ISTITUTO ITALIANO DI TECNOLOGIA
iCUB FACILITY

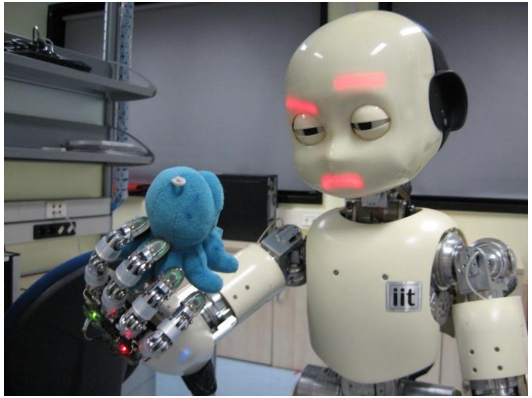
Yale University
Social Robotics Lab

A CARTESIAN 6-DOF GAZE CONTROLLER FOR HUMANOID ROBOTS

Alessandro Roncone
Ugo Pattacini
Giorgio Metta
Lorenzo Natale

THE TASK

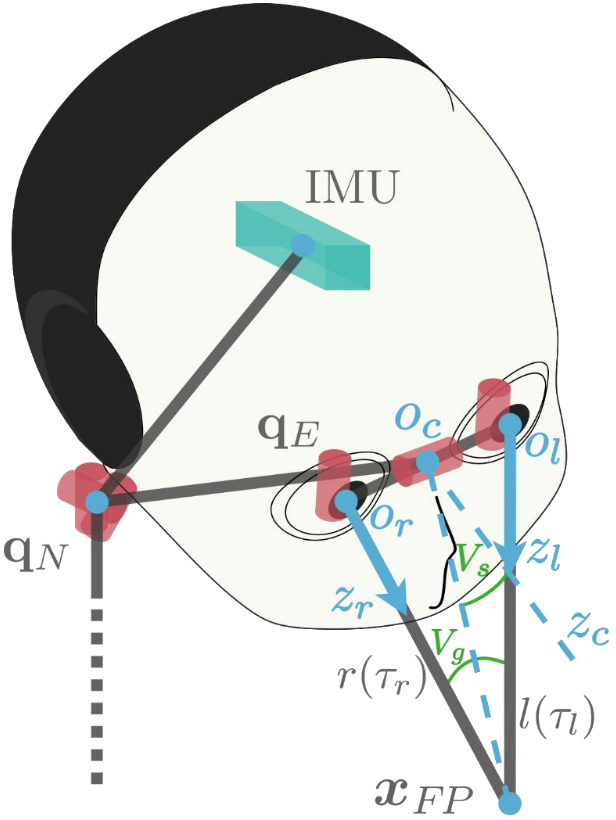
- Control the Gaze of the iCub head
- It is a 6-DoF binocular system:
  - 3-DoF neck
  - 3-DoF eyes with antropomorphic arrangement



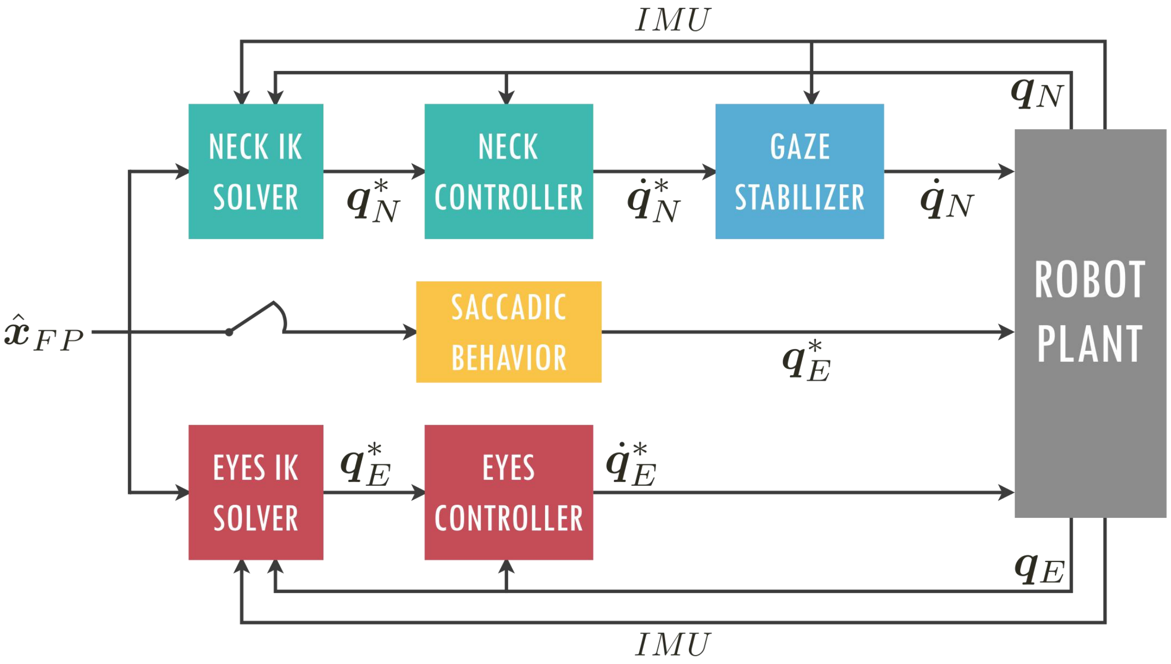
- Multiple applications: image stabilization, tracking, attention systems, ..
- HRI: human-like movements are effective in signaling non-verbal cues during cooperative tasks [Boucher et al. 2012]

THE TASK

- Target: control the 3D Fixation Point x_{FP}
- The control task is redundant!
- Additional behaviors:
  - Vestibulo-Ocular Reflex (VOR)
  - Gaze Stabilization
  - Saccadic Behavior

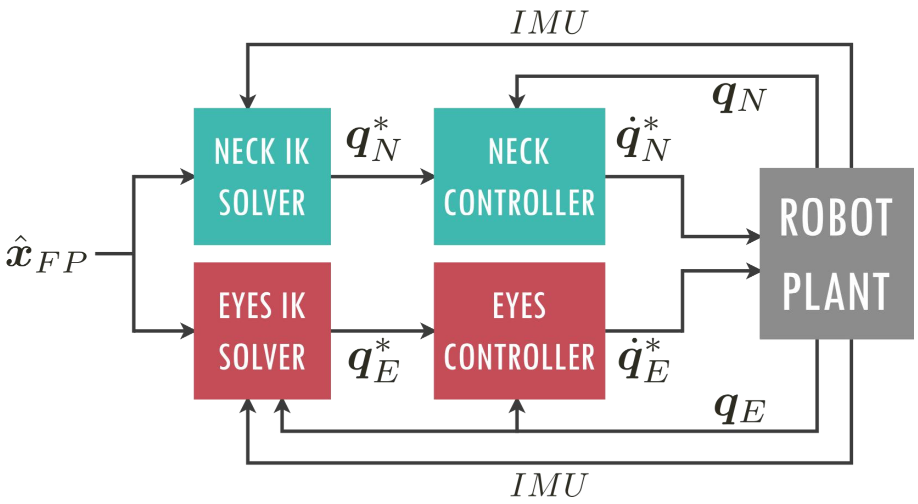


THE ARCHITECTURE



THE GAZE CONTROLLER

- Two independent subsystems account for neck and eyes
- Two-stage design for each sub-system (Inverse Kinematics Solver + Velocity Controller)



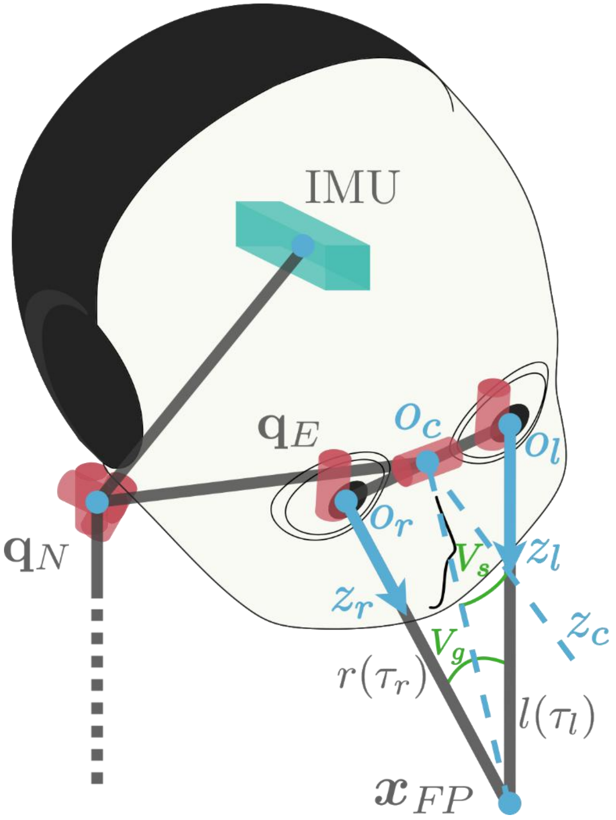
THE NECK SOLVER

Goal: point the forehead toward the desired fixation point

$$cos(\theta) = \frac{z_c(\boldsymbol{q}_N) \cdot (O_c - \hat{\boldsymbol{x}}_{FP})}{\left\|O_c - \hat{\boldsymbol{x}}_{FP}\right\|}$$

$$\boldsymbol{q}_N^* = \arg \min_{\boldsymbol{q}_N \in \mathbb{R}^n} \left\|\hat{\boldsymbol{q}_N} - \boldsymbol{q}_N\right\|^2$$

$$\text{s.t.} \begin{cases} \cos(\theta) < -1 + \epsilon \\ \boldsymbol{q}_l < \boldsymbol{q}_N < \boldsymbol{q}_u \end{cases}$$



THE EYES SOLVER

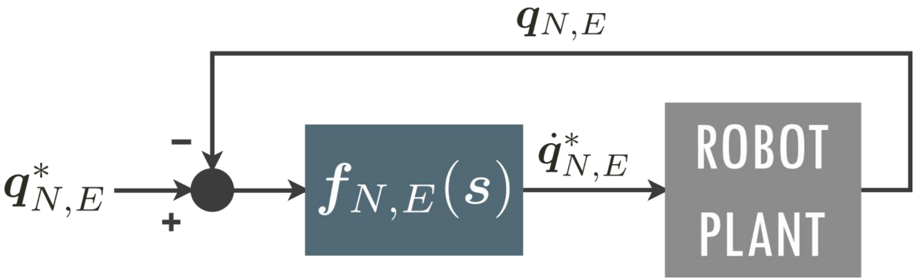
The inverse kinematics task at the eyes is not redundant and always invertible:

$$\dot{\boldsymbol{q}}_E = G \cdot J^{-1} \cdot \left[\hat{\dot{\boldsymbol{x}}}_{FP} - K_{FP}\big(\boldsymbol{q}_E\big)\right]$$

- Vestibulo-Ocular Reflex (VOR): it is possible to account for the counter-rotation required to compensate for head movements:

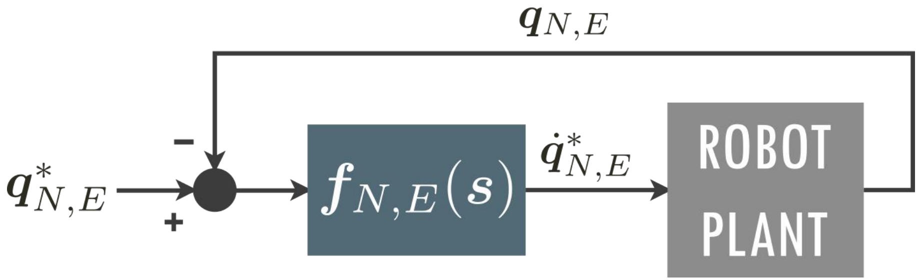
$$\dot{\boldsymbol{q}}_E = G \cdot J^{-1} \cdot \left[\hat{\dot{\boldsymbol{x}}}_{FP} - K_{FP}\big(\boldsymbol{q}_E\big)\right] - \dot{\boldsymbol{q}}_c$$

THE CONTROL PROBLEM



- Two independent (albeit identical) controllers compute velocity profiles to command the neck and eyes motors
- They provide biologically-inspired minimum-jerk trajectories to replace the exponential profiles generated by the (eyes) IK solver

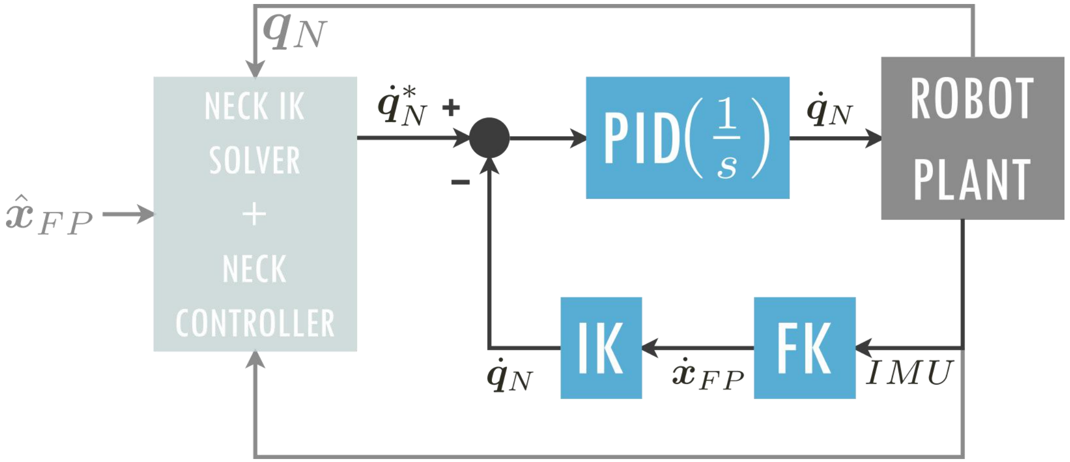
THE CONTROL PROBLEM



The minimum-jerk controller operates all the six head joints independently

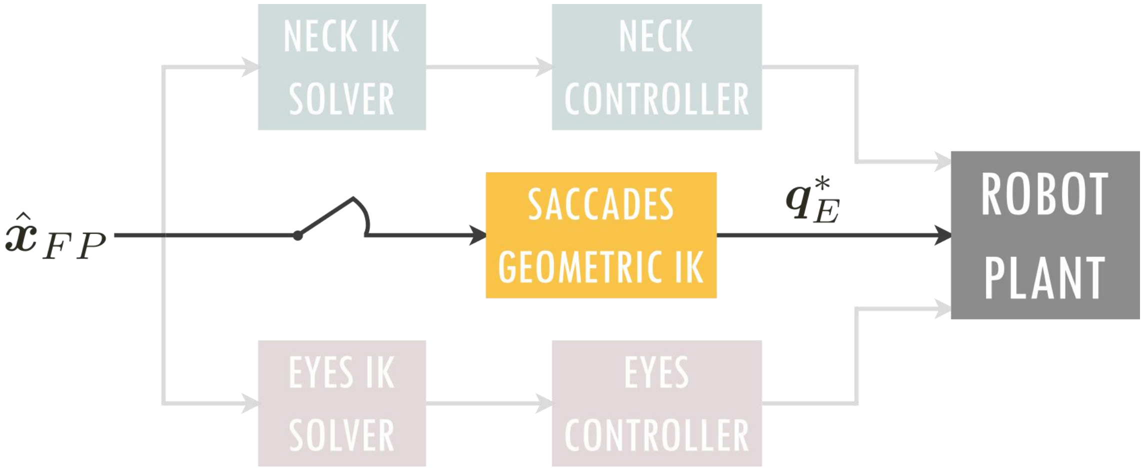
$$\frac{\dot{q}_{N,E}}{q^*_{N,E} - q_{N,E}} = \frac{a/T_{N,E}}{s^2 + \left(c/T^3_{N,E}\right) \cdot s + b/T^2_{N,E}}$$

(NECK) GAZE STABILIZATION



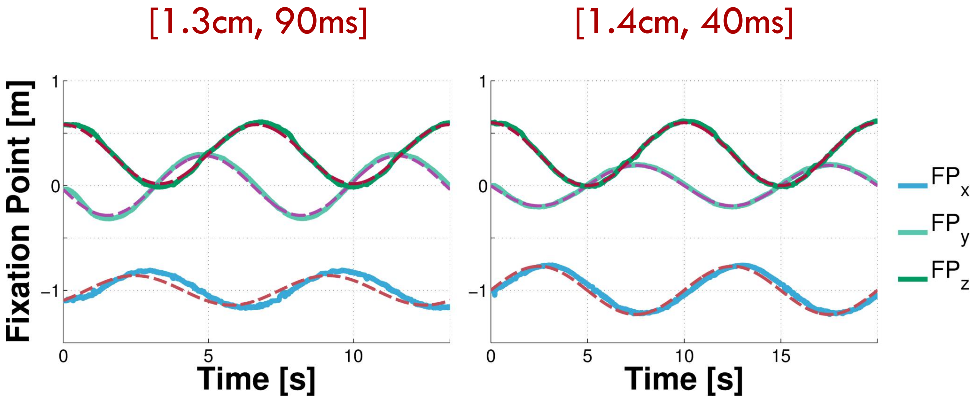
The robot is able to counteract for external disturbances measured at the IMU while accomplishing the main gazing task.

SACCADIC BEHAVIOR



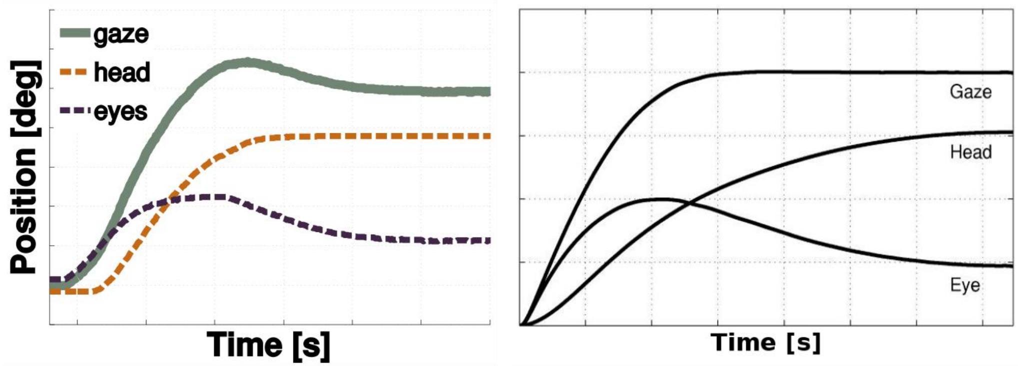
Saccadic behaviors are fast feedforward commands that exploit the faster dynamic of the eyes to quickly foveate on target.

TRACKING A 3D MOVING TARGET



The Gaze Controller is successfully able to track 3D circular trajectories with varying speeds and orientations

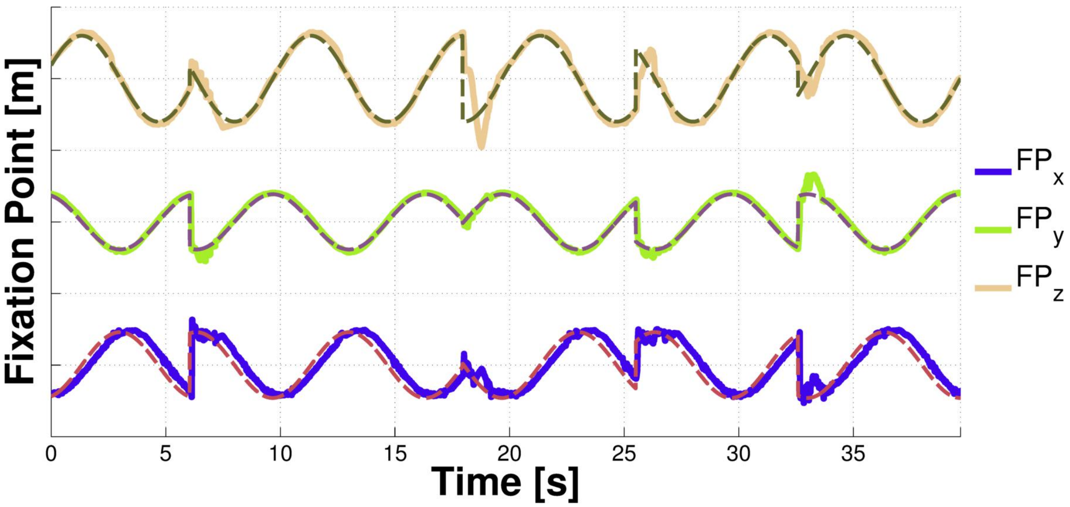
COMPARISON WITH HUMAN GAZE SHIFTS



- The faster dynamics of the eyes lets the robot foveate on target, and then counter-balance when the neck catches up (with VOR)
- Human-like gaze shifts are useful in signaling non verbal cues

SACCADIC BEHAVIOR

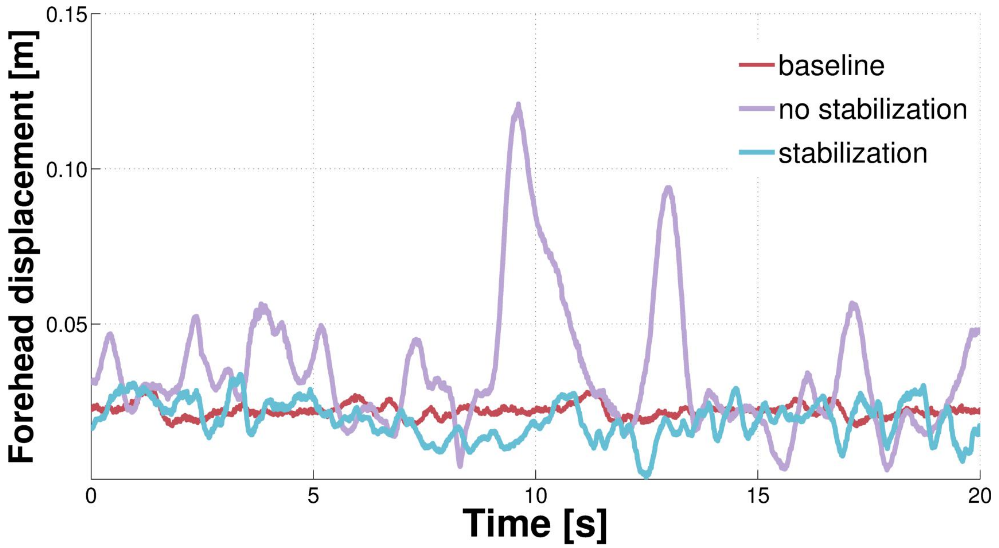
[3.3cm, 30ms] → [1.8cm, 30ms]



Saccades are able to successfully cope with abrupt changes in the target, and significant gaze shifts

GAZE STABILIZATION

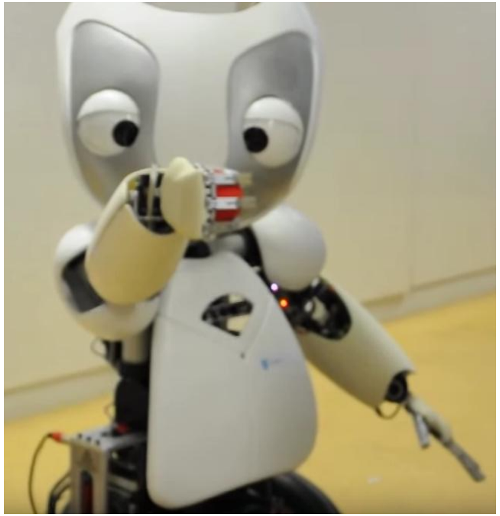
External disturbances are compensated for by the neck stabilization system while accomplishing the main gazing task



CONCLUSIONS

the Vizzy robot

[http://vislab.isr.ist.utl.pt/]



- Comprehensive architecture for the explicit control of the fixation point of a generic binocular system
- Flexible software interface that can be implemented in different robots
- Rich set of additional behaviors
- Software available at https://github.com/robotology/icub-main