Leveraging the Cloud to Develop Service Robotics Applications

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Outline

- Introduction and Motivations
    - Context of my PhD Activity
    - Overview on Service Robotics and Cloud Robotics
- Cloud Robotics Platform (by TIM) and my contributions
- Architectural Patterns to develop Cloud based Robotics Applications
    - Environmental Monitoring
    - Telepresence and Telemanipulation
- Service Robotics applications prototypes
    - Robot@CED
    - PARLOMA
- Other Results and Conclusions

TIM JOINT Open Lab

CRAB
Connected Robotics Applications Lab

- Research Labs of TIM placed in several Italian Universities under a Open Innovation Program
- **Main Goal**: encourage universities and researchers to develop market ready technologies
- **TIM JOL CRAB**: Connected Robotics Application Lab

Service Robotics

A service robot is a robotic system design to assists human beings

Service Robotics: professional VS personal

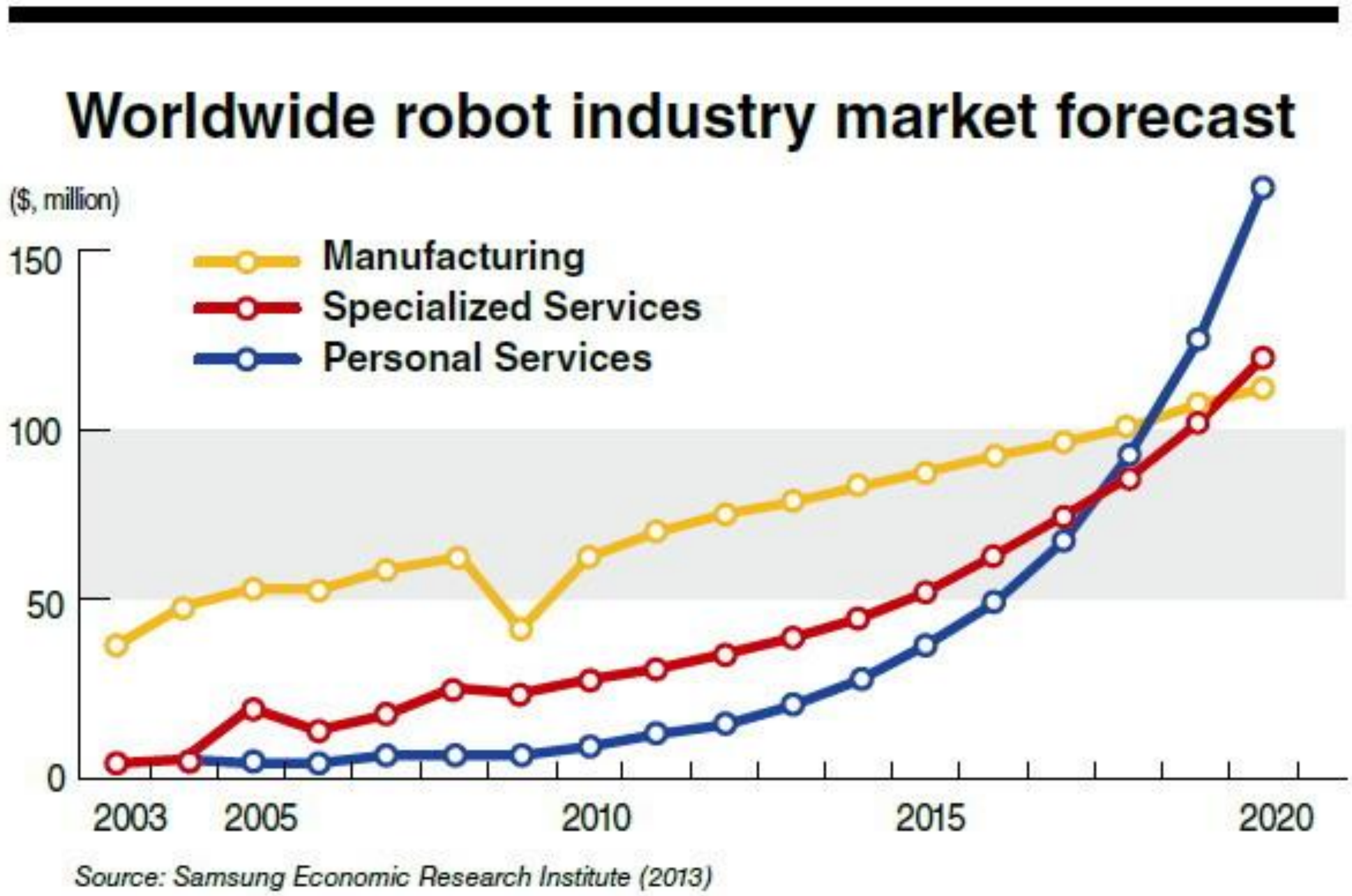
Professional Service Robots help people in their workplace:

- Agriculture
- Logistics
- Security & Monitoring
- ...

Personal Service Robots assist people to perform domestic tasks:

- Vacuum Cleaners
- Toys & Education
- Disable people assistant
- ...

Service Robotics Market is Growing fast



Service Robotics - Technological Constraints

A Service Robot usually runs under **unstructured environment**:

- high intelligence needed to solve tasks that are very simple for humans (Navigation, Grasping ...)
  - Manage high quantity of data from the environment
  - Develop high level models
  - Make decision fast
- Battery Capacity
- Size and weight of the Robot (drones)
- Costs

Cloud Robotics

- A paradigm to solve the constraints of Onboard Intelligence of Service Robotics
- Leverage Internet Based Technologies in order to offload
- Introduced in 2010 by James Kuffner
- IoT, Industry 4.0
- It aims at **leveraging internet based technologies to enhance robotics application**

Cloud Robotics - Advantages and Issues

According to [Ben Kehoe et al.], the advantages of Cloud Robotics are:

- Cloud Computing
- Big Data
- Collective Robot Learning
- Human Computation (telepresence)

And also some Issues:

- New level of Complexity in the development of a Robot Application
- Real Time is not guaranteed

Ben Kehoe, Sachin Patil, Pieter Abbeel, and Ken Goldberg. A survey of research on cloud robotics and automation. Automation Science and Engineering, IEEE Transactions on, 12(2):398–409, 2015.

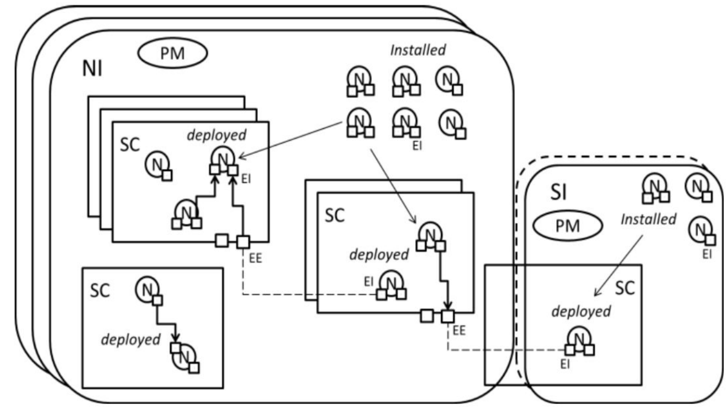
ROS: the Robot Operating System

- **Framework for Robot Application Development**
  - OS-like functionalities (meta-operating system)
  - Hardware Abstraction / Drivers
  - Multiprocess Communication
  - Package Management
- **Collection of Libraries, Tools and Conventions**
  - Stacks
  - Packages
- **Ecosystem and Community**

TIM Cloud Robotics Platform

TIM Cloud Robotics Platform

- Platform as a Service (PaaS) to develop Robot Application
- ROS Network Across Remote Machines and Robots
- Simple Restful API to manage the Platform



My Contributions

- Develop a Cloud Manager to remotely handle a ROS Network (shared by the platform).
- Design novel Robot Frameworks to develop service robotic applications.
- Prototype Robot Applications based on those frameworks.
    - Robot@CED
    - PARLOMA
    - ...

Cloud Robot Application Manager - Specifications

- Common Needs in a Cloud Robotics Application
  - Cloud Storage (TIM)
  - Cloud Computing (TIM)
  - Web-based User Interface
  - Development Tools
- Developing a general pattern to simplify the development of a cloud robotics application
  - RESTFul API to Interact with ROS Machines
  - Remote programming and debugging the application

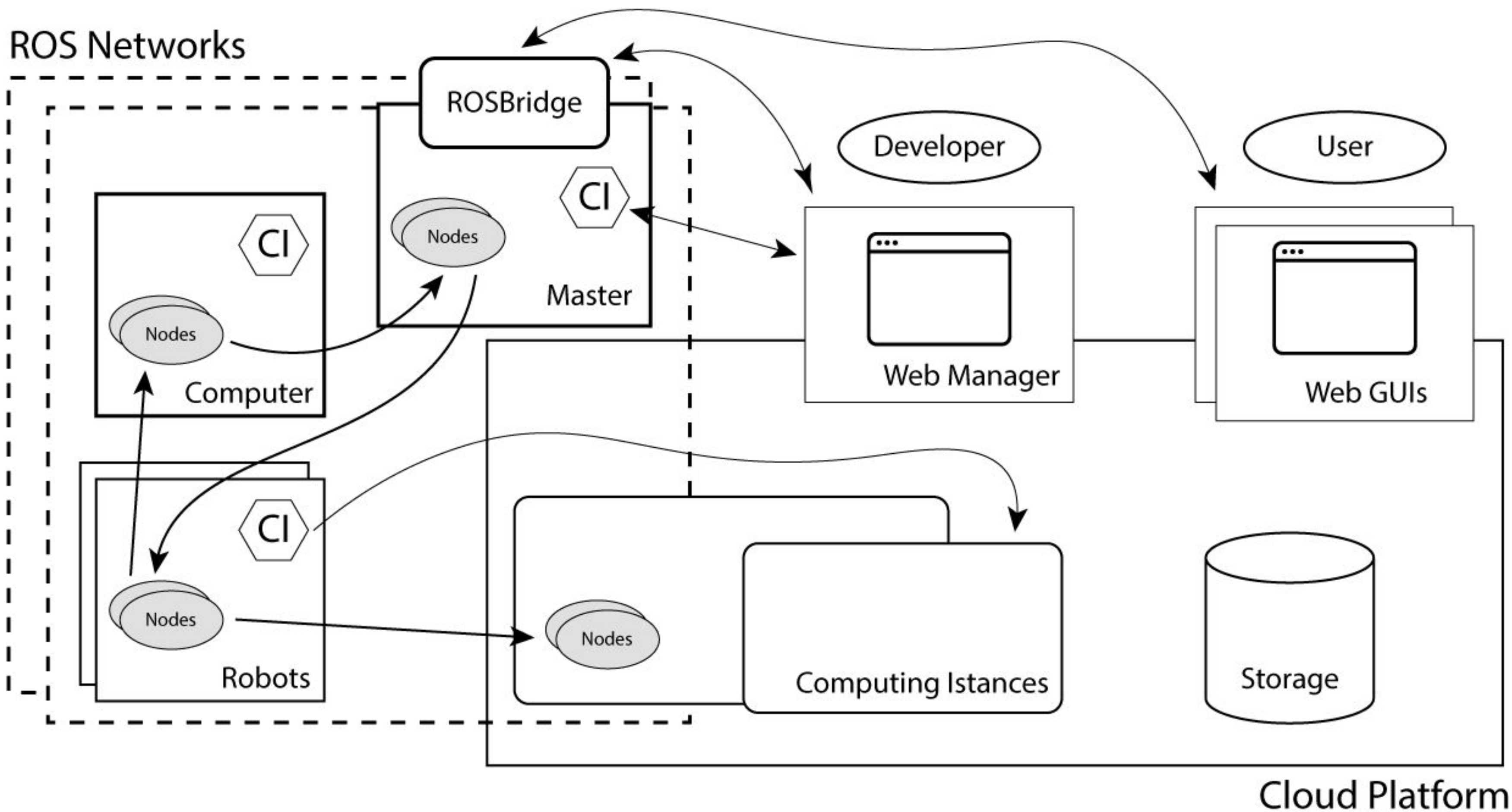
Topics List

Name	Type	Actions
/hotbot/led	dotbot_msgs/Led	Close
/rosout	rosgraph_msgs/Log	Echo
/hotbot/speed	dotbot_msgs/Speed	Echo
/rosout_agg	rosgraph_msgs/Log	Echo
/diagnostics	diagnostic_msgs/DiagnosticArray	Echo
/hotbot/input	dotbot_msgs/Input	Echo

/hotbot/led


```
{
  "led1": false,
  "led3": false,
  "led2": false
}
```

Cloud Robot Application Manager - Architecture



Robot Based Environmental Monitoring

Robot Based Environmental Monitoring

Sensor Networks

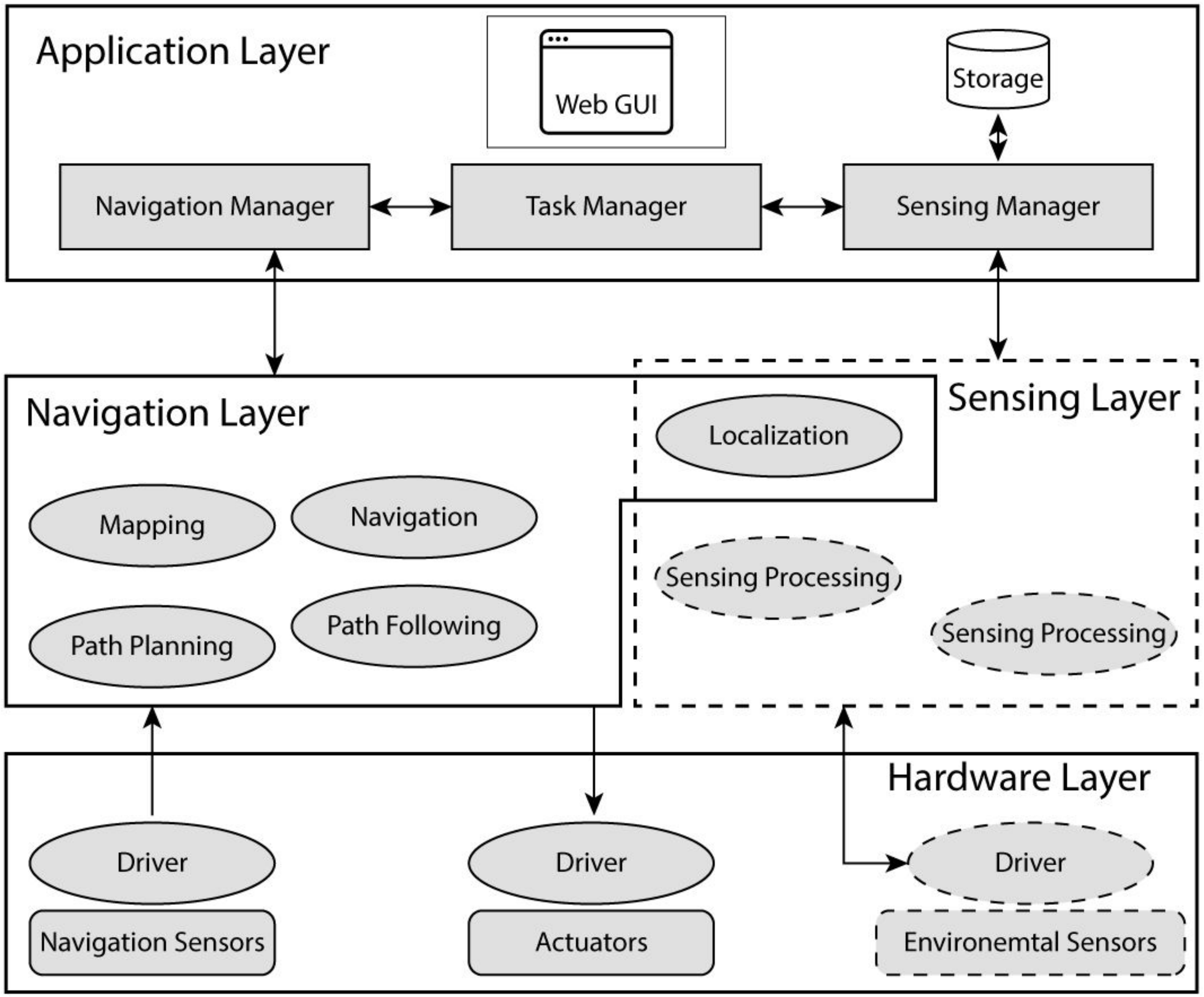
- Sensor Networks are a common application of IoT
    - Distributed Network of Sensors managed by a cloud application
- Application
    - Monitoring
    - Diagnostic

Real Case Applications
- Robot@CED
- Wifi Coverage Monitoring (future works)

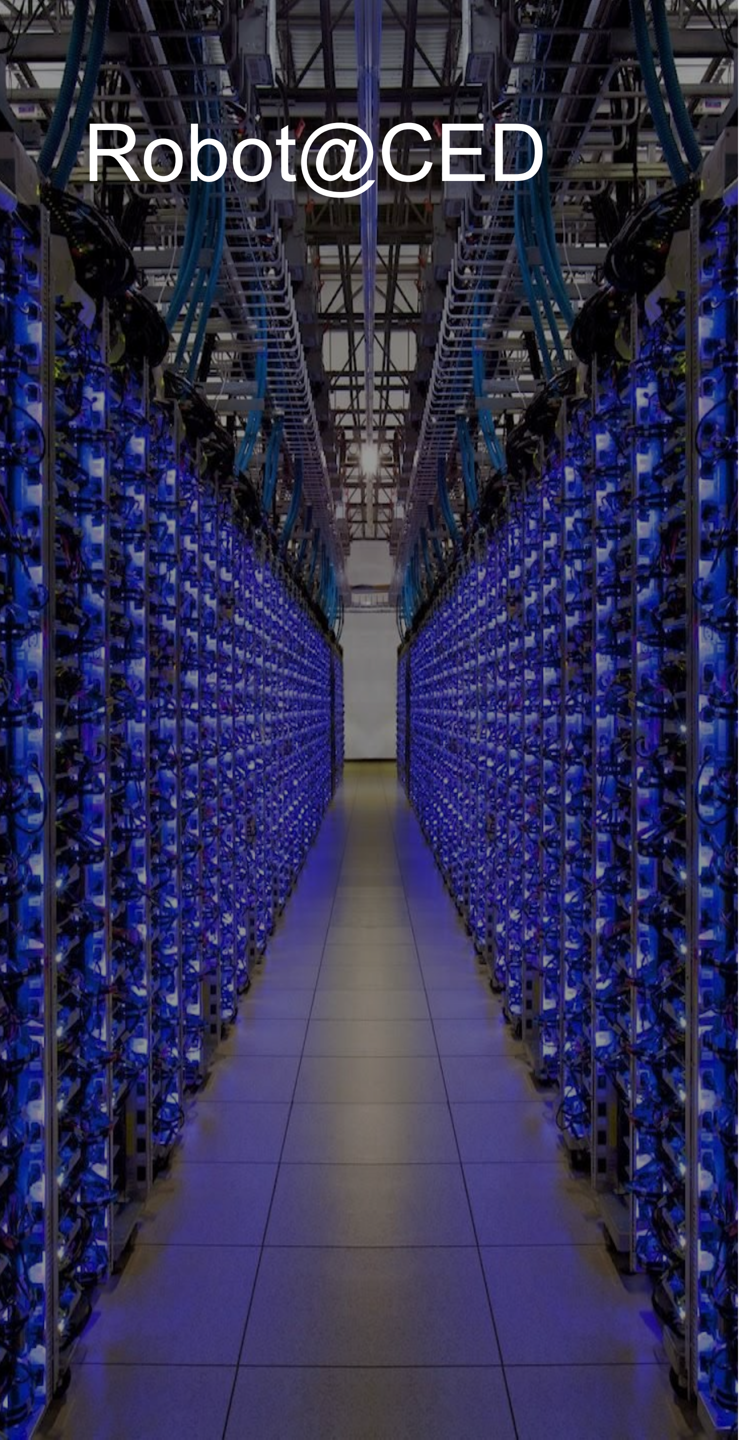
Virtual Sensor Network

- A Cloud Robotics Alternative to Sensor Networks:
    - Mobile Robot
    - Autonomous Navigation
    - Environmental Sensors Onboard
    - Centralized Management
- PROS:
    - Simple to manage and configure
    - No Intervention on the environment
    - Reconfigurable
    - Scalable
- CONS:
    - No RT Measurements
- Why Virtual?
    - Transparent to the User
    - Robot Tasks are localized sources of Measurements
    - The User can Reconfigure the system from a Web Interface

Virtual Sensor Network - Architecture



Robot@CED

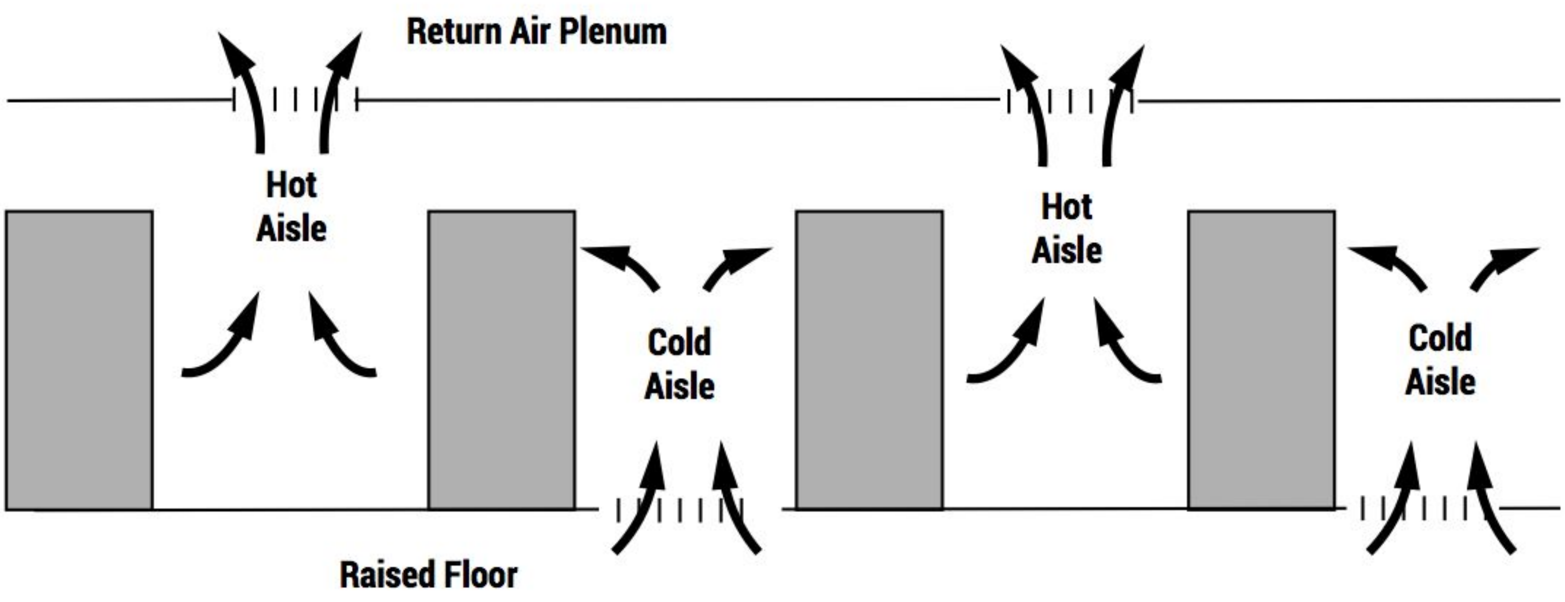


- Data Center are the most energy consumption building in the world
  - 1.5% of total electrical energy demand
- Energy Management of datacenter is expensive
  - Power the Servers
  - Cooling System
- PUE: Power Usage Effectiveness
  - 1.7 avarage

$$PUE = \frac{P_{tot}}{P_{IT}}$$

Free Air Cooling System

- The hot/cold Aisles layout maximizes the air cooling capacity
- Cold Air temperature and humidity must be controlled
  - **Optimal Ranges [20-24]°C - [40-55]%**



Data Center Monitoring

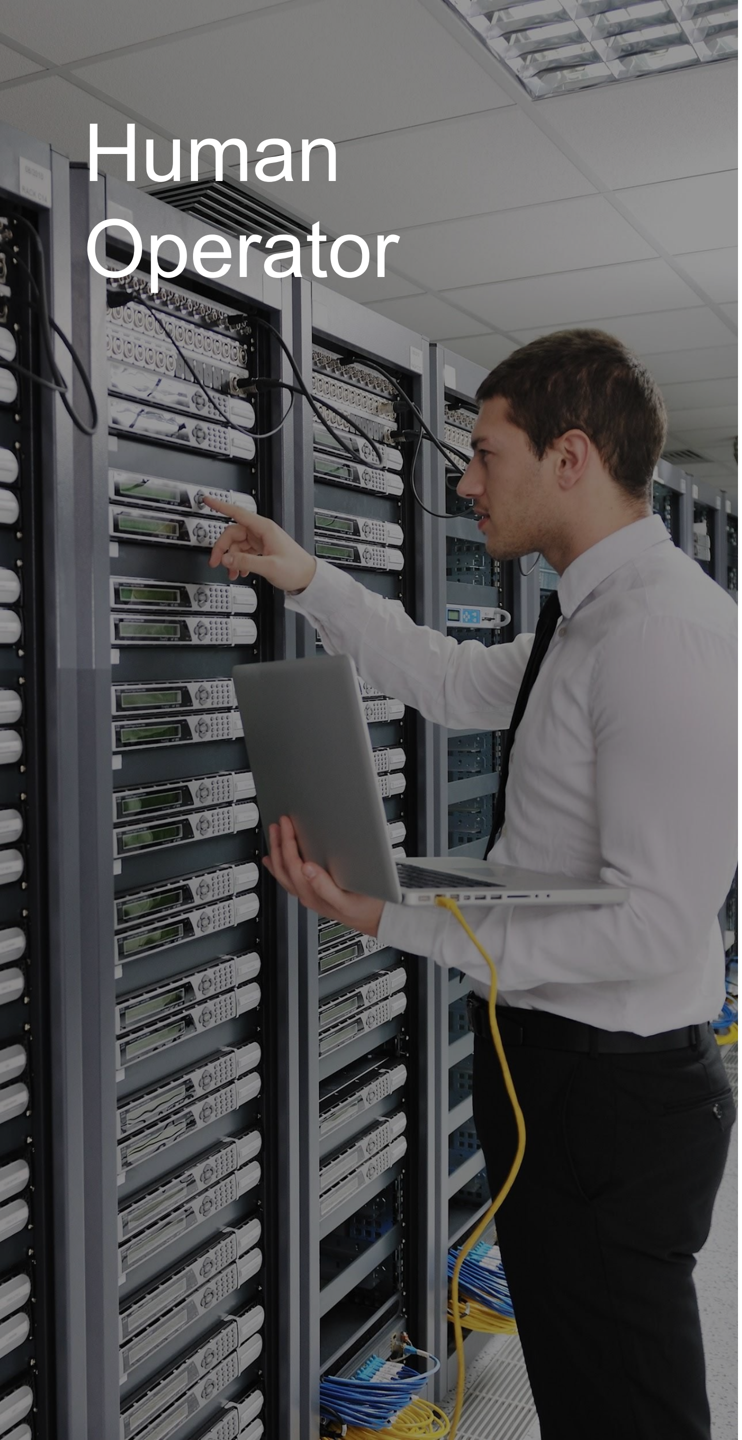
All the solutions aimed at monitor temperature and humidity values in datacenter in order to

- Maintain the Air values in the suggested optimal ranges
- Detect HotSpots

Environmental Sensor Networks

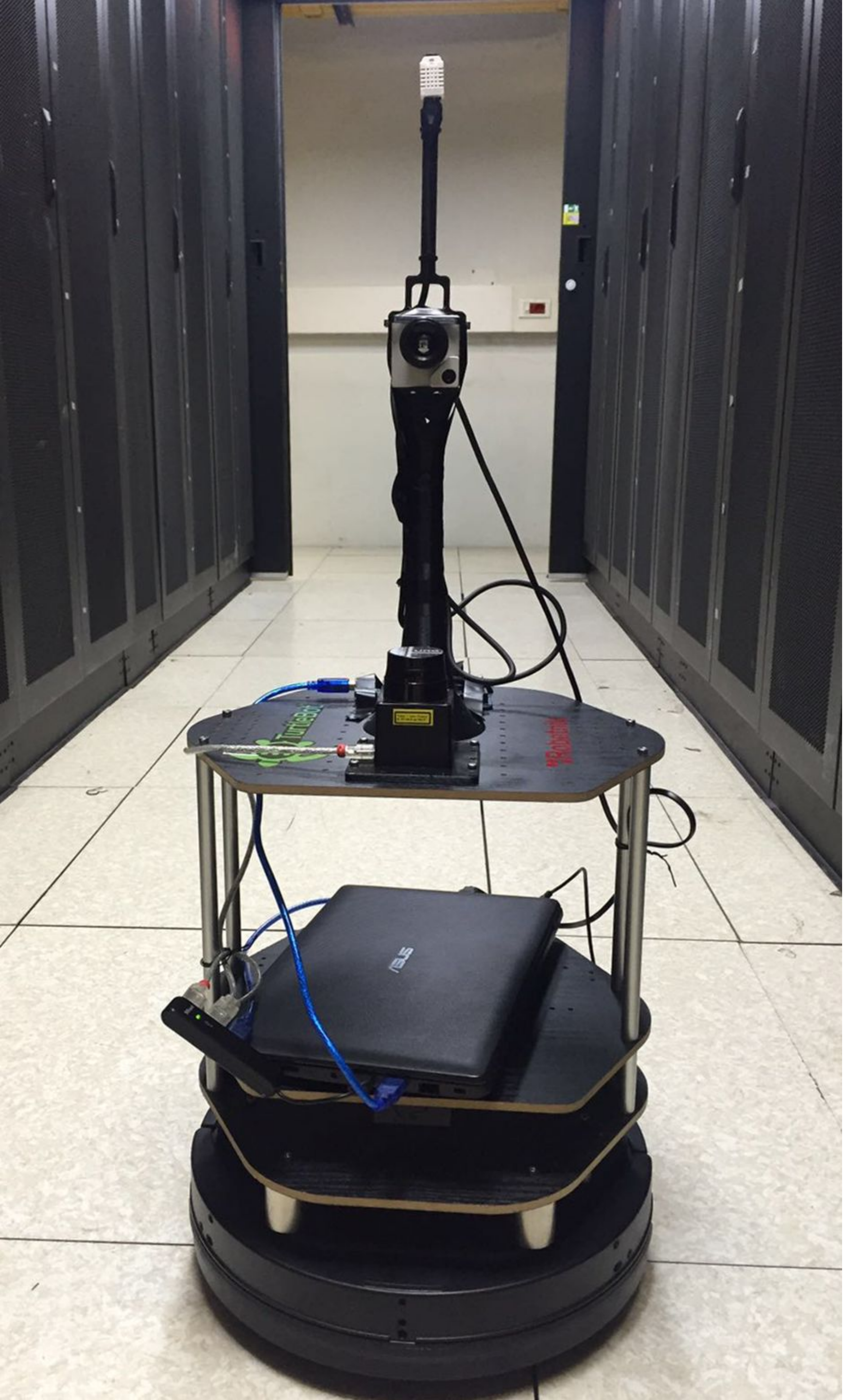
State of the Art Solution to fully measure the Area

- Dense Sensing Network
  - Measurements Nodes (sensors) placed in each rack
- PRO:
  - RT measurements
- CONS
  - Not scalable
  - High installation and maintenance costs
  - Difficult to manage



Practical Solution Adopted by Data Center Managers

- Sparse Sensor Network
  - Few Nodes each Room
- Human Operator that periodically inspect the Room



Robot@CED

Data Center Monitoring

Hardware Layer

- A Turtlebot 2 Robot base platform
- Temperature/Humidity Sensor
- Thermal Camera
- Laser Range Finder
- Laptop running ROS

Sensing Layer

- Localized Temperature/Humidity logger
- Localized Thermal Images logger
- HotSpot Autodetection Algorithm

Experiments and Results

We tested the application in two Real Scenarios:

1. Rozzano Data Center of Telecom Italia
   a. the bigger Data Center in Italy
   b. Tests performed in two rooms
   c. NDA agreement
2. Data Center of Politecnico di Torino
   a. Composed by three small rooms
   b. Hold the University IT Infrastructure

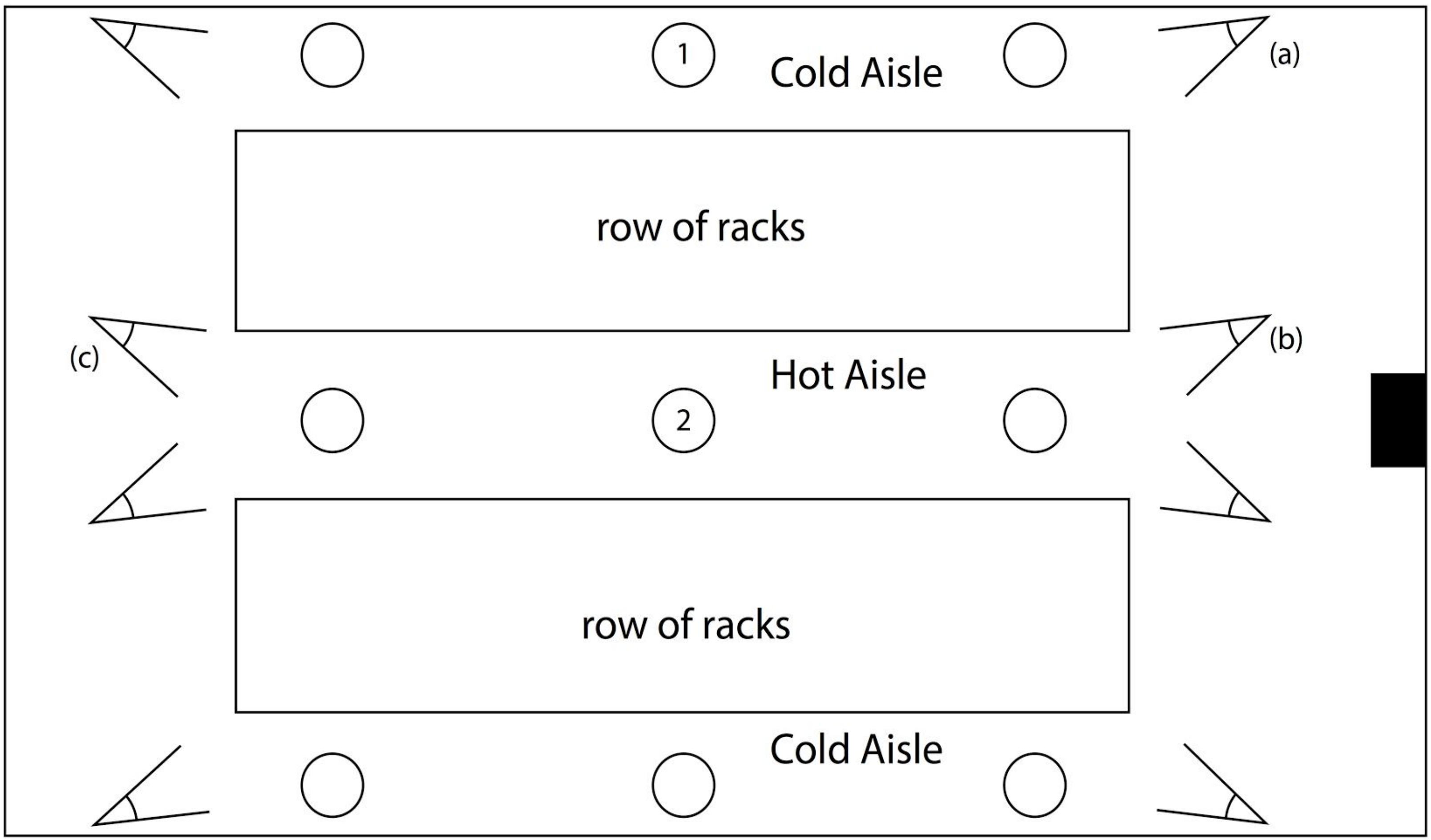
Experimental Setup

Thanks to
- Marcello Maggiora

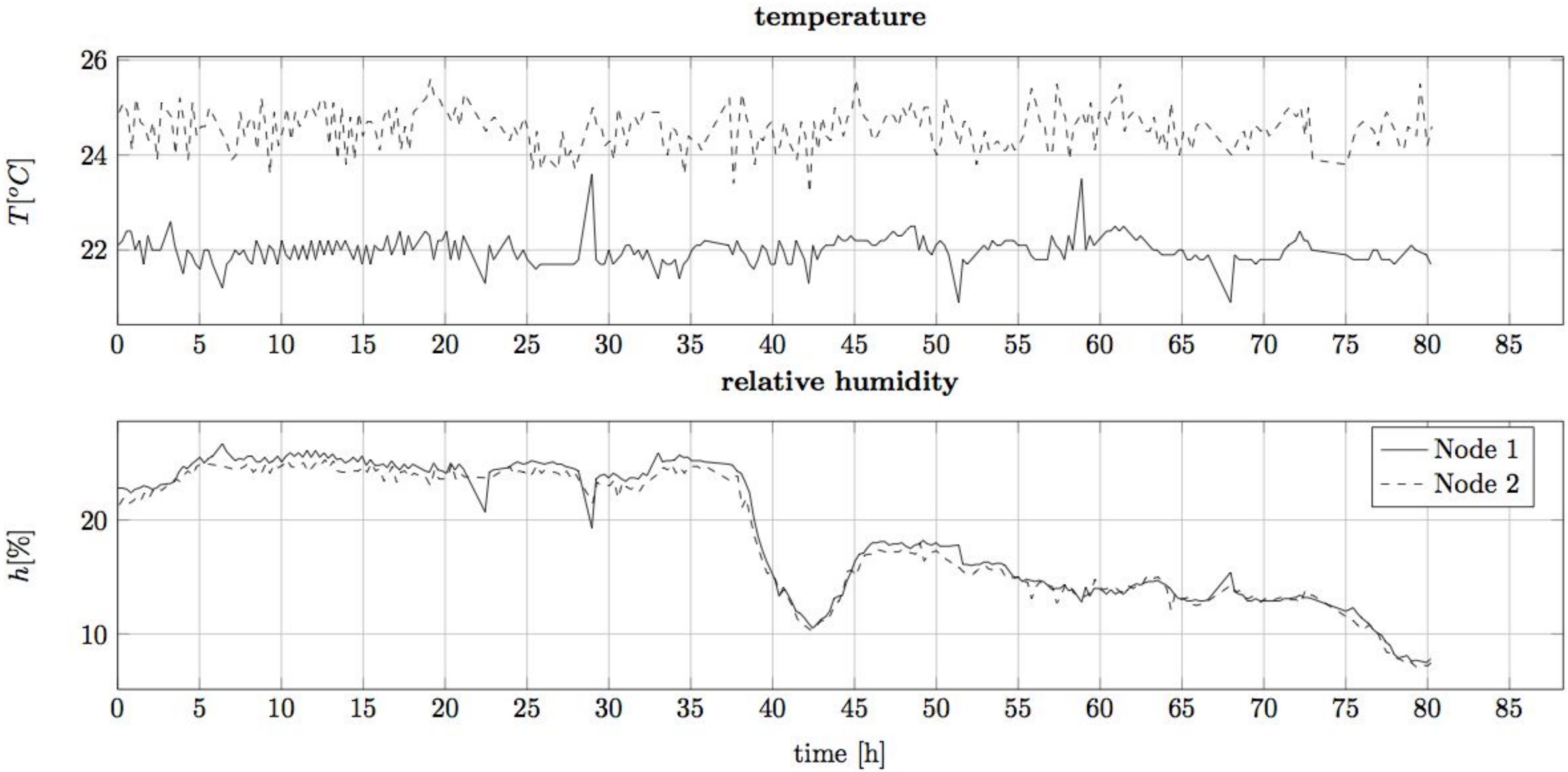
- Data Center of Politecnico di Torino
  - PUE = 1.53
  - 2 racks rows: 1 hot aisle and 2 cold aisles
- Security
  - Dedicated WiFi network
  - VPN to remote access
- Mapping in 5min
- 10 minute of recharging after each mission

Mission Setup

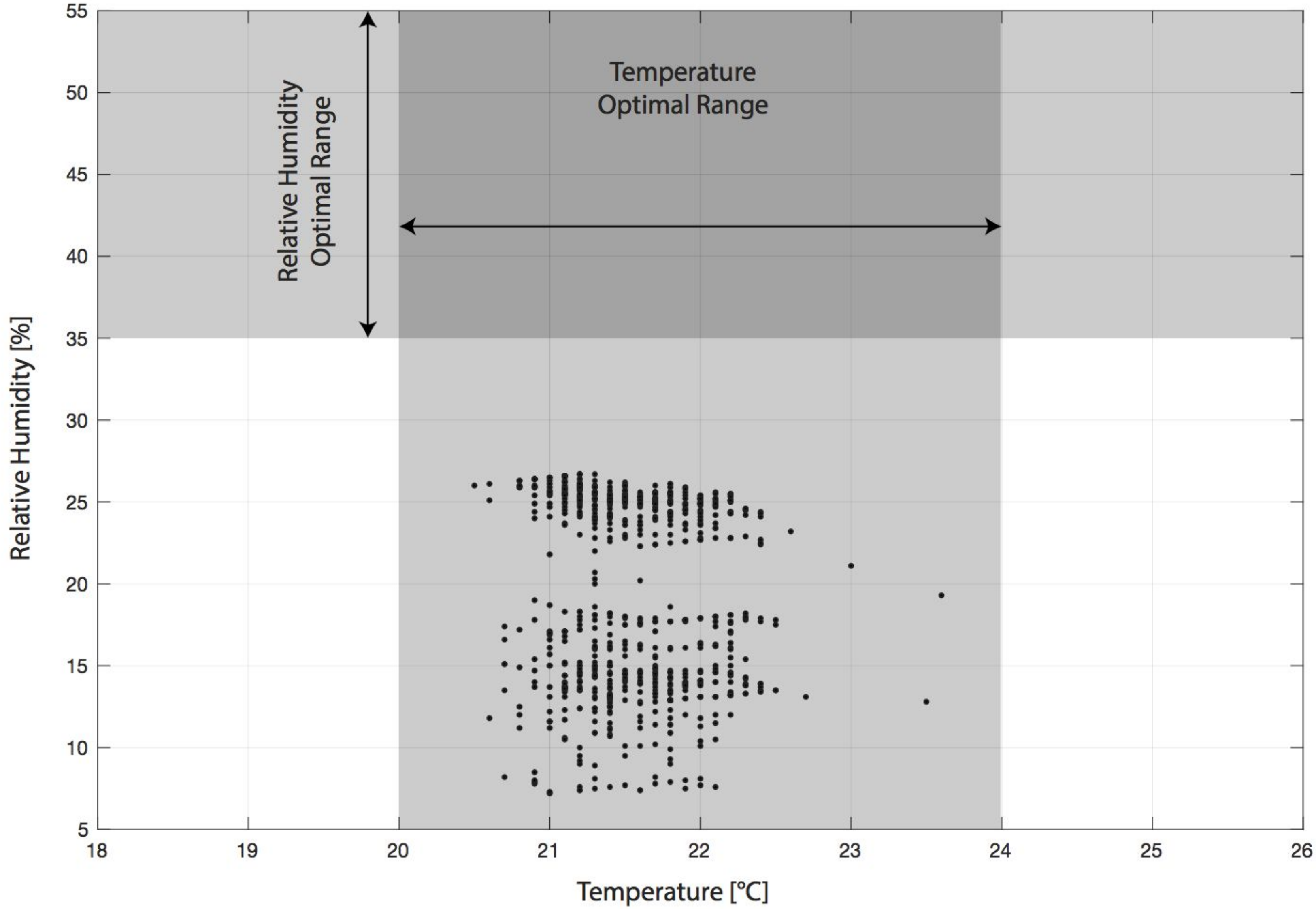
Each Mission takes about 6min



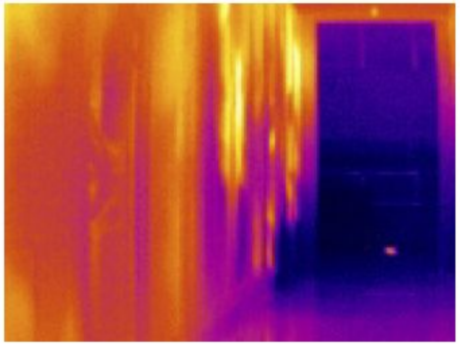
Collected Temperature/Humidity data (1)

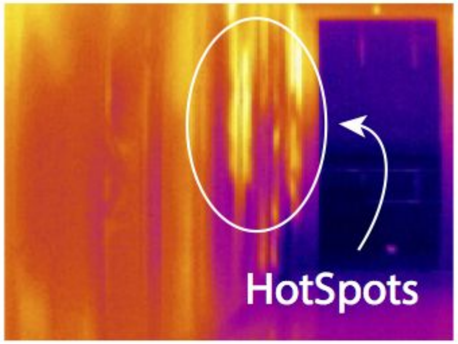


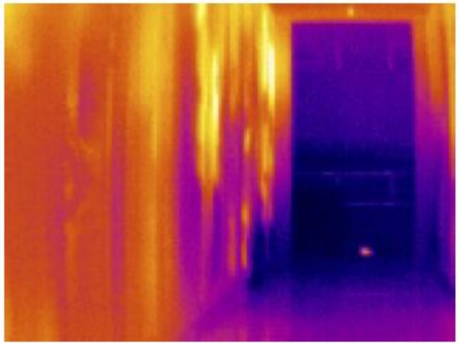
Collected Temperature/Humidity data (2)

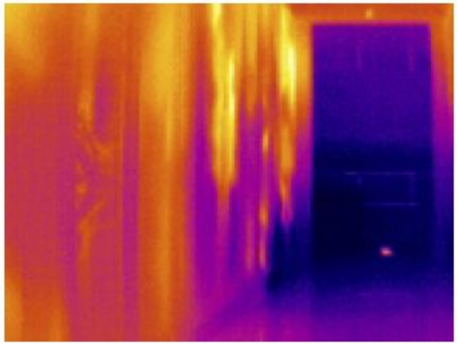


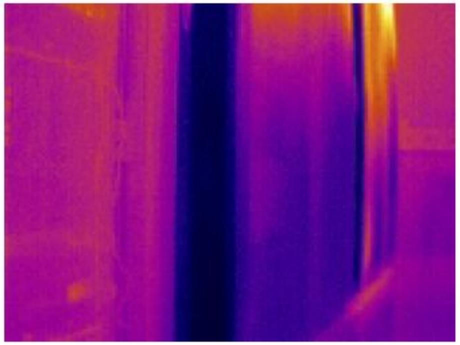
Thermographic analysis (1)

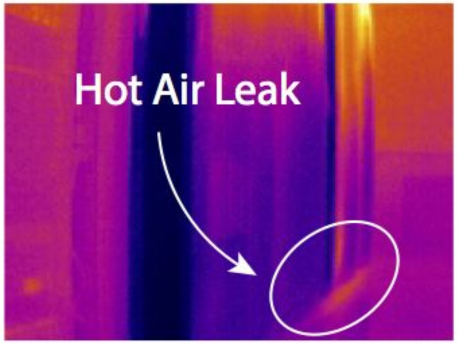


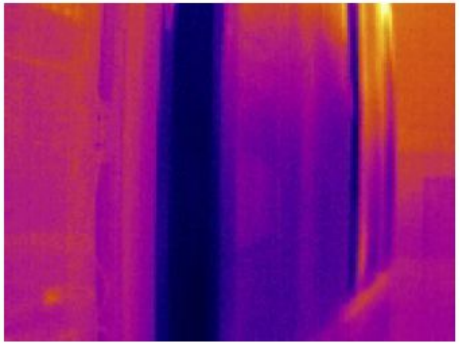


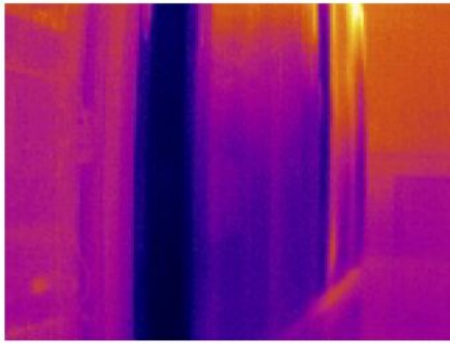










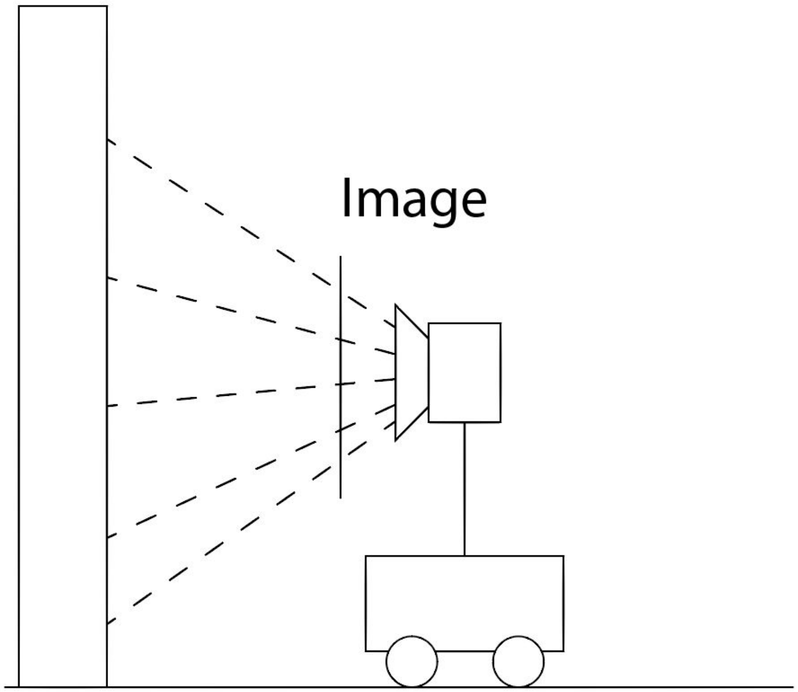


Thermographic analysis (2)

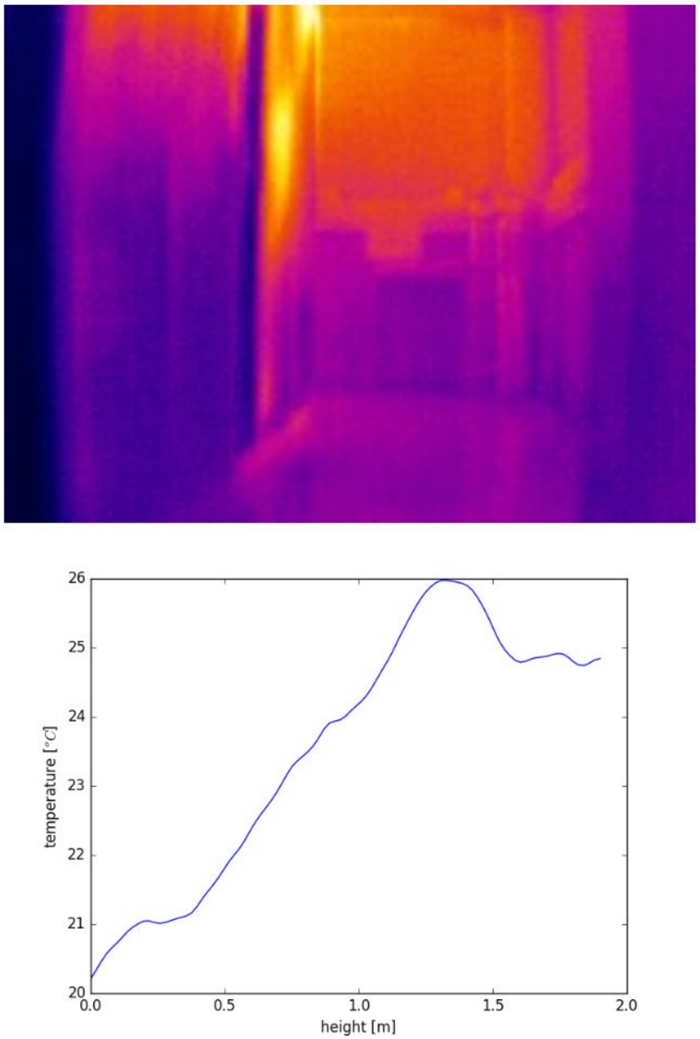
$$p_i^{(k)} = \begin{pmatrix} x_i \\ y_i \\ h_i^{(k)} \end{pmatrix}, h_i^{(k)} = \frac{k}{N+1} h_{max}, k = 1, ..., N.$$

$$\tilde{p}_i^{(k)} = \lambda \begin{pmatrix} p_i^{(k)} \\ 1 \end{pmatrix} = KT \begin{pmatrix} p_i^{(k)} \\ 1 \end{pmatrix}$$

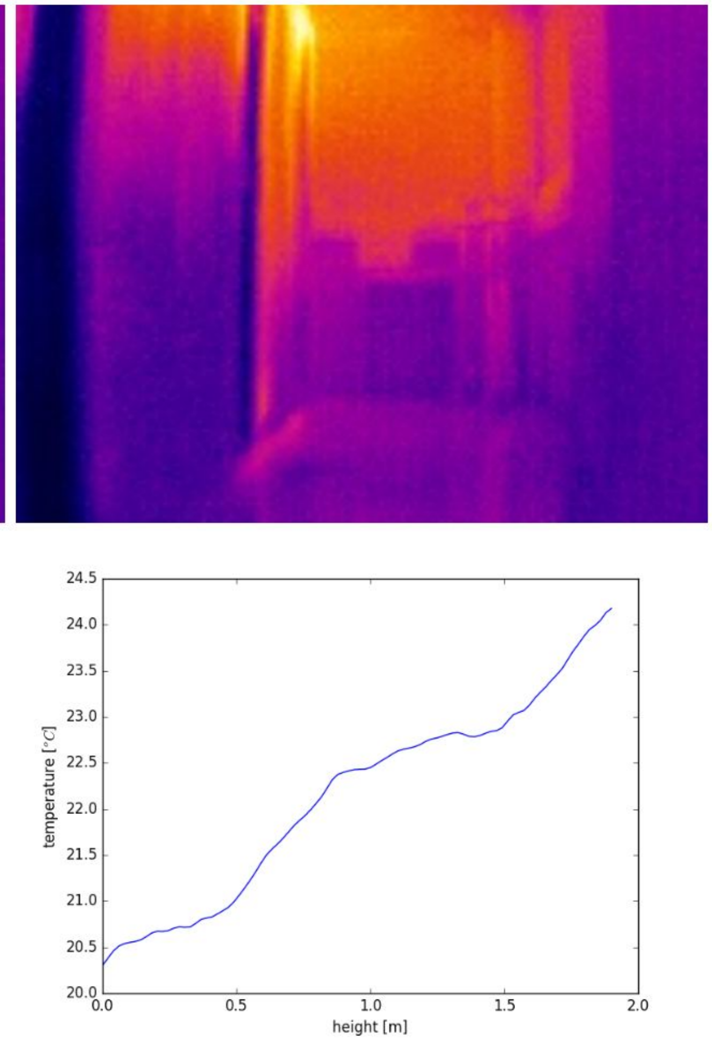
$$T_i^{(k)} = \mathcal{I}\left(p_i^{(k)}\right).$$



Thermographic analysis (3)



(a) Rack without protection panel.



(b) Rack with protection panel.

Telepresence and Telemanipulation

Robot Teleoperation Based on Natural Interfaces

Telepresence

- New application of Robotics that allow a user to interact with a remote environment

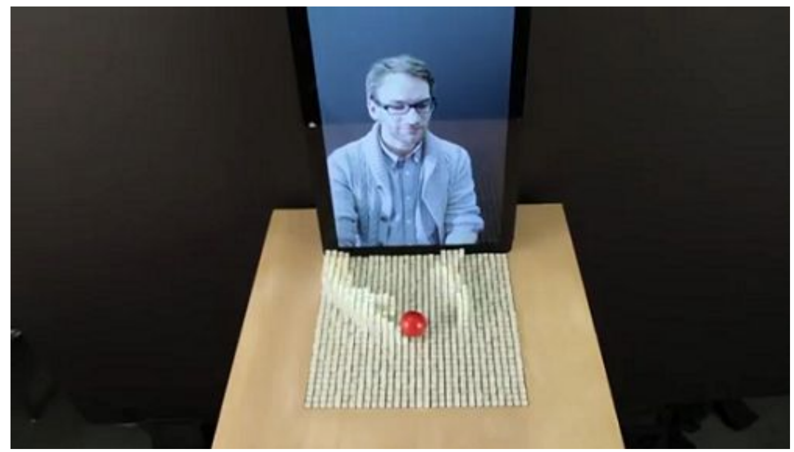
Common Needs

- An Internet communication channel
- Input Processing
- Classification Algorithm

Real Case Application
- PALOMA
- Tele-rehabilitation

Natural Interface

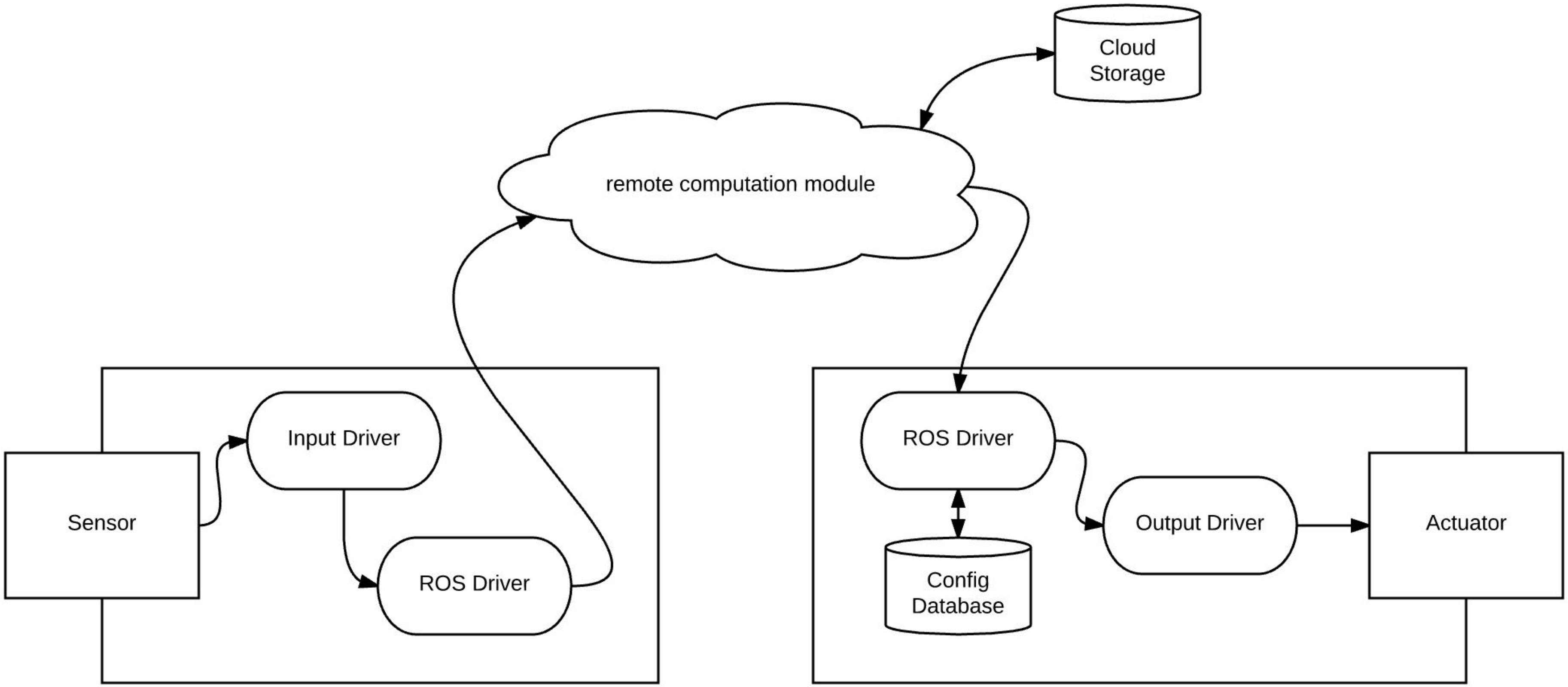
- An Intuitive Interface between the User and a Computer.

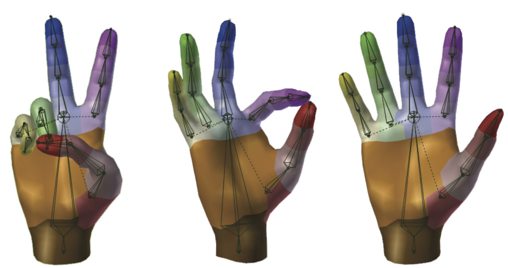


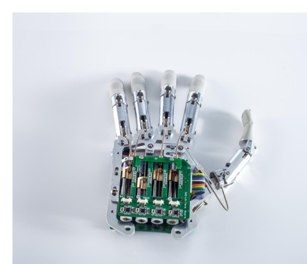
Contributions

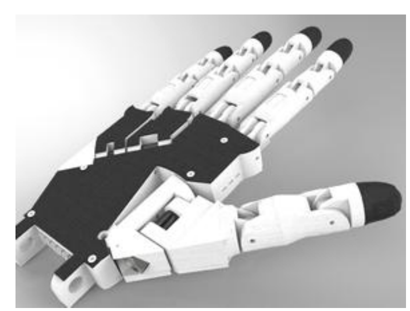
- Giuseppe Airò Farulla (PhD prof. Prinetto)
- Sant'Anna di Pisa, Biorobotics Institute
- CNR IEIIT

Robot Teleoperation Based on NI - Architecture









PARLOMA: A Telecommunication System for deafblind People

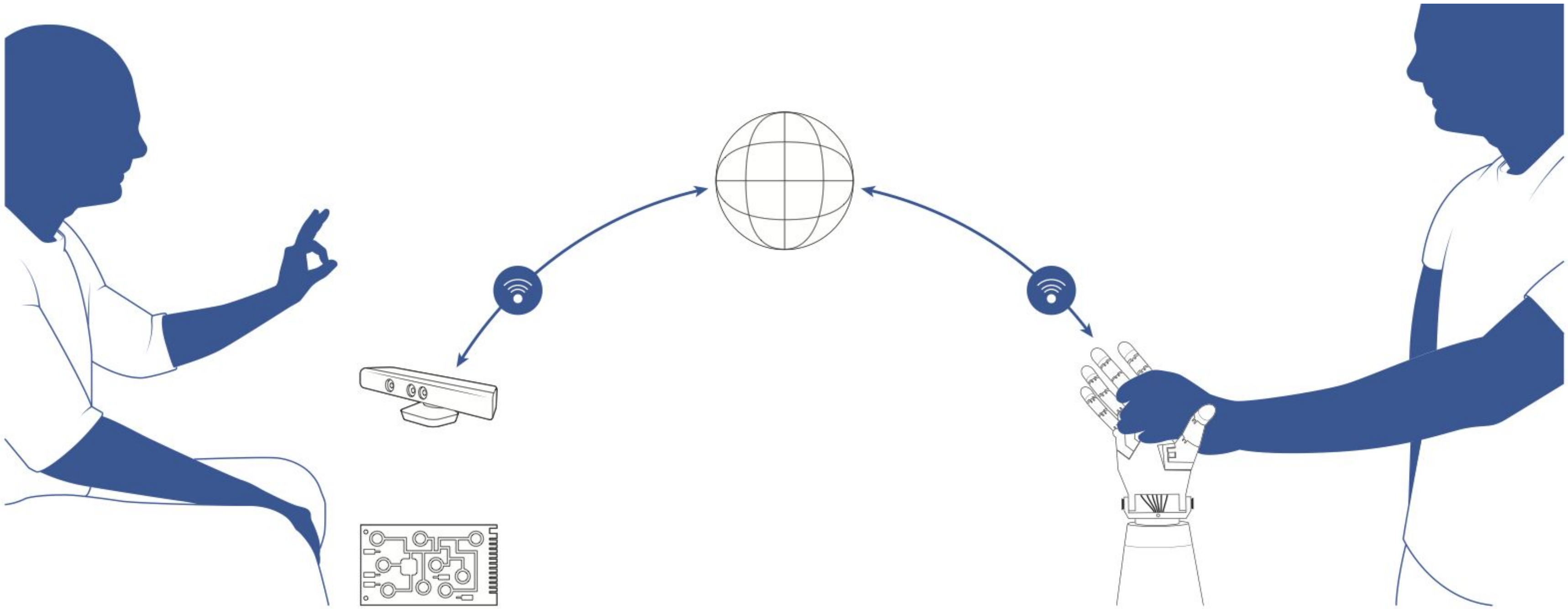
Deafblindness force people to live in isolation:

- Severe disease
- Strong limitation in communication
- Communication capabilities depends on the nature of this condition

One (but not unique) group of communication languages are the **Tactile Sign Languages (tSLs)**:

- pseudo-languages derived from SLs
- Tact sense used instead of sight
- People needs to be in the same place to communicate in tSL.

PARLOMA is a research project that aims at developing a system able to remotize tSL communication, to help deafblind people to communicate



Input Device

Cloud Robotic Platform

Reproduction

Robotic Hand printed Using the Open Source 3D printer Ultimaker

Experiment 1: Feasibility of the Project

- Prensilia Robot Hand, designed by Sant’Anna di Pisa
- Deafblind person was asked to recognize different handshapes performed manually by the hand
- The user was able to recognize all the handshapes that the hand was able to reproduce.

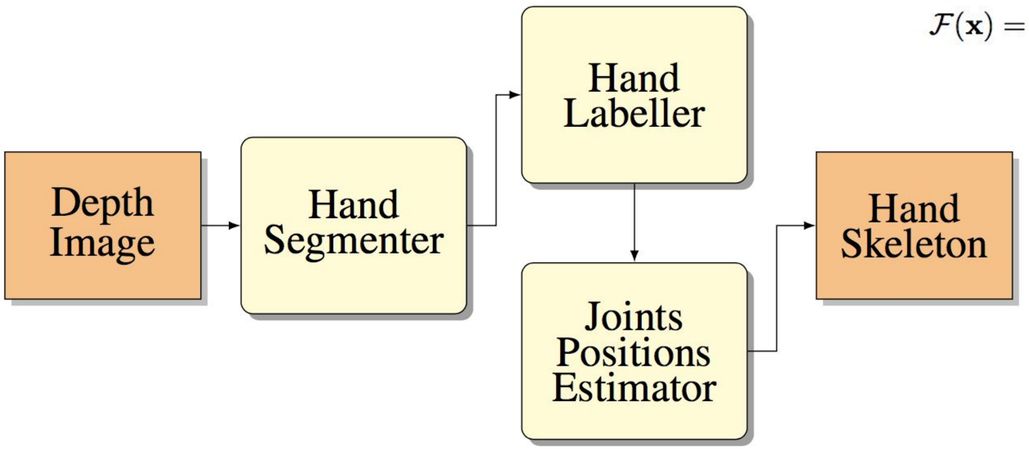
Problems:

- Not enough DoF to reproduce all LIS Signs
- Thump difficult to recognize

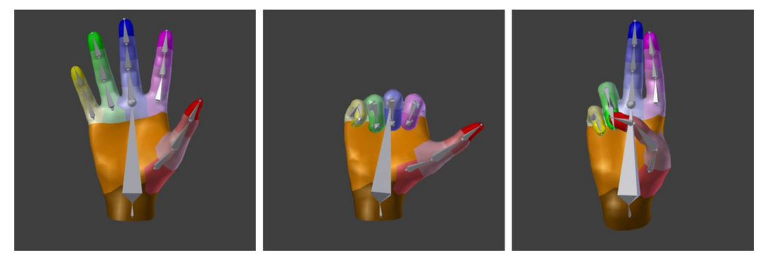
Hand Tracking (RGBD)

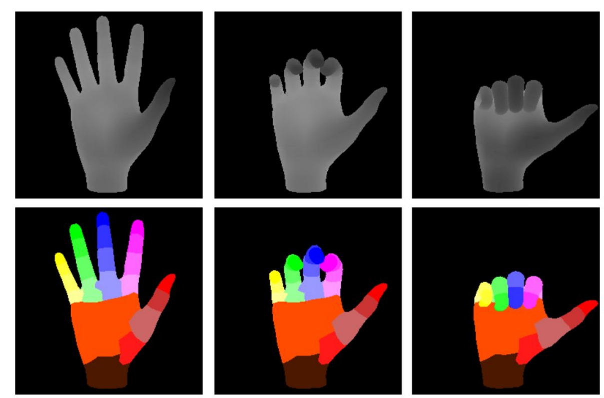
Hand Labeler using a per-pixel classification based on Random Forest Classifier

$$\mathcal{F}(\mathbf{x}) = \left\{ F_{\mathbf{u},\mathbf{v}}(I,\mathbf{x}) = \sum_{\mathbf{j}\in(\mathbf{u},\mathbf{v})} I\left(\mathbf{x}+\frac{\mathbf{j}}{I\left(\mathbf{x}\right)}\right), ||\mathbf{u}||<R, ||\mathbf{v}||<R \right\}$$



The system has been trained using synthetic data generated by a parametric 3D module





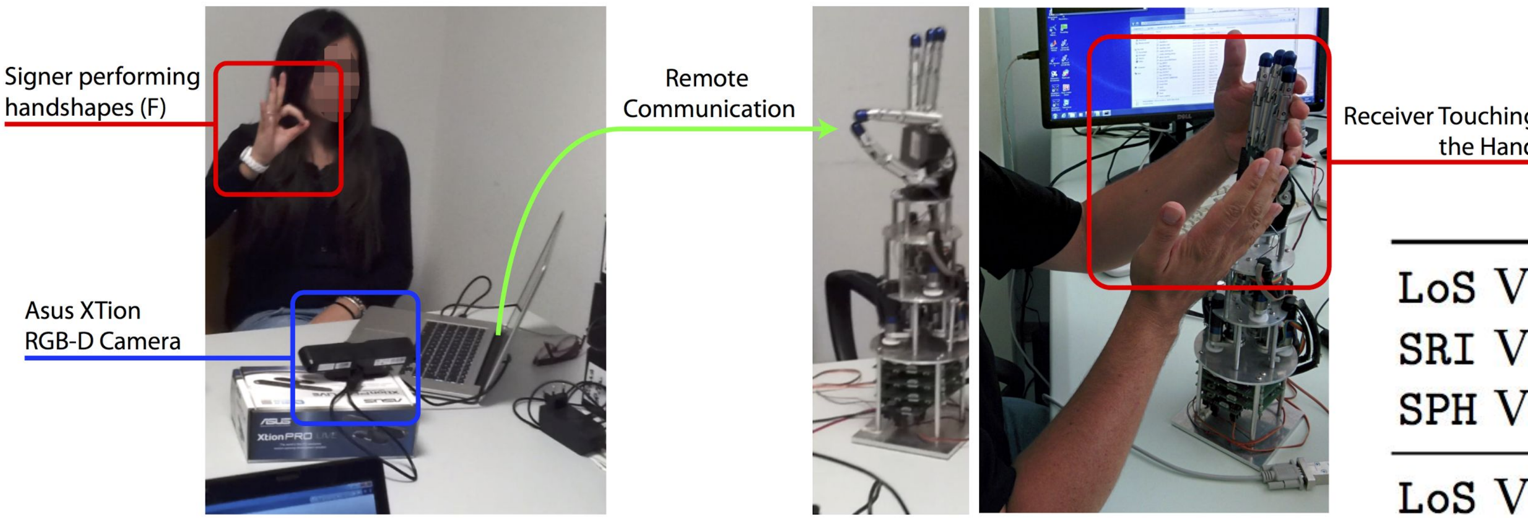
Hand Shape Classifier

- Recognizing the handshape from the skeleton

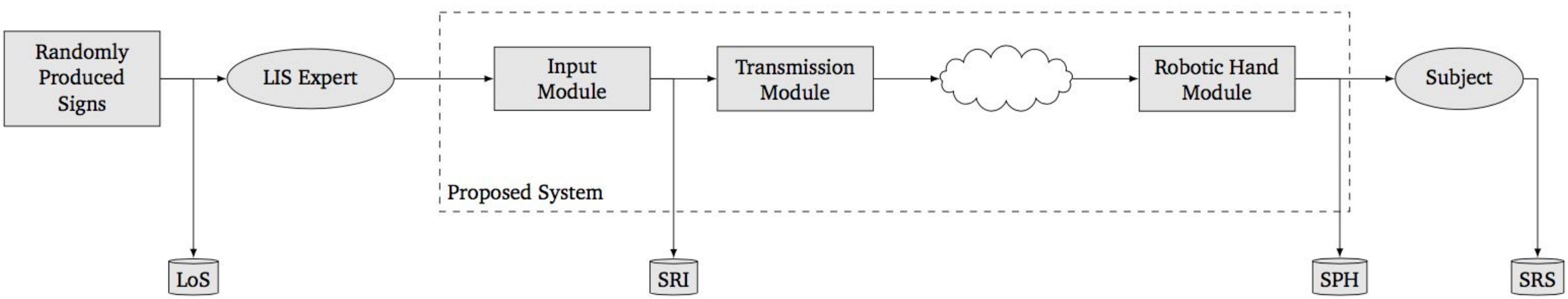
$$\mathcal{P}(\mathcal{S}) = \left\{ d_{k,l} = \|\mathbf{j}_k - \mathbf{j}_l\|, \forall \mathbf{j}_k, \mathbf{j}_l \in \mathcal{S}, k < l \right\},$$

- Feature: list of distances between each pair of joints.

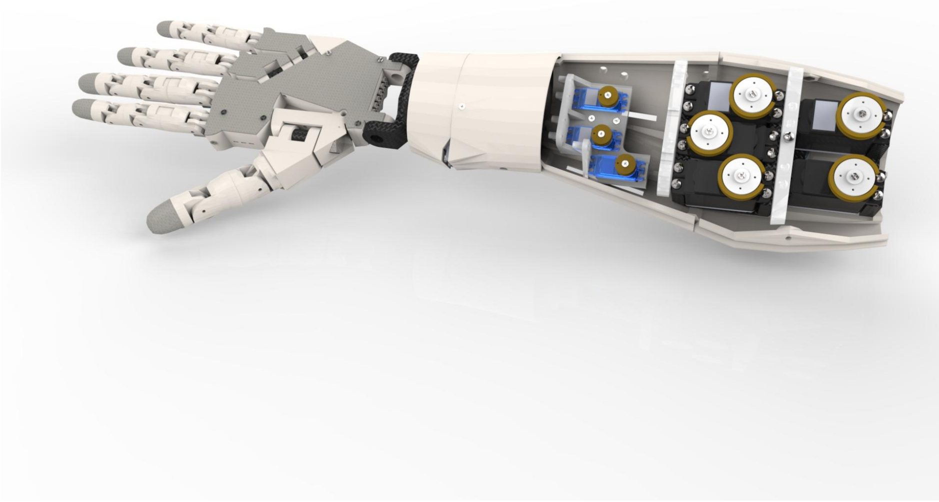
Experiment 2: testing the main architecture



LoS	VS	SRI	95%
SRI	VS	SPH	100%
SPH	VS	SRS	96%
LoS	VS	SRS	91%



Open Source Robot Hand



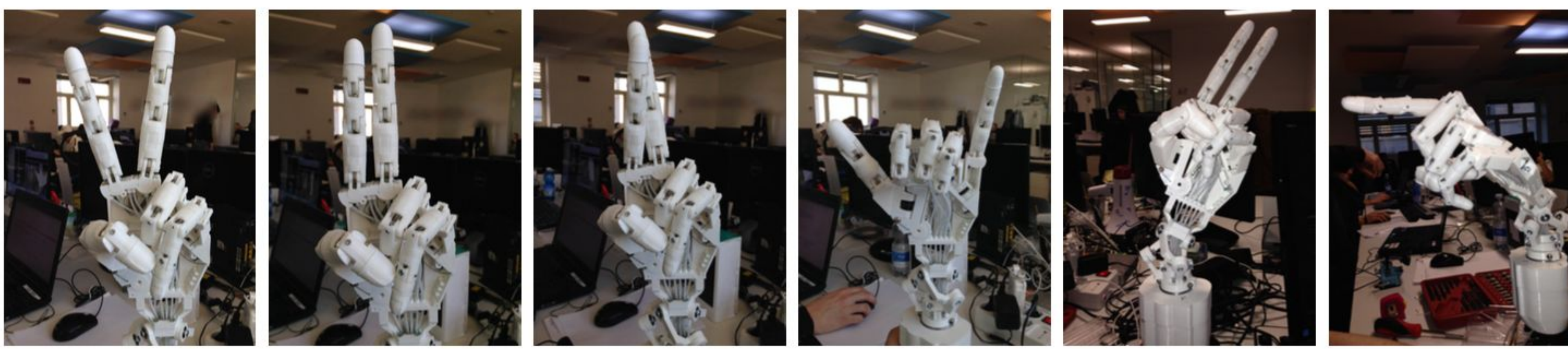
- Branch of the Inmoov Hand project
- 3D printed
- 9 DoF
- Bio Inspired
- 3 DoF Wrist based on the Agile Wrist mechanics

Experiment 3: Testing the Parloma Hand

- Expert in SL (visual) + deaf person (tactile)
- Both confirmed improvements from previous hand

Problems:

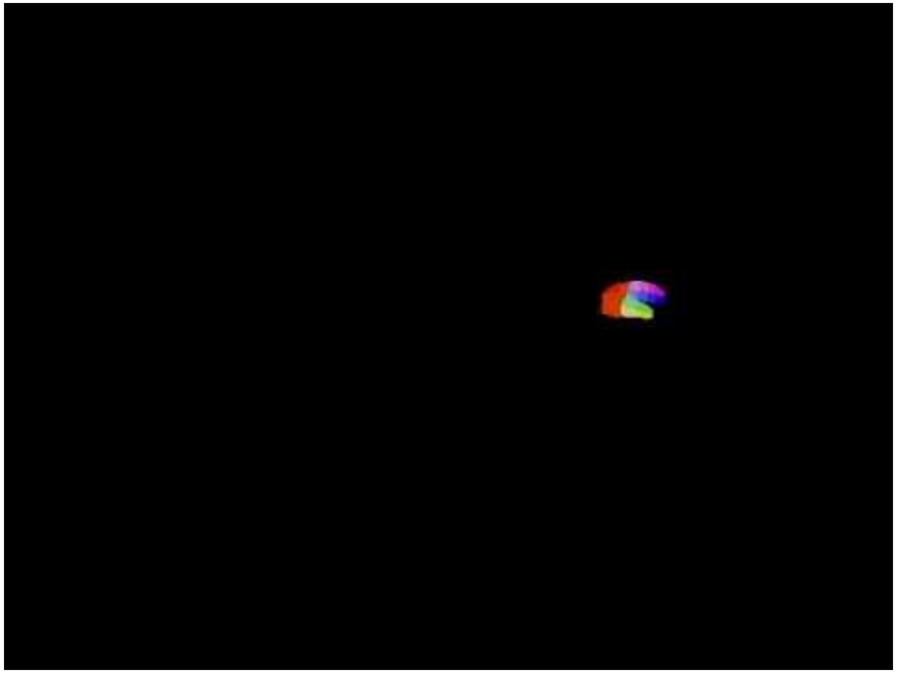
- Precision in Finger Position
- Finger cross should be more clear



(a) Letter *V* (b) Letter *U* (c) Letter *R* (d) Letter *Y* (e) Letter *H* (f) Letter *P*

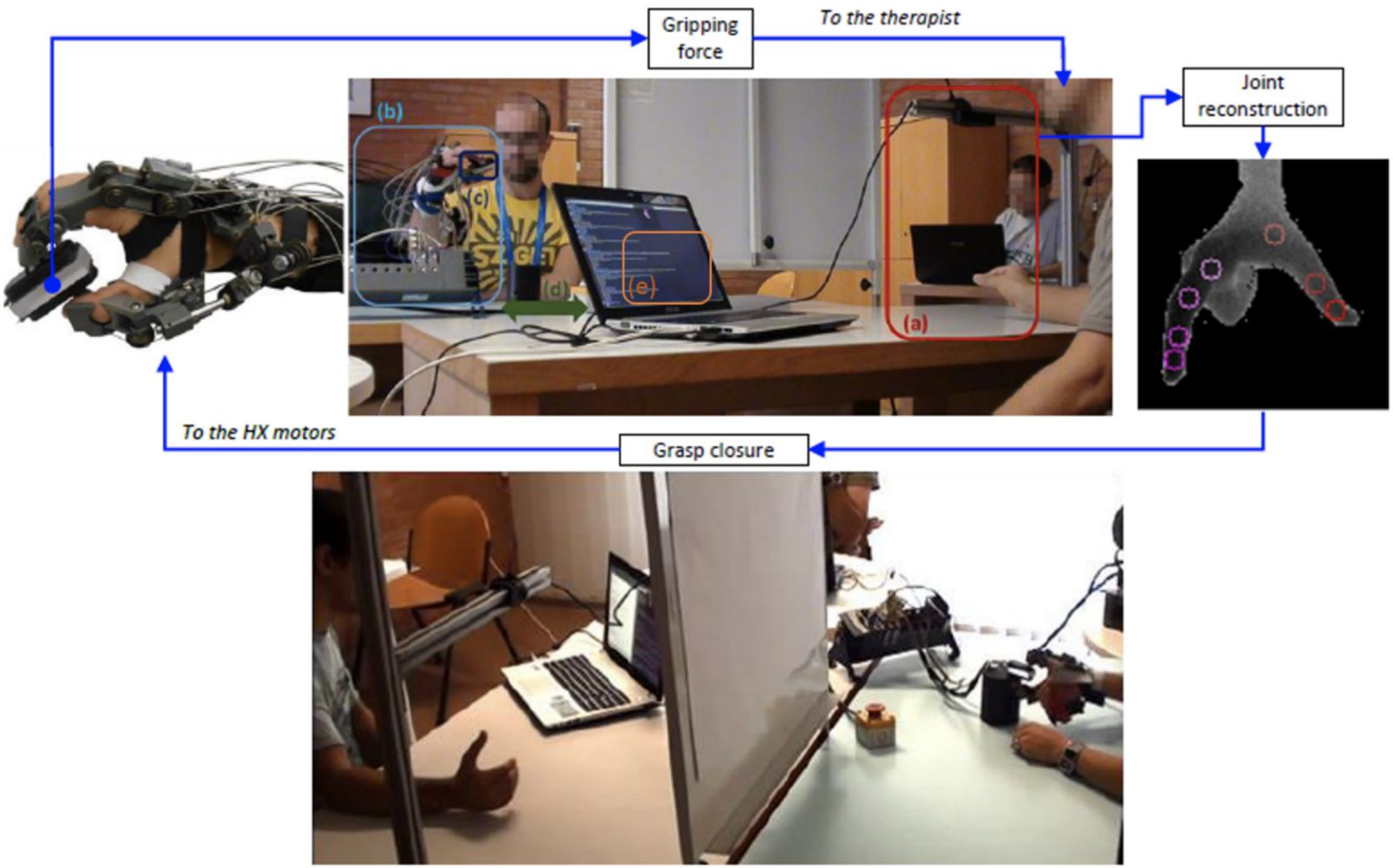
PARLOMA: future works

- Development of arm and shoulder
- Improvements of the mechanics
- Dynamic Signs recognition and reproduction
- Leap Motion implementation

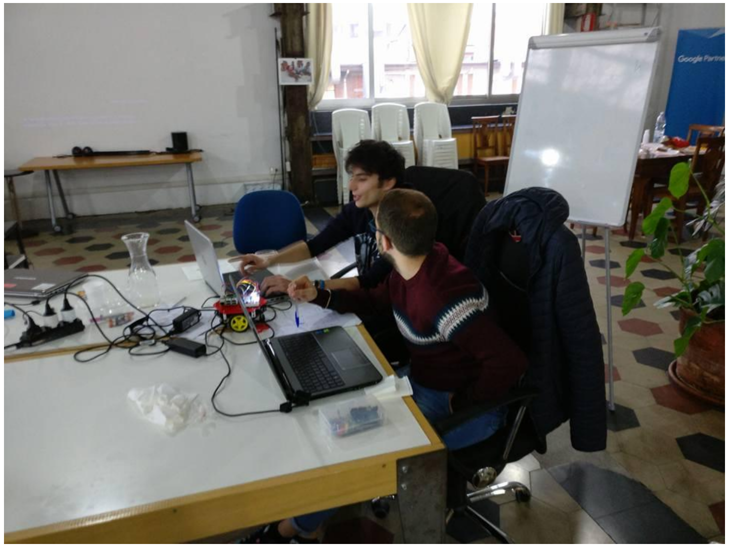


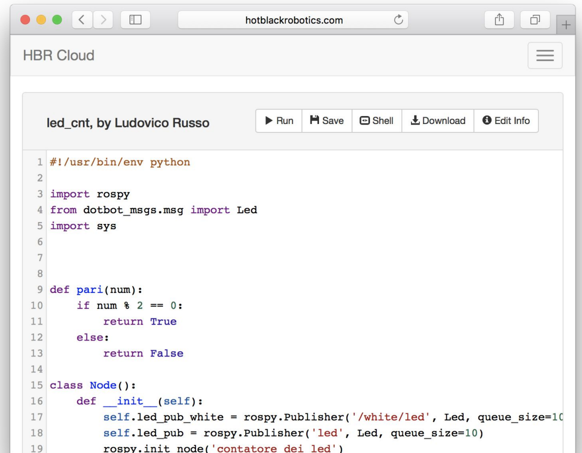
Other Results and Conclusions

Tele-rehabilitation



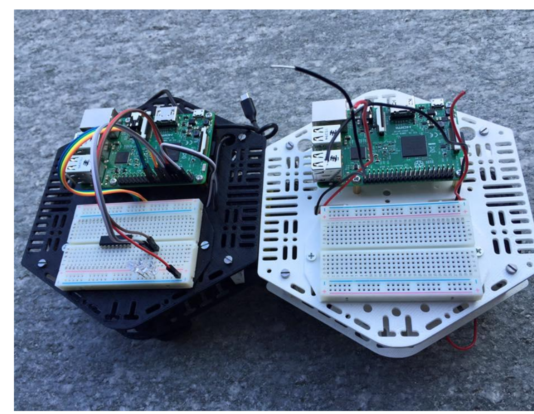
DotBot - Open Source Robot to Teach Cloud Robotics





HotBlack
ROBOTICS

- Open Source and Open Hardware
- Connected to a Cloud Robotic Platform
- Developed for the Robot@School Project
- Used by some institutions in Italy
    - Liceo Federico II di Svevia Melfi (PZ)
    - ITIS Avogrado Torino
    - IIS Vallauri Fossano (TO)
    - ...



Conclusions

- Cloud Robotics can be applied to real service robotics applications
  - Robot@CED is ready help datacenter manager to improve energy efficiency
  - PARLOMA has the possibility to help deafblind person to communicate remotelly
- Future Works
  - Explore the projects from a Business point of view
  - Manage Security in the IT communication

Thank You!