ISTITUTO
DI TECNOLOGIE DELLA
COMUNICAZIONE,
DELL'INFORMAZIONE
E DELLA
PERCEZIONE

Scuola Superiore
Sant'Anna

A Networked Haptic Embedded Controller

Carlo Alberto Avizzano, Emanuele Ruffaldi,
Daniele Leonardis and Massimo Bergamasco
PERCRO Scuola Superiore Sant'Anna, Pisa, Italy

Speaker: Daniele Leonardis: d.leonardis@sssup.it

PERCRO Perceptual
Robotics Laboratory

Haptic Devices

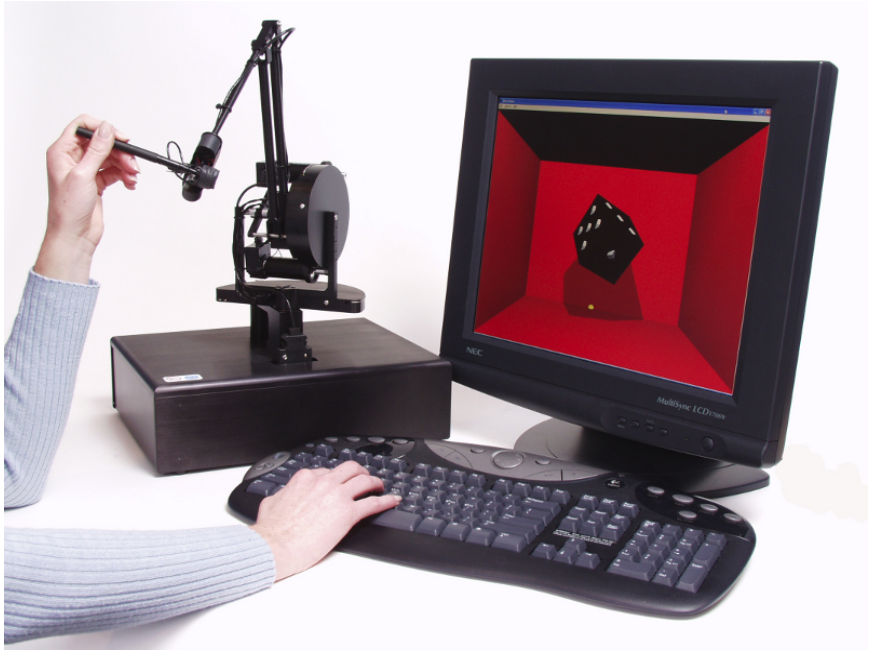
Haptic devices are robotic manipulators providing **force-feedback** to the user:

- **Haptic rendering** of virtual/augmented environments
- **Teleoperation** with a second robotic manipulator/haptic device

[ALEx exoskeleton, SSSA]

Typical haptic systems **do not provide** enough **flexibility**:

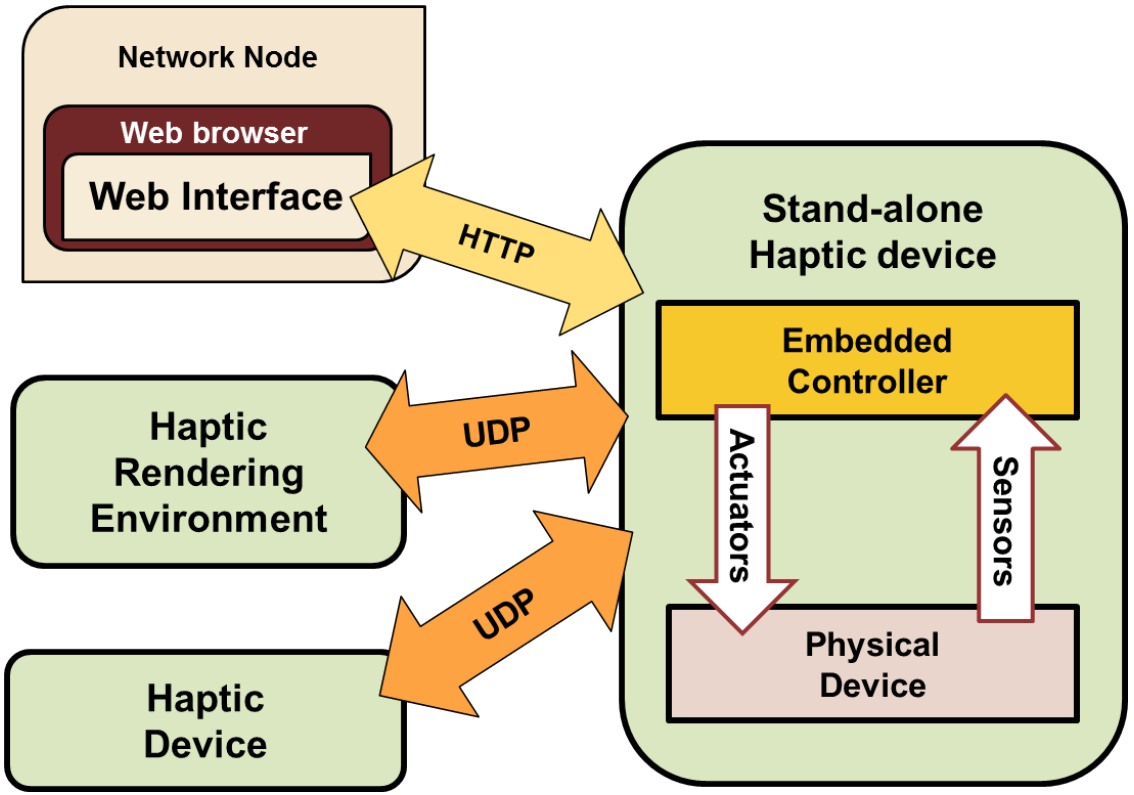
- **Dedicated PC** managing communication and interface with the user
- **Dedicated boards** for control and driving actuators **(1KHz closed-loop required)**
- **Dedicated drivers** per device (**no standards**)



[Phantom, Sensable]

Embedded Haptic Controller

The present work proposes a **stand-alone haptic controller**, **embedded** on a **single, low-cost board**, providing both:



Robotic control :

- Sensors/actuators interface
- Control loops and kinematics
- Calibration, safety limits

Communication, interfacing:

- Network accessibility
- User interface with configuration and diagnostics
- Closed-loop haptic feedback with other netwrok nodes

Dual-Subsystem MCU

Texas Instruments Concerto MCU: integrates an ARM Cortex M3 core and a C28 DSP core in a single microcontroller

TI Concerto MCU

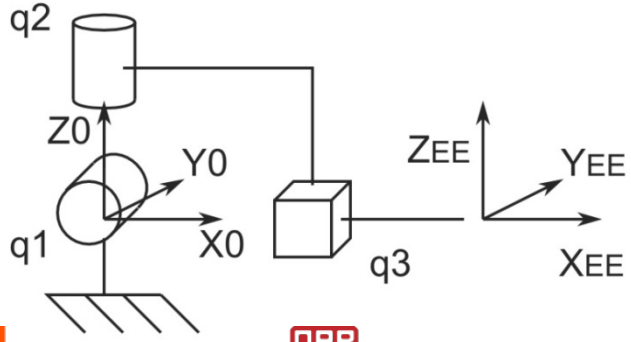
C28x 32 bit DSP	Shared Memory	ARM Cortex M3
- 150 Mhz - Floating Point Unit - 256 KB Flash - 32KB RAM - 12 PWM modules - 3 QEP modules - 12ch 12 bit ADCs	- 64 KB RAM	- 125 Mhz - 32KB RAM - 32C-ch DMA - 10/100 Ethernet - USB - 4x UART

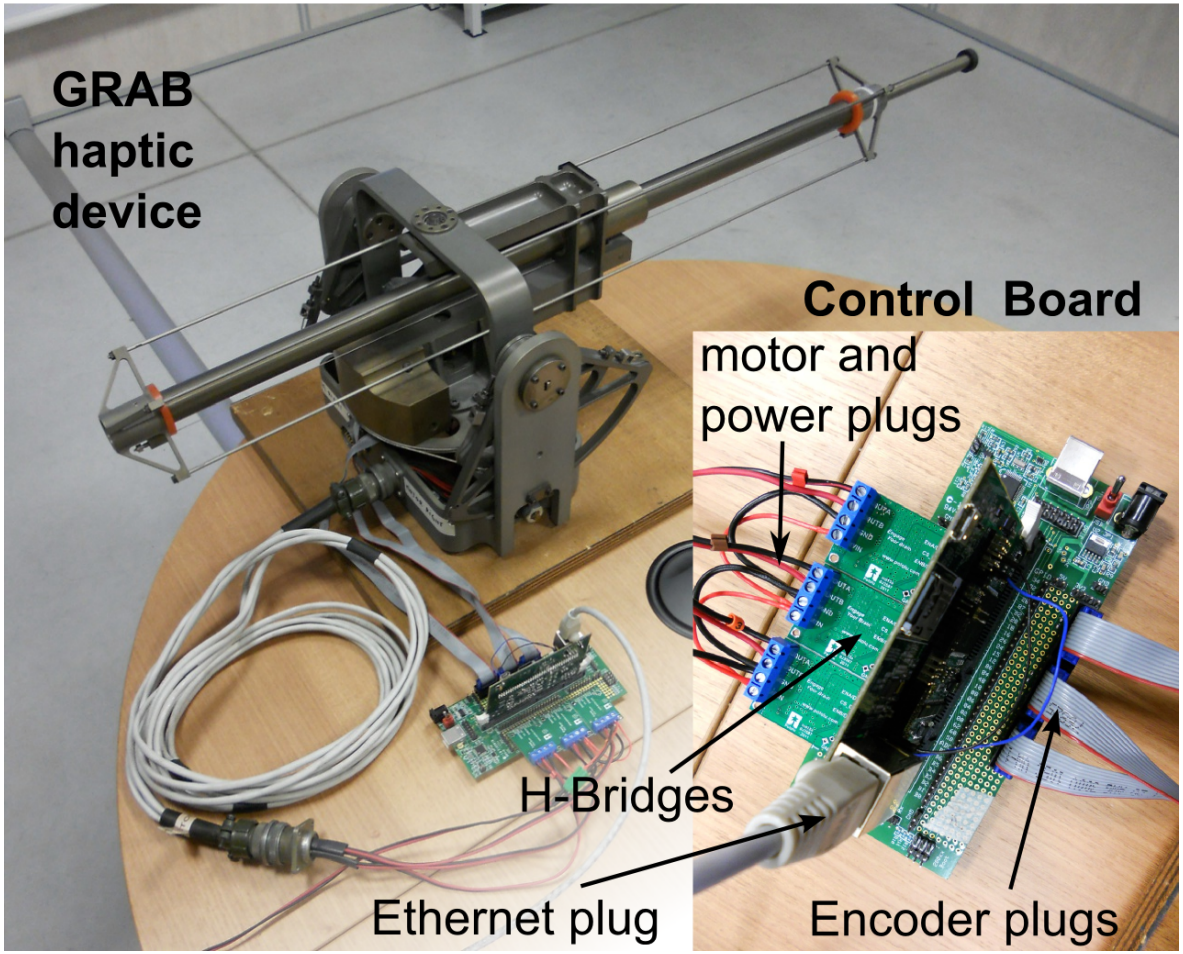
Experimental Setup

Electronics:
- Texas Instruments Concerto:
- Vishay VNH2SP30 H-Bridge

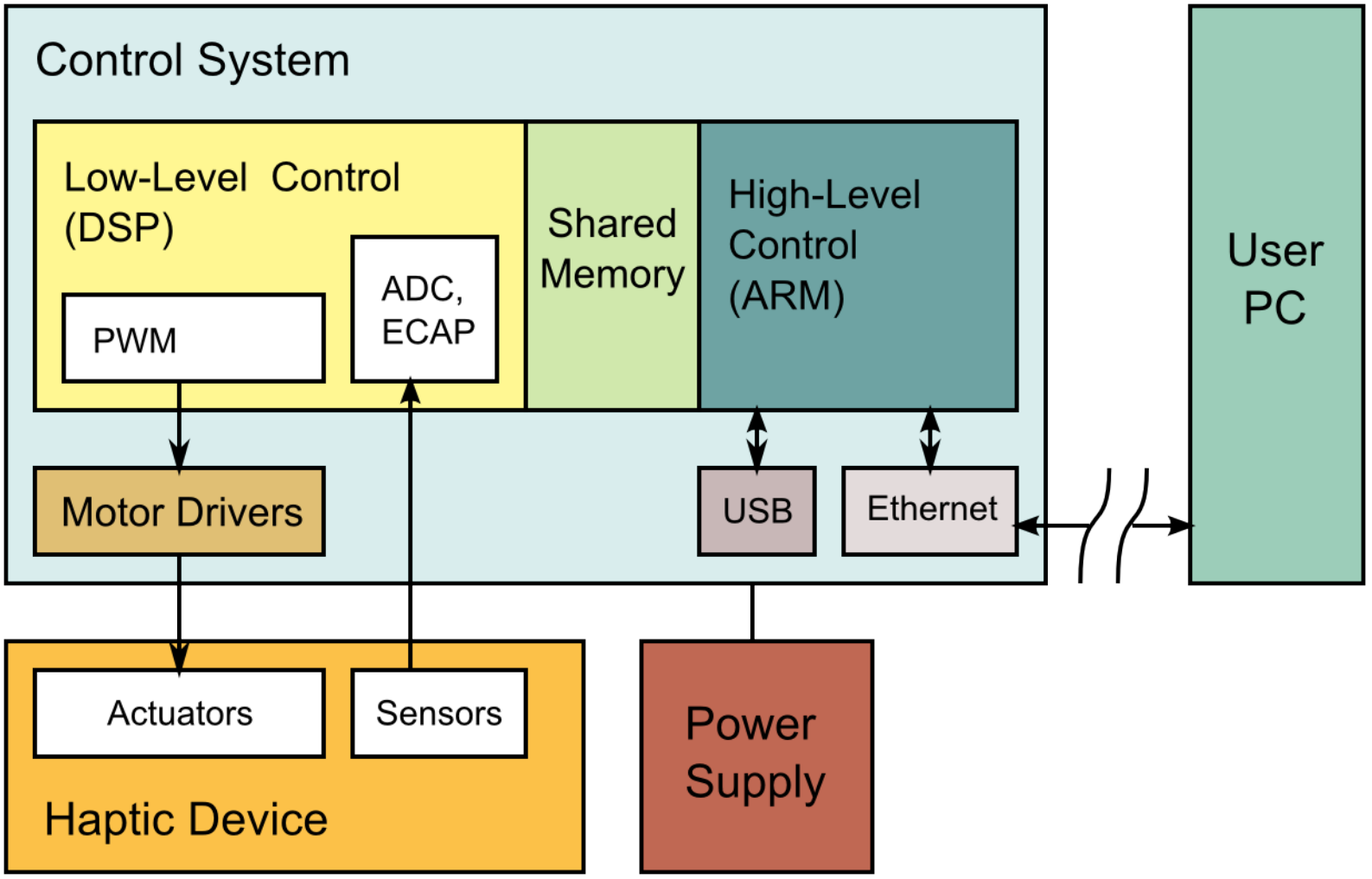
Manipulator:
GRAB (Percro Laboratory)
Haptic device

-3 DOF, Spherical
-0.5 mm – 2 mm resolution
-Cable-driven for back-drivability





Resources Distribution

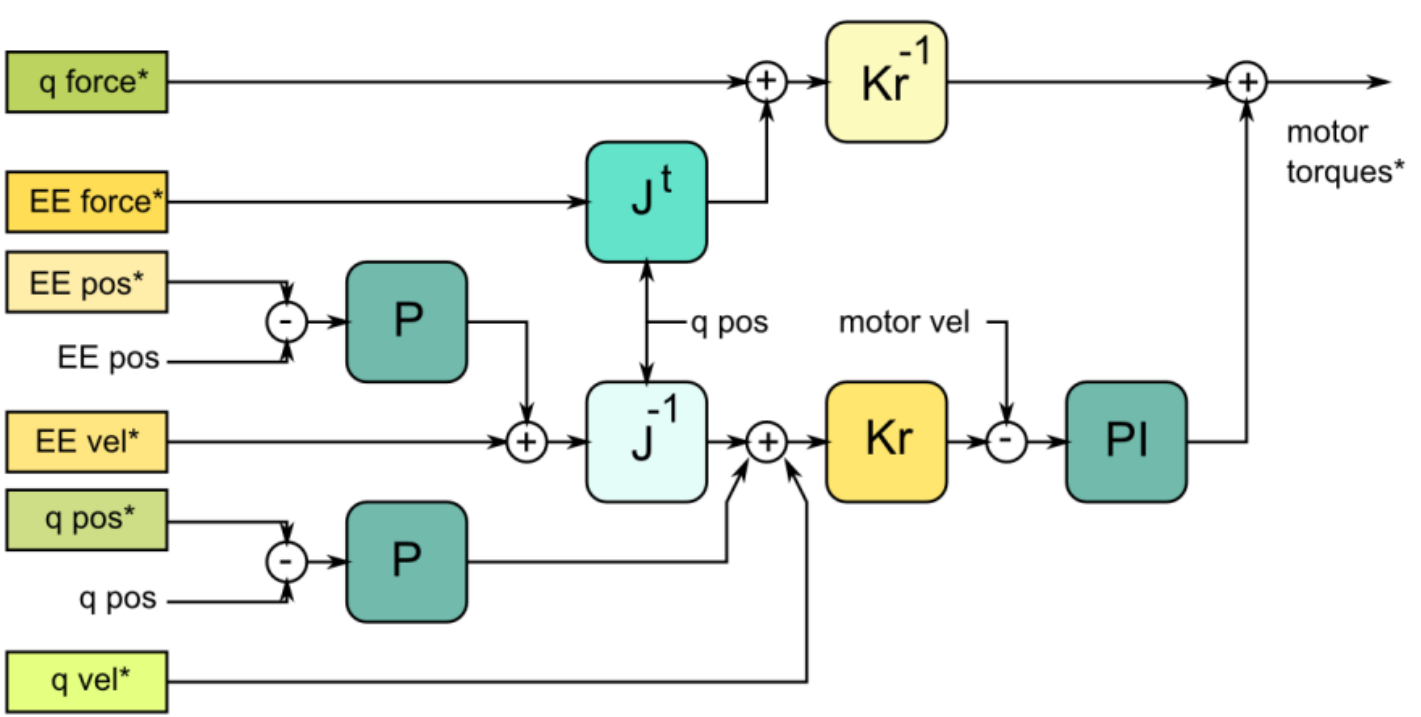


Low-Level Control (C28 DSP)

- Flexible control design for supporting different modalities: Haptic Rendering, Teleoperation, Robotic assistance/guidance, Calibration

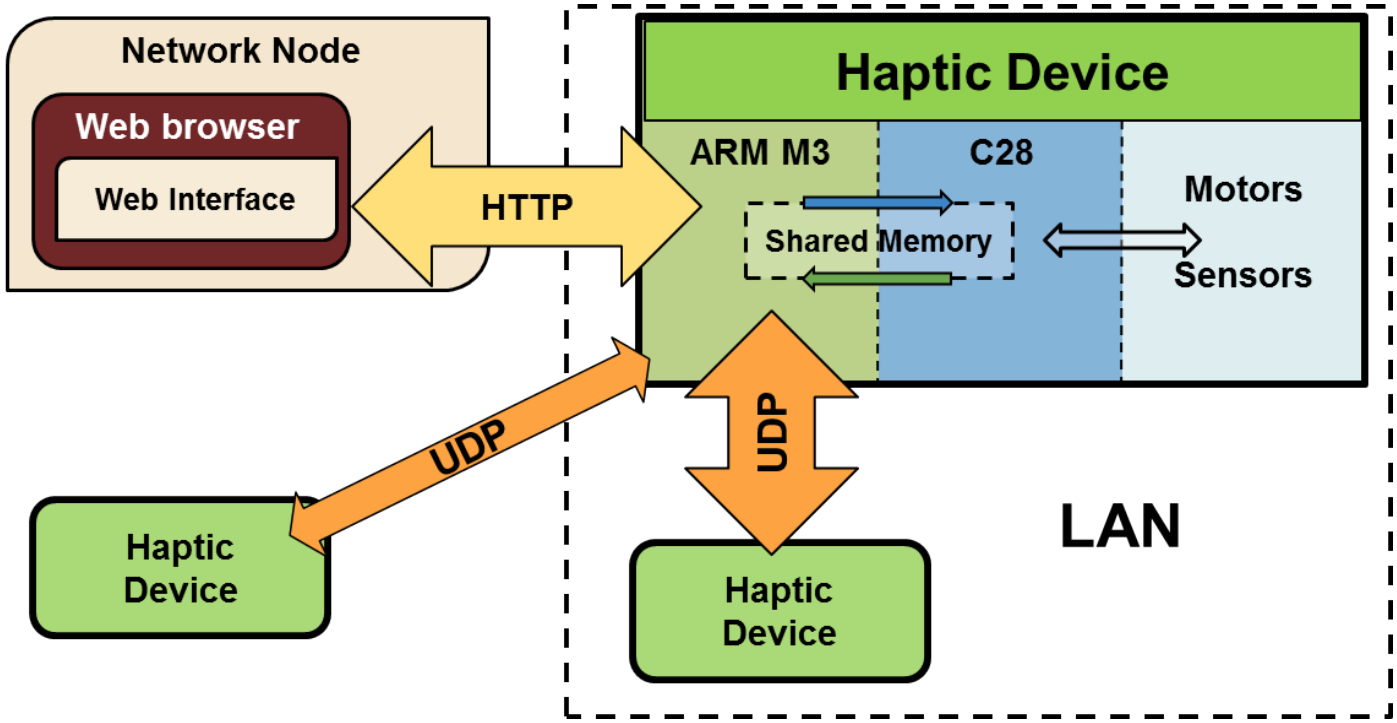
- Safety limits implemented on force, velocity , position at joints and end-effector

- DSP programmed through Matlab Simulink and TI C2000 compiler



High-Level Interface And Networking

- Networking and user interface managed by the ARM Cortex-M3 core, with **basic Web Server functionalities**
  - Network capabilities provided by lwIP
- **Graphic interface accessible** by a **Web browser**, with full access to low-level variables and configuration saved on a SD card.
  - HTTP requests with JSON messages
- **UDP** communication configurable for fast data exchange (force-feedback loops) between nodes



Operative Modalities

Communication protocols for different operative modalities:

Web User Interface (HTTP)

Diagnostics (HTTP):

- Parameters tuning
- Control loop test
- Data record/ graphs

Embedded Haptic Rendering (HTTP):

- Programmed local position-force law
- Embedded position-force loop

Remote Haptic Rendering (UDP) :

- Position-force loop with connected clients

Teleoperation (UDP):

- Position - position loop with second haptic device

System Evaluation and Performances

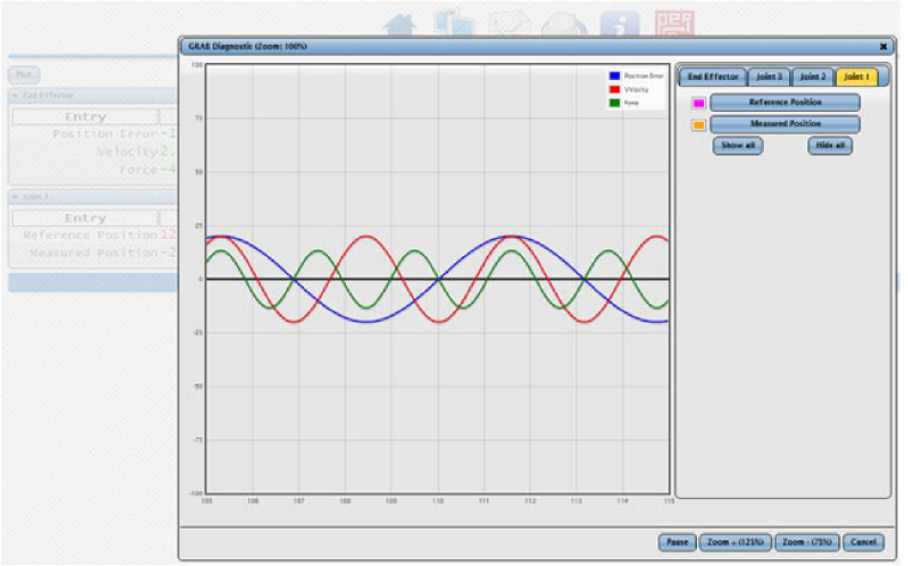
HTTP 1.1 services performances:

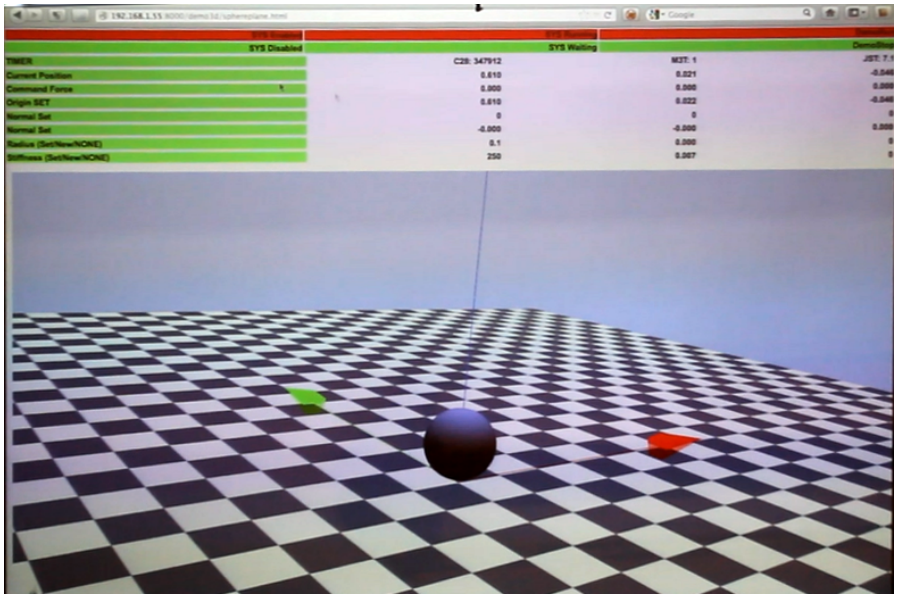
- 150 Hz serving AJAX requests, 200 bytes max. tested payload

- Tested using the **Web interface**, diagnostics (parameters set and read for **real-time plotting**), **embedded haptic rendering**
- HTTP 1.1 implemented as a customization of lwIP

UDP communication performances:

- 2 KHz roundtrip, 50 bytes payload.
- Tested with **haptic rendering** and **teleoperation**, (position-force **closed-loop** at **1 KHz**).





System Evaluation and Performances

Remote, haptic enhanced web application (physics demo from Box2D library) was implemented using **implicit spring**:

- Physics are computed remotely by the Web browser

- Virtual and real end-effectors connected by an imaginary over-damped spring (this overcomes instability due to latency and low data rate).

VIDEO

Conclusions

We presented an embedded haptic controller providing the following functionalities

- **Stand alone**, low cost control board (Concerto microcontroller with double DSP ARM core), only power and Ethernet cablesneeded.

- Implements **full control** of the haptic device, including kinematics, control loops, sensor acquisition and actuator's driving, safety limits.

- Provides **high-level communications** through HTTP and UDP and stand alone networking functionalities (Web Server, web applications)

- **Web accessible user interface**, with diagnostics and system configuration

- **Flexible operative modalities**, including haptic rendering, teleoperation, embedded haptic rendering

Future Work

Possible directions:

- **Support for autodiscovery through mDNS or UPnP**

- Websocket for higher data rates over HTTP

- Implementation of model based rendering on the embedded system with limited computational cost (splines for fixtures or implicit surface rendering)

- Testing in different architecture, e.g. STM32, when no dual-subsystem is present

ISTITUTO
DI TECNOLOGIE DELLA
COMUNICAZIONE,
DELL'INFORMAZIONE
E DELLA
PERCEZIONE

Scuola Superiore
Sant'Anna

Thank you for your attention,

Questions?

Daniele Leonardis: d.leonardis@sssup.it

PERCRO Perceptual
Robotics Laboratory