

# Multimodal sensor-based control for human-robot interaction

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LIRMM CNRS – UM  
IDH Group

HLR - Humanoid and Legged Robots  
December 7<sup>th</sup>, 2016



# Physical Human Robot Interaction

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« Short circuit » (1986)

# Applications of physical HRI

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- Cobots for the industry



- Assistive robots



# Objectives of physical HRI

- 1) Safety
- 2) Precision
- 3) Flexibility



- 4) Ease of use → human intention recognition

! human optima are hard to model and generalize (e.g. QWERTY)

→ Sensor-based control



# Perception to action

## Peripheral nervous system

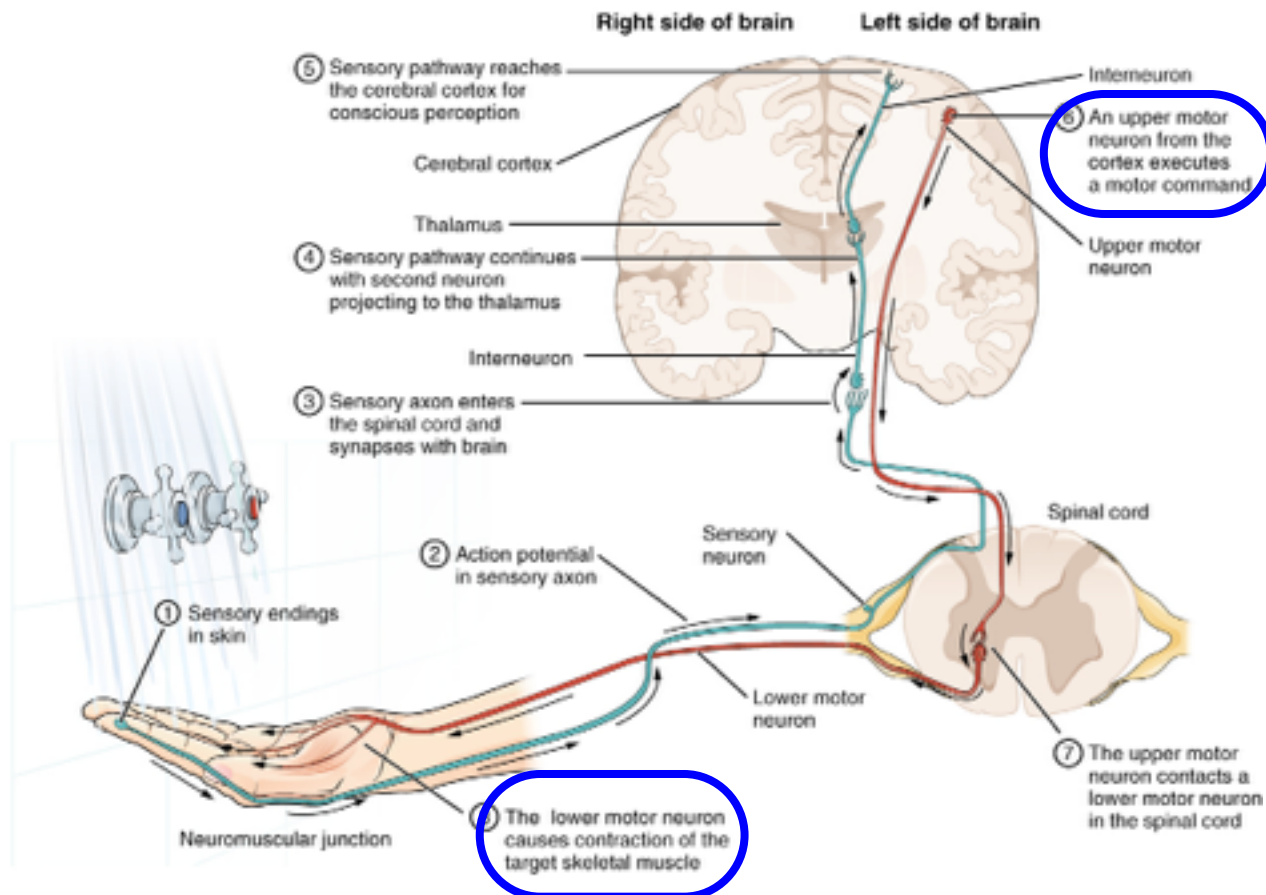
Sensorimotor

Act

## Central nervous system

Cognitive

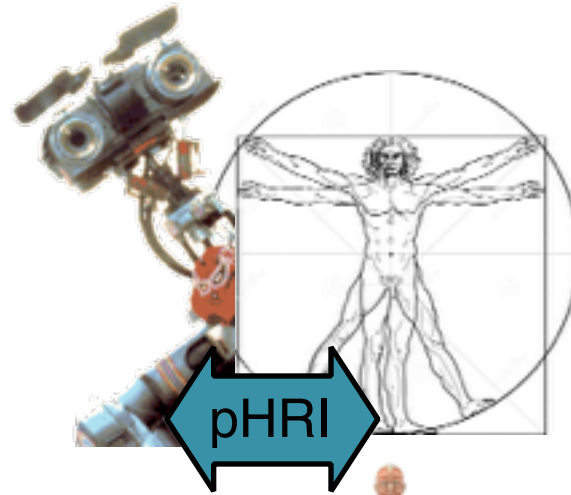
Understand/decide



# Outline



VISION

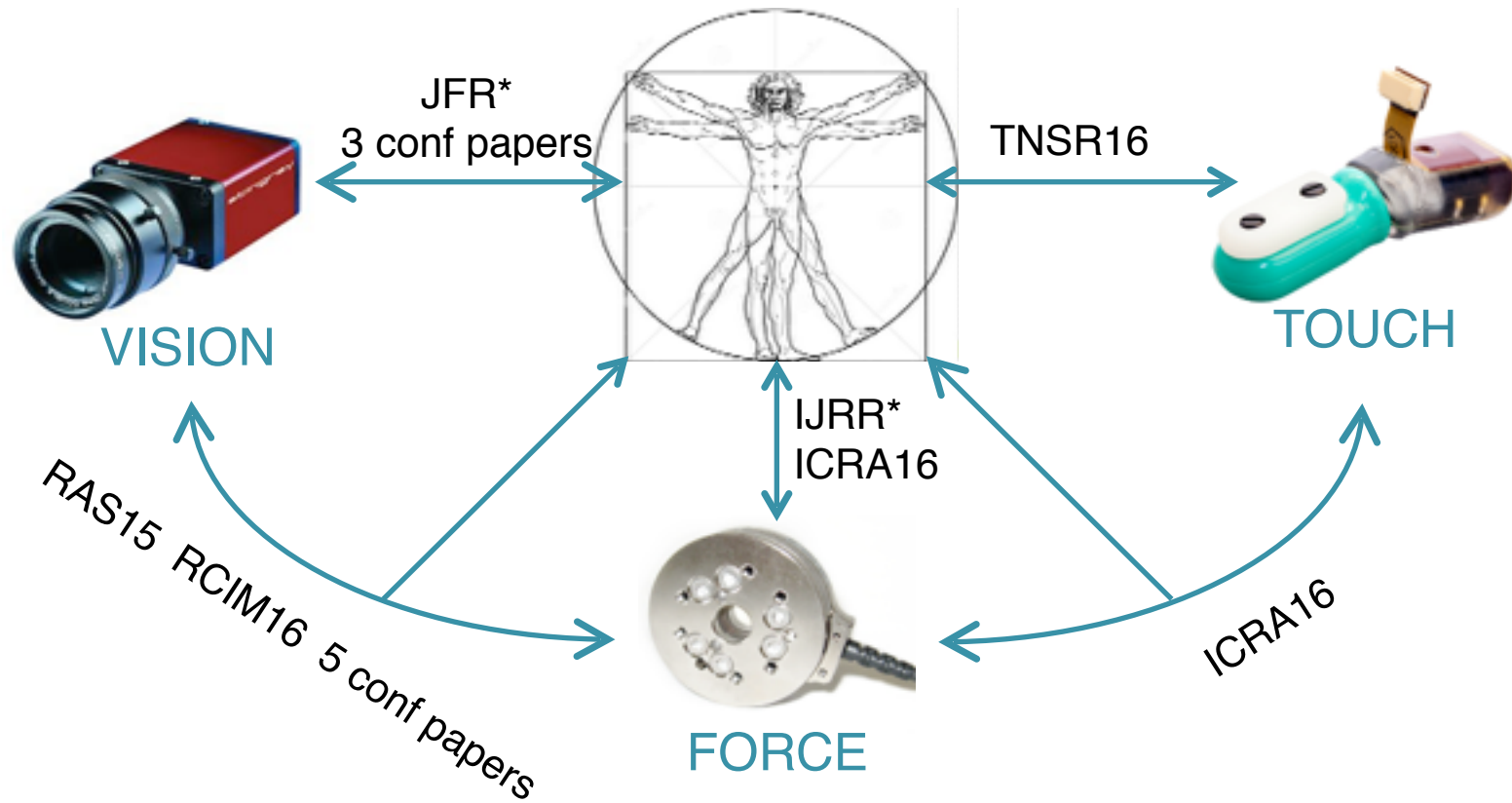


TOUCH



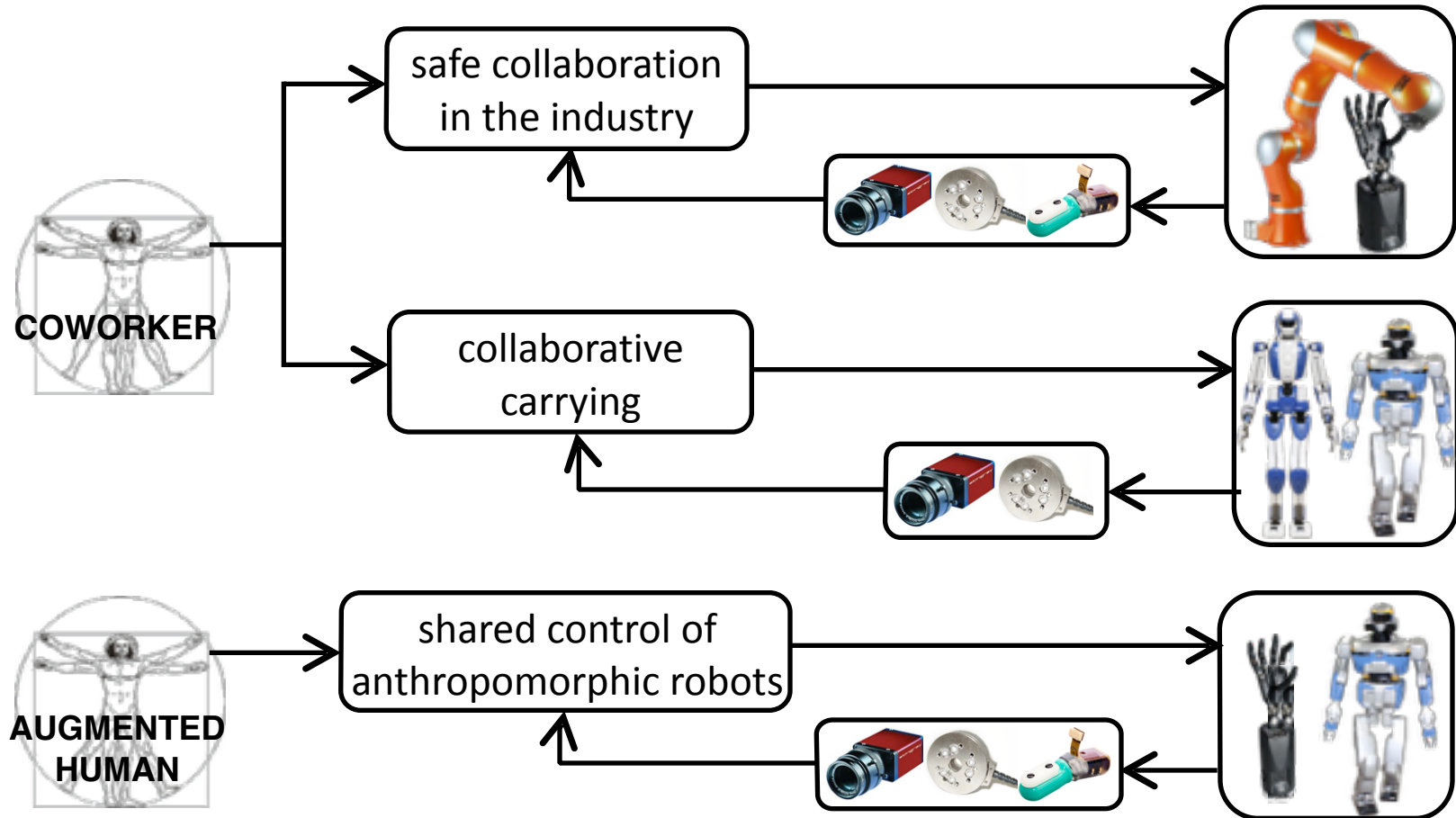
FORCE

# Outline



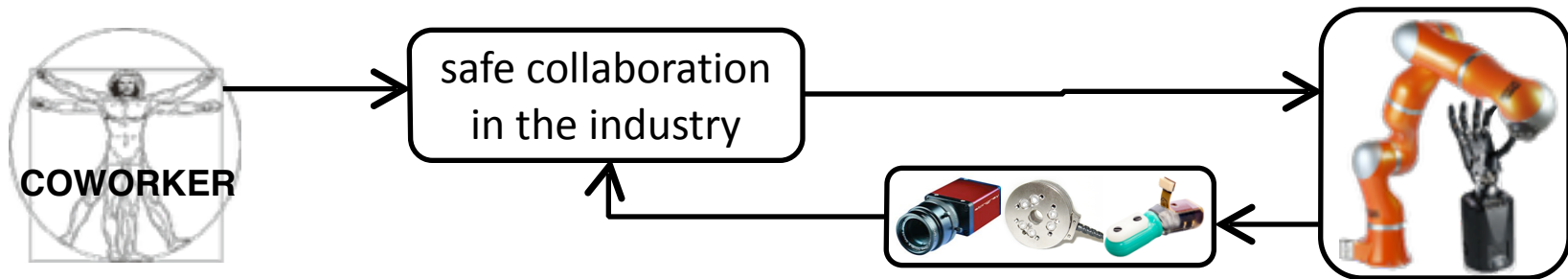
\*under revision

# Outline





# Sensing for industrial cobots



## MOTIVATION

- reduce ergonomic problems
- merge H adaptability precision  
R power speed

## SCIENTIFIC CHALLENGES

- safety
- intention recognition
- smooth sensor changes

## An adaptive damping controller for safe Physical Human-Robot Interaction

B. Navarro A. Cherubini A. Fonte R. Passama G. Poisson P. Fraise

PRISME - University of Orléans INSA CVL  
Orléans, France

LIRMM - University of Montpellier CNRS  
Montpellier, France





# Adaptive admittance cobot



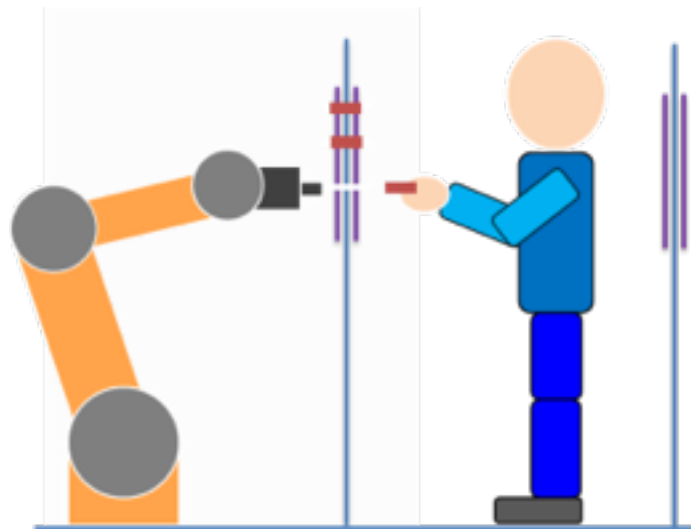
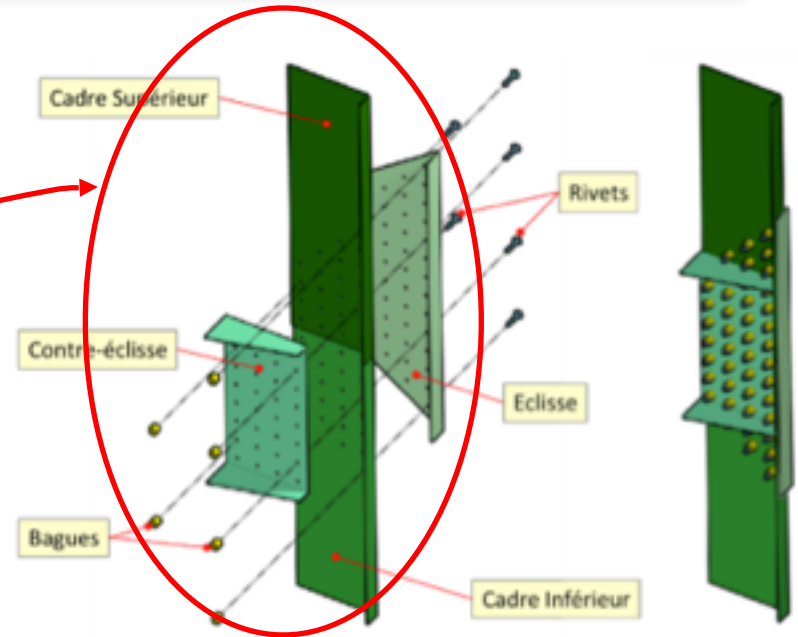
- ISO10218 upper bounds on velocity force and power
- Adaptive admittance controller

$$\dot{x}^* = \alpha B^{-1} (h - K\Delta x - M\Delta \ddot{x}) + \dot{x}^r \quad \text{with } \alpha = \begin{cases} \min \{ \alpha_v, \alpha_p, 1 \} & \text{if } |f| \leq F_M \\ \min \{ \alpha_v, \alpha_p \} & \text{otherwise} \end{cases}$$

- touch used for intuitive programming



# Collaborative screwing





# Collaborative screwing

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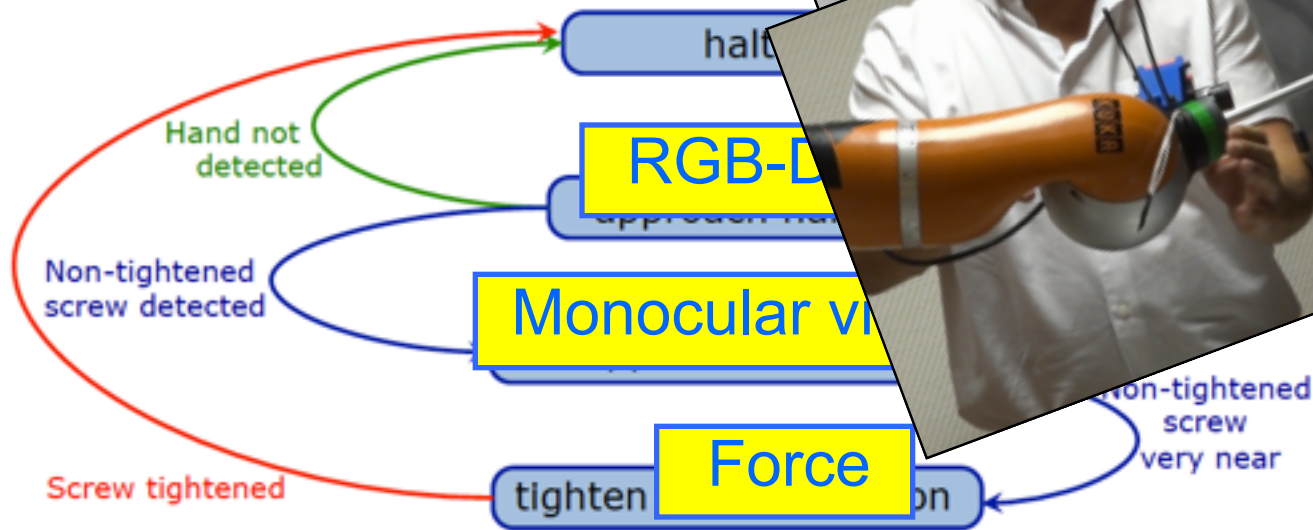
## **A unified multimodal control framework for human-robot interaction**

**A. Cherubini R. Passama P. Fraise A. Crosnier**

**LIRMM - University of Montpellier 2 CNRS  
Montpellier, France**



# Unified multimodal framework



$$v = -(1 - S)J_s^{-1}e_s - SJ_u^{-1}e_u$$

$$v = -\sum_i^n S_i J_i^{-1} e_i \quad \text{with } S_i \text{ diagonal selection matrices}$$

Converges IF:

- All  $e_i$  are in the same frame
- each sensor controls a different component of  $v$

$$v = -\left(\sum_i^n S_i J_i\right)^{-1} \begin{bmatrix} S_1 & \dots & S_n \end{bmatrix} \begin{bmatrix} e_1 \\ \dots \\ e_n \end{bmatrix}$$

**Hybrid** (sensors act on different DOF) but **also Shared** (no separation on DOF) during **transitions**  
**[Nelson et al., 1995]**

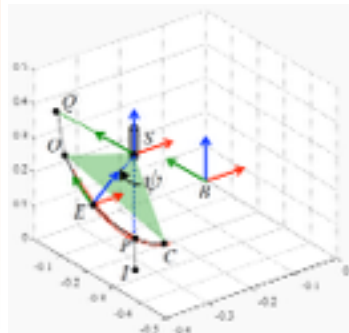


# Collaborative assembly cell

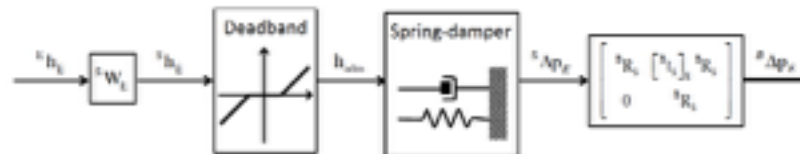
## Human-robot collaborative assembly for a manufacturing application

A. Cherubini R. Passama P. Fraise A. Crosnier

LIRMM - University of Montpellier CNRS  
Montpellier, France

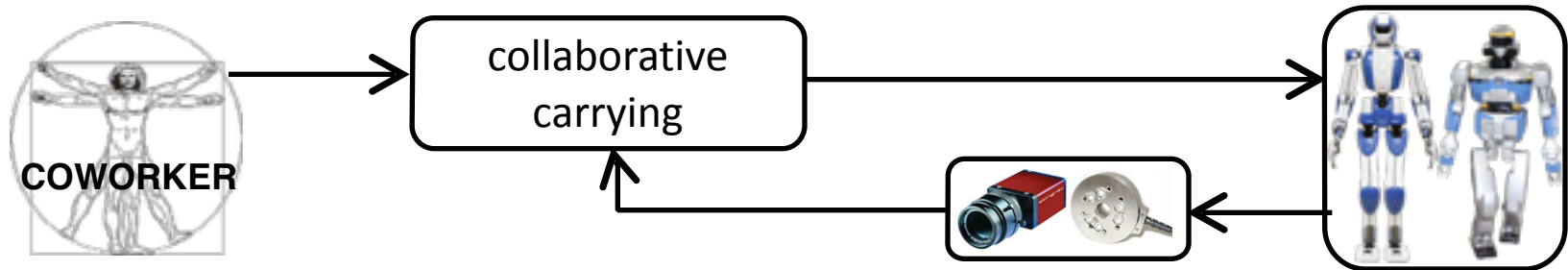


- Nominal trajectory is pre-taught...  
...then deformed by an admittance controller



- Vision is used as security trigger

# Collaborating with humanoids



## MOTIVATION

- extend cobot mobility
- empathy with the collaborator

## SCIENTIFIC CHALLENGES

- walk under sustained forces
- whole body control

Université Montpellier 2-CNRS LIRMM  
CNRS-AIST Joint Robotics Laboratory UMI3218/CRT

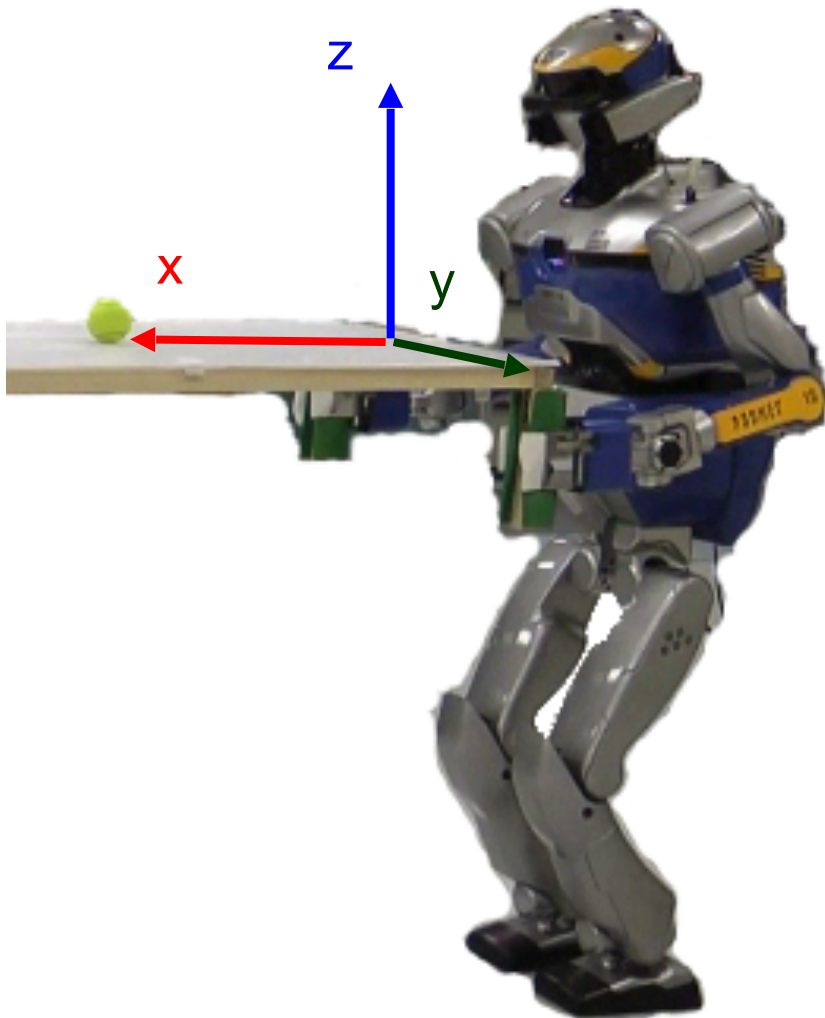
**Carrying a free-moving ball on a table  
by human-humanoid dyad  
using vision and haptic sensing**

Don Joven Agravante  
Andrea Cherubini  
Antoine Bussy  
Pierre Gergondet  
Abderrahmane Kheddar





# Combining vision and force



- $x$   $y$   $\Phi_z$  help the human force control
- $\Phi_y$  keep table flat  
force + pose (yaw) control
- $z$   $\Phi_x$  avoid ball from falling  
force + visual control

**Shared control** : no separation on DOF





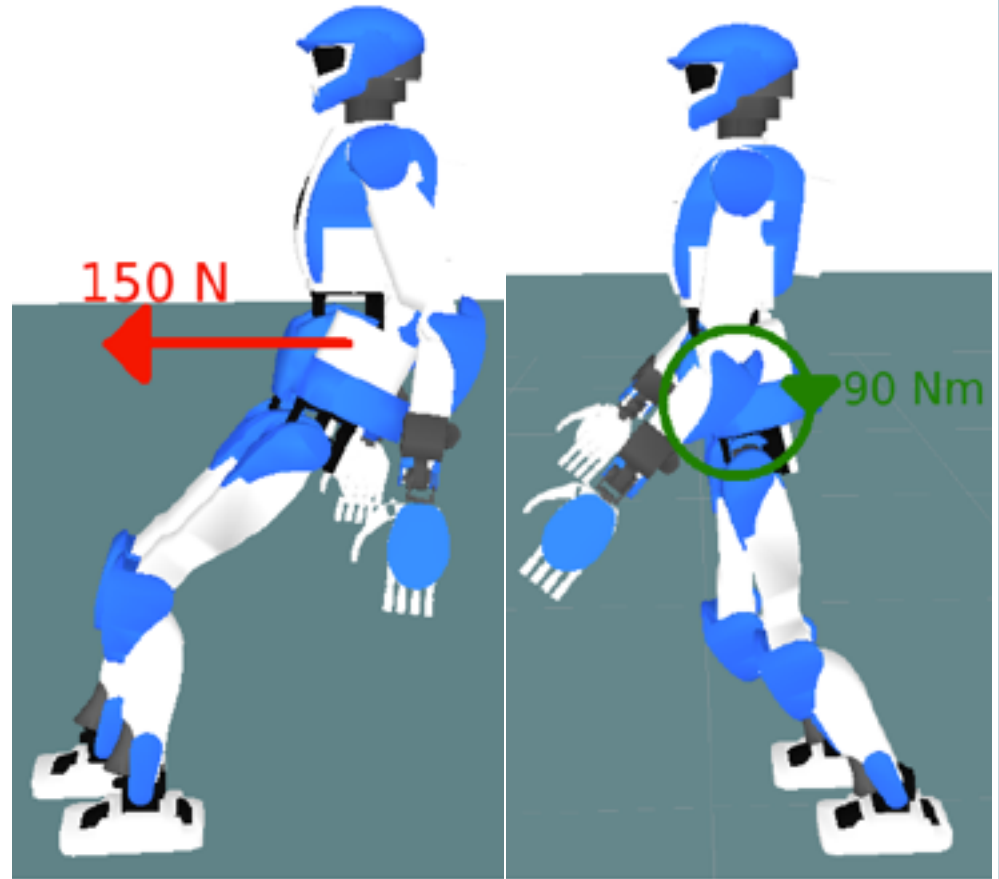
# Walking under sustained forces

## Classic Zero Moment Point

$$\begin{cases} x_{zmp} = x_{com} - \frac{z_{com}}{g} \ddot{x}_{com} \\ y_{zmp} = y_{com} - \frac{z_{com}}{g} \ddot{y}_{com} \end{cases}$$

## Zero Moment Point with external wrench

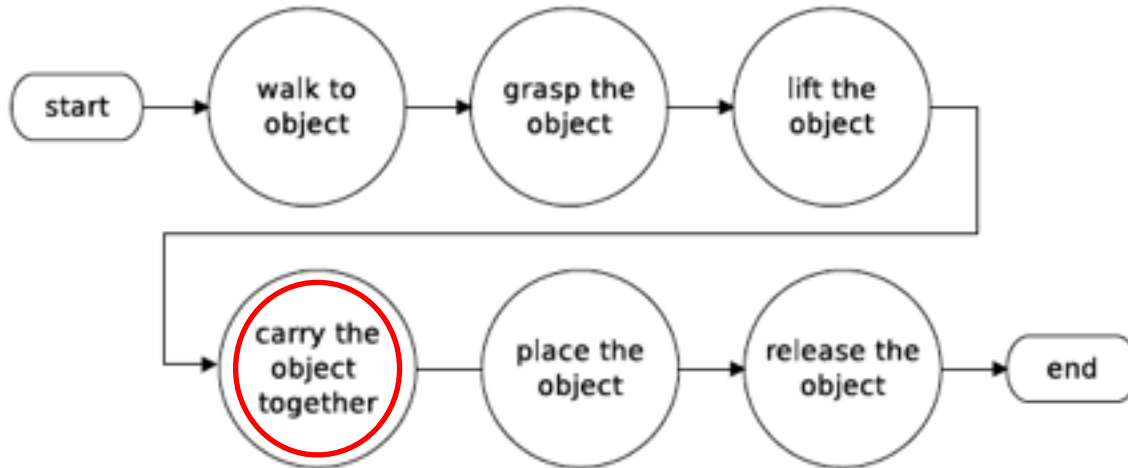
$$\begin{cases} x_{zmp} = x_{com} + \frac{z_{com} f_x + n_y}{mg - f_z} - \frac{z_{com}}{g - \frac{f_z}{m}} \ddot{x}_{com} \\ y_{zmp} = y_{com} + \frac{z_{com} f_y - n_x}{mg - f_z} - \frac{z_{com}}{g - \frac{f_z}{m}} \ddot{y}_{com} \end{cases}$$



→ Model predictive control to determine center of mass jerk and footsteps



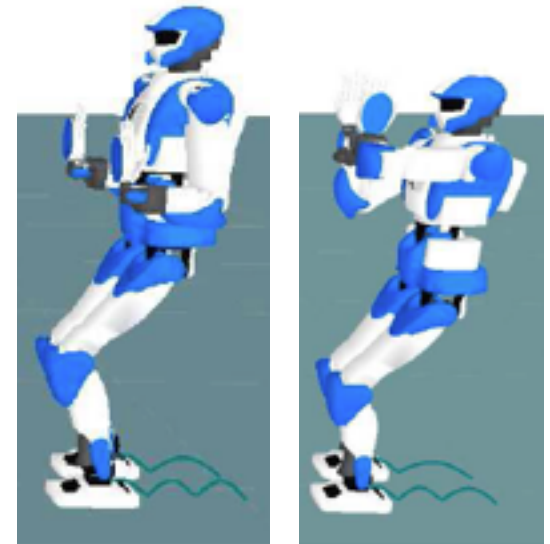
# Whole-body control for collaborative carrying



$$\operatorname{argmin}_x \sum_i w_i (x^T Q_i x + c_i^T x)$$

subject to:  $Ax \leq b$

Both **leader** and **follower** behaviors are designed





# Collaborative carrying framework

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## Human-humanoid collaborative carrying

D. J. Agravante<sup>1,2</sup> A. Cherubini<sup>1</sup> A. Sherikov<sup>3</sup> P.-B. Wieber<sup>3</sup> A. Kheddar<sup>1,4</sup>

1 CNRS/UM LIRMM, IDH group, Montpellier, France

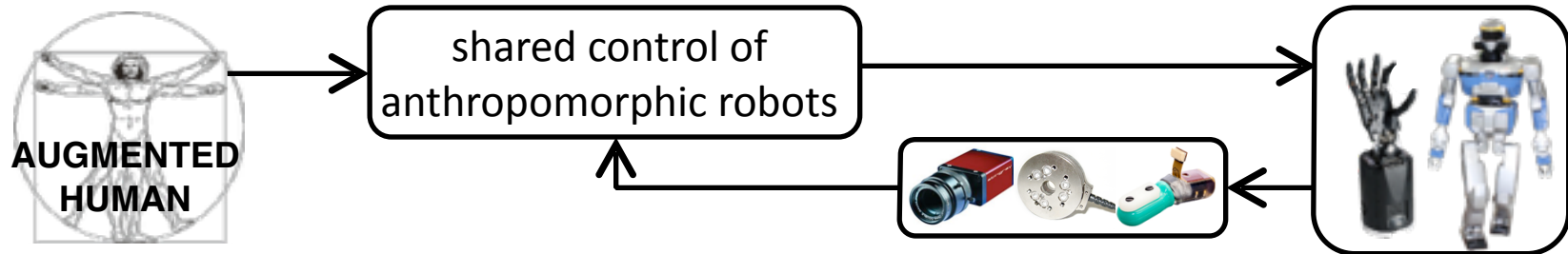
2 INRIA Rennes - Bretagne Atlantique, Lagadic group, Rennes, France

3 INRIA Rhône-Alpes, BIPOP group, Montbonnot, France

4 CNRS-AIST Joint Robotics Laboratory, Tsukuba, Japan

IJRR Multimedia extension - Video 1 of 1

# Shared robot control



## MOTIVATION

- augment human capabilities
- assistive and rescue applications

## SCIENTIFIC CHALLENGES

- embodiment in a robotic system
- transparent control from the user viewpoint

CNRS-UM2 LIRMM, UMR5506, Montpellier, France  
CNRS-AIST Joint Robotics Laboratory (JRL), UMI 3218/CRT, Tsukuba, Japan

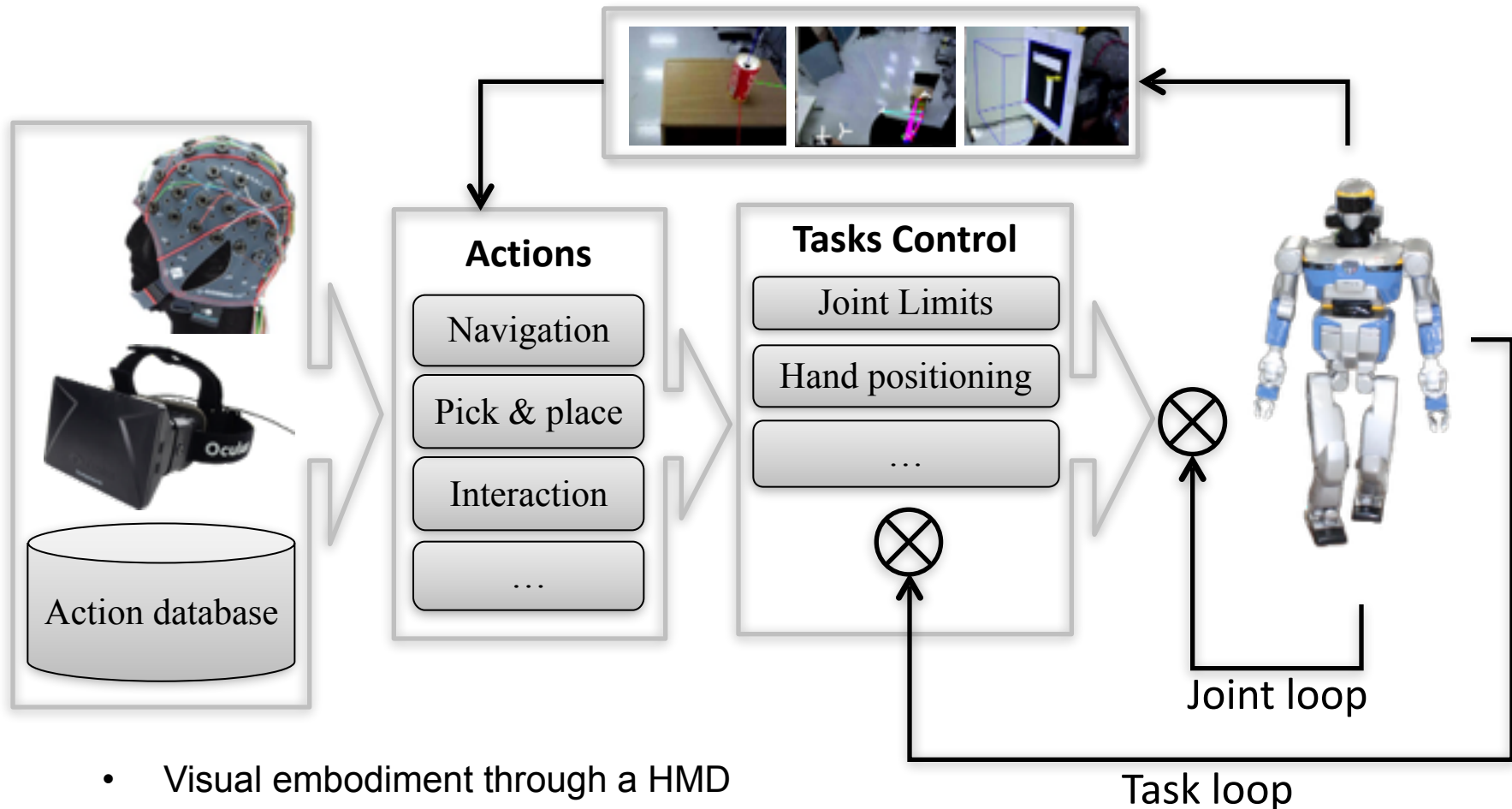
## An integrated framework for humanoid embodiment with a BCI

Damien Petit, Pierre Gergondet  
Andrea Cherubini, Abderrahmane Kheddar





# Human-humanoid embodiment

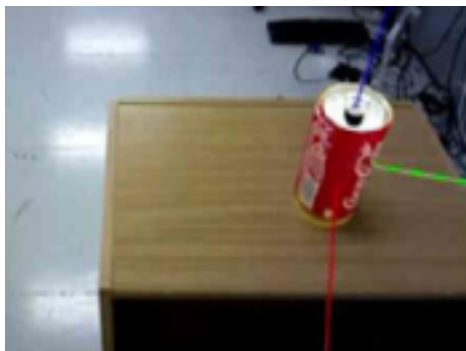


- Visual embodiment through a HMD
- Actions determined via a Brain Computer Interface
- Kinematic task control to move the robot
- Problem: BCI low frequency + high level actions  
→ image processing and vision to aid shared control

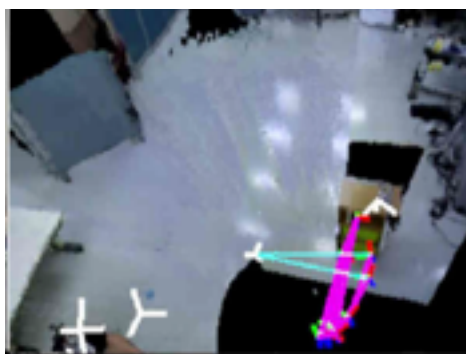


# Visual solutions aiding human control

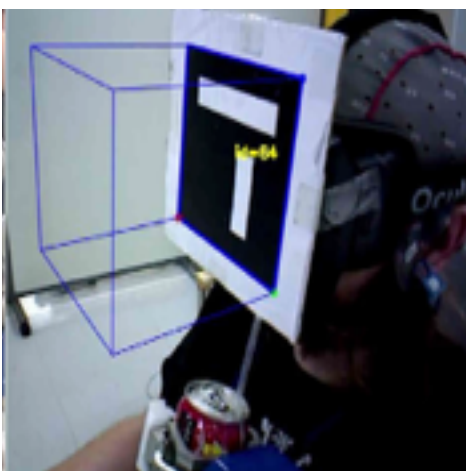
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object recognition and pose tracking  
[BLORT Vision Toolbox]



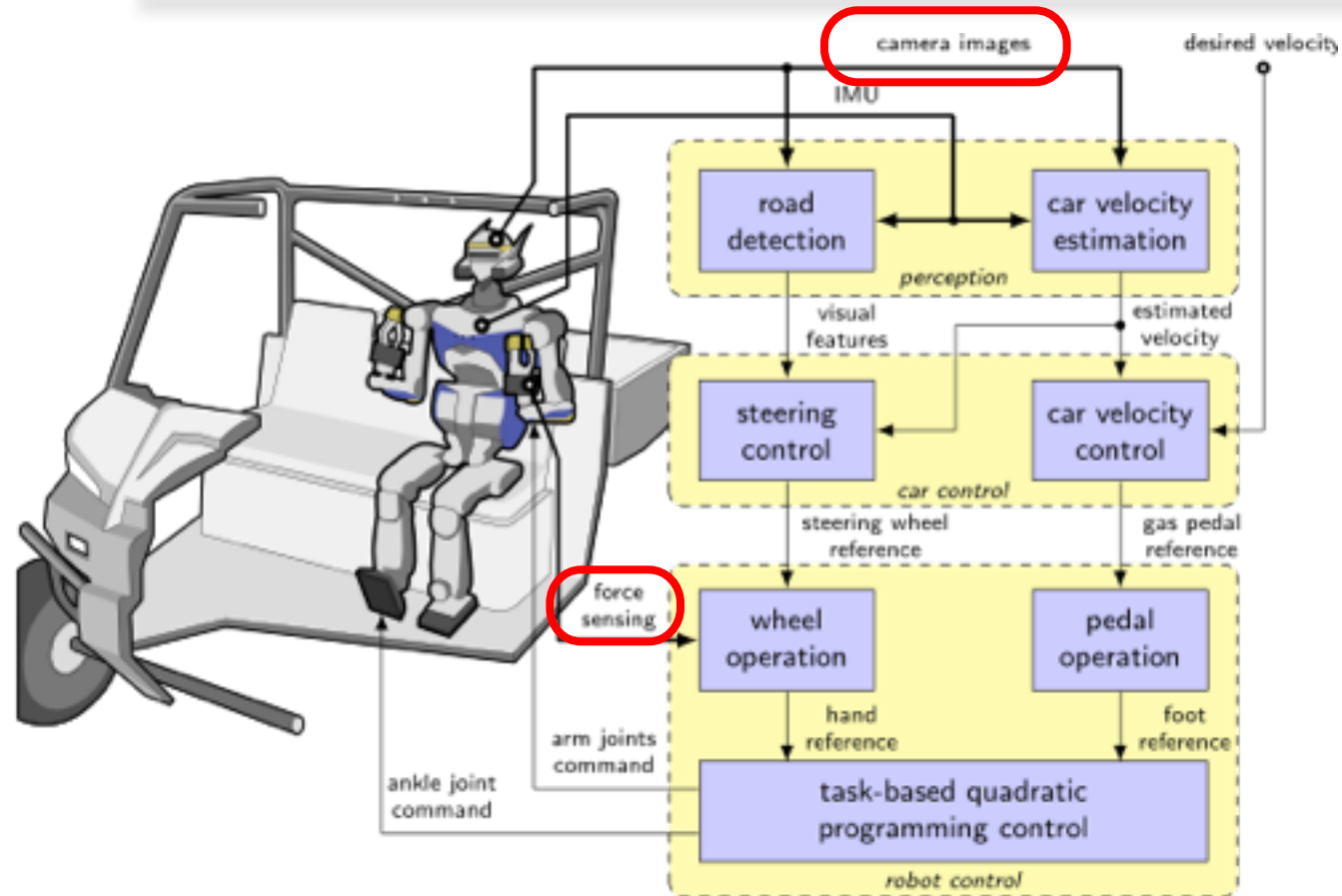
localization based on D6DSlam  
[Meilland, Comport, 2013]



precise positioning with ARUCO  
fiducial markers [[www.uco.es](http://www.uco.es)]



# Shared control of a humanoid car driver



## Driving modes:

- **autonomous:** the robot autonomously drives the car without any human aid
- **teleoperated:** both the robot hand and foot are teleoperated by a human



# Shared control of a humanoid car driver

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## Autonomous car driving by a humanoid robot

A. Paolillo, P. Gergondet, A. Cherubini, M. Vendittelli, A. Kheddar

CNRS-AIST JRL  
Tsukuba, Japan

CNRS-UM LIRMM  
Montpellier, France

DIAG, Sapienza University  
Rome, Italy

January 2016





# EMG to pilot a robotic hand

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## EMG interface for tetraplegic individuals to pilot a robot hand

W. Tigra<sup>1,2</sup> B. Navarro<sup>3</sup> A. Cherubini<sup>3</sup> X. Gorron<sup>3</sup>  
A. Gelis<sup>4</sup> C. Fattal<sup>5</sup> D. Guiraud<sup>1</sup> C. Azevedo Coste<sup>1</sup>

1 INRIA LIRMM, Montpellier, France

2 MXM-AXONIC, Sophia-Antipolis, France

3 IDH LIRMM, Montpellier, France

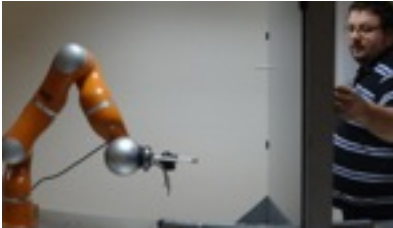
4 Propara Center, Montpellier, France

5 CRF COS DIVIO, Dijon, France

Touch used to stop grasping action

# Contributions

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- generalization of the multimodal framework



- whole-body sensor-based control



- sensor-based control for inner feedback loop

# EU H2020 Versatile Project (2017-2020)

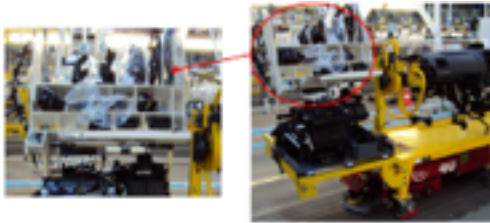


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Part Name	Country
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	France
BUS	Spain
	Greece
IAU	Italy
	Spain
ERMODALICS	Belgium
	Greece
LIRMM	France



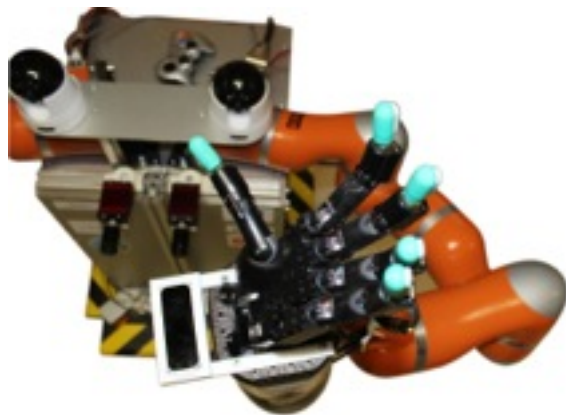
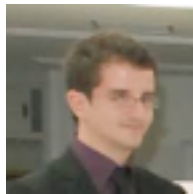
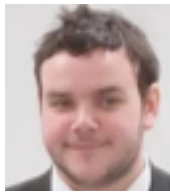
- Automotive pilot case



- Aerospace pilot case

- Consumer good pilot





*Thank you!!*

