

Corso di Robotica (ROB)



C. Modulo di Robotica Bioispirata

Visione artificiale retinica

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Sommario della lezione



- Principi di base della visione retinica
- Alcune proprietà delle immagini retiniche
- Le relazioni matematiche tra immagini retiniche e cartesiane
- La foveazione
- Una testa robotica antropomorfa
- Esempi di applicazione in robotica

Riferimenti bibliografici:

G. Sandini, G. Metta, "Retina- like sensors: motivations, technology and applications". in Sensors and Sensing in Biology and Engineering. T.W. Secomb, F. Barth, and P. Humphrey, Editors. Springer-Verlag. 2002.

Principi di base della visione retinica

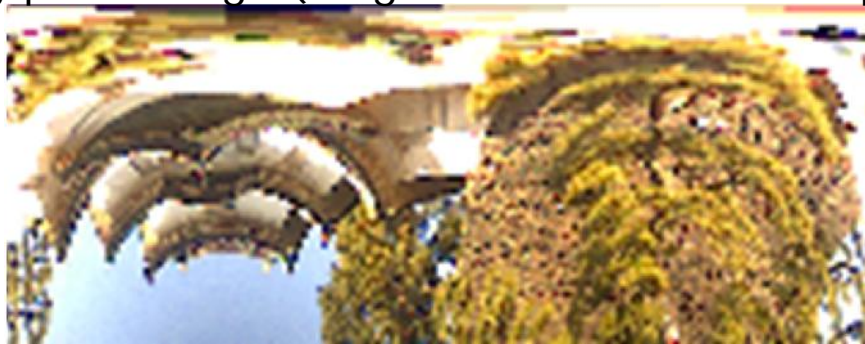
Standard image



Retina-like image



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



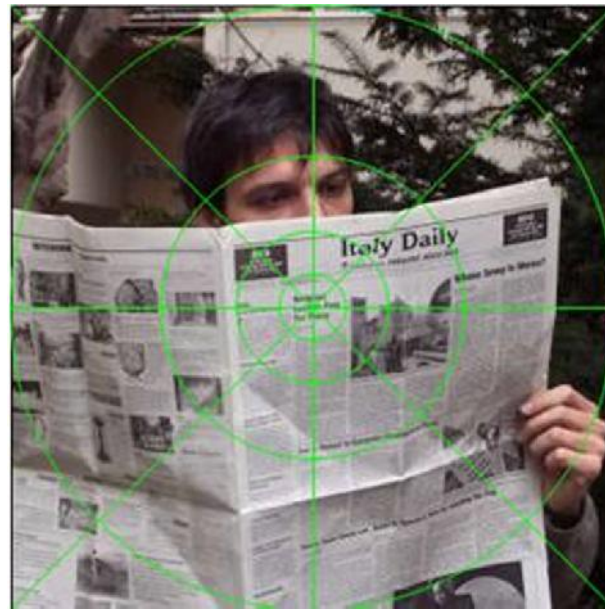
Log-polar projection



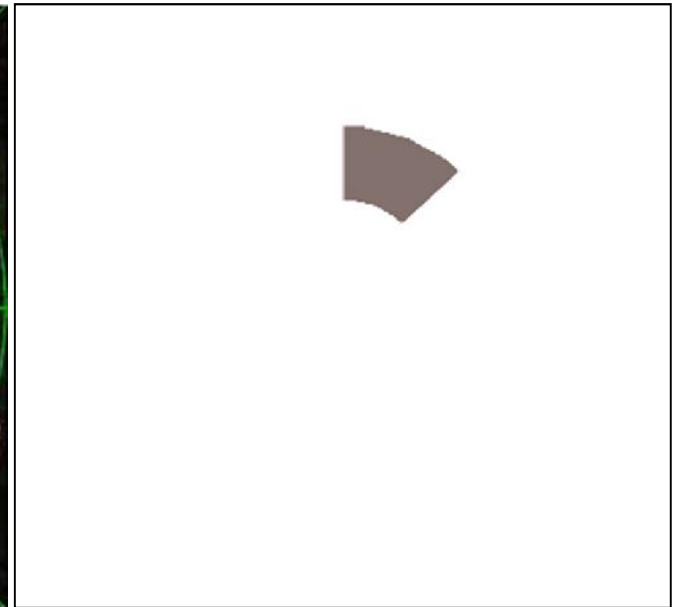
Costruzione di un'immagine retinica



Immagine cartesiana tradizionale

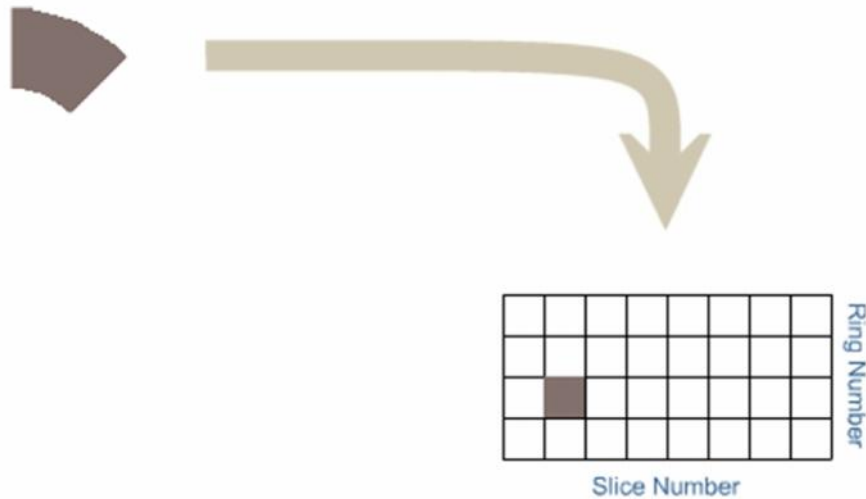


Divisione in circonferenze e spicchi



Calcolo del valore medio di un settore

Costruzione di un'immagine retinica



Copia del valore medio di un settore in un pixel di un'immagine polare

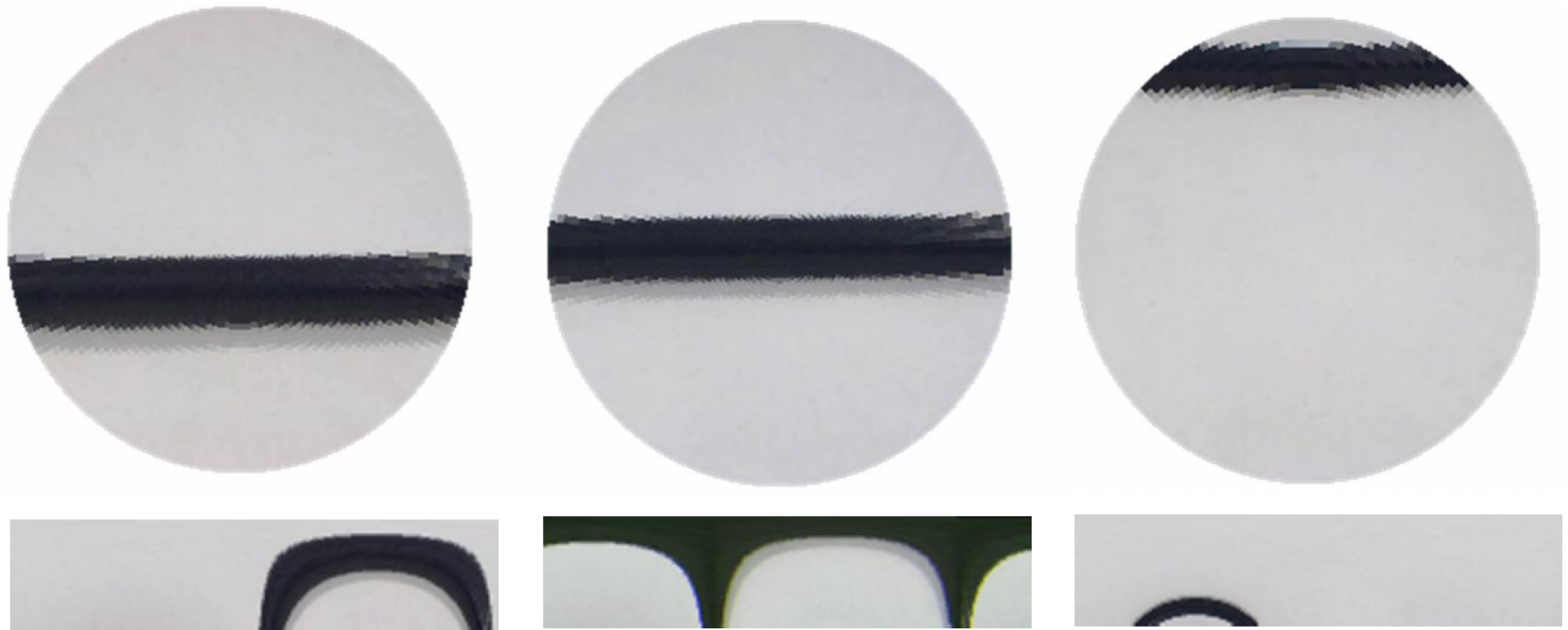


Immagine polare risultante

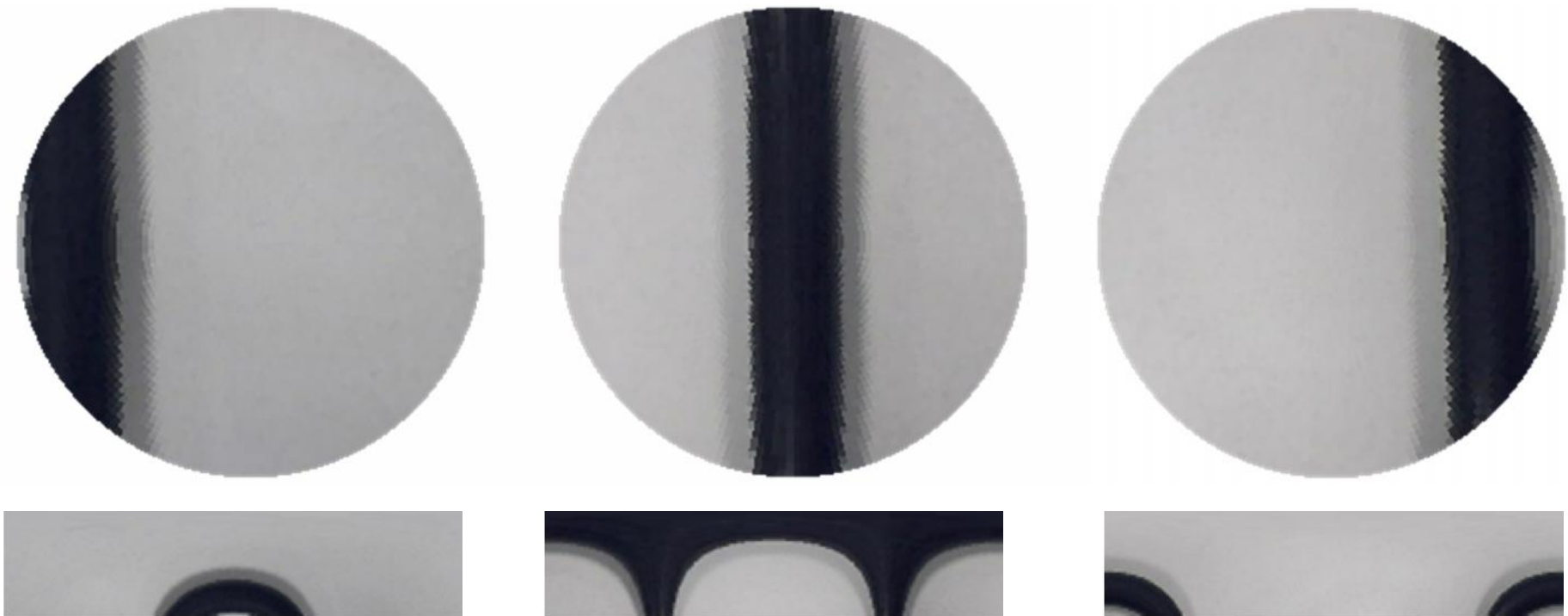


Immagine cartesiana ricostruita dalla polare

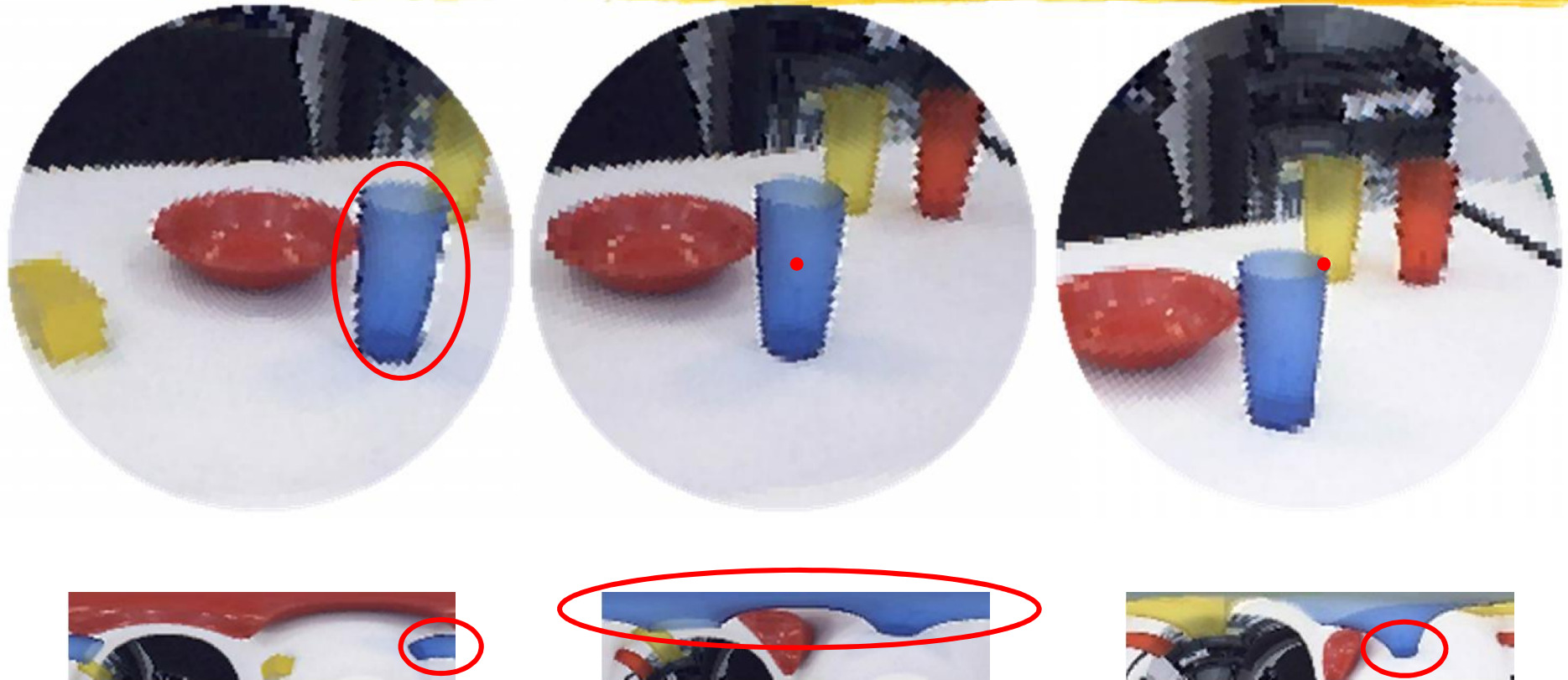
An example of pattern translation



An example of pattern translation



An example of simulated foveation



Object detection
in the periphery

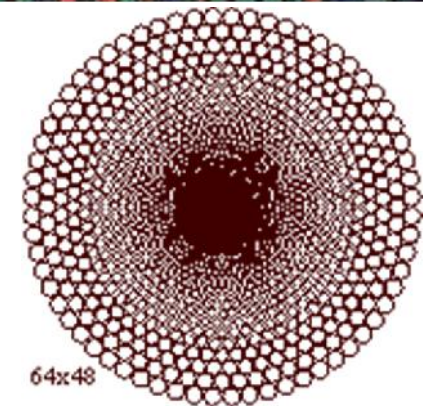
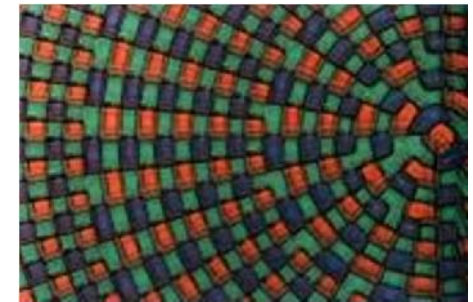
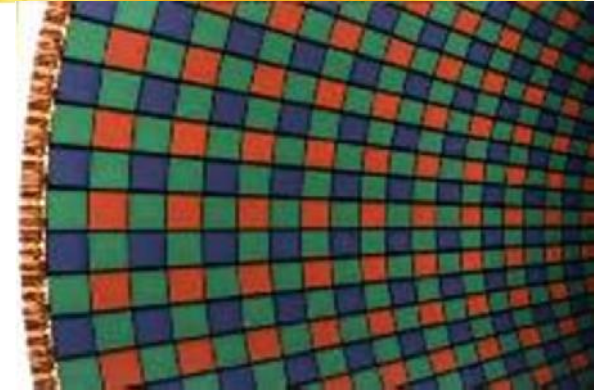
Object foveation

Foveation of a
point of interest
(edge)



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



Le relazioni matematiche

From standard image to log-polar image

$$r(x, y) = \begin{cases} (F - 1) + \log_3 \left[\left(F - \frac{1}{2} - \sqrt{x^2 + y^2} \right) (1 - \frac{1}{3}) + \frac{1}{3} \right] & \text{if } \sqrt{x^2 + y^2} > (F - \frac{1}{2}) \\ \left(\sqrt{x^2 + y^2} + \frac{1}{2} \right) & \text{if } \sqrt{x^2 + y^2} < (F - \frac{1}{2}) \end{cases}$$

$$r(\dots) = \left[\left(F - \frac{1}{2} \right) + \frac{1 - \dots^{-F}}{1 - \dots} \right] \text{ if } \dots > F$$

$$\theta(x, y) = \frac{\pi}{2f} \cdot \arctan\left(\frac{y}{x}\right) + \frac{\pi}{2} + \text{Shift Factor}$$

$$F=42$$

$$P=152$$

$$Q=252$$

$$X=545$$

$$Y=545$$

$$\lambda=1.02314422608633$$

F = size of the fovea in rings.

R = total number of rings.

Q = maximum # of pixels in each ring.

$2X$ = horizontal size of the cartesian image.

$2Y$ = vertical size of the cartesian image.

r = ring number in the log polar image.

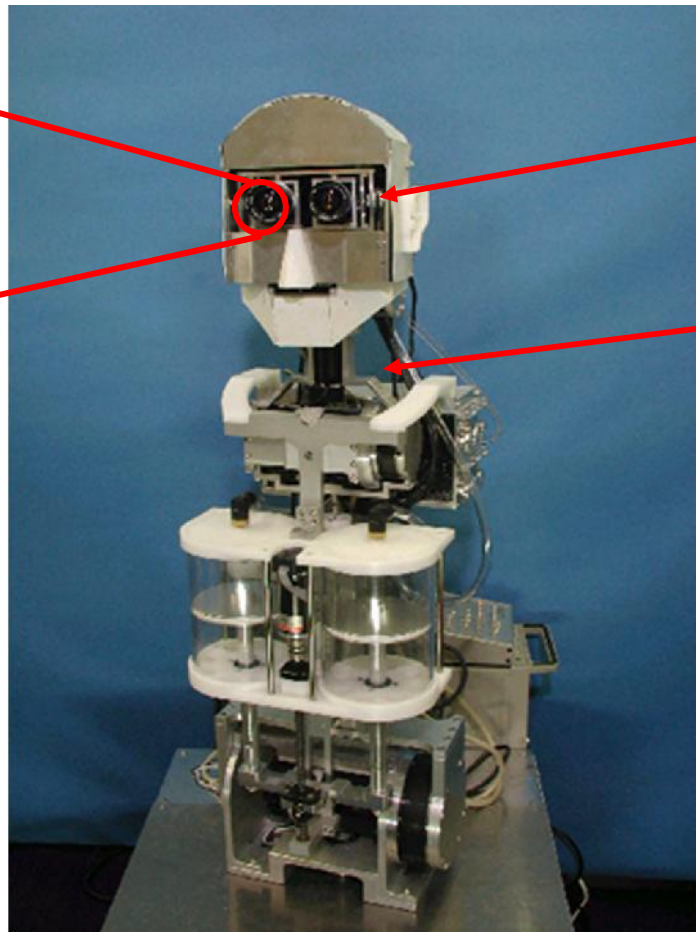
q = angular polar coordinate.

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

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*

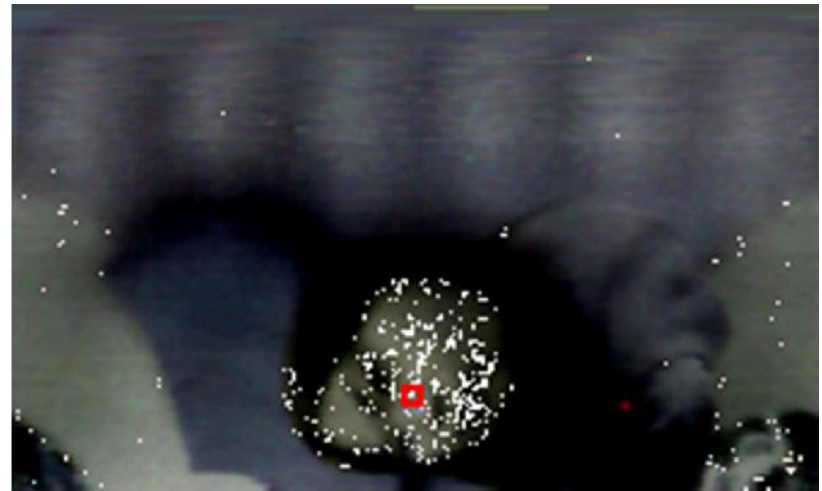
Face detection by hue

Hue = information on the color

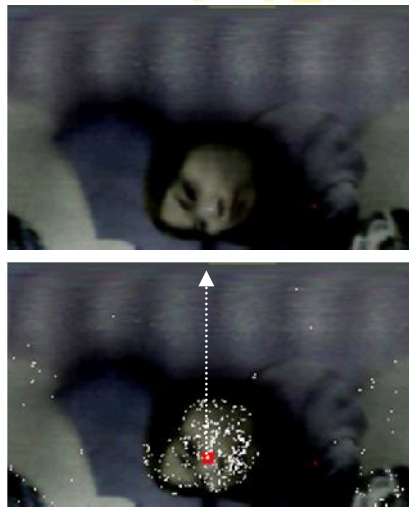
$$\text{Hue} = \cos^{-1} \left(\frac{(R - G) + (R - B)}{2\sqrt{(R - G)^2 + (R - B)(G - B)}} \right)$$

if $B > G$ then $\text{Hue} = 2\pi - \text{Hue}$

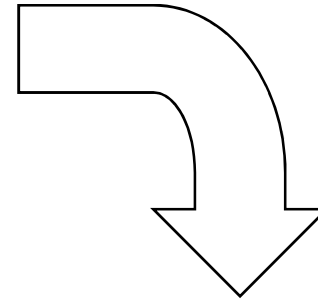
R, G, B = RED, GREEN, BLUE components, respectively



An example of foveation

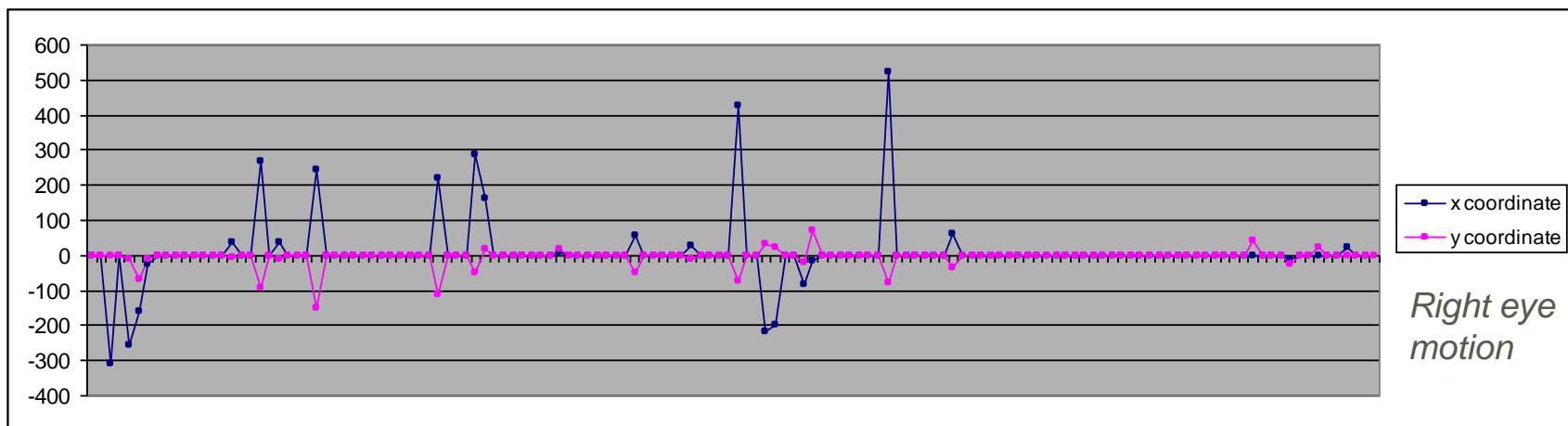


Eye/neck movements



Proportions are rescaled for display purposes

Experimental trials



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

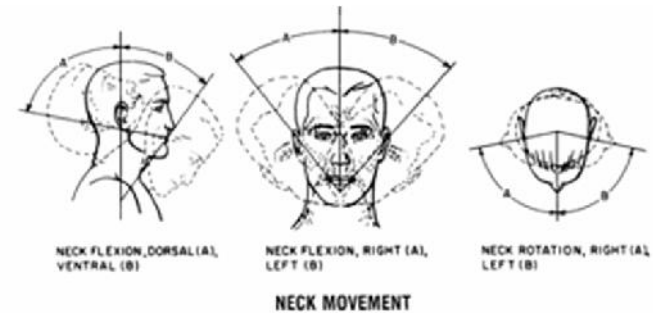
Example of design and development of a human-like robotic head



The ARTS humanoid robot head

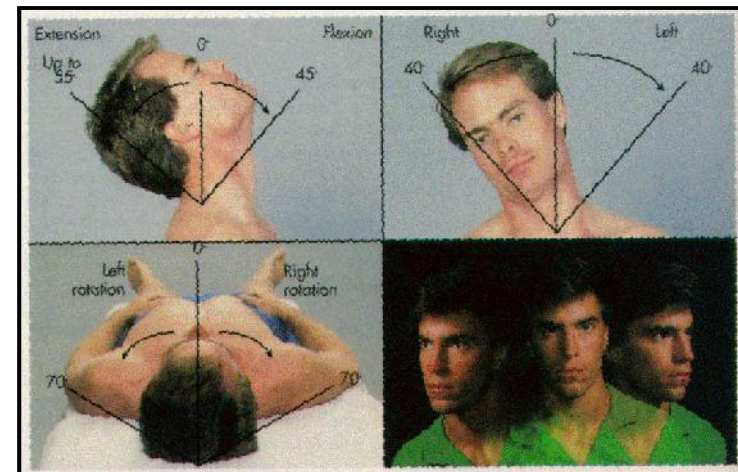
Synthesis of characteristics of the human oculo-motor system

- Eye movements:
 - Saccades
 - Vergence
 - Pursuit
- Ranges of motion:
 - 120° for the tilt eye movements
 - 60° for the pan eye movements
- Eye speed:
 - Up to 900°/sec (in saccades)
- Inter-ocular distance: between 60 and 80 mm



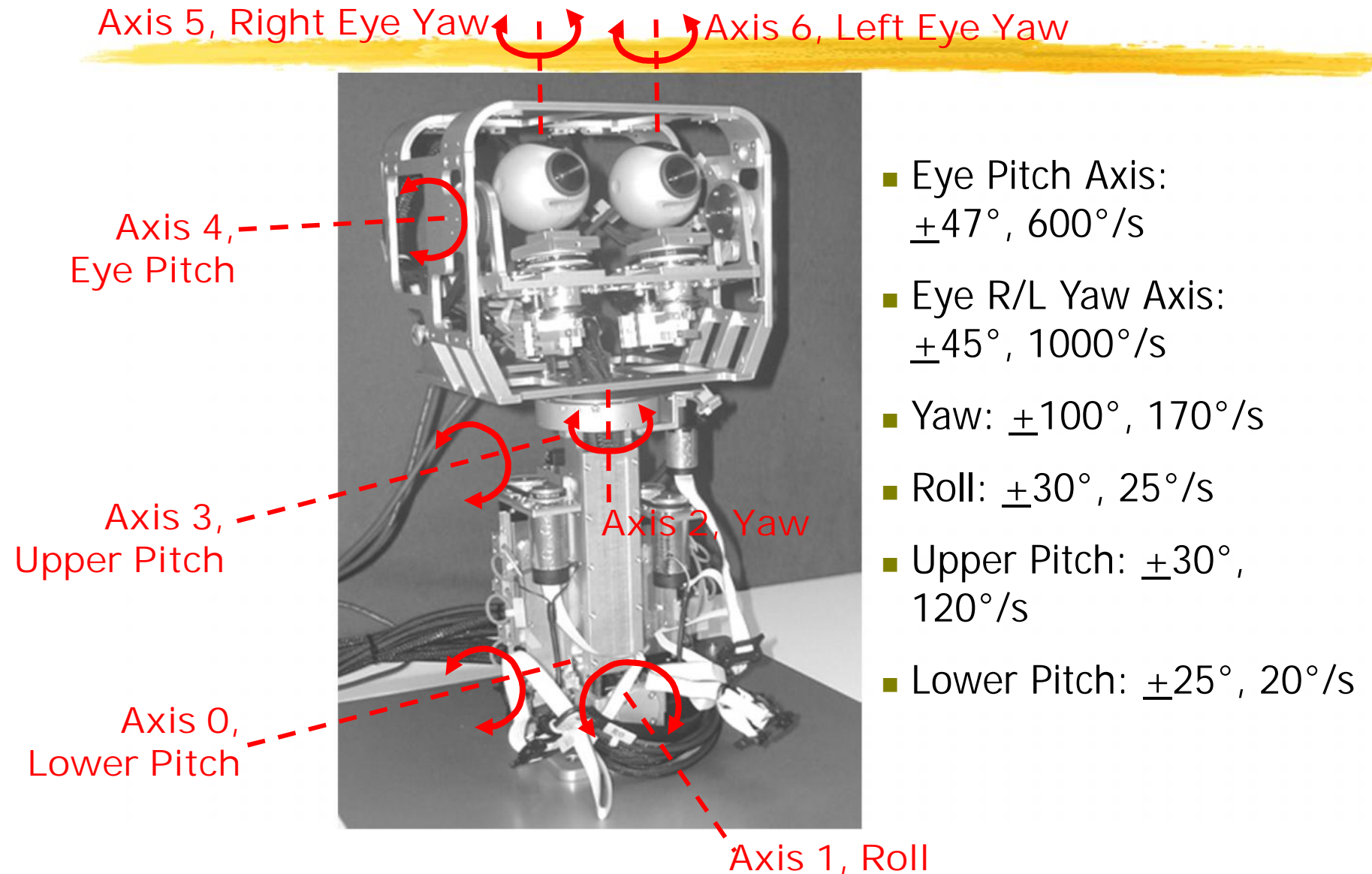
	Average	SD
Ventral flexion	60°	12
Dorsal flexion	51°	12
Right-left flexion	41°	7
Right-left rotation	79°	14

RANGE OF MOVEMENT AT THE NECK JOINT
*Male civilians



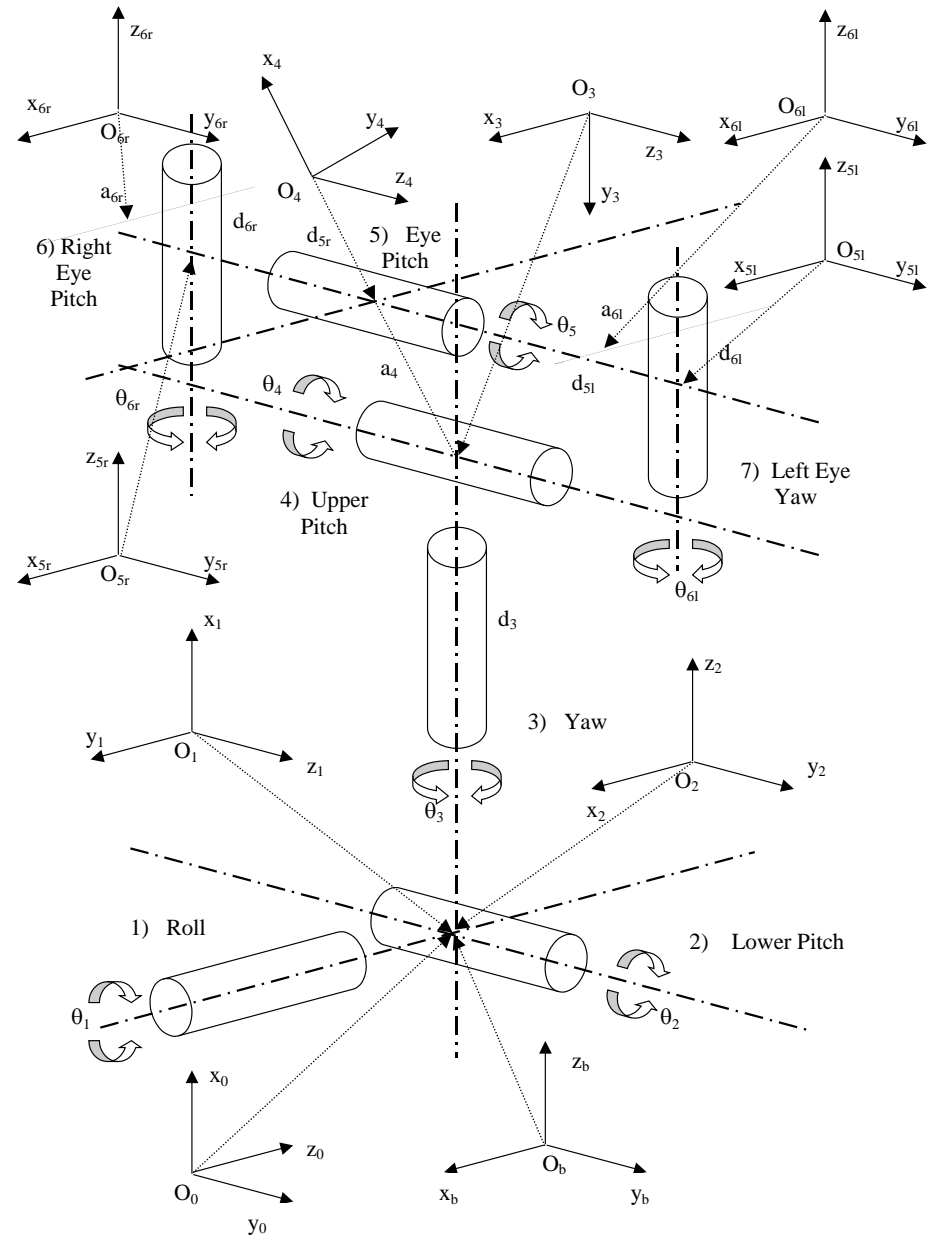
[Thibodeau & Patton, 1996]

Kinematic structure of the SSSA Robot Head



Head kinematic chain and Denavit-Hartenberg parameters

Joint	a_i (mm)	d_i (mm)	r_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
J6 _r	a_{6r}	d_{6r}	0

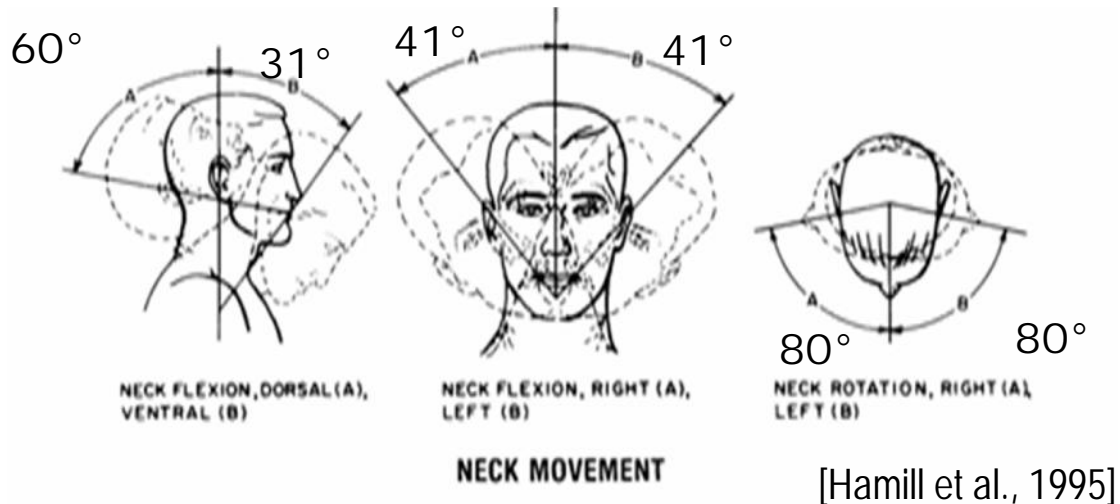


Comparison of performances between human and robotic head

Neck:

Eye:

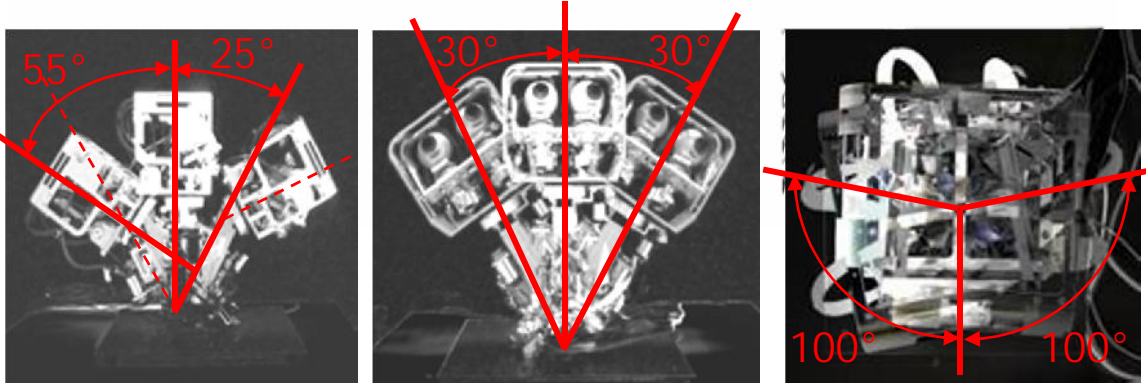
Human



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

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

Robot



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

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

The movements of the 7 dofs of the robotic head



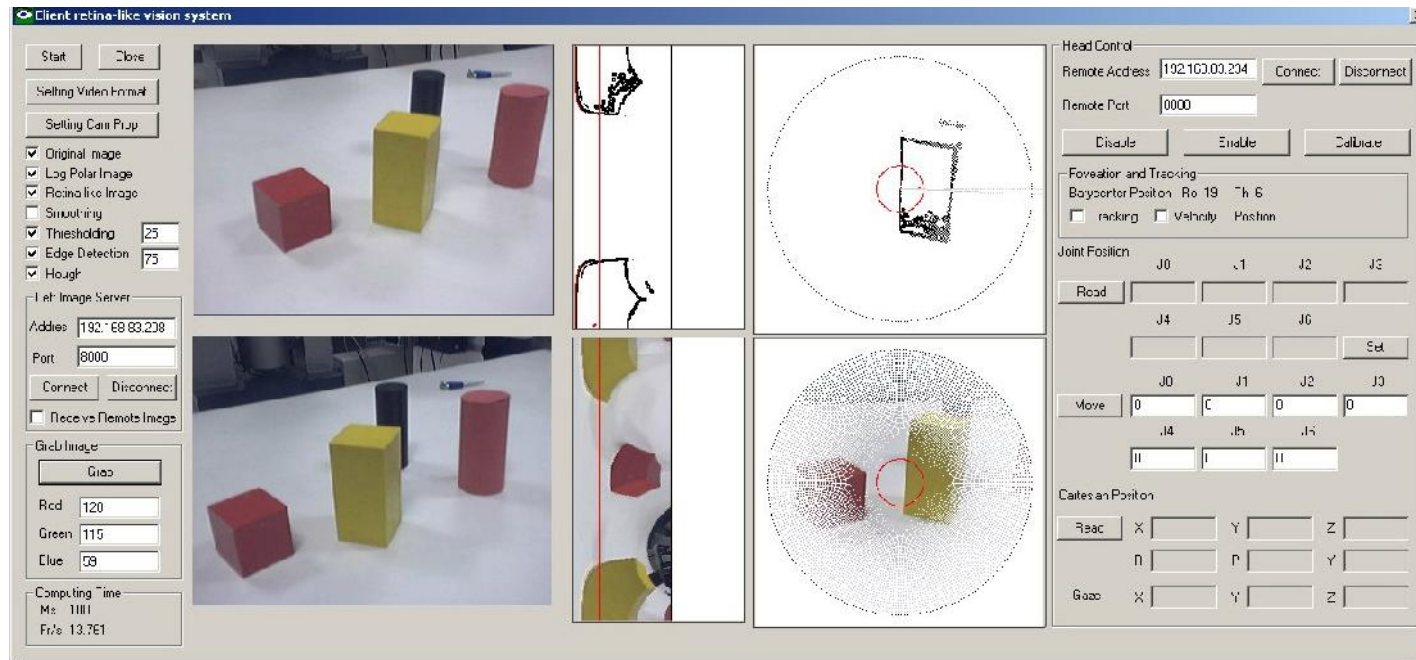
Examples of algorithms developed for retina-like image processing



- 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

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



Thresholding of image based on RGB and HUE

The screenshot displays the PALOMA Robotic Artefact Control Panel software interface. The main window is divided into several sections:

- Left Panel:** Contains control buttons (Start, Close, Setting Video Format, Setting Cam Prop) and a list of image processing options: Original Image, Log Polar Image, Retina-like Image, Smoothing, Thresh (100), HSV, Edge Detection (75), and Hough. It also includes a Left Image Server section with fields for Address (PALDMA1) and Port (8000), and a Grab Image section with a Grab button and RGB/HSV values.
- Image Display Area:** Shows a sequence of images: the original camera feed, a vertical strip of the image, and two circular regions of interest (ROIs) around a yellow cube. The top ROI shows the cube with a red circle, and the bottom ROI shows the cube with a red circle and a dashed white circle.
- Right Panel:** Contains control sections for Head Control (Remote Address: HEAD, Remote Port: 8000, STATUS: CONNECTED), 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, Move, J0-J6, Vel, T), Cartesian Position (Read, Gaze, X, Y, Z), and Head Neurocontroller (X, Y, Z, Clamped Joints, Value Joints, Sym, Move).

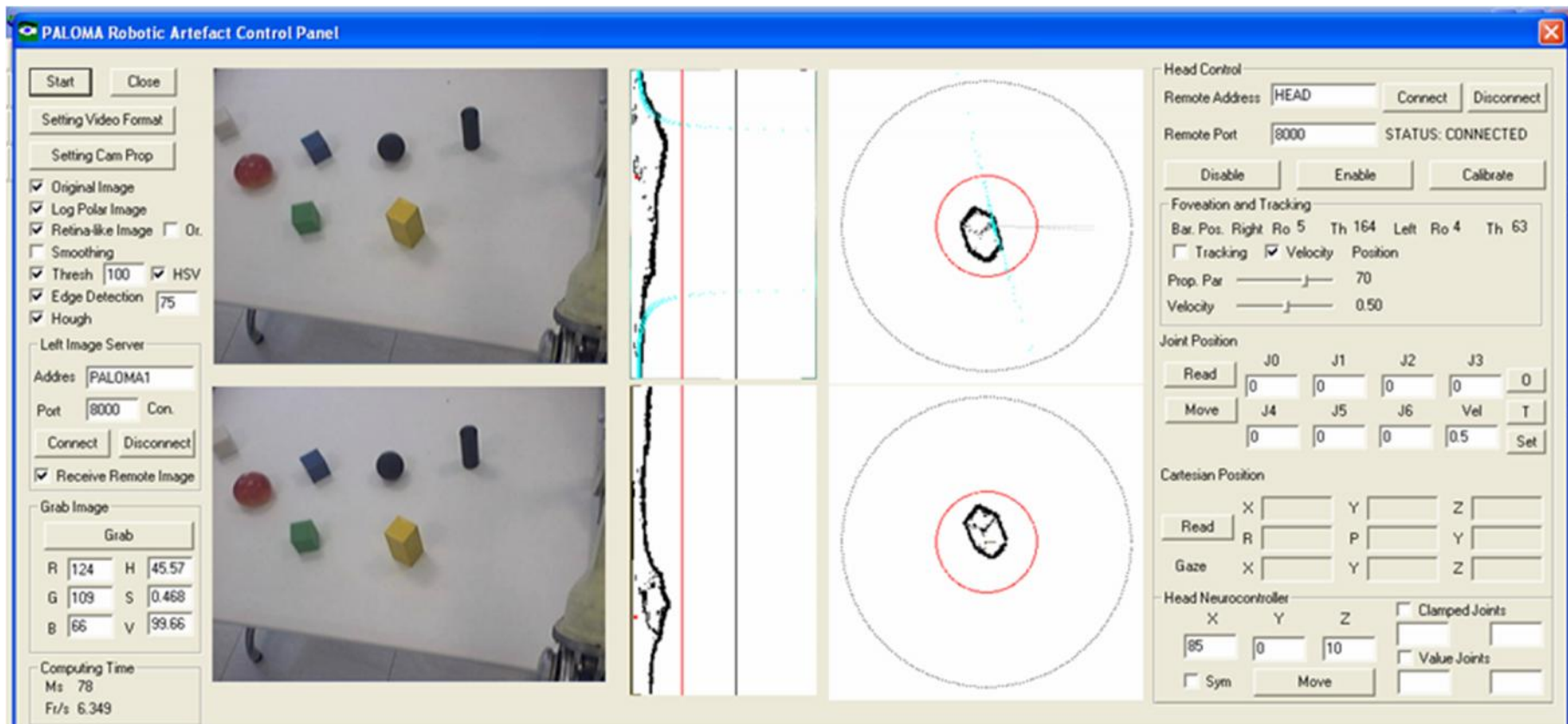
Computing Time: Ms: 62, Fr/s: 6.340

Edge Detection (gradient based method)

The screenshot displays the PALOMA Robotic Artefact Control Panel interface. The main window is divided into several sections:

- Left Panel:** Contains control buttons (Start, Close, Setting Video Format, Setting Cam Prop) and a list of image processing options: Original Image, Log Polar Image, Retina-like Image, Smoothing, Thresh (100), Edge Detection (75), and Hough. It also includes a Left Image Server section with address (PALOMA1), port (8000), and connection status, and a Grab Image section with a Grab button and color/position data (R: 124, H: 45.57, G: 109, S: 0.468, B: 66, V: 99.66). A Computing Time section shows Ms: 47 and Fr/s: 6.347.
- Image Area:** A 2x3 grid of images. The top-left and bottom-left images show the original camera feed of a table with a red sphere, blue cube, black cylinder, green cube, and yellow cube. The top-middle and bottom-middle images show the edge detection results, with a vertical red line indicating a detected edge. The top-right and bottom-right images show the detected object (a black shape) within a red circular boundary, overlaid on a larger dashed circle.
- Right Panel:** Contains control sections for Head Control (Remote Address: HEAD, Remote Port: 8000, STATUS: CONNECTED), Foveation and Tracking (Bar. Pos: Right Ro 5 Th 164, Left Ro 4 Th 63, Tracking: unchecked, Velocity: checked, Prop. Par: 70, Velocity: 0.50), Joint Position (Read/Move buttons for J0-J6 and Vel/T), Cartesian Position (Read buttons for X, Y, Z, R, P, Y), Gaze (X, Y, Z), and Head Neurocontroller (X: 85, Y: 0, Z: 10, Clamped Joints, Value Joints, Sym, Move).

Line detection (Hough method)



- Applied only to pixels belonging to the fovea

Line detection

PALOMA Robotic Artefact Control Panel

Start Close

Setting Video Format

Setting Cam Prop

Original Image
 Log Polar Image
 Retina-like Image Or.
 Smoothing
 Thresh 40 HSV
 Edge Detection 75
 Hough

Left Image Server

Address PALOMAT

Port 8000 Con.

Connect Disconnect


Receive Remote Image


Grab Image

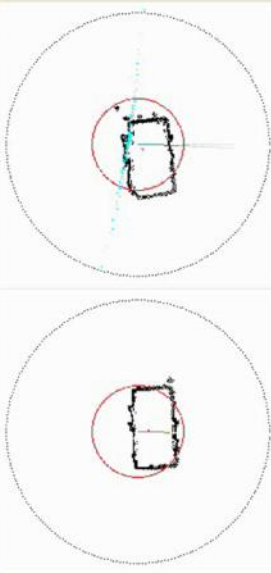
Grab

R	147	H	52.49
G	134	S	0.626
B	55	V	112.0

Computing Time
Ms 125
Fr/s 6.372







Head Control

Remote Address HEAD Connect Disconnect

Remote Port 8000 STATUS: CONNECTED

Disable Enable Calibrate

Foveation and Tracking

Bar. Pos. Right Ro 8 Th 223 Left Ro 10 Th 7

Tracking Velocity Position -0.004,0.014,0.023

Prop. Par 70

Velocity 0.35

Joint Position

Read	J0	J1	J2	J3				
	0	10	0	10	0			
Move	J4	J5	J6	Vel	T			
	-15	-4	8	0.5	Set			

Cartesian Position

Read	X	Y	Z				
	R	P	Y				
Gaze	X	Y	Z				

Head Neurocontroller

X	Y	Z	Clamped Joints
85	0	10	Value Joints

Sym Move

Hand Control Panel

Arm Control Panel

Enable Arm Disable Arm

Move	J0	J1	J2	J3	J4	J5	J6	J7	
	90.0	0.0	135.0	0.0	-90.0	0.0	0.0	0.0	POS INIT
Read									

Move	X	Y	Z	Roll	Pitch	Yaw	J0	Elbow	Vel
Read									

Block Compliant

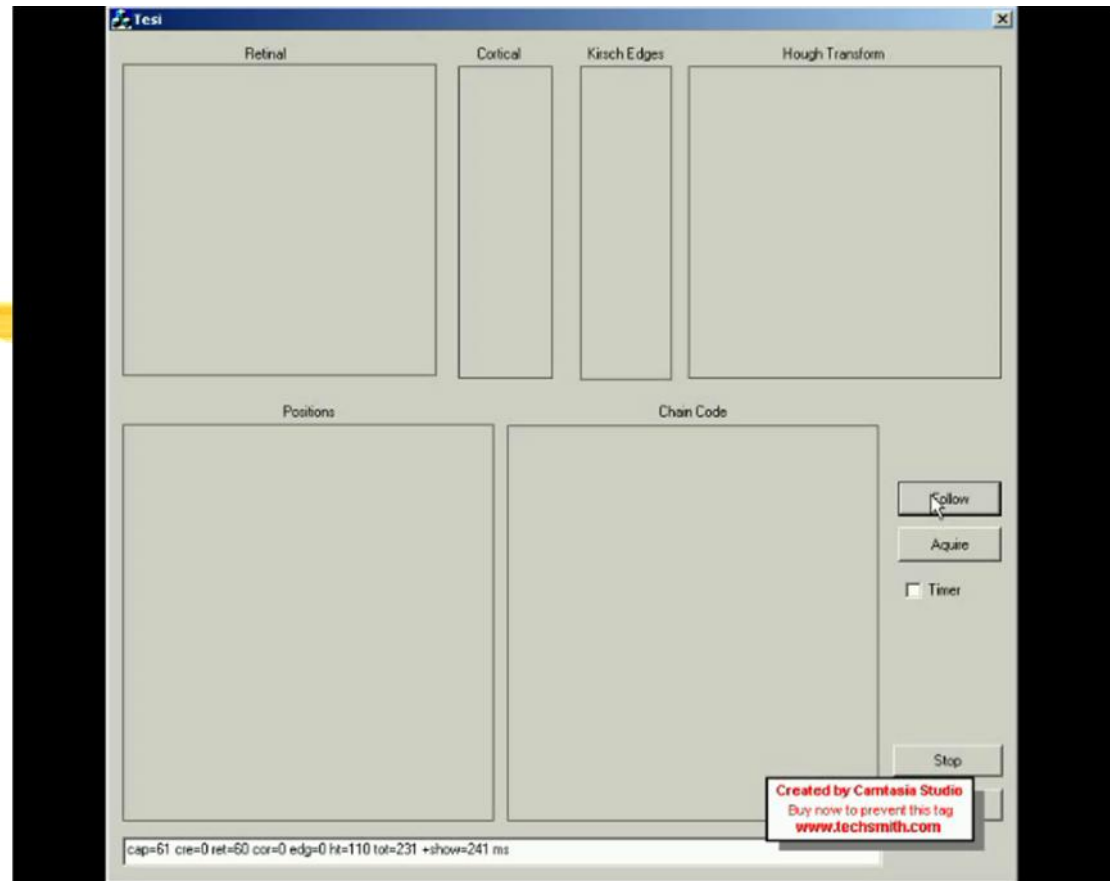
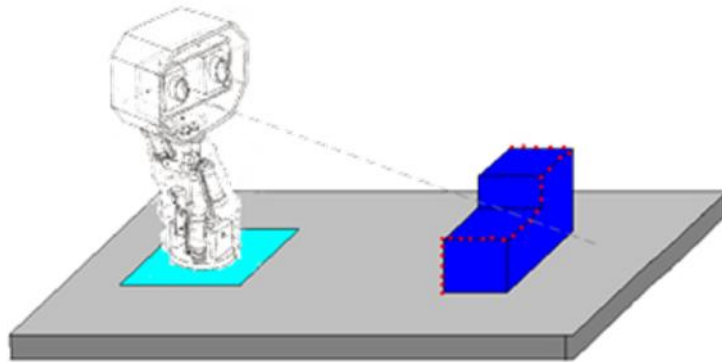
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5

Arm Neurocontroller

<input type="checkbox"/> No Vision	Move	X	Y	Z	Pos Init	Table
		85	0	10		
<input type="checkbox"/> Clamped						
Clamped Joint	<input checked="" type="checkbox"/> Tool	Length Tool				
		-10	0	0		

Pos Toma Head Saccades Pos Toma

Foveation and tracking of borders of object and reconstruction of the geometry of the object



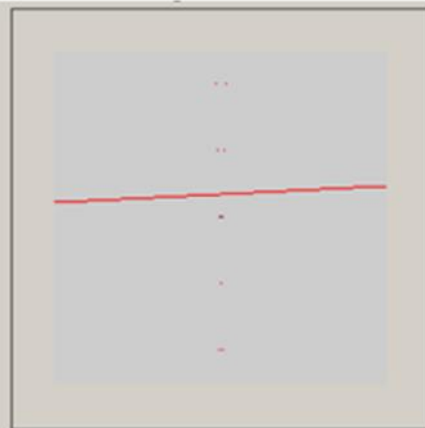
Retina Like image



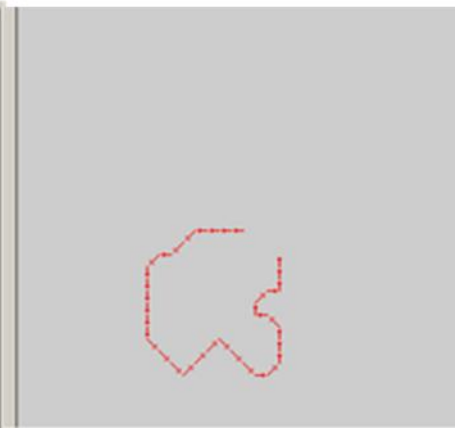
Log Polar Image



Edge of log polar image



Detected lines (Boundaries)



Boundary reconstruction based on eye positions