



Outline

➤ Theory: Cartesian Controller

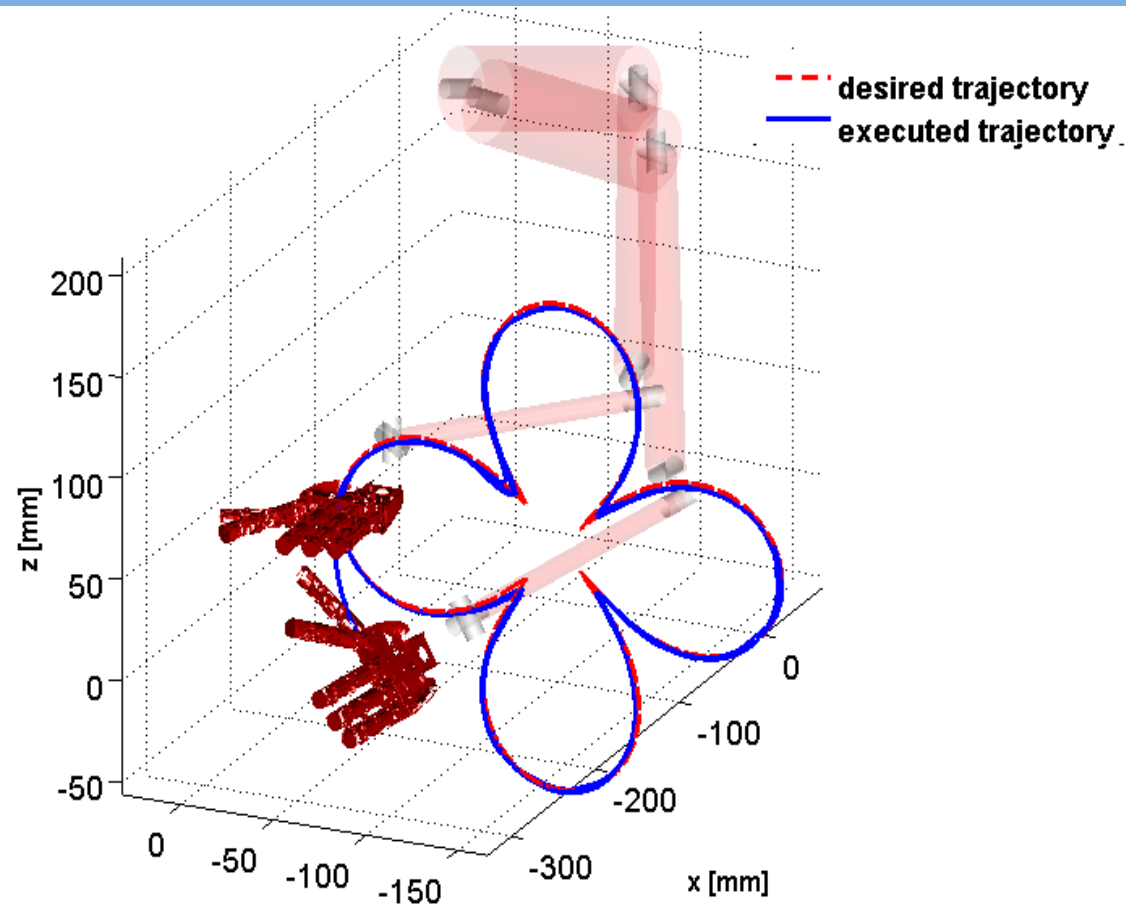
➤ Theory: Gaze Controller

➤ Installation

➤ Tutorials

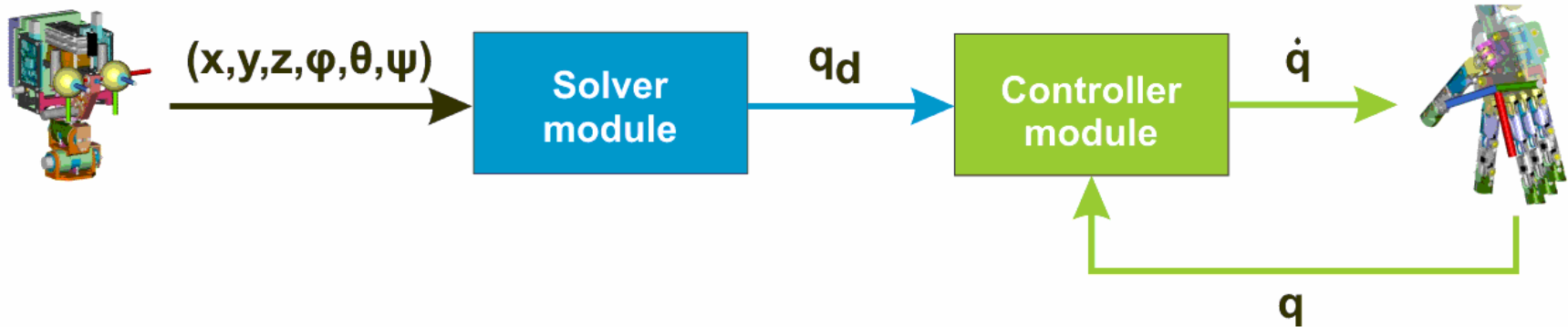


The Problem





Cartesian Controller Structure





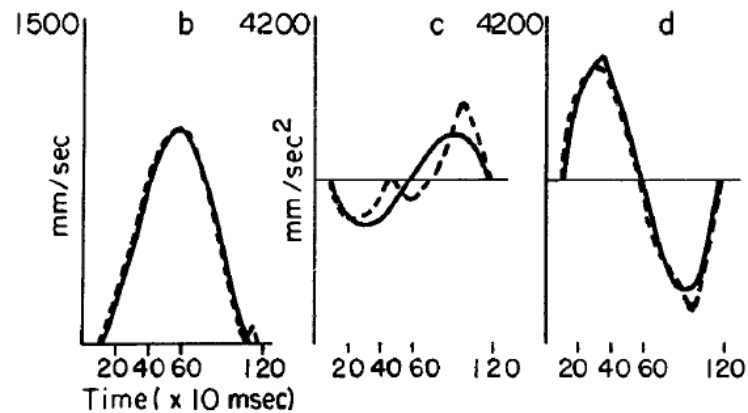
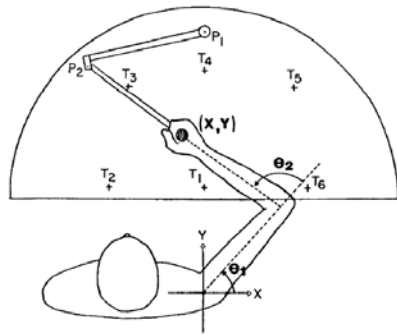
The Solver: the IpOpt choice

$$\tilde{q}_d = \arg \min_{q \in \mathbb{R}^n} \left(\left\| \alpha_d - K_\alpha(q) \right\|^2 + \lambda \cdot (q_{\text{rest}} - q)^T W (q_{\text{rest}} - q) \right)$$
$$\text{s.t.} \quad \begin{cases} \left\| x_d - K_x(q) \right\|^2 < \varepsilon \\ q_L < q < q_U \\ \text{other obstacles ...} \end{cases}$$

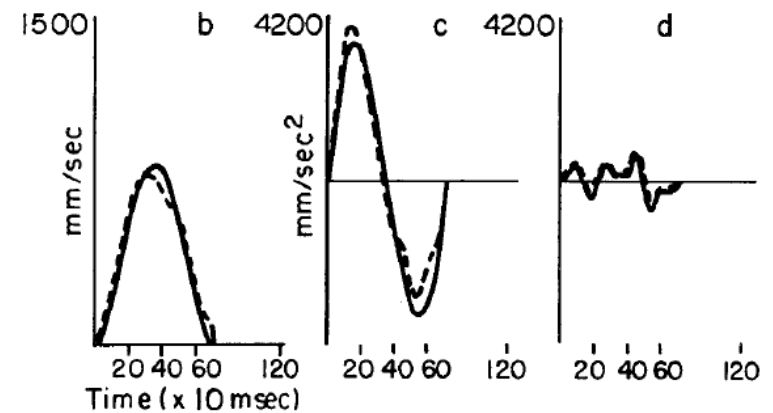
- Quick convergence (real-time compliant: < **20 ms**)
- Scalability
- Singularities and joints bound handling
- Tasks hierarchy
- Complex constraints



The Controller: Trajectory Generation



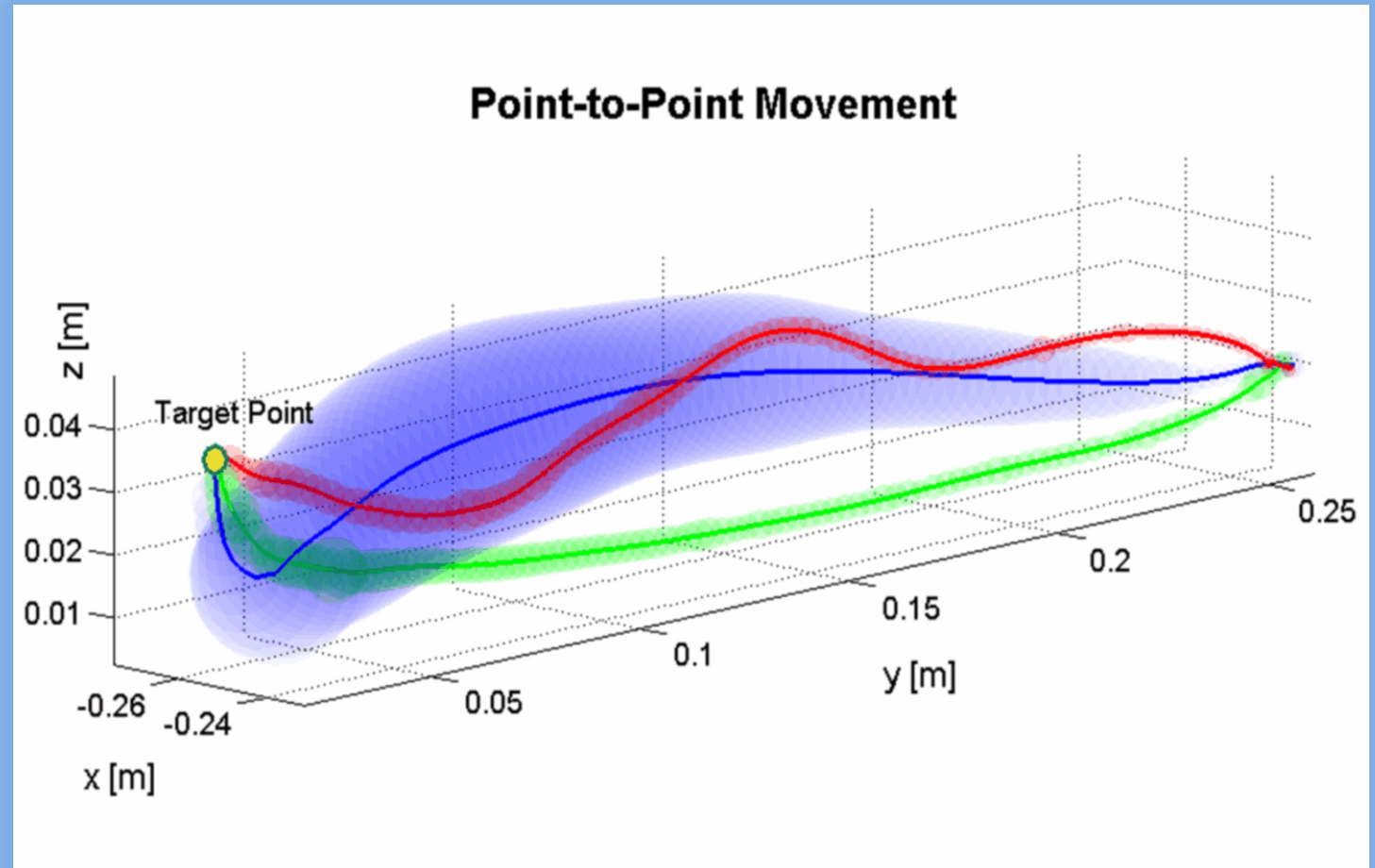
A



B

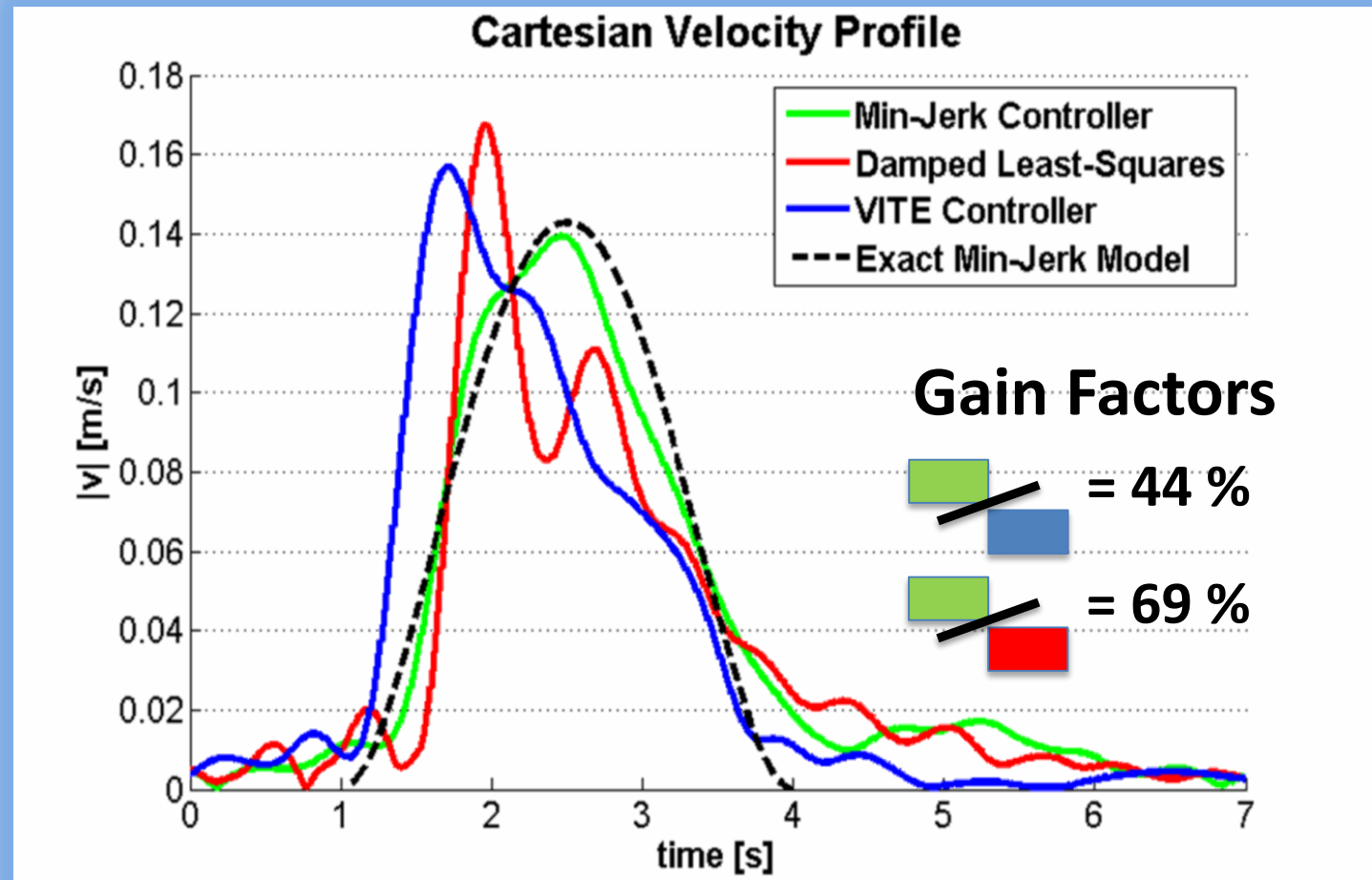


Evaluation: the P2P case





Is it Minimum-Jerk in the Task-Space?



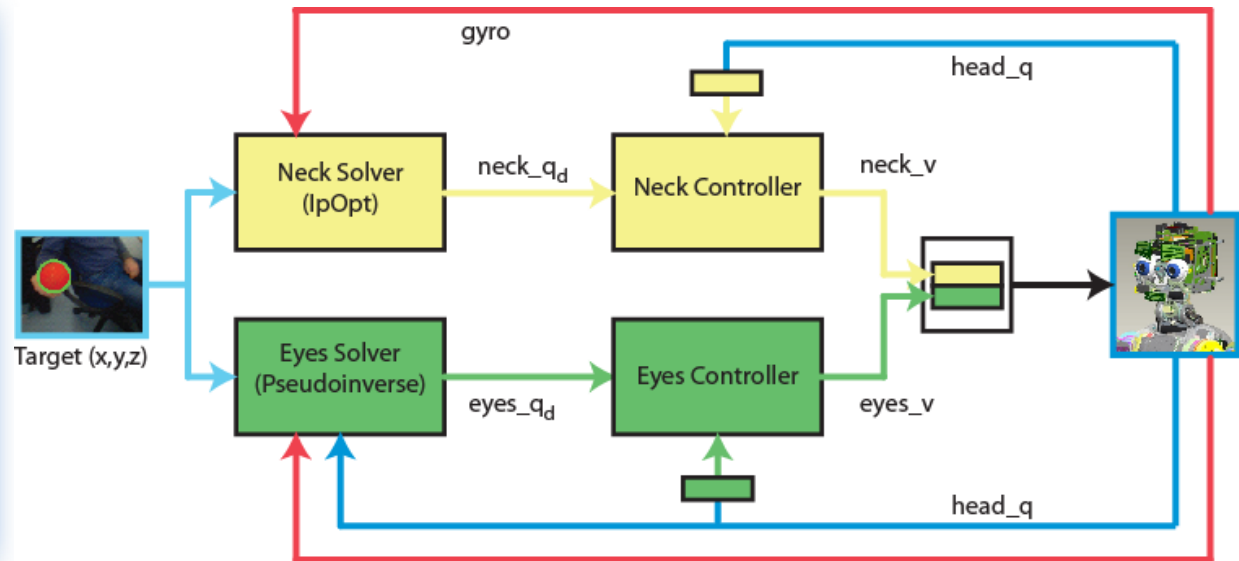
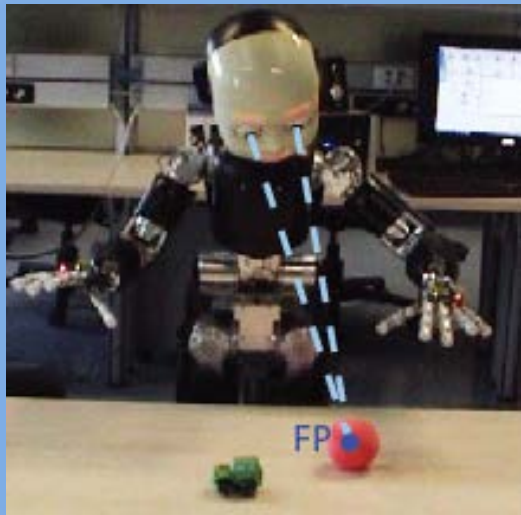
Min-Jerk

DLS

VITE



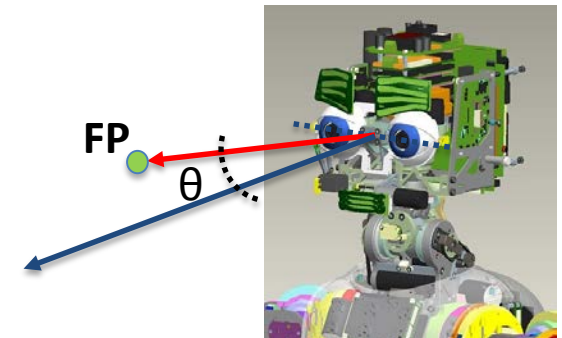
The Gaze Controller (1/7)



Yet another Cartesian Controller: reuse ideas ...

Then, apply easy transformations from Cartesian to ...

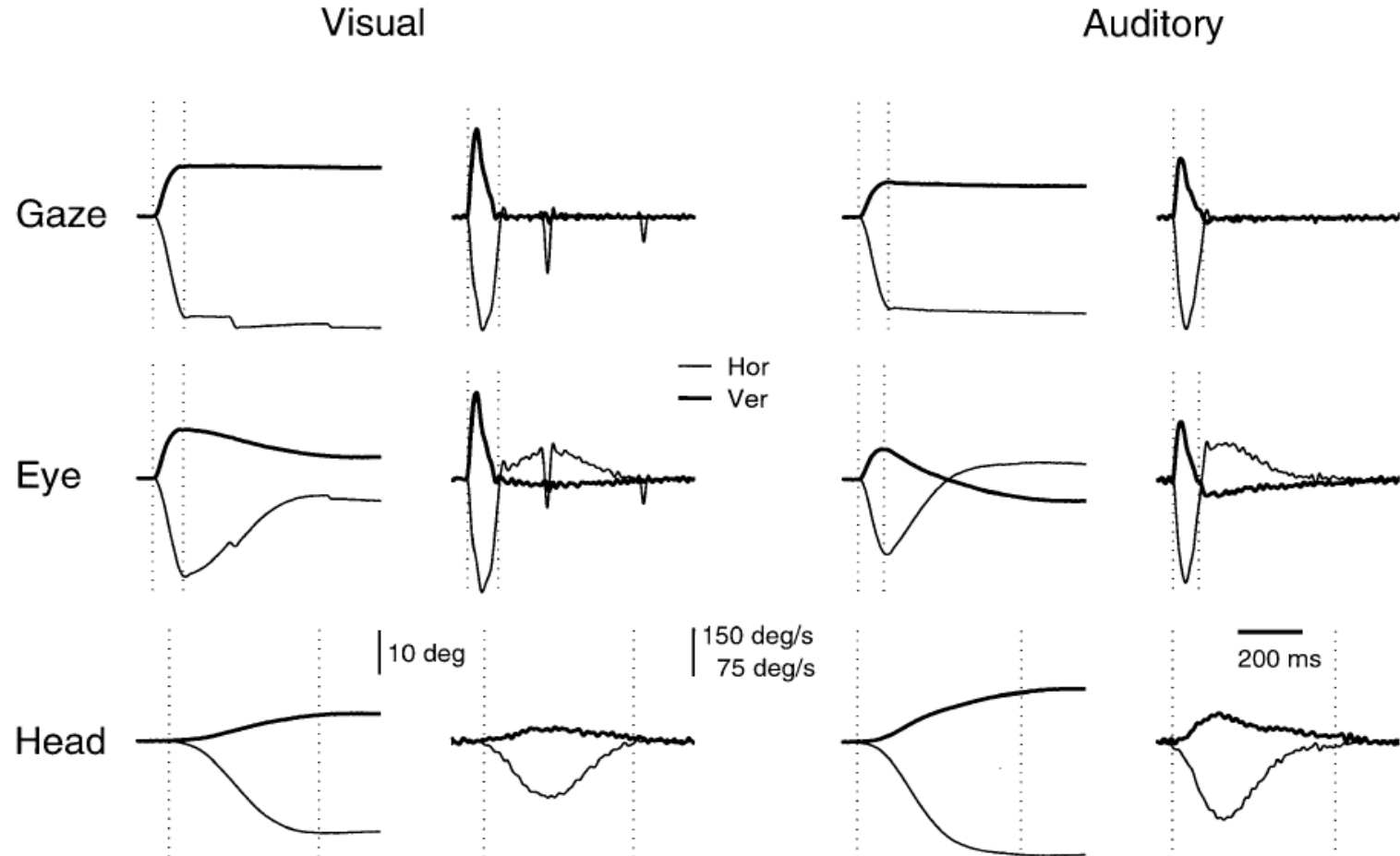
1. Egocentric angular space
2. Image planes (mono and stereo)





The Gaze Controller (2/7)

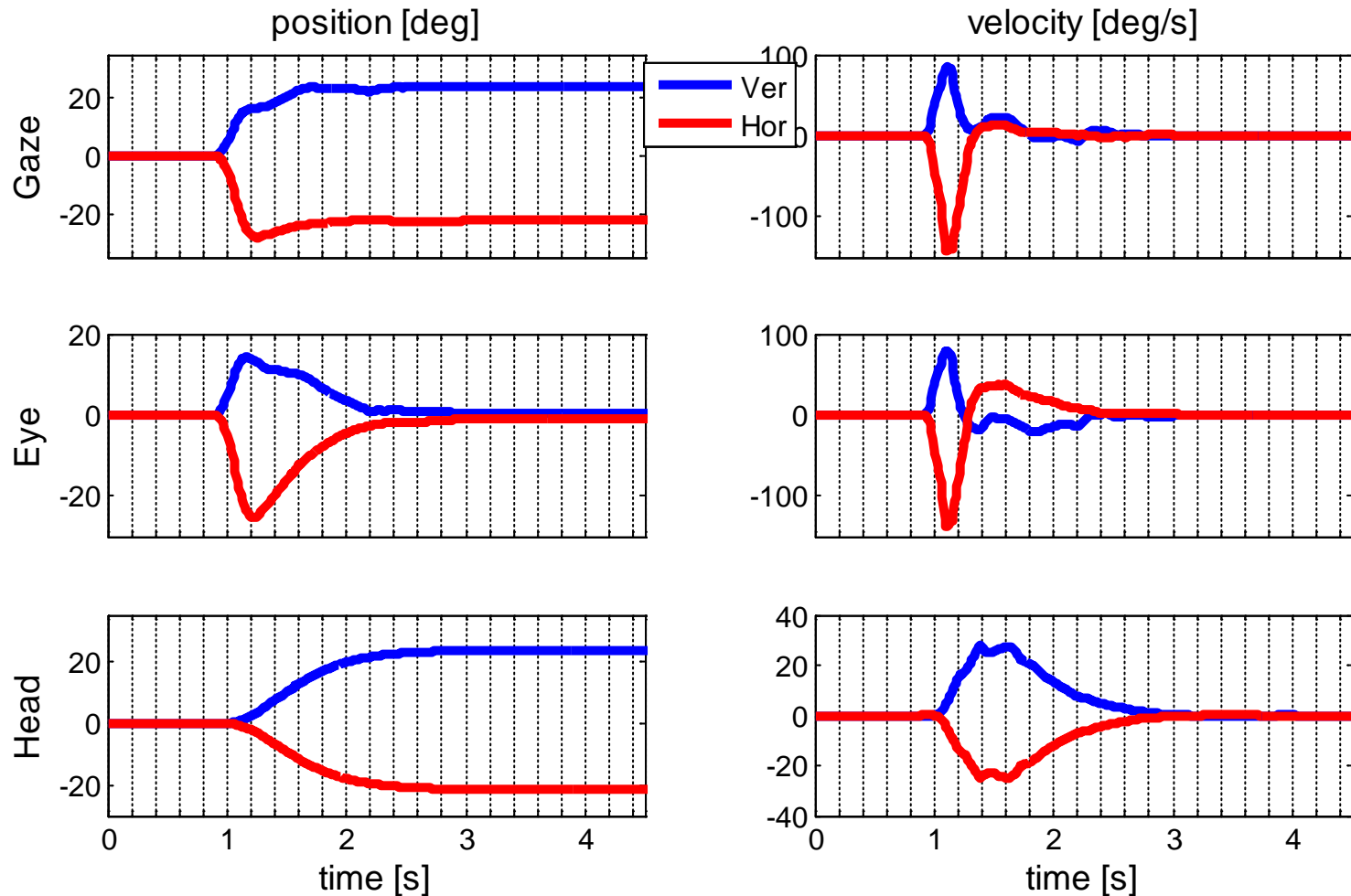
Studies on humans ...





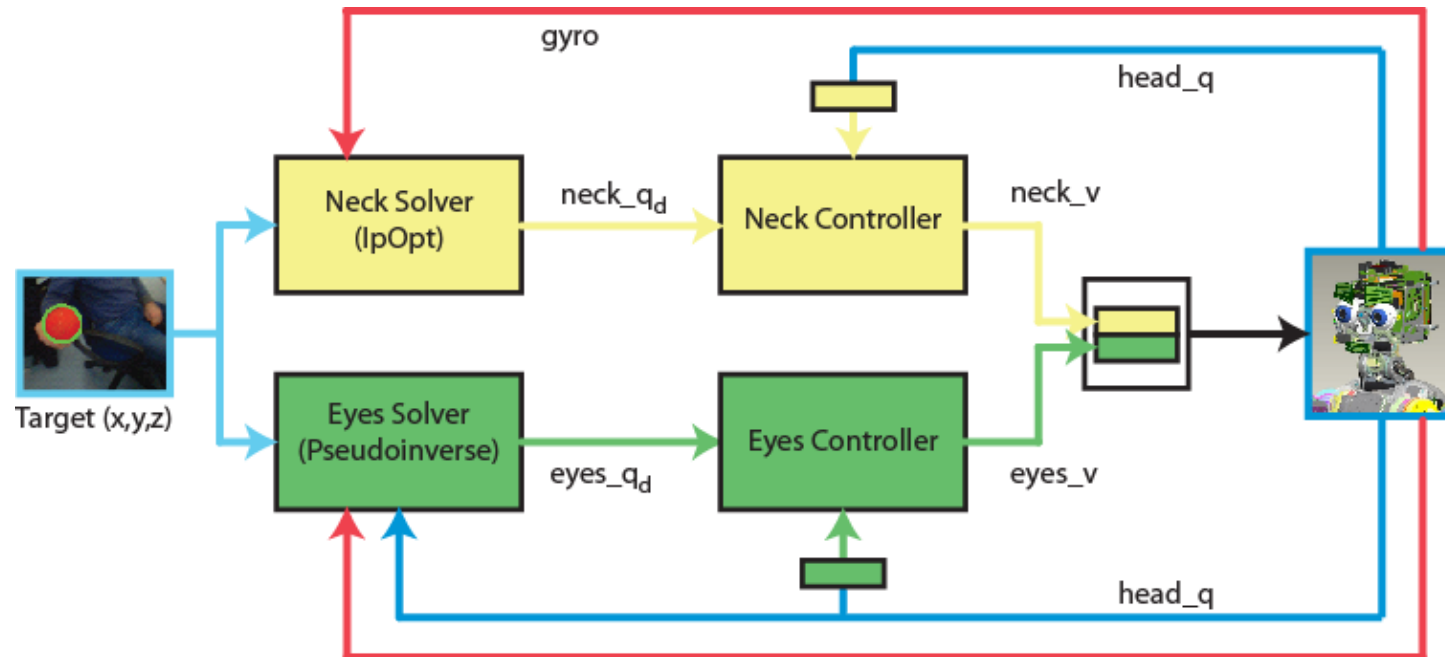
The Gaze Controller (3/7)

Results on iCub ...



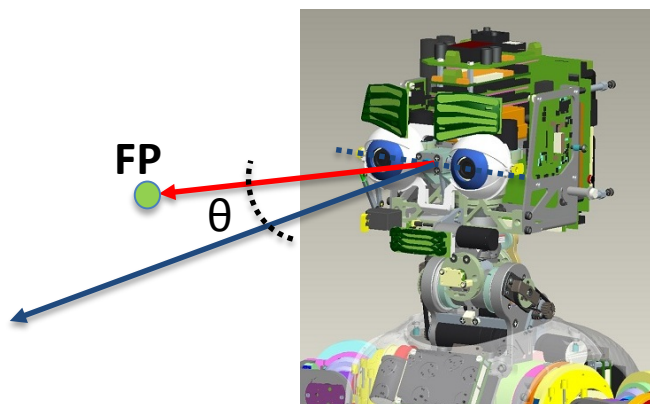
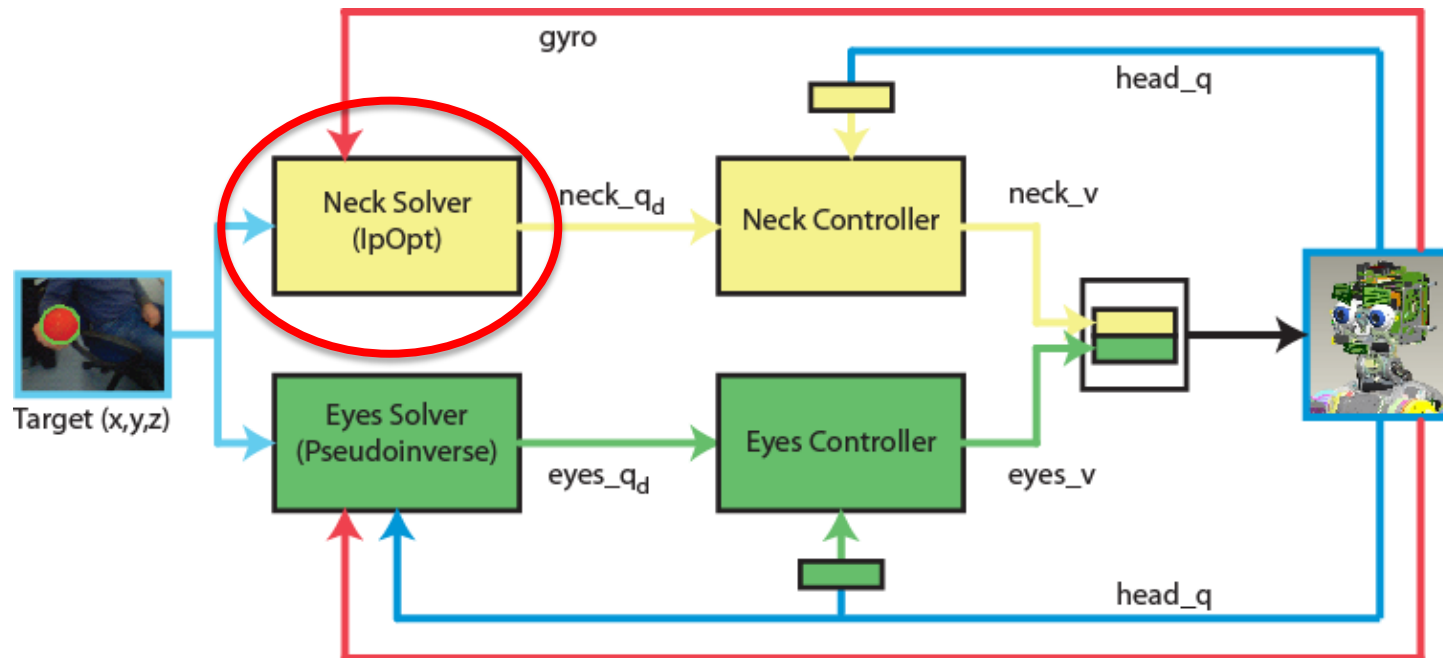


The Gaze Controller (4/7)





The Gaze Controller (5/7)

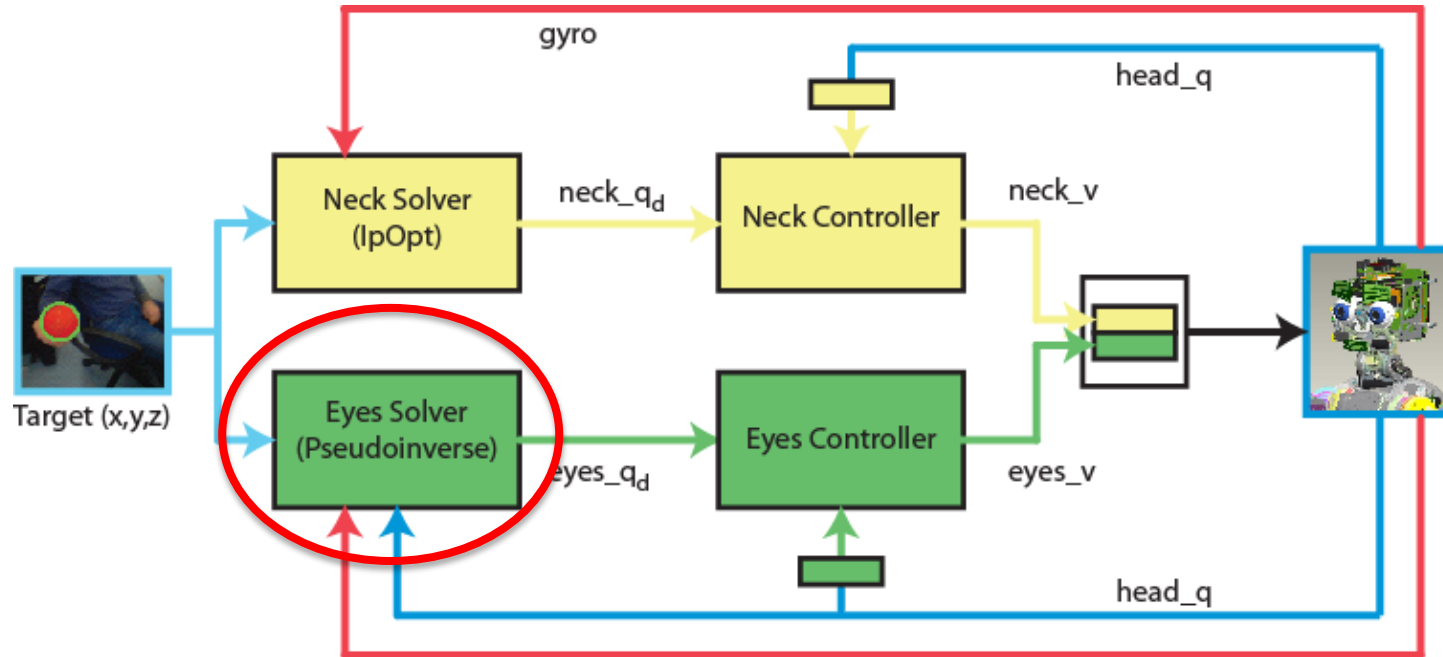


$$q_{\text{neck}}^* = \arg \min_{q_{\text{neck}} \in \mathbb{R}^3} \|q_{\text{rest}} - q_{\text{neck}}\|^2$$

$$\text{s.t.} \begin{cases} \cos(\theta(q_{\text{neck}})) > 1 - \varepsilon \\ q_{\text{neck}_L} < q_{\text{neck}} < q_{\text{neck}_U} \end{cases}$$



The Gaze Controller (6/7)



$$q_{\text{eyes}}^* = \arg \min_{q_{\text{eyes}} \in \mathbb{R}^3} \|FP_d - K_{FP}(q_{\text{eyes}})\|^2$$

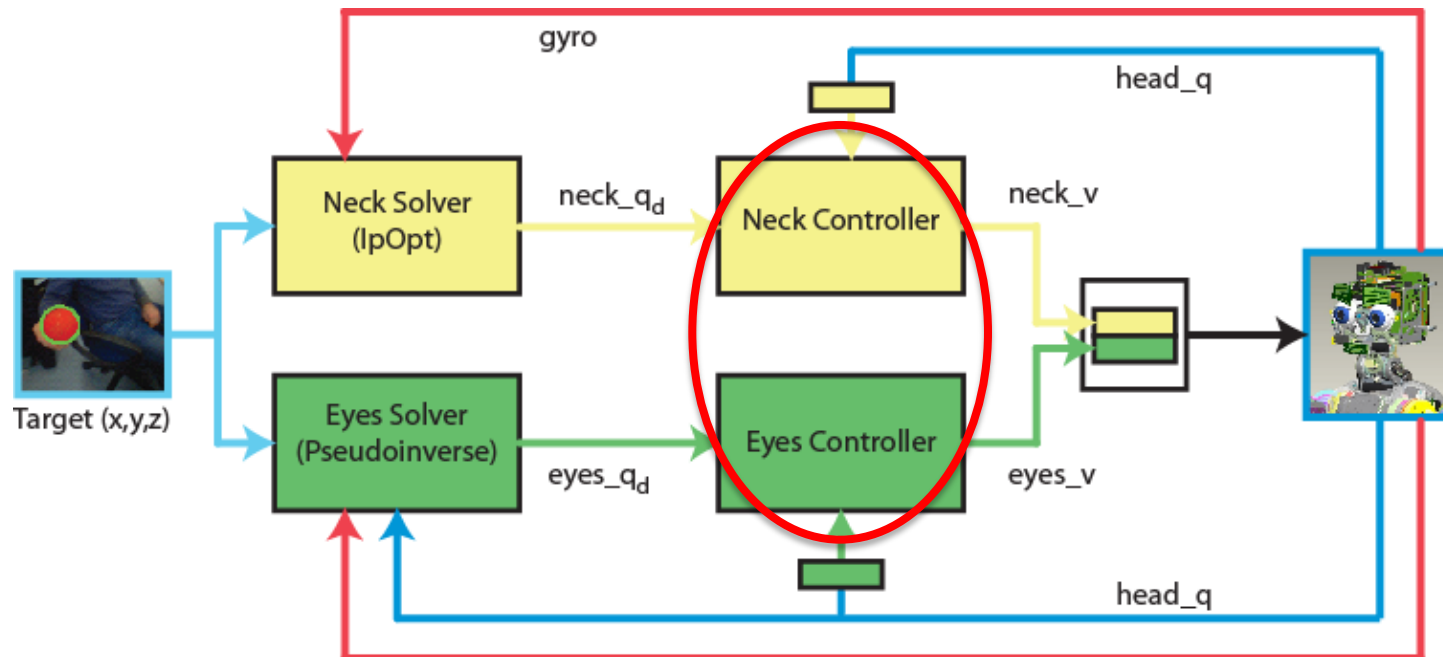
$$q_{\text{eyes}_{t+1}} = q_{\text{eyes}_t} + \Delta T \left(G \cdot J^\# \cdot \left(FP_d - K_{FP}(q_{\text{eyes}_t}) \right) - \dot{q}_c \right)$$

Gyro





The Gaze Controller (7/7)



**Retain
Controllers Laws**

$$\frac{\dot{q}_{\text{neck}}}{q_{\text{neck}_d} - q_{\text{neck}}} = \frac{-a/T_{\text{neck}}}{s^2 - \left(c/T_{\text{neck}}^3\right)s - b/T_{\text{neck}}^2}$$

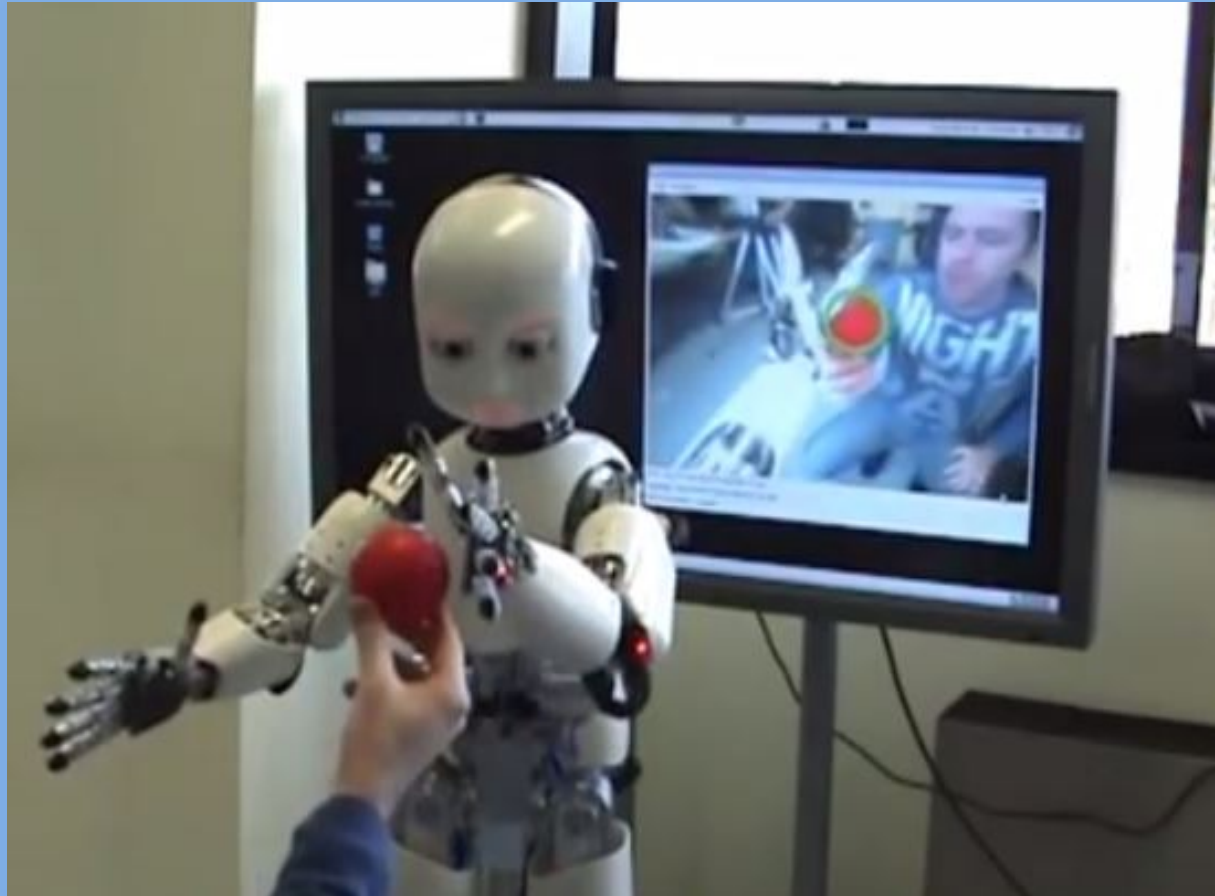
$$\frac{\dot{q}_{\text{eyes}}}{q_{\text{eyes}_d} - q_{\text{eyes}}} = \frac{-a/T_{\text{eyes}}}{s^2 - \left(c/T_{\text{eyes}}^3\right)s - b/T_{\text{eyes}}^2}$$



Feed Forward term delivered with low-level Position Control to implement **fast saccades**



An old video...



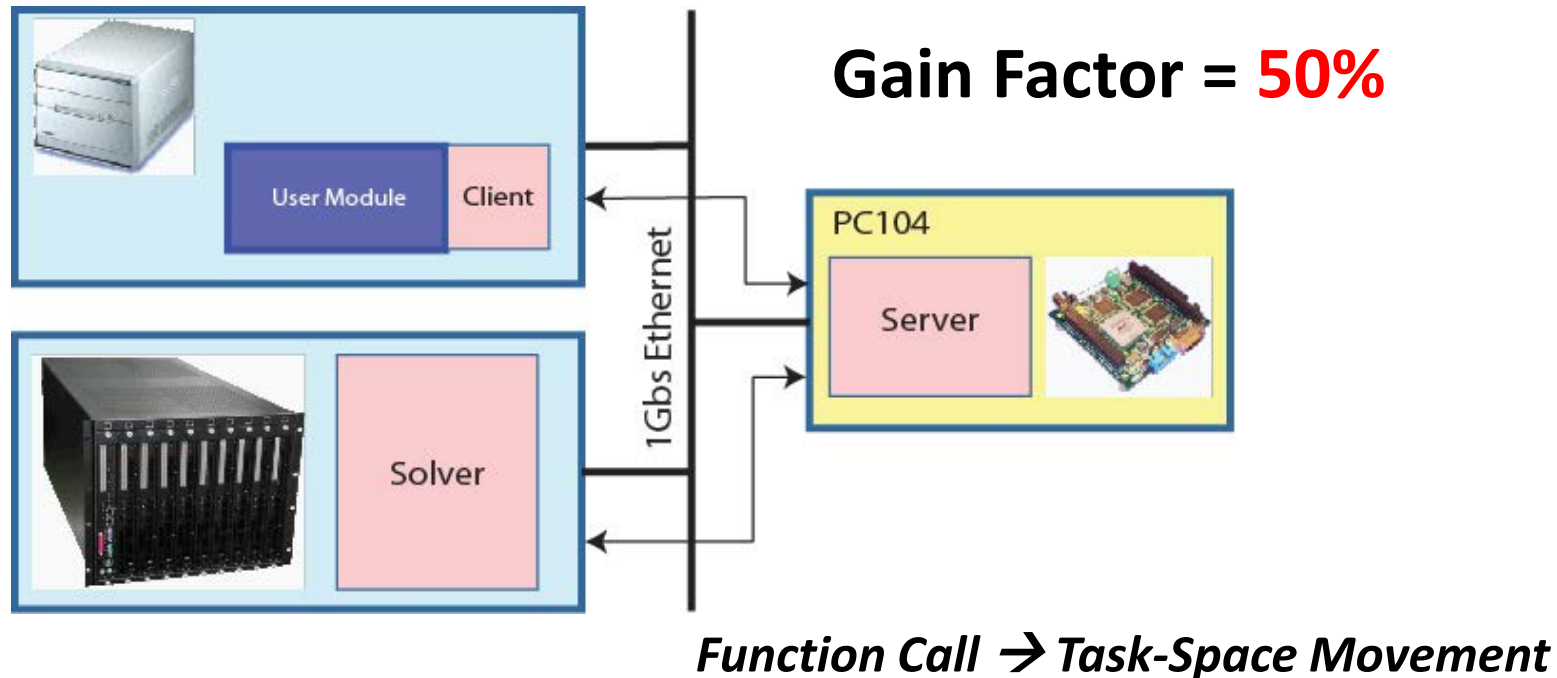
<https://www.youtube.com/watch?v=LMGSok5tN4A>



Software Development

Abstraction Layers from low to high:

1. Open-source library **iKin** for generic kinematic chains (vs. KDL)
2. Design YARP **Cartesian Interfaces**





Enabling Device Drivers (1/2)

IpOpt installation: http://wiki.icub.org/wiki/Installing_IPOPT

Tick the drivers from within the CMake mask

ENABLE_icubmod_canmotioncontrol	<input type="checkbox"/>
ENABLE_icubmod_cartesiancontrollerclient	<input checked="" type="checkbox"/>
ENABLE_icubmod_cartesiancontrollerserver	<input checked="" type="checkbox"/>
ENABLE_icubmod_cfw2can	<input type="checkbox"/>
ENABLE_icubmod_debugInterfaceClient	<input type="checkbox"/>
ENABLE_icubmod_dragonfly2	<input type="checkbox"/>
ENABLE_icubmod_ecan	<input type="checkbox"/>
ENABLE_icubmod_esdsniffer	<input type="checkbox"/>
ENABLE_icubmod_fakecan	<input type="checkbox"/>
ENABLE_icubmod_gazecontrollerclient	<input checked="" type="checkbox"/>
ENABLE_icubmod_icubarmcalibrator	<input type="checkbox"/>
ENABLE_icubmod_icubarmcalibratorj4	<input type="checkbox"/>
ENABLE_icubmod_icubarmcalibratorj8	<input type="checkbox"/>
ENABLE_icubmod_icubhandcalibrator	<input type="checkbox"/>
ENABLE_icubmod_icubheadcalibrator	<input type="checkbox"/>



Enabling Device Drivers (2/2)

Check the final availability with “*icubmoddev --list*”

```
C:\DEV\work>icubmoddev --list
Here are devices listed for your system:
Device "test_grabber", C++ class TestFrameGrabber, wrapped by "grabber"
Device "test_motor", C++ class TestMotor, wrapped by "controlboard"
Device "remote_grabber", C++ class RemoteFrameGrabber, wrapped by "grabber"
Device "grabber", C++ class ServerFrameGrabber, is a network wrapper.
Device "inertial", C++ class ServerInertial, is a network wrapper.
Device "sound_grabber", C++ class ServerSoundGrabber, is a network wrapper.
Device "pipe", C++ class DevicePipe, has no network wrapper
Device "group", C++ class DeviceGroup, has no network wrapper
Device "remote_controlboard", C++ class RemoteControlBoard, wrapped by "controlboard"
Device "controlboard", C++ class ServerControlBoard, is a network wrapper.
Device "analogsensorclient", C++ class AnalogSensorClient, has no network wrapper
Device "cartesiancontrollerserver", C++ class ServerCartesianController, wrapped by "cartesiancontrollerclient"
Device "cartesiancontrollerclient", C++ class ClientCartesianController, is a network wrapper.
Device "gazecontrollerclient", C++ class ClientGazeController, is a network wrapper.
```



Interfaces Documentation

In the search field: type **ICartesianControl/IGazeControl**

Main Page Related Pages Modules Namespaces Data Structures Files Examples

Welcome to YARP

YARP stands for Yet Another Robot Platform. What is it? If data is the bloodstream of your robot, then YARP is the brain. More specifically, YARP supports building a robot control system as a **collection of programs** communicating via udp, multicast, local, MPI, mjpeg-over-http, XML/RPC, tpross, ...) that can be swapped in and out to match different hardware devices. Our strategic goal is to increase the longevity of robot software projects [1].

YARP is *not* an operating system for your robot. We figure you already have an operating system, or perhaps a package manager we have). We're not out for world domination. It is easy to interoperate with YARP-U (see the **YARP without YARP** tutorial. YARP is written in C++, and can be compiled without external libraries on Linux and Mac OSX. A small portion of the ACE library is used for Windows builds, and to support extra protocols (this portion can easily be embedded). YARP is free and open, under the LGPL (*).

• • •

Public Member Functions

virtual	<code>~ICartesianControl ()</code>	Destructor.
virtual bool	<code>setTrackingMode (const bool f)=0</code>	Set the controller in tracking or non-tracking mode.
virtual bool	<code>getTrackingMode (bool *f)=0</code>	Get the current controller mode.
virtual bool	<code>getPose (yarp::sig::Vector &x, yarp::sig::Vector &o)=0</code>	Get the current pose of the end-effector.
virtual bool	<code>getPose (const int axis, yarp::sig::Vector &x, yarp::sig::Vector &o)=0</code>	Get the current pose of the specified link belonging to the kinematic chain.
virtual bool	<code>goToPose (const yarp::sig::Vector &xd, const yarp::sig::Vector &od, const double t=0.0)=0</code>	Move the end-effector to a specified pose (position and orientation) in cartesian space.
virtual bool	<code>goToPosition (const yarp::sig::Vector &xd, const double t=0.0)=0</code>	Move the end-effector to a specified position in cartesian space, ignore the orientation.
virtual bool	<code>goToPoseSync (const yarp::sig::Vector &xd, const yarp::sig::Vector &od, const double t=0.0)=0</code>	Move the end-effector to a specified pose (position and orientation) in cartesian space.
virtual bool	<code>goToPositionSync (const yarp::sig::Vector &xd, const double t=0.0)=0</code>	Move the end-effector to a specified position in cartesian space, ignore the orientation.
virtual bool	<code>getDesired (yarp::sig::Vector &xdhat, yarp::sig::Vector &odhat, yarp::sig::Vector &qdhat)=0</code>	Get the actual desired pose and joints configuration as result of kinematic inversion.
virtual bool	<code>askForPose (const yarp::sig::Vector &xd, const yarp::sig::Vector &od, yarp::sig::Vector &xdhat, yarp::sig::Vector &odhat, yarp::sig::Vector &qdhat)=0</code>	Ask for inverting a given pose without actually moving there.
virtual bool	<code>askForPose (const yarp::sig::Vector &q0, const yarp::sig::Vector &xd, const yarp::sig::Vector &od, yarp::sig::Vector &xdhat, yarp::sig::Vector &odhat, yarp::sig::Vector &qdhat)=0</code>	Ask for inverting a given pose without actually moving there.
virtual bool	<code>askForPosition (const yarp::sig::Vector &xd, yarp::sig::Vector &xdhat, yarp::sig::Vector &odhat, yarp::sig::Vector &qdhat)=0</code>	Ask for inverting a given position without actually moving there.

Doxygen Documentation



Interfaces Tutorials



The iCub manual



iCub hardware SVN



iCub software



Yarp software

- **Software** - most of the software (including **iCub modules**)
- **Applications** - a list of documented applications (collections of modules)
- **Tutorials** - a set of tutorials to learn how to use the software
- The documentation for contributed software is here: [Contrib documentation](#)
- Programmer's checklist:
 - **Compile status** - check if your code is compiling on a test server
 - **Licensing** - have you declared your authorship, and rights granted?
 - **Coding guidelines** - some tips on how to write your code
 - **Modules and CMake** - some tips on how to make your code compilable
 - **Committing to the repository** - things to check before committing files to the repository
- Reference material:
 - The [iCub manual](#)
 - The [RobotCub Website](#).
 - [Getting the software](#).
 - Our software architecture, [YARP](#).

- **The classic hello world** - how to write the very first program
- **Getting accustomed with motor interfaces** - a tutorial on how to use the motor interfaces
- **Getting accustomed with torque/impedance interfaces** - a tutorial on how to use the joint level torque/impedance interface
- **Basic Image Processing** - a tutorial on a basic image processing
- **The ResourceFinder Class (basic)** - a tutorial on how to organize the command line parameters of your modules
- **The ResourceFinder Class (advanced)** - organizing parameters: advanced tutorial
- **The RFModule Class** - a tutorial on how to use the module helper class to write a program
- **The RunThread Class** - a tutorial on how to write a control loop using threads
- **The Cartesian Interface** - a tutorial on how to control a robot's limb in the operational space
- **The Gaze Interface** - a tutorial on how to control the robot gaze through a Yarp interface
- **A short introduction to iDyn** - a short introduction to the iDyn library
 - **Computation of torques in a single chain, using iDyn** - how to compute torques in a single chain, using iDyn library



Interfaces Communalities (1/4)

CMAKE

```
find_package(ICUB)
...
include_directories($ICUB_INCLUDE_DIRS)
...
target_link_libraries(${PROJECTNAME} icubmod)
```

CODE SKELETON

```
...
#include <yarp/dev/all.h>
YARP_DECLARE_DEVICES(icubmod)
...
int main()
{
YARP_REGISTER_DEVICES(icubmod)
...
}
```



Interfaces Communalities (2/4)

OPENING THE CARTESIAN INTERFACE

Property option;

```
option.put("device", "cartesiancontrollerclient");  
option.put("remote", "/icub/cartesianController/right_arm");  
option.put("local", "/client/right_arm");
```

```
PolyDriver clientCartCtrl(option);
```

```
ICartesianControl *icart=NULL;  
if (clientCartCtrl.isValid()) {  
    clientCartCtrl.view(icart);  
}
```



Interfaces Communalities (3/4)

OPENING THE GAZE INTERFACE

Property option;

```
option.put("device","gazecontrollerclient");  
option.put("remote","/iKinGazeCtrl");  
option.put("local","/client/gaze");
```

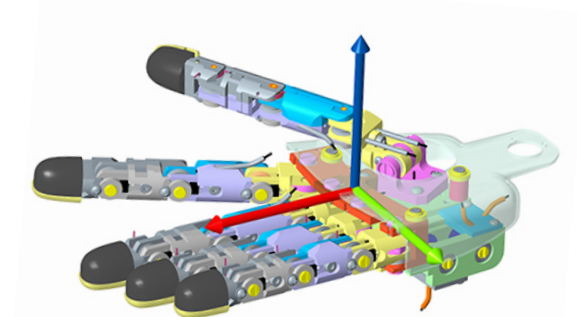
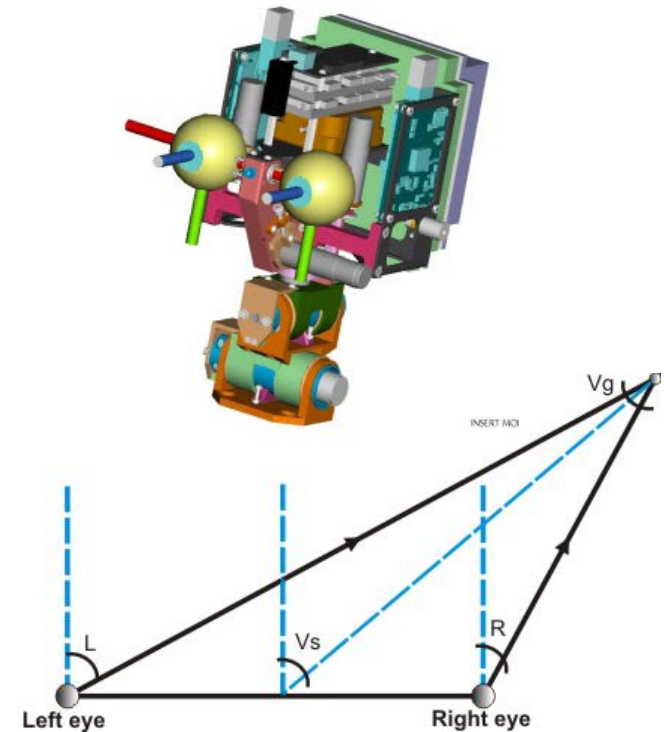
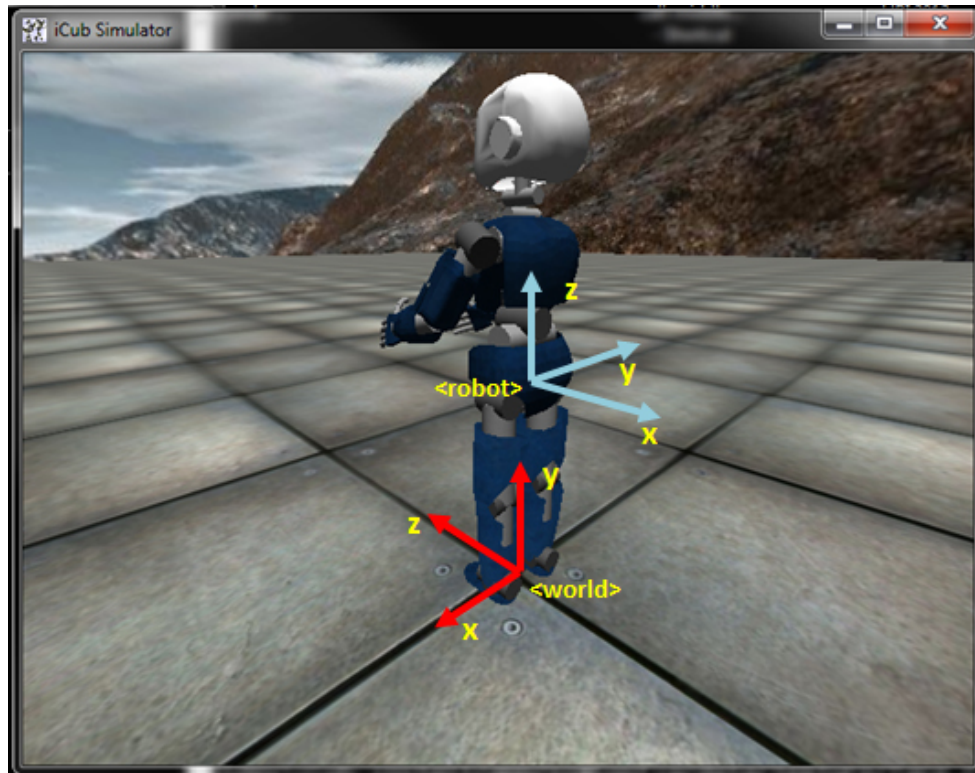
```
PolyDriver clientGazeCtrl(option);
```

```
IGazeControl *igaze=NULL;  
if (clientGazeCtrl.isValid()) {  
    clientGazeCtrl.view(igaze);  
}
```



Interfaces Communalities (4/4)

Coordinate Systems



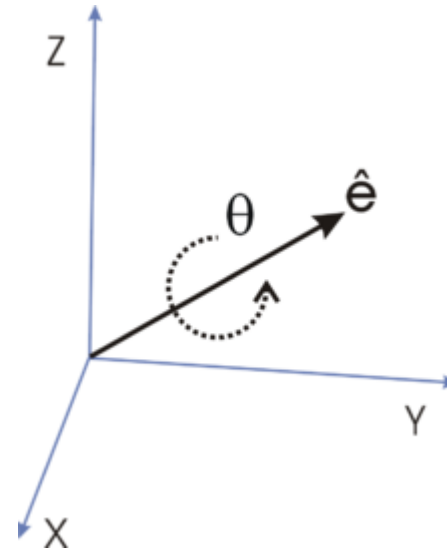


Cartesian Interface (1/7)

Orientation: Axis-Angle

$$r = \left[\underbrace{e_x \ e_y \ e_z}_{\|e\| = 1} \ \theta \right]$$

$\rightarrow rad$



TARGET ORIENTATION through DIRECTION COSINE MATRIX

```
Matrix R(3,3);
// pose x-axis    y-axis    z-axis
R(0,0)= 0.0;  R(0,1)= 1.0;  R(0,2)= 0.0;  // x-coordinate
R(1,0)= 0.0;  R(1,1)= 0.0;  R(1,2)=-1.0;  // y-coordinate
R(2,0)=-1.0;  R(2,1)= 0.0;  R(2,2)= 0.0;  // z-coordinate

Vector o=ctrl::dcm2axis(R);
```



Cartesian Interface (2/7)

RETRIEVE CURRENT POSE

```
Vector x,o;  
icart->getPose(x,o);
```

REACH FOR A TARGET POSE (SEND-AND-FORGET)

```
icart->goToPose(xd,od);  
icart->goToPosition(xd);
```

REACH FOR A TARGET POSE (WAIT-FOR-REPLY)

```
icart->goToPoseSync(xd,od);  
icart->goToPositionSync(xd);
```

REACH AND WAIT

```
icart->goToPoseSync(xd,od);  
icart->waitMotionDone();
```



Cartesian Interface (3/7)

ASK FOR A POSE (without moving)

```
Vector xdhat, odhat, qdhat;  
icart->askForPose(xd, xdhat, odhat, qdhat);
```

MOVE FASTER/SLOWER

```
icart->setTrajTime(1.5); // point-to-point trajectory time
```

REACH WITH GIVEN PRECISION

```
icart->setInTargetTol(0.001);
```

KEEP THE POSE ONCE DONE

```
icart->setTrackingMode(true);
```



Cartesian Interface (4/7)

ENABLE/DISABLE DOF

```
Vector curDof;  
icart->getDOF(curDof); // [0 0 0 1 1 1 1 1 1]  
  
Vector newDof(3);  
newDof[0]=1; // torso pitch: 1 => enable  
newDof[1]=2; // torso roll: 2 => skip  
newDof[2]=1; // torso yaw: 1 => enable  
icart->setDOF(newDof,curDof);
```

GIVE PRIORITY TO REACHING IN POSITION/ORIENTATION

```
icart->setPosePriority("position"); // default  
icart->setPosePriority("orientation");
```



Cartesian Interface (5/7)

CONTEXT SWITCH

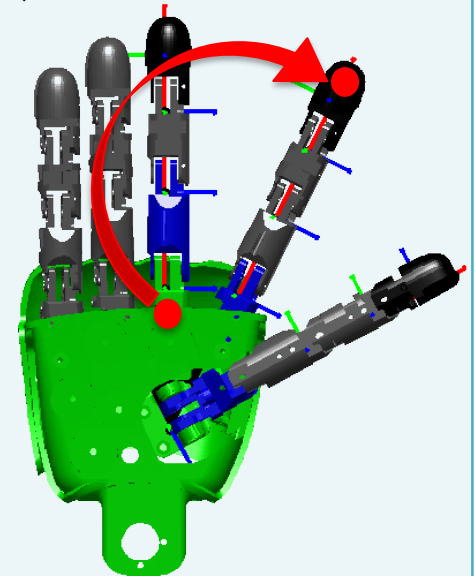
```
icart->setDOF(newDof1,curDof1);    // prepare the context  
icart->setTrackingMode(true);  
  
int context_0;  
icart->storeContext(&context_0);  // latch the context  
  
icart->setDOF(newDof2,curDof2);    // perform some actions  
icart->goToPose(x,o);  
  
icart->restoreContext(context_0);  // retrieve context_0  
icart->goToPose(x,o);             // perform with context_0
```



Cartesian Interface (6/7)

DEFINING A DIFFERENT EFFECTOR

```
iCubFinger finger("right_index");  
Vector encs; iencs->getEncoders(encs.data());  
Vector joints; finger.getChainJoints(encs,joints);  
Matrix tipFrame=finger.getH((M_PI/180.0)*joints);  
  
Vector tip_x=tipFrame.getCol(3);  
Vector tip_o=ctrl::dcm2axis(tipFrame);  
  
icart->attachTipFrame(tip_x,tip_o);  
  
icart->getPose(x,o);  
icart->goToPose(xd,od);  
  
icart->removeTipFrame();
```





Cartesian Interface (7/7)

Find out more (e.g. **Events Callbacks ...**):

http://wiki.icub.org/iCub/main/dox/html/icub_cartesian_interface.html

USING THE INTERFACE ALONG WITH THE SIMULATOR

```
1> iCub_SIM
2> simCartesianControl
3> iKinCartesianSolver --context simCartesianControl --part left_arm

option.put("device","cartesiancontrollerclient");
option.put("remote","/iCubSim/cartesianController/left_arm");
option.put("local","/client/right_arm");
```



Gaze Interface (1/4)

GET CURRENT FIXATION POINT IN CARTESIAN DOMAIN

```
Vector x;  
igaze->getFixationPoint(x);
```

GET CURRENT FIXATION POINT IN ANGULAR DOMAIN

```
Vector ang;  
igaze->getAngles(ang);  
// ang[0] => azimuth [deg]  
// ang[1] => elevation [deg]  
// ang[2] => vergence [deg]
```

LOOK AT 3D POINT

```
igaze->lookAtFixationPoint(xd);
```

... IN ANGULAR DOMAIN

```
igaze->lookAtAbsAngles(ang);  
igaze->lookAtRelAngles(ang);
```




Gaze Interface (2/4)

LOOK AT POINT IN IMAGE DOMAIN

```
int camSel=0; // 0 => left, 1 => right
Vector px(2);
px[0]=100;
px[1]=50;
double z=1.0;

igaze->lookAtMonoPixel(camSel,px,z);
```



... EQUIVALENT TO

```
Vector x;
igaze->get3DPoint(camSel,px,z,x);
igaze->lookAtFixationPoint(x);
```



Gaze Interface (3/4)

GEOMETRY OF PIXELS

```
Vector x;  
igaze->get3DPointOnPlane(camSel,px,plane,x);  
igaze->get3DPointFromAngles(mode,ang,x);  
igaze->triangulate3DPoint(px1,pxr,x);
```

LOOK AT POINT WITH STEREO APPROACH => LOOPING!

```
Vector c(2); c[0]=160.0; c[1]=120.0;  
bool converged=false;  
  
while (!converged) {  
    Vector px1(2),pxr(2);  
    px1[0]=...; px1[1]=...; // retrieve data from vision  
    pxr[0]=...; pxr[1]=...;  
  
    igaze->lookAtStereoPixels(px1,pxr);  
    converged=(0.5*(norm(c-px1)+norm(c-pxr))<5);  
}
```



Gaze Interface (4/4)

Find out more (e.g. **Events Callbacks, Fast Saccadic Mode ...**):

http://wiki.icub.org/iCub/main/dox/html/icub_gaze_interface.html

USING THE INTERFACE ALONG WITH THE SIMULATOR

```
1> iCub_SIM
2> iKinGazeCtrl --from configSim.ini

option.put("device","gazecontrollerclient");
option.put("remote","/iKinGazeCtrl");
option.put("local","/client/right_arm");
```