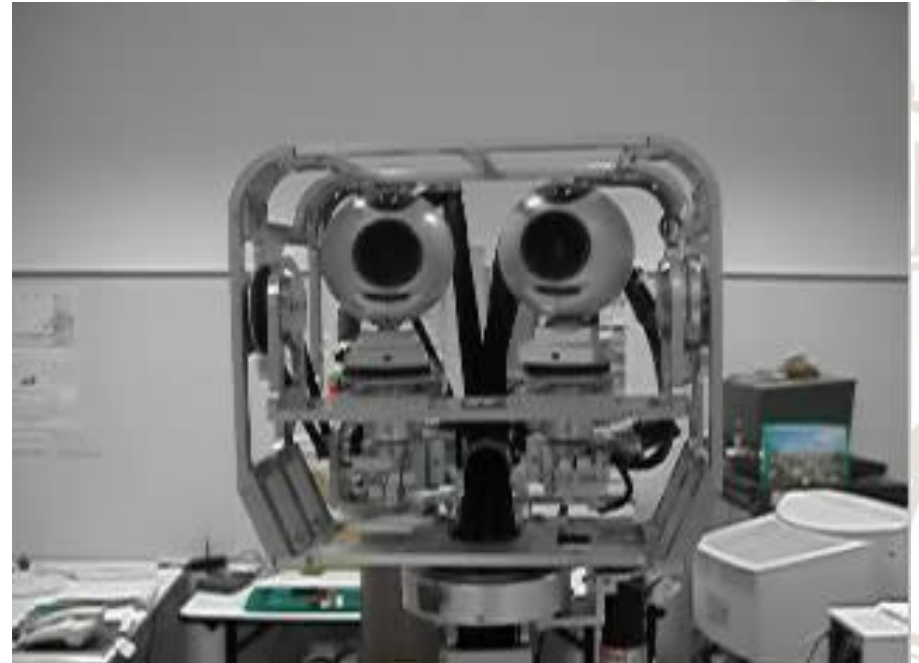


The movements of the 7 dofs of the robotic head

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Sant'Anna



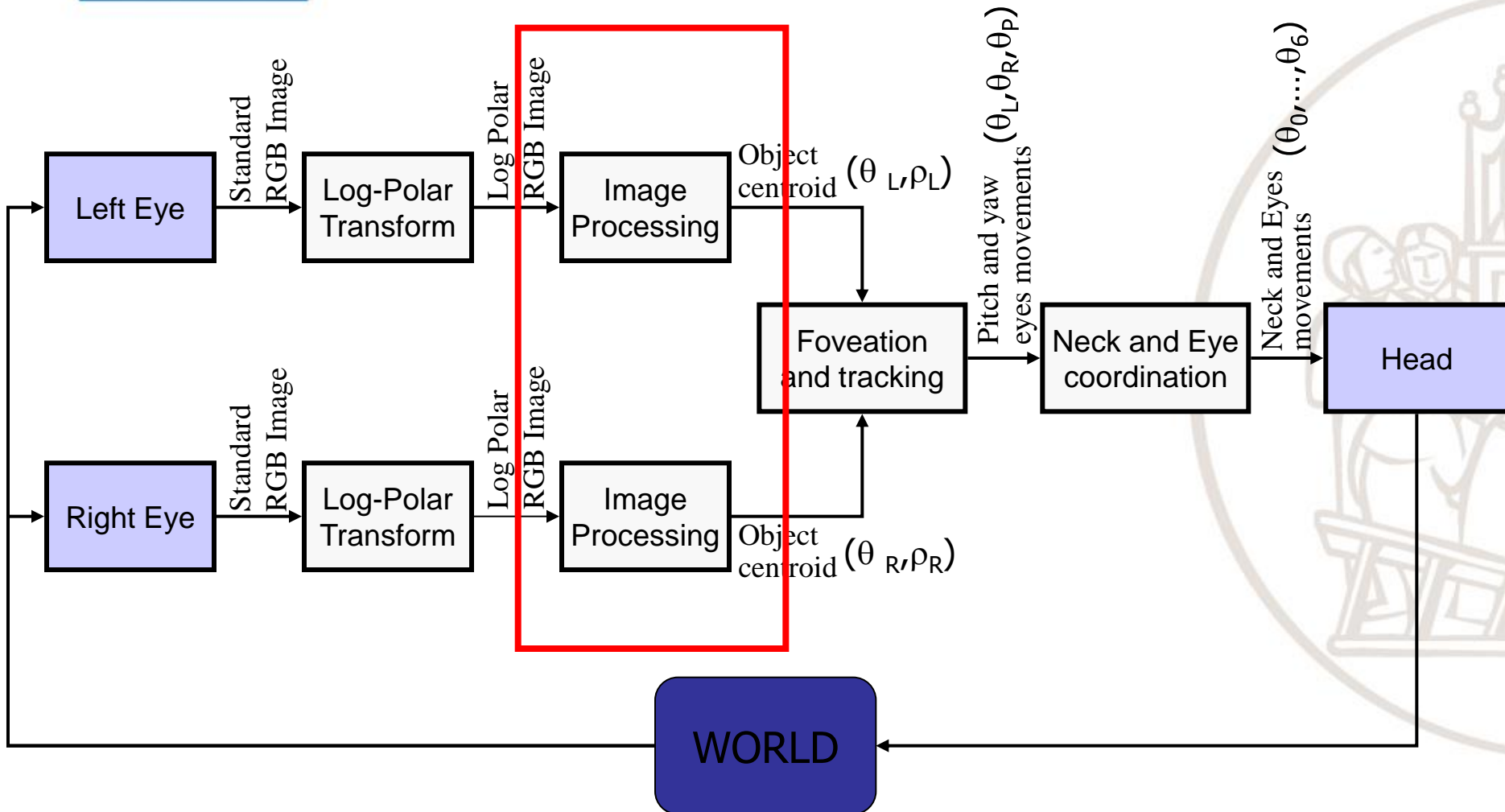
Neck Movements



Saccades, $400^\circ/\text{sec}$

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

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Sant'Anna

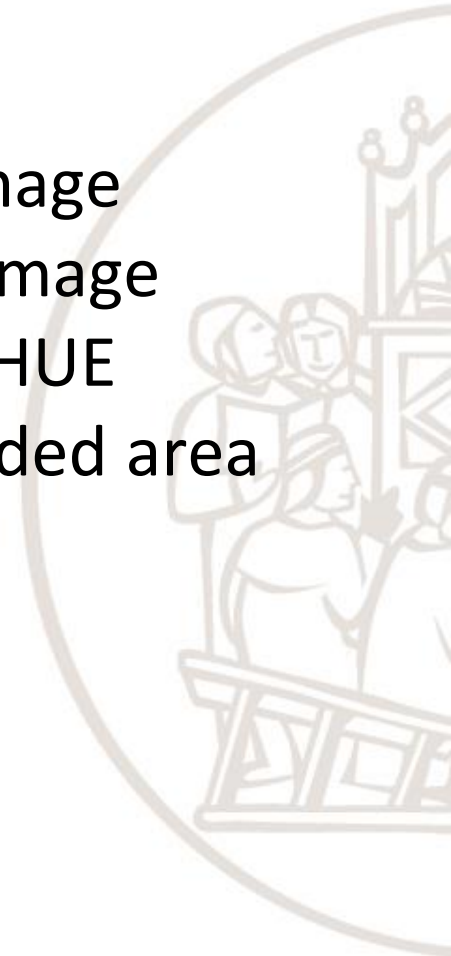




Examples of algorithms developed for retina-like image processing

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- 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





Simulation of retina-like cameras and basic image processing

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Sant'Anna

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

Client retina-like vision system

Start Close

Setting Video Format

Setting Cam Prop

Original Image
 Log Polar Image
 Retina-like Image
 Smoothing
 Thresholding 25
 Edge Detection 75
 Hough

Left Image Server
 Address 192.168.83.208
 Port 8000
 Connect Disconnect
 Receive Remote Image

Grab Image
 Grab

Red 120
 Green 115
 Blue 59

Computing Time
 Ms 100
 Fr/s 13.761

Head Control
 Remote Address 192.168.83.234 Connect Disconnect
 Remote Port 8000
 Disable Enable Calibrate

Foveation and Tracking
 Baycenter Position Ro 19 Th 6
 Tracking Velocity Position

Joint Position
 J0 J1 J2 J3
 Read
 J4 J5 J6 Set
 J0 J1 J2 J3
 Move 0 0 0 0
 J4 J5 J6
 0 0 0

Cartesian Position
 Read X Y Z
 R P Y
 Gaze X Y Z



Thresholding of image based on RGB and HUE

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Sant'Anna

PALOMA Robotic Artefact Control Panel

Start Close

Setting Video Format

Setting Cam Prop

Original Image

Log Polar Image

Retina-like Image Or.

Smoothing

Thresh 100 HSV

Edge Detection 75

Hough

Left Image Server

Address: PALDMA1

Port: 8000 Con.

Connect Disconnect

Receive Remote Image

Grab Image

Grab

R 124 H 45.57

G 109 S 0.468

B 66 V 99.66

Computing Time

Ms 62

Fr/s 6.340

Head Control

Remote Address HEAD Connect Disconnect

Remote Port 8000 STATUS: CONNECTED

Disable Enable Calibrate

Foveation and Tracking

Bar. Pos. Right Ro 5 Th 164 Left Ro 4 Th 62

Tracking Velocity Position

Prop. Par 70

Velocity 0.50

Joint Position

| | | | | | |
|------|----|----|----|-----|-----|
| Read | J0 | J1 | J2 | J3 | |
| | 0 | 0 | 0 | 0 | 0 |
| Move | J4 | J5 | J6 | Vel | T |
| | 0 | 0 | 0 | 0.5 | Set |

Cartesian Position

| | | | |
|------|---|---|---|
| Read | X | Y | Z |
| | | | |
| | R | P | Y |
| | | | |
| Gaze | X | Y | Z |
| | | | |

Head Neurocontroller

| | | | | |
|------------------------------|----|------|----|---|
| | X | Y | Z | <input type="checkbox"/> Clamped Joints |
| | 85 | 0 | 10 | |
| | | | | <input type="checkbox"/> Value Joints |
| <input type="checkbox"/> Sym | | Move | | |



Edge Detection (gradient based method)

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Sant'Anna

PALOMA Robotic Artefact Control Panel

Start Close

Setting Video Format

Setting Cam Prop

Original Image

Log Polar Image

Retina-like Image Or.

Smoothing

Thresh 100 HSV

Edge Detection 75

Hough

Left Image Server

Address PALOMA1

Port 8000 Con.

Connect Disconnect

Receive Remote Image

Grab Image

Grab

R 124 H 45.57

G 109 S 0.468

B 66 V 99.66

Computing Time

Ms 47

Fr/s 6.347

Head Control

Remote Address HEAD Connect Disconnect

Remote Port 8000 STATUS: CONNECTED

Disable Enable Calibrate

Foveation and Tracking

Bar. Pos. Right Ro 5 Th 164 Left Ro 4 Th 63

Tracking Velocity Position

Prop. Par 70

Velocity 0.50

Joint Position

| | J0 | J1 | J2 | J3 | |
|------|----|----|----|-----|-----|
| Read | 0 | 0 | 0 | 0 | 0 |
| Move | J4 | J5 | J6 | Vel | T |
| | 0 | 0 | 0 | 0.5 | Set |

Cartesian Position

| | X | Y | Z |
|------|---|---|---|
| Read | | | |
| | R | P | Y |
| Gaze | X | Y | Z |

Head Neurocontroller

| | X | Y | Z | Clamped Joints | |
|------------------------------|----|------|----|----------------|--|
| | 85 | 0 | 10 | | |
| | | | | Value Joints | |
| <input type="checkbox"/> Sym | | Move | | | |

Line detection (Hough method)

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Sant'Anna

- Applied only to pixels belonging to the fovea

PALOMA Robotic Artefact Control Panel

Start Close

Setting Video Format

Setting Cam Prop

Original Image

Log Polar Image

Retina-like Image Dr.

Smoothing

Thresh 100 HSV

Edge Detection 75

Hough

Left Image Server

Address PALOMA1

Port 8000 Con.

Connect Disconnect

Receive Remote Image

Grab Image

Grab

R 124 H 45.57

G 109 S 0.468

B 66 v 99.66

Computing Time

Ms 78

Fr/s 6.349



Head Control

Remote Address HEAD Connect Disconnect

Remote Port 8000 STATUS: CONNECTED

Disable Enable Calibrate

Foveation and Tracking

Bar. Pos. Right Ro 5 Th 164 Left Ro 4 Th 63

Tracking Velocity Position

Prop. Par 70

Velocity 0.50

Joint Position

| | | | | | |
|------|----|----|----|-----|-----|
| Read | J0 | J1 | J2 | J3 | |
| | 0 | 0 | 0 | 0 | 0 |
| Move | J4 | J5 | J6 | Vel | T |
| | 0 | 0 | 0 | 0.5 | Set |

Cartesian Position

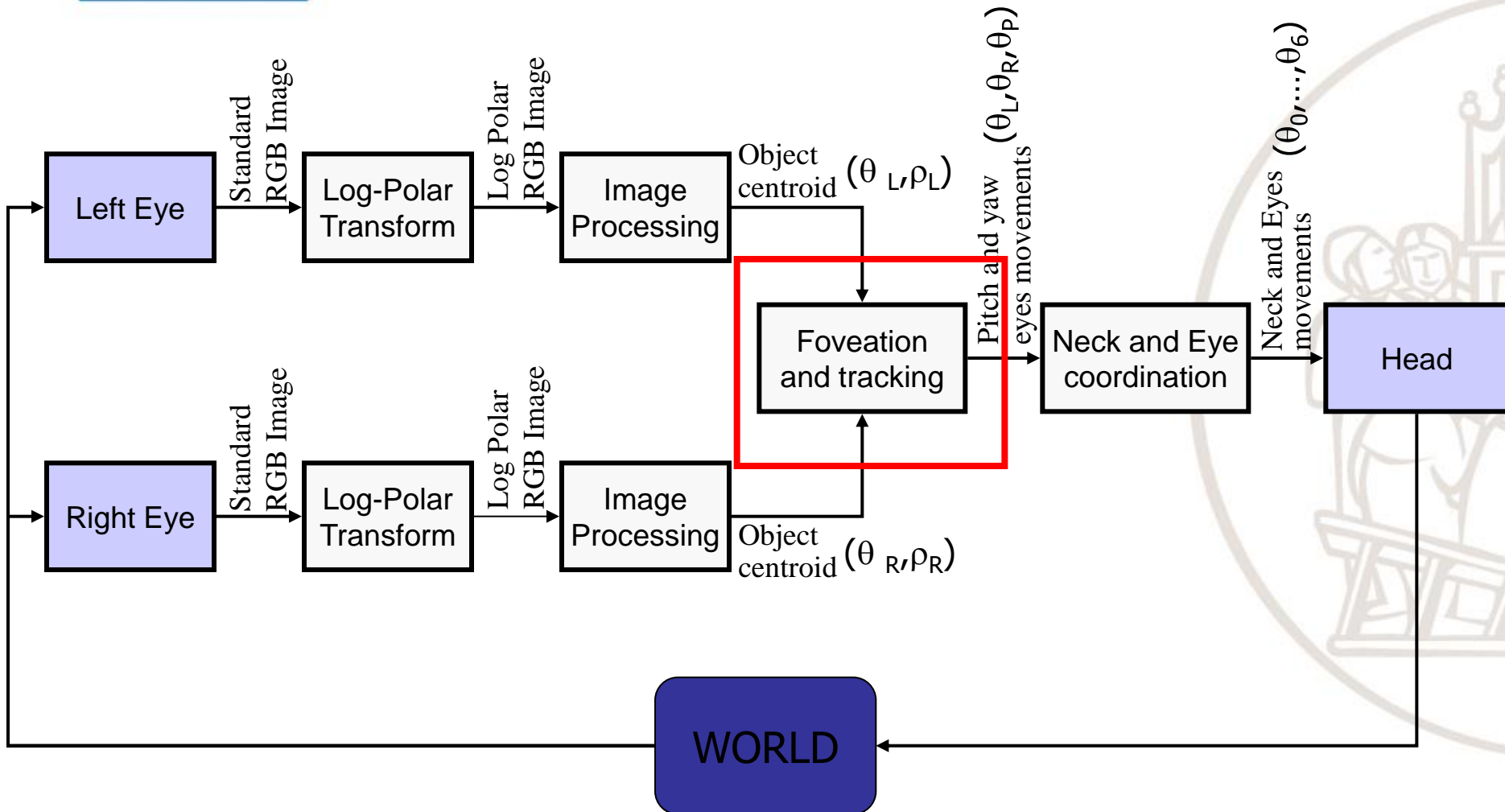
| | | | |
|------|---|---|---|
| Read | X | Y | Z |
| | | | |
| | R | P | Y |
| Gaze | X | Y | Z |
| | | | |

Head Neurocontroller

| | | | |
|----|---|----|---|
| X | Y | Z | <input type="checkbox"/> Clamped Joints |
| 85 | 0 | 10 | |
| | | | <input type="checkbox"/> Value Joints |

Sym Move

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



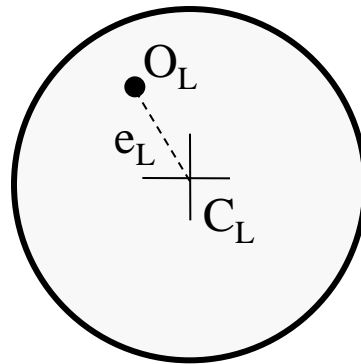


Foveation of the object centroid

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Proportional control based on the visual error

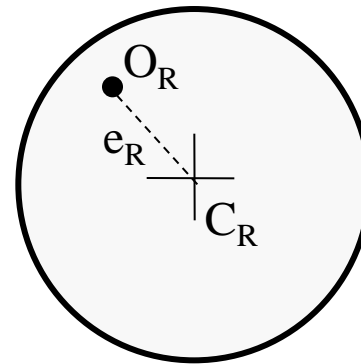
Left Image



$$O_L = (\rho_L, \theta_L)$$

$$e_L = \rho_L / M_{ro}$$

Right Image



$$O_R = (\rho_R, \theta_R)$$

$$e_R = \rho_R / M_{ro}$$

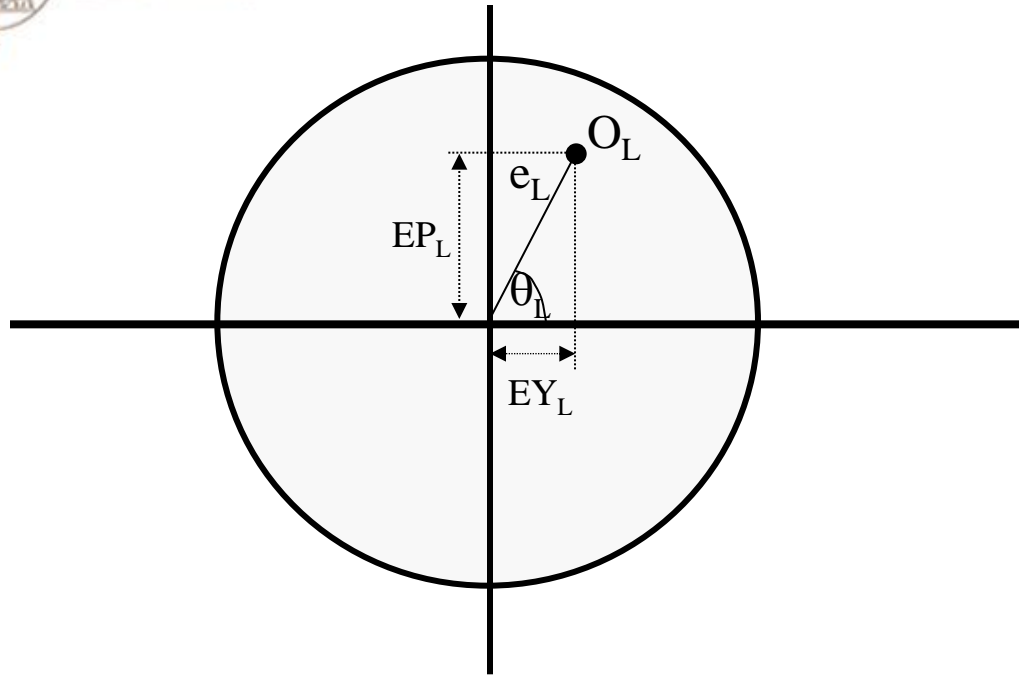
M_{ro} is the maximum ρ value (i.e. 152)





Computation of yaw and pitch eye movements

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Sant'Anna



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

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

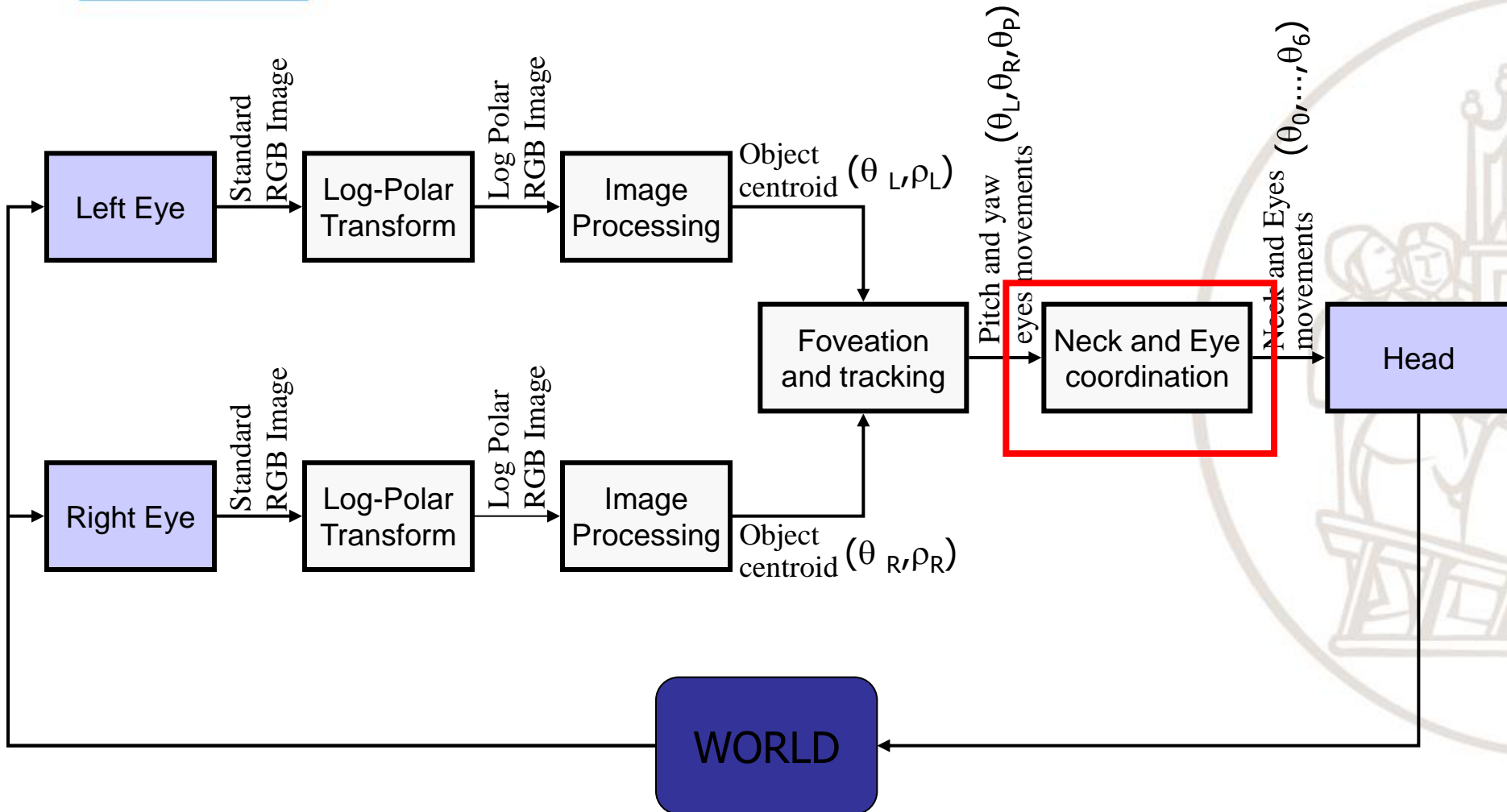
$$EY_R = e_R * \cos(\theta_R) * P_R$$

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

$$EP = (EP_L + EP_R) / 2$$

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

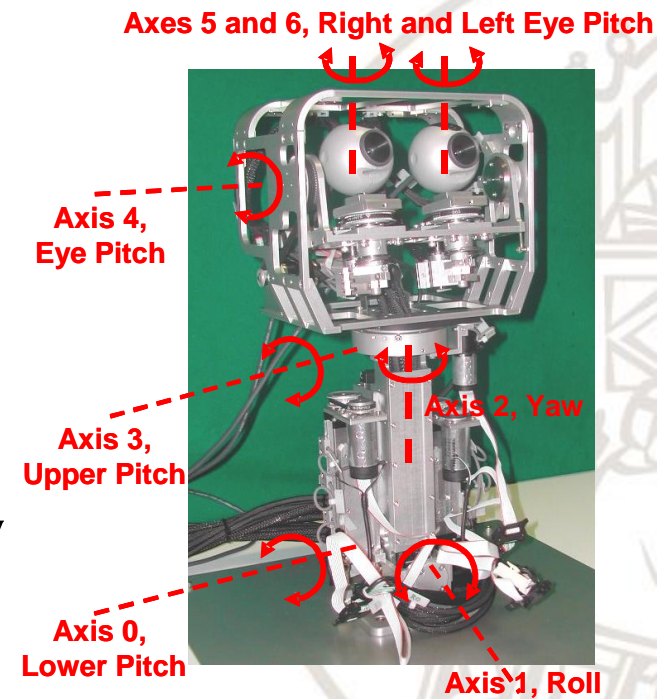
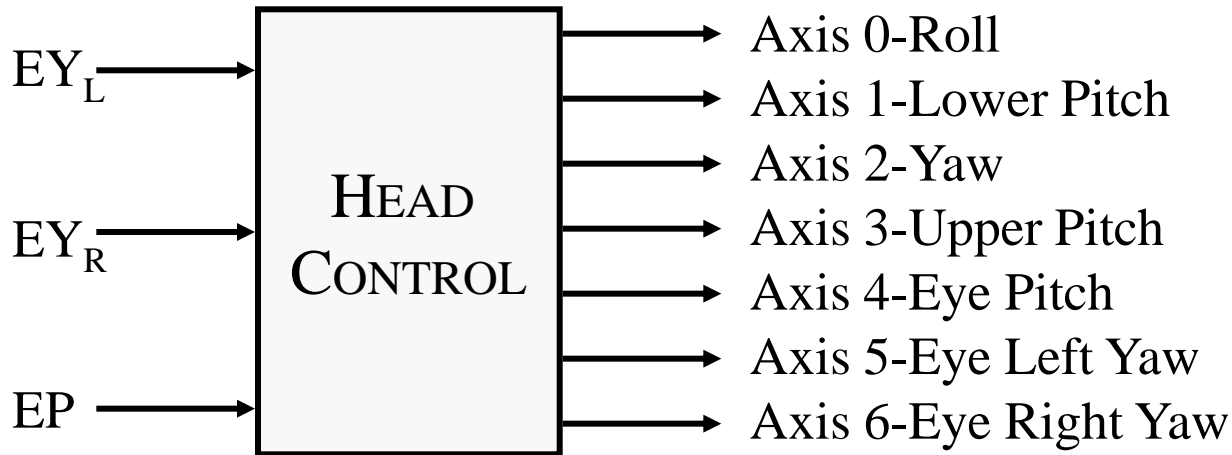
Example of sensory-motor scheme for a retina-like vision system





Eye-neck coordination

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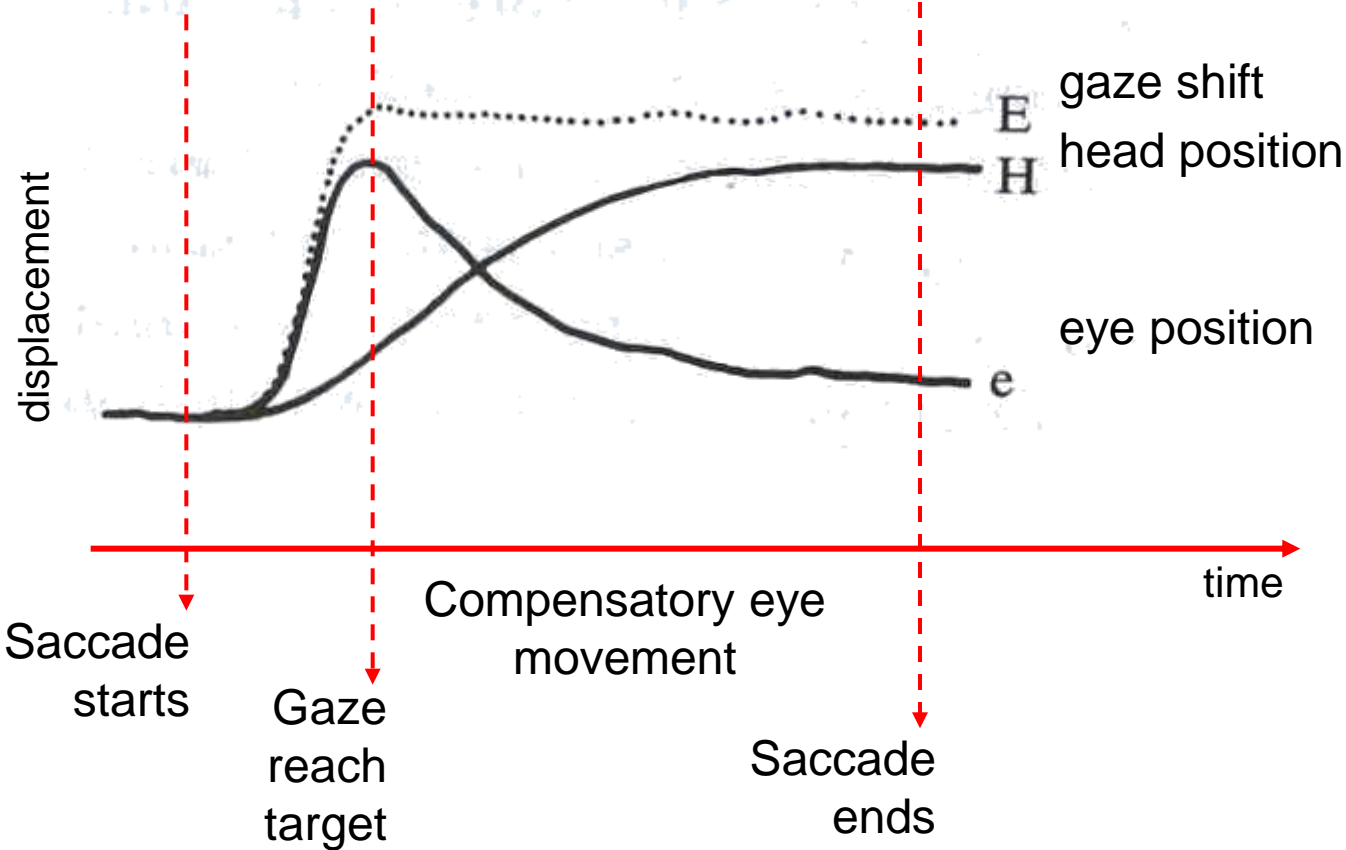
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Implementation of a biological model of head-eye coordination

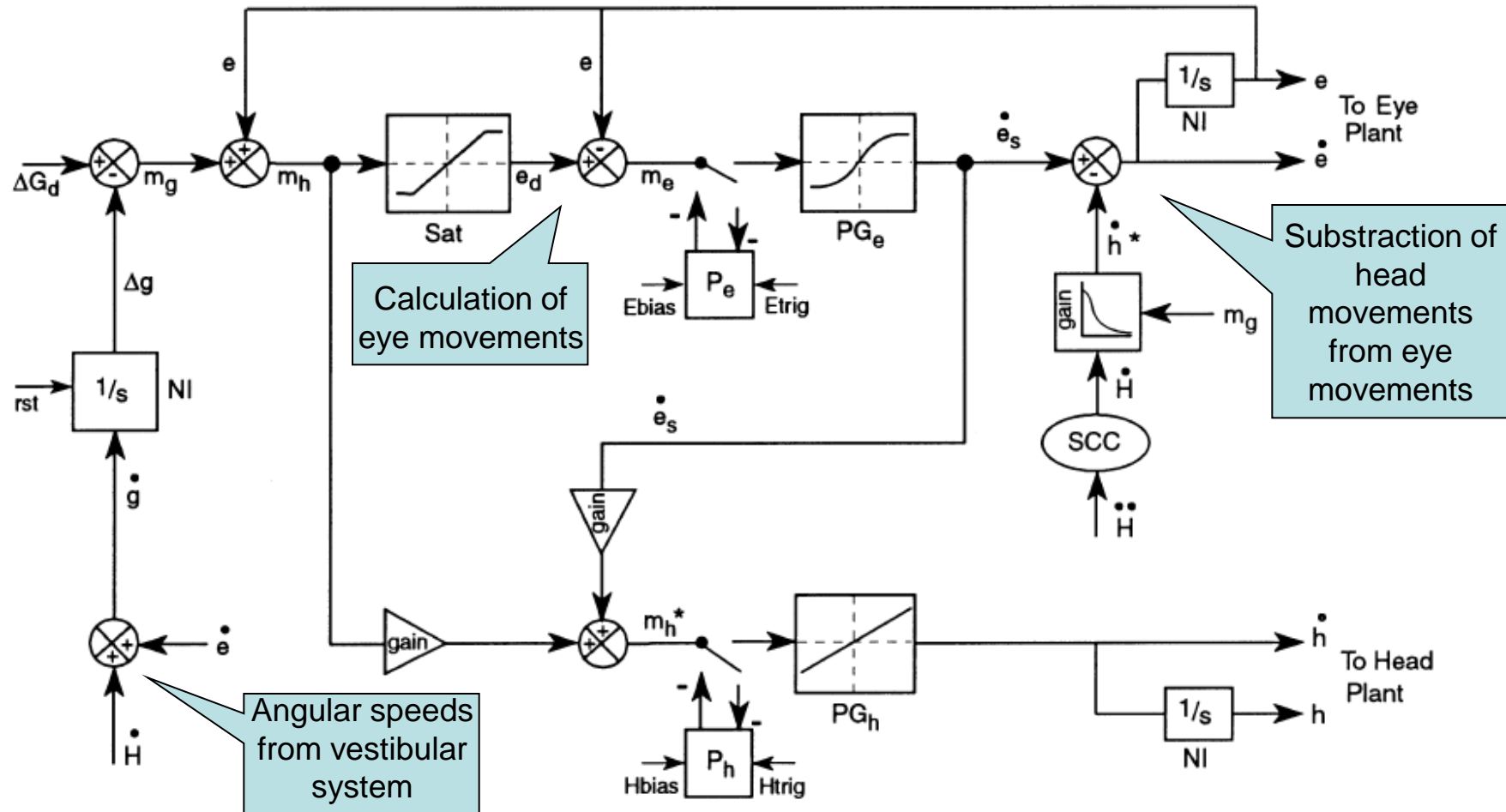


E.S. Maini, G. Teti, C. Laschi, M. Rubino, P. Dario, "Bio-inspired control of eye-head coordination in a robotic anthropomorphic head", *IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics*, Pisa, Italy, February 20-22, 2006

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



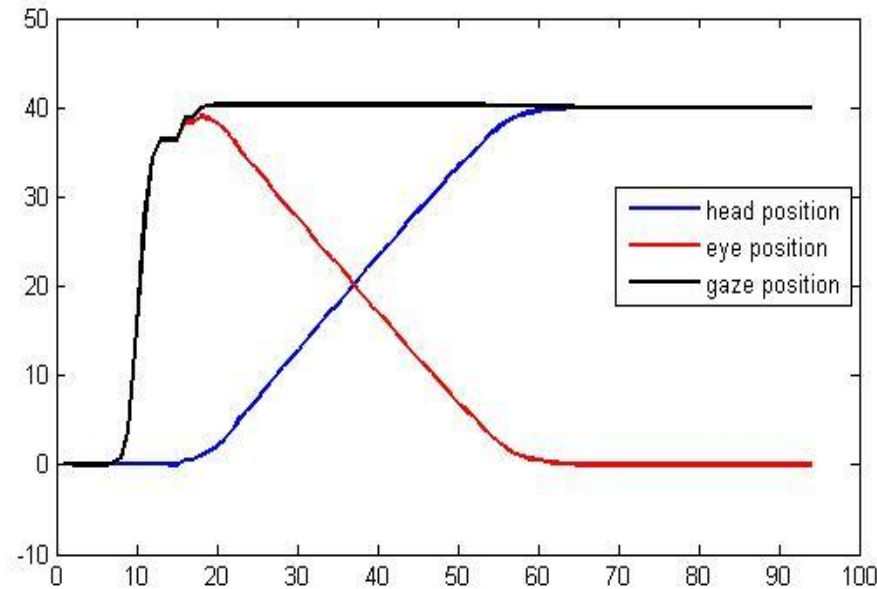
Model of fast gaze shift

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

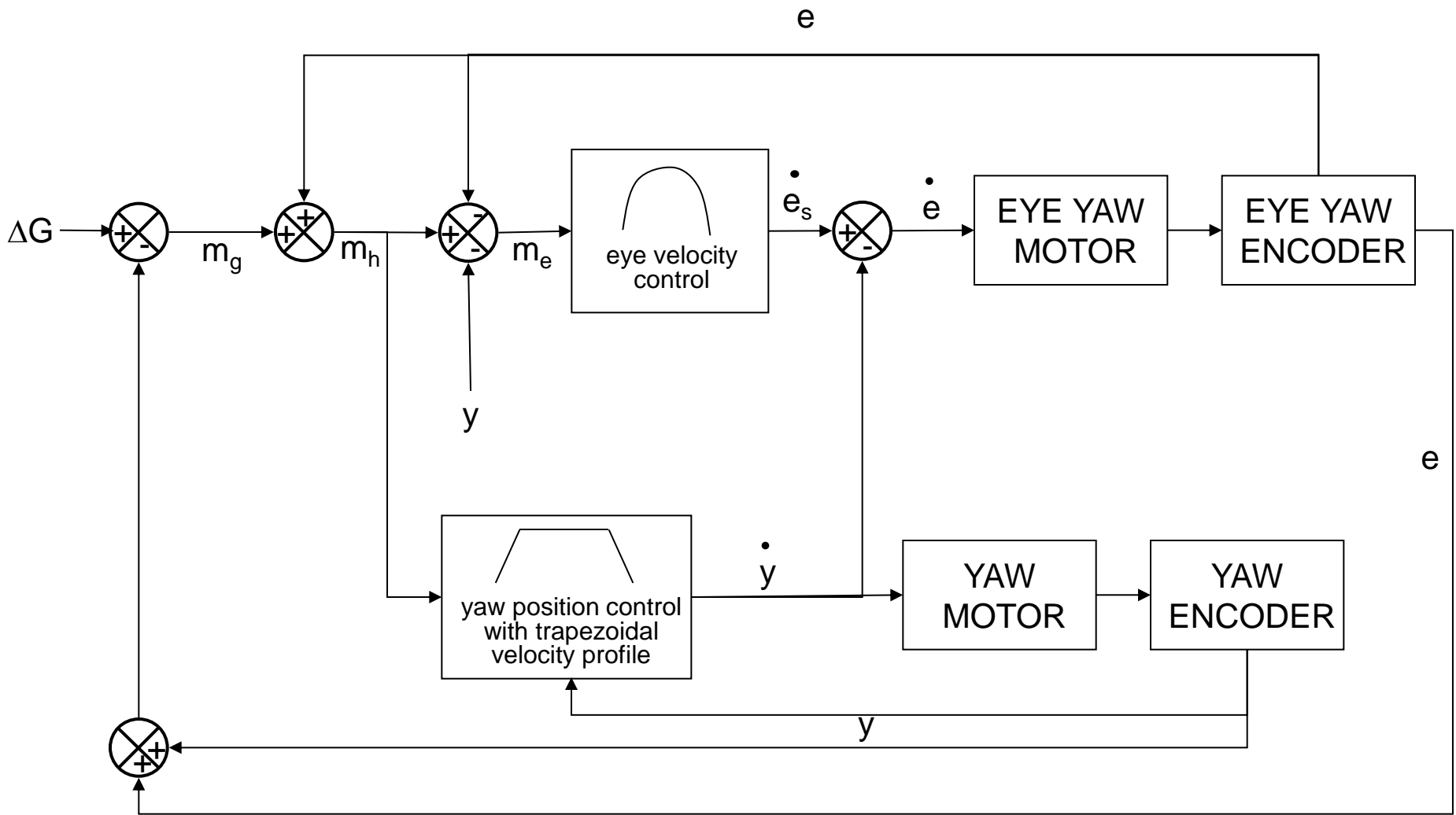
At the same time the head does not move, but it will start moving only after the head delay time is passed.

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



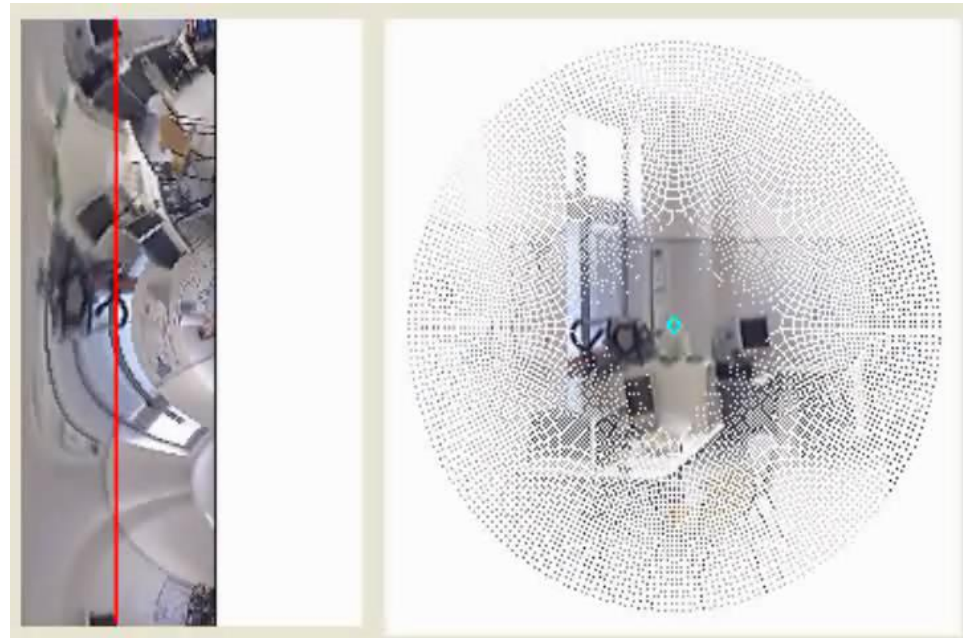
The robotic model for horizontal motion



Robotic implementation: horizontal saccades



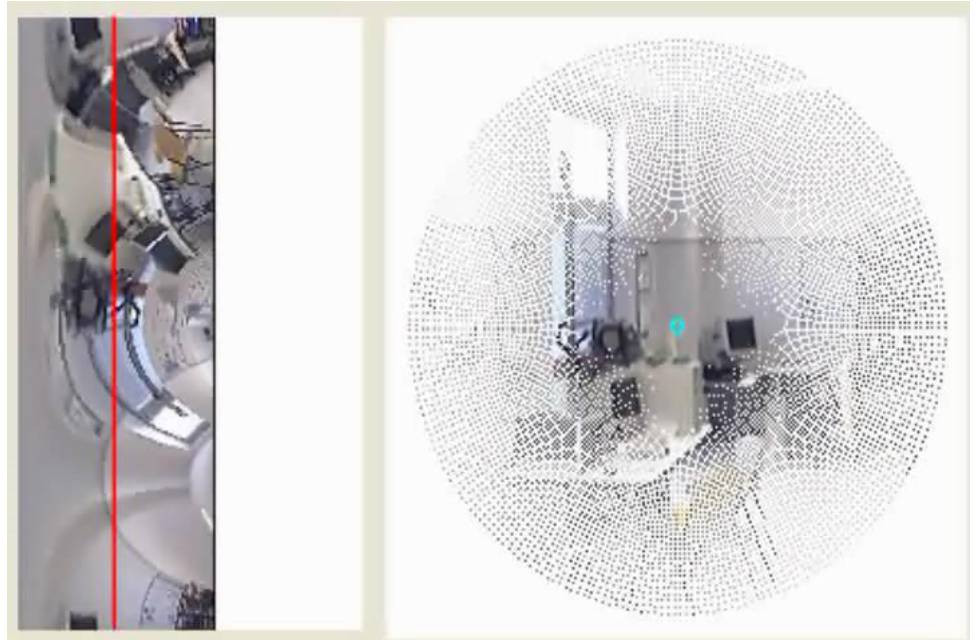
Left eye only



Camera View



Robotic implementation: vertical saccades



Camera View



Experimental Results

