# Multimodal sensor-based control for human-robot interaction

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HLR - Humanoid and Legged Robots
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# Physical Human Robot Interaction

« Short circuit » (1986)

# Applications of physical HRI

- 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

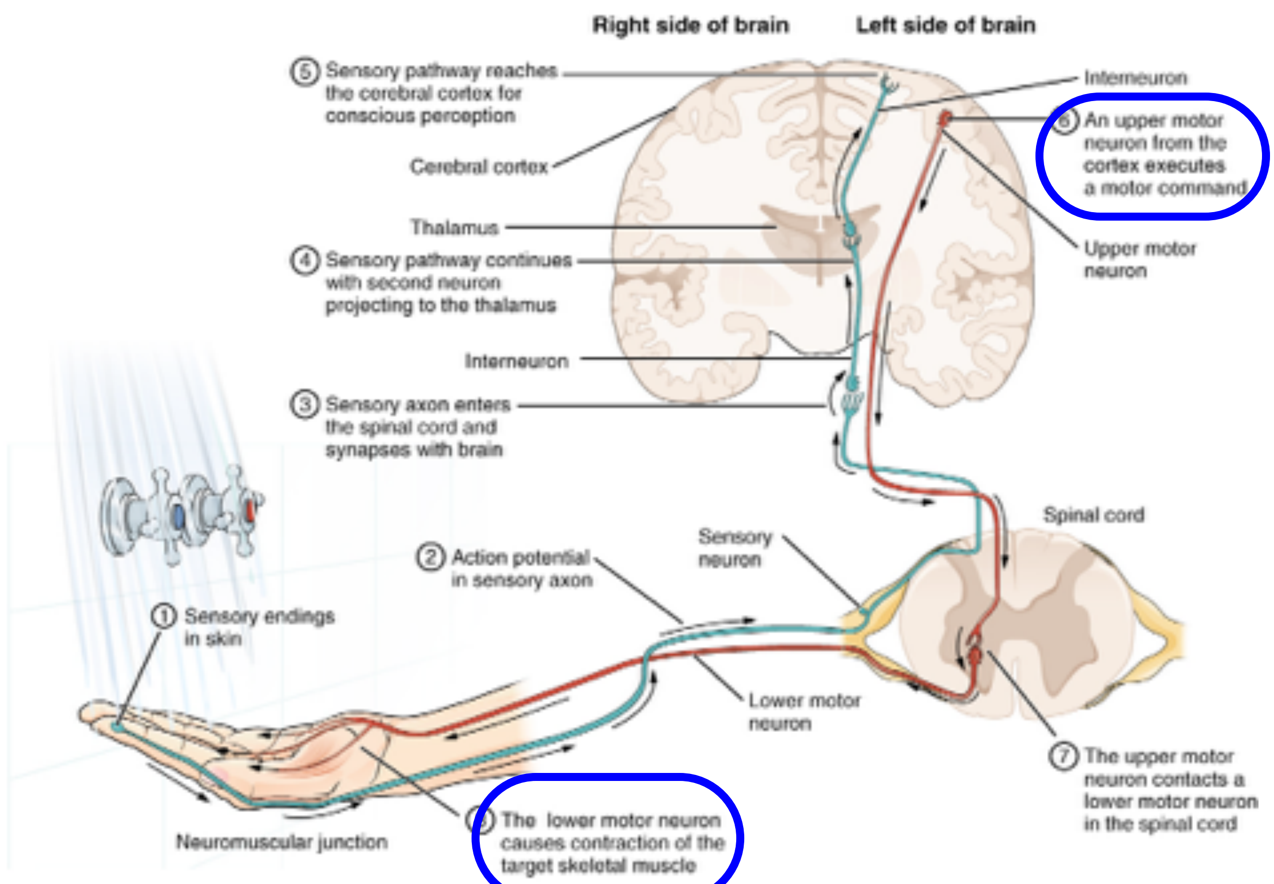
Sensorimotor

Act

## Central nervous system

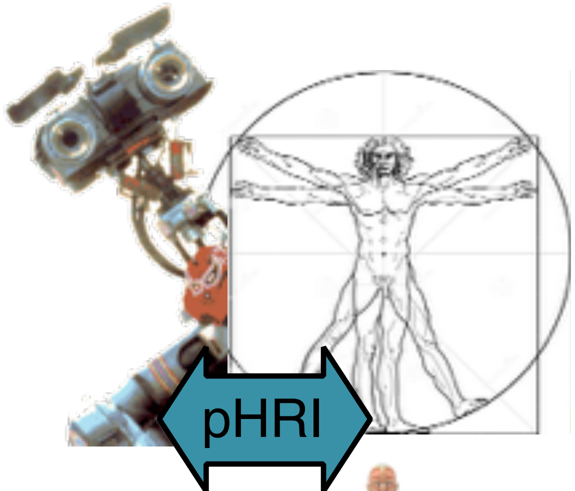
Cognitive

Understand/decide



# Outline

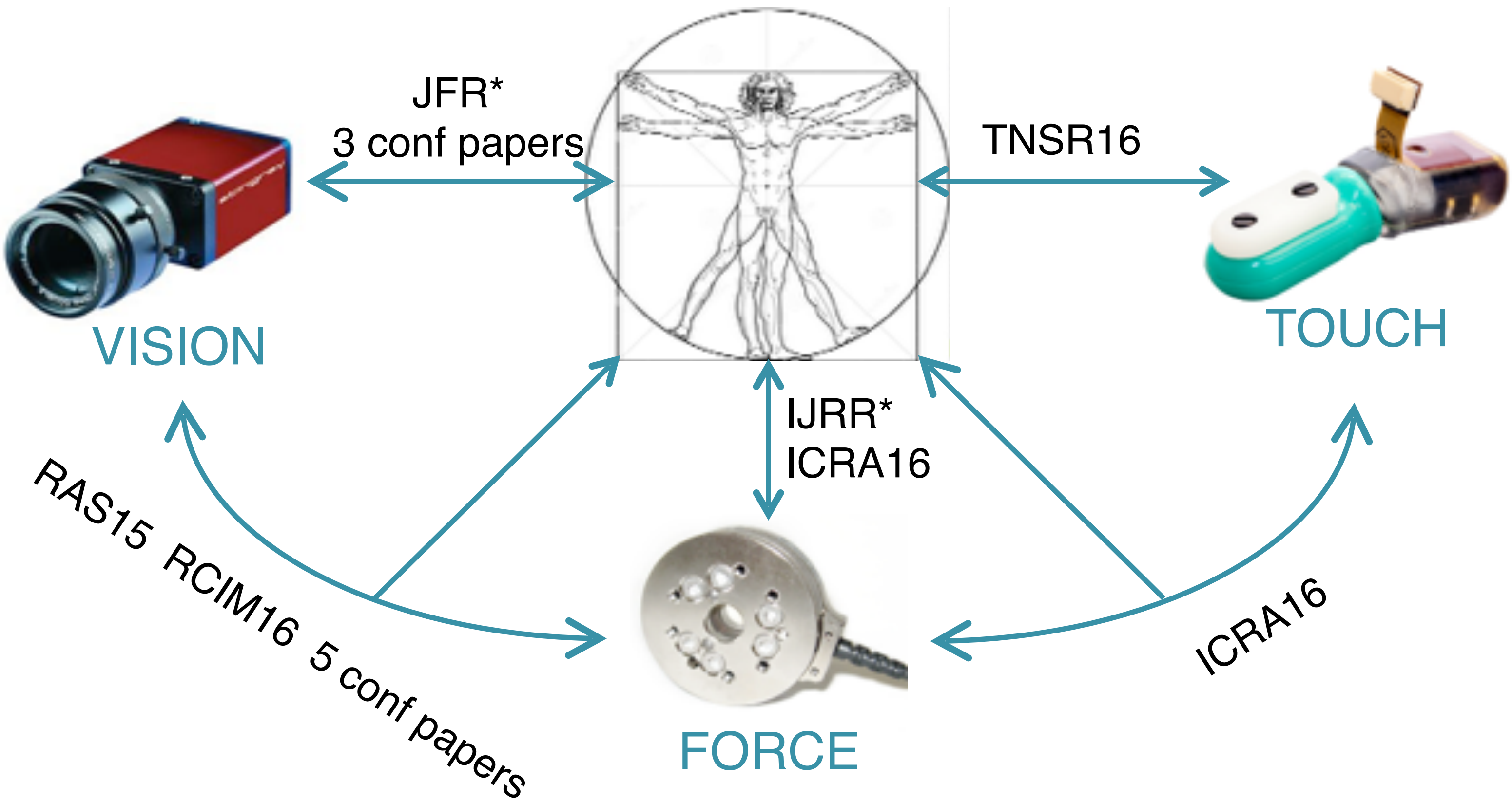
VISION




TOUCH

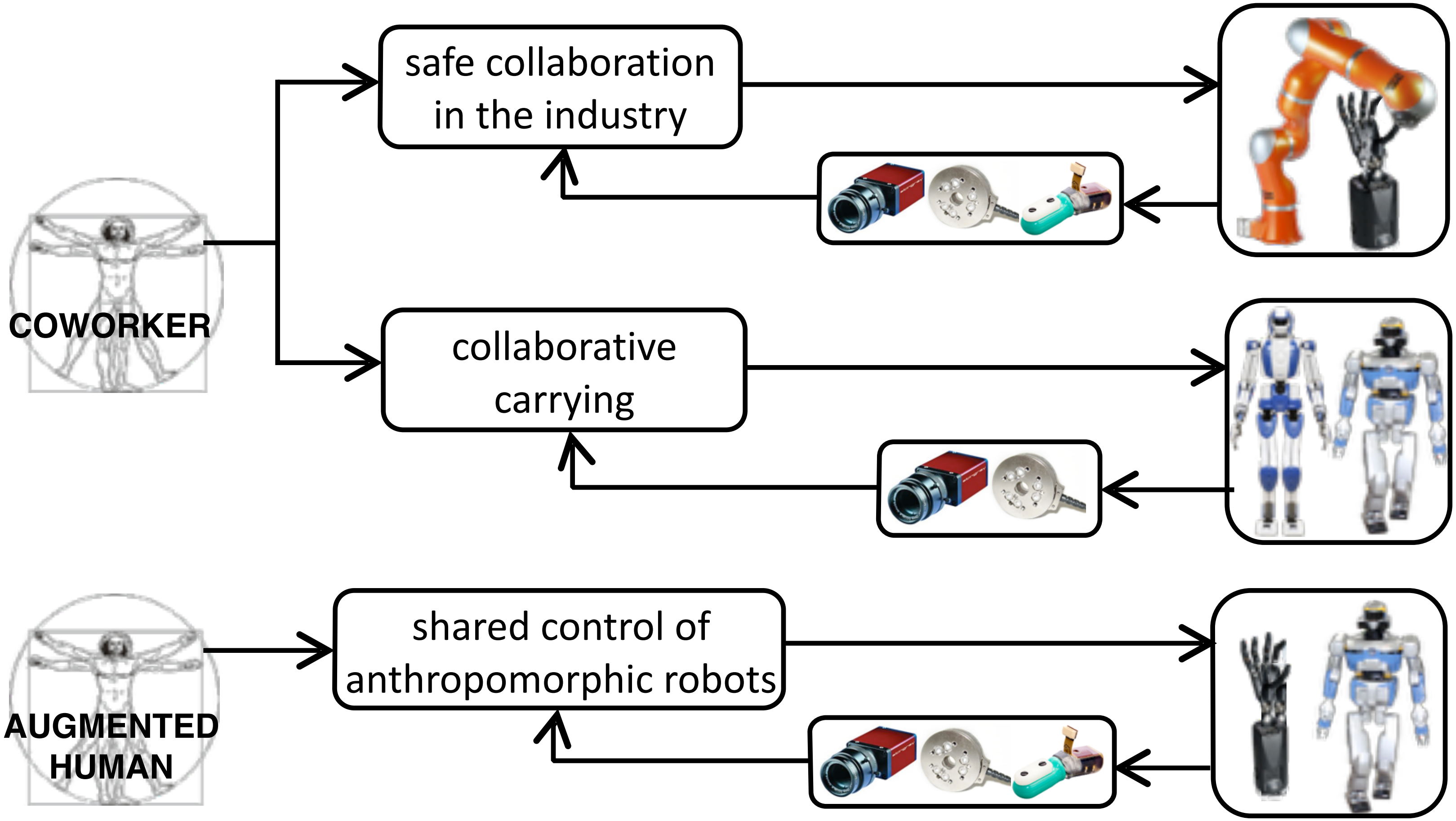
FORCE

# Outline



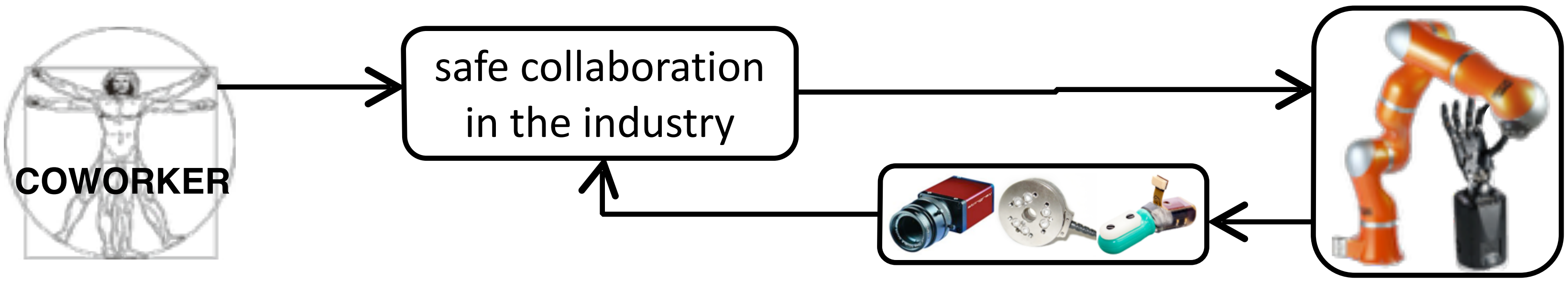

*under revision

# Outline



COWORKER
safe collaboration in the industry
collaborative carrying
AUGMENTED HUMAN
shared control of anthropomorphic robots

# 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**

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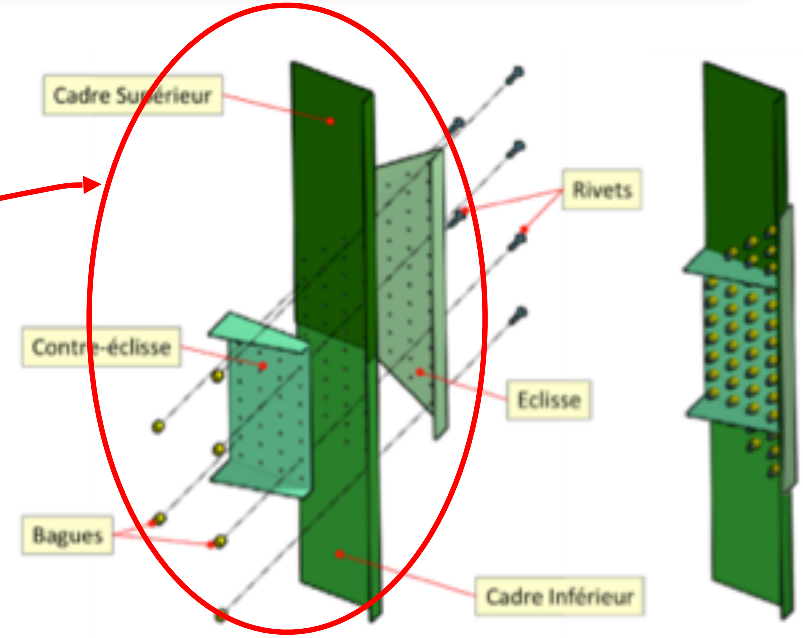
# Adaptive admittance cobot

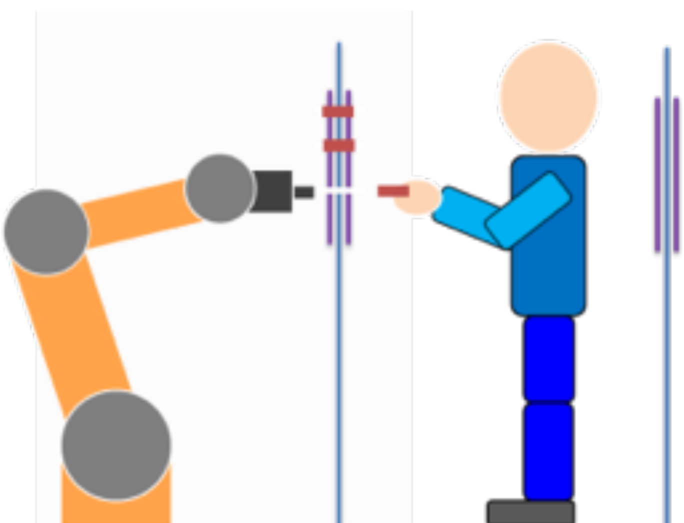
- ISO10218 upper bounds on velocity force and power
- Adaptive admittance controller

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

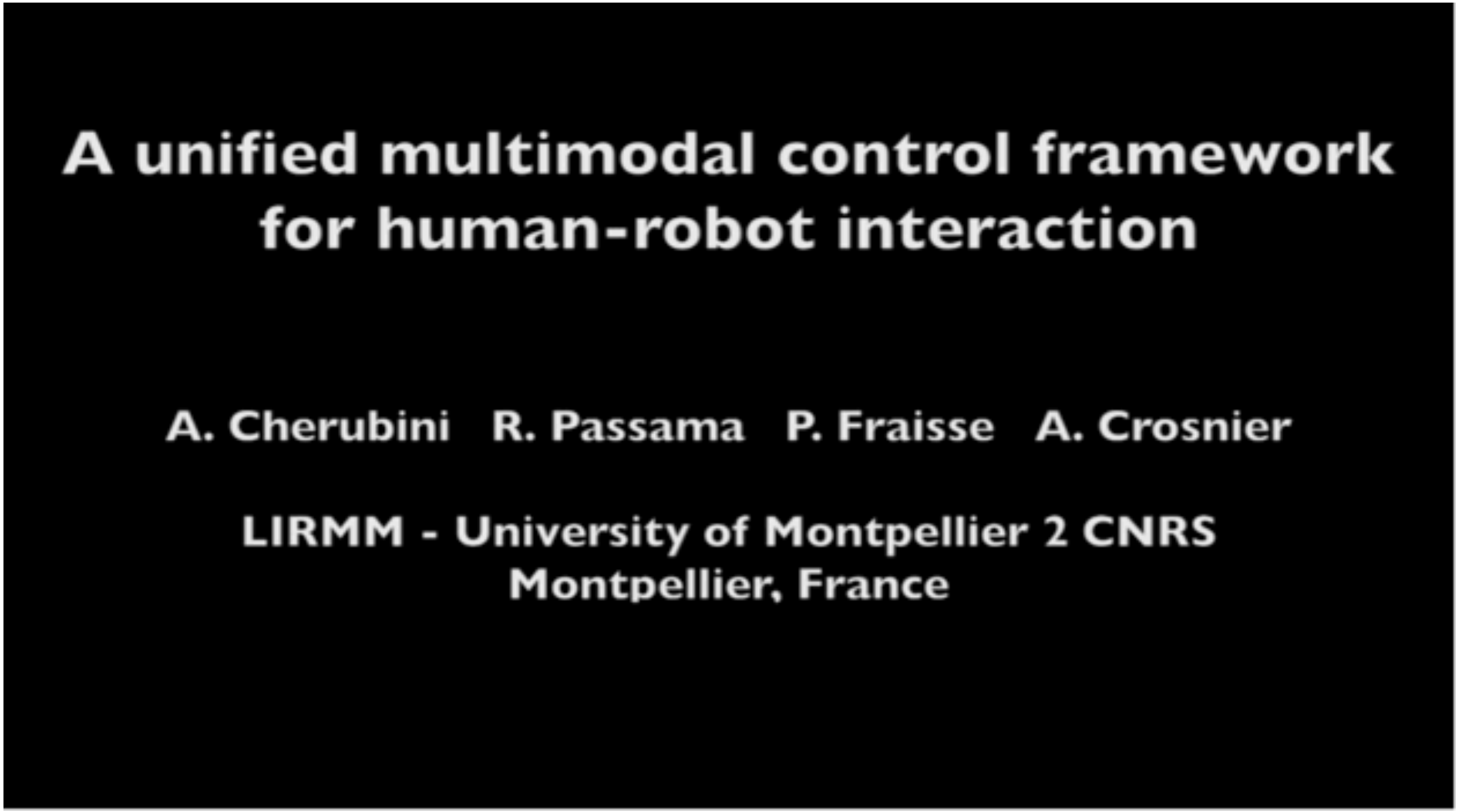
- touch used for intuitive programming

# Collaborative screwing

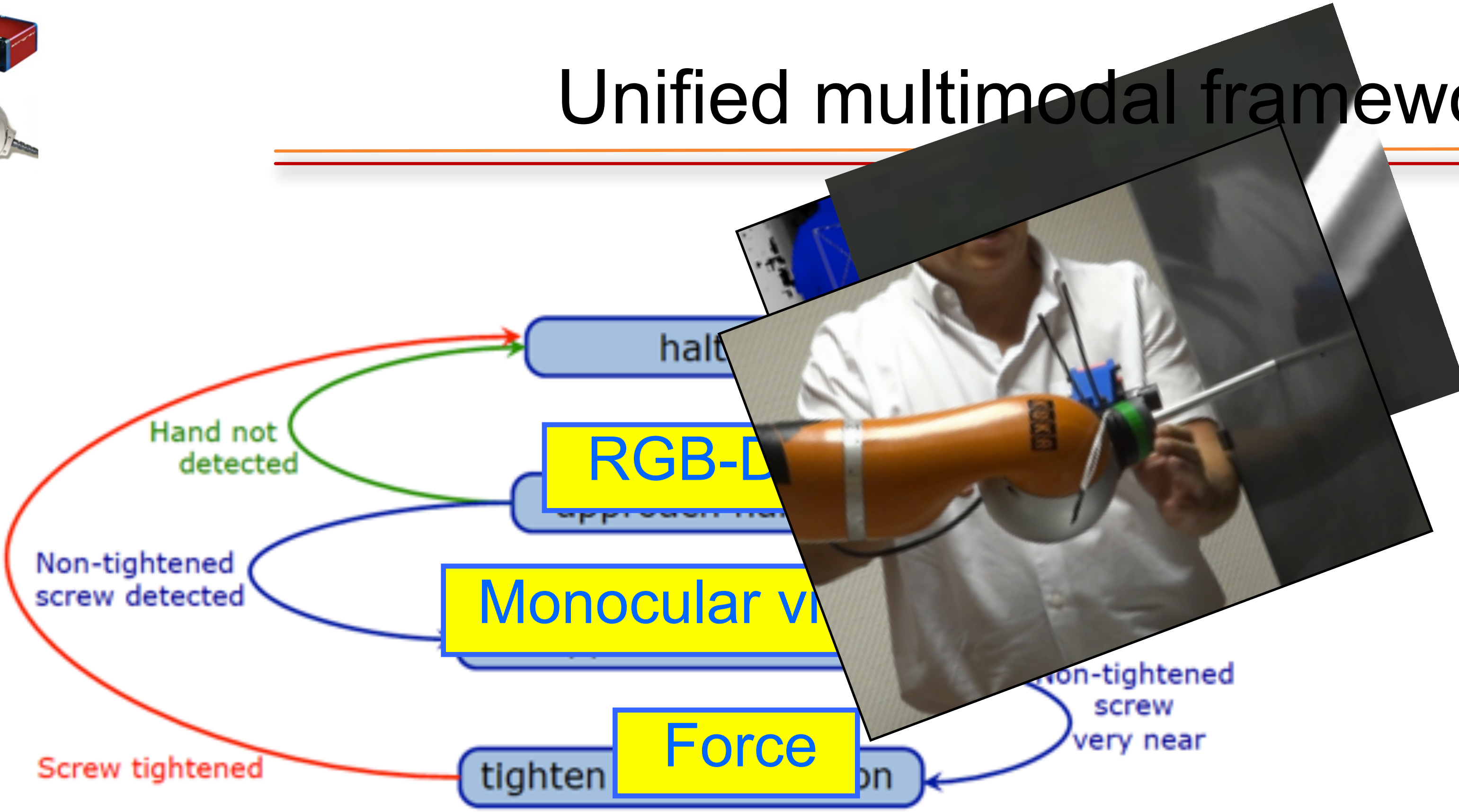


# Collaborative screwing



# Unified multimodal framework




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

$$v = -\sum^{n} \mathrm{S}_i \mathrm{J}_i^{-1} e_i$$ with $\mathbf{S_i}$ diagonal selection matrices

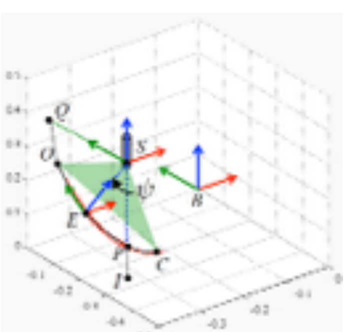
Converges IF:

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

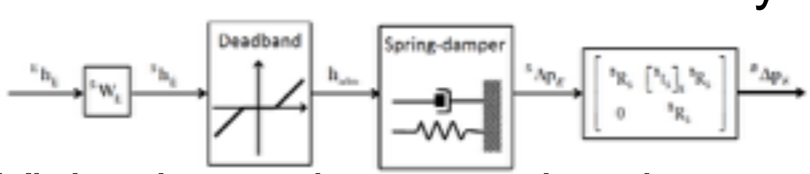
$$v = -\left(\sum^{n} \mathrm{S}_i \mathrm{J}_i\right)^{-1} \left[\mathrm{S}_1 \dots \mathrm{S}_n\right] \begin{bmatrix} e_1 \\ \dots \\ e_n \end{bmatrix}$$

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

# Collaborative assembly cell

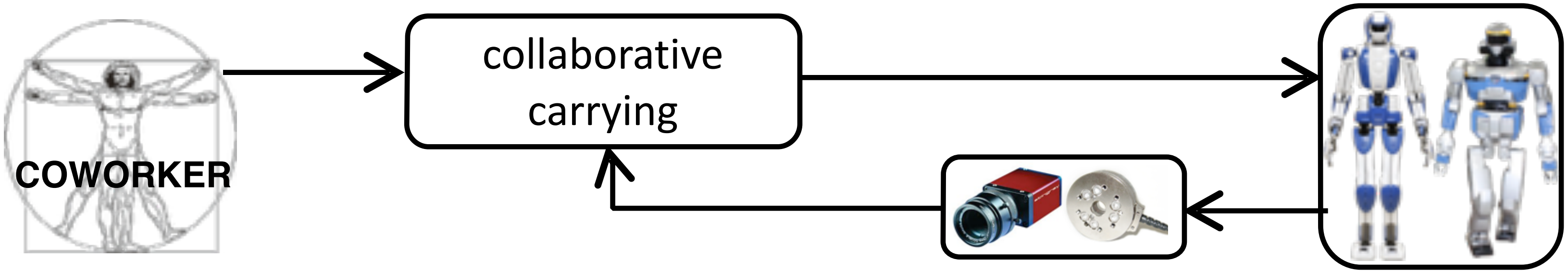



- Nominal trajectory is pre-taught…
  …then deformed by an admittance controller




- Vision is used as security trigger

# Collaborating with humanoids



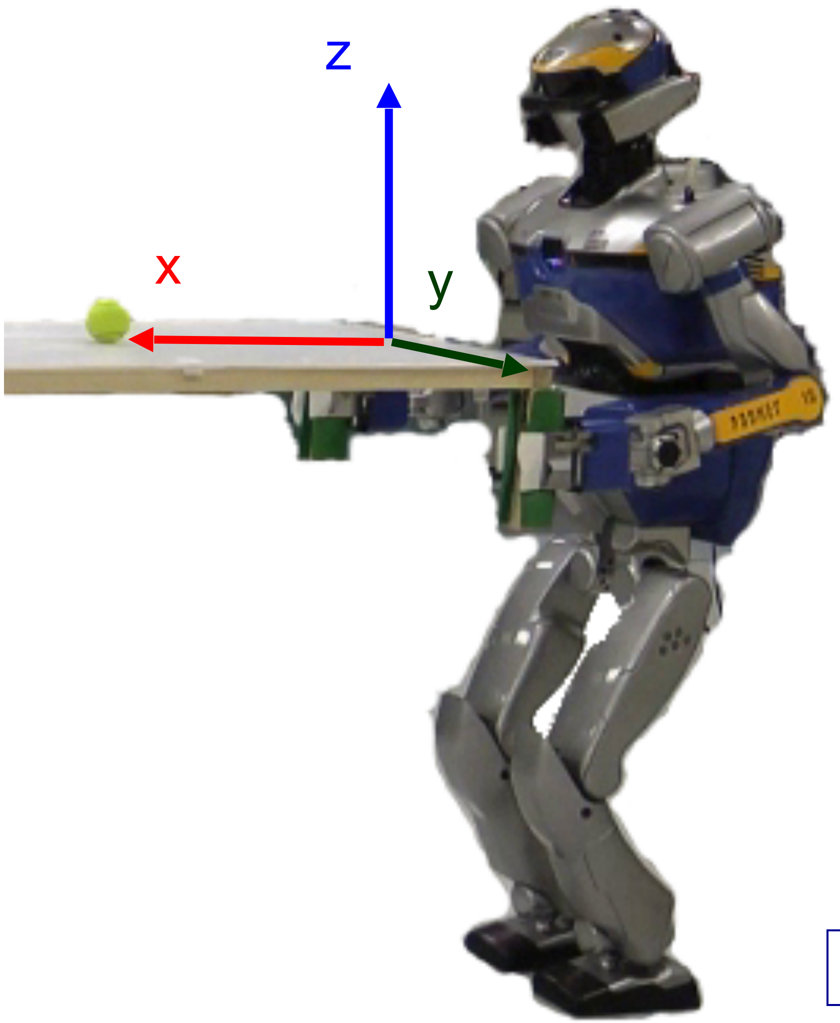

## MOTIVATION

- extend cobot mobility
- empathy with the collaborator

## SCIENTIFIC CHALLENGES

- walk under sustained forces
- whole body control

# 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

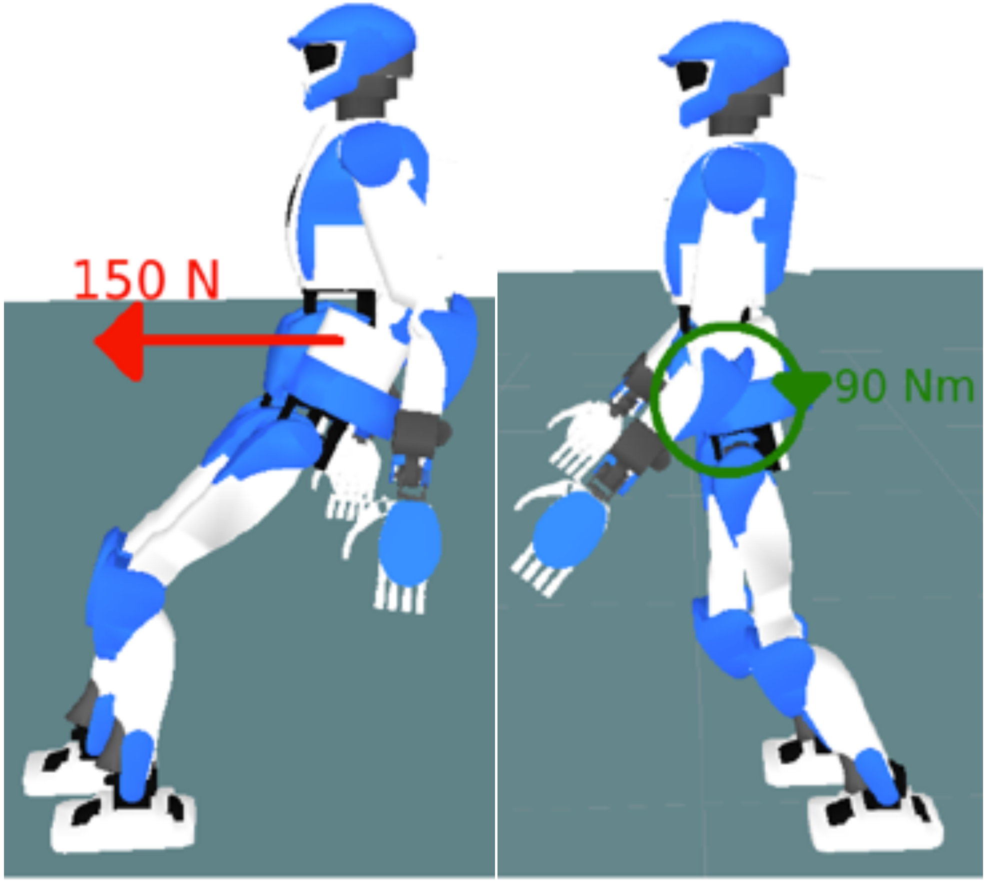
# Walking under sustained forces

Classic Zero Moment Point

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

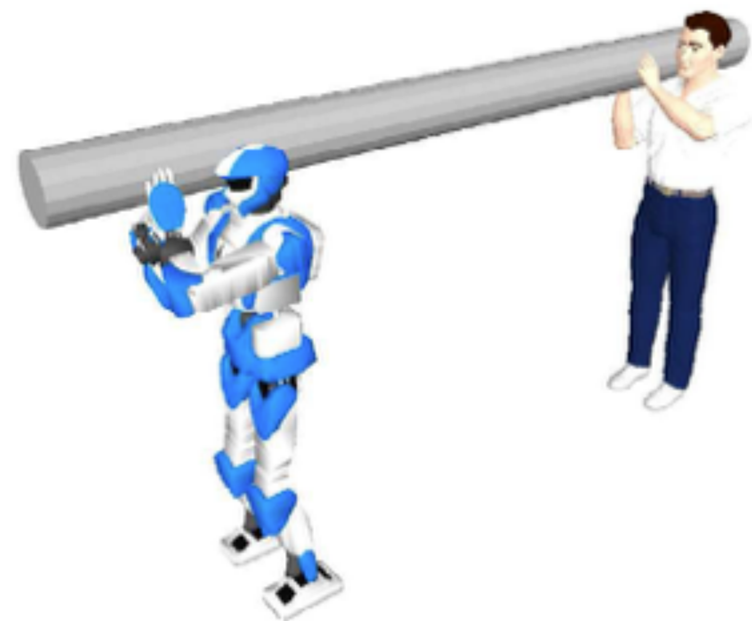
Zero Moment Point with external wrench

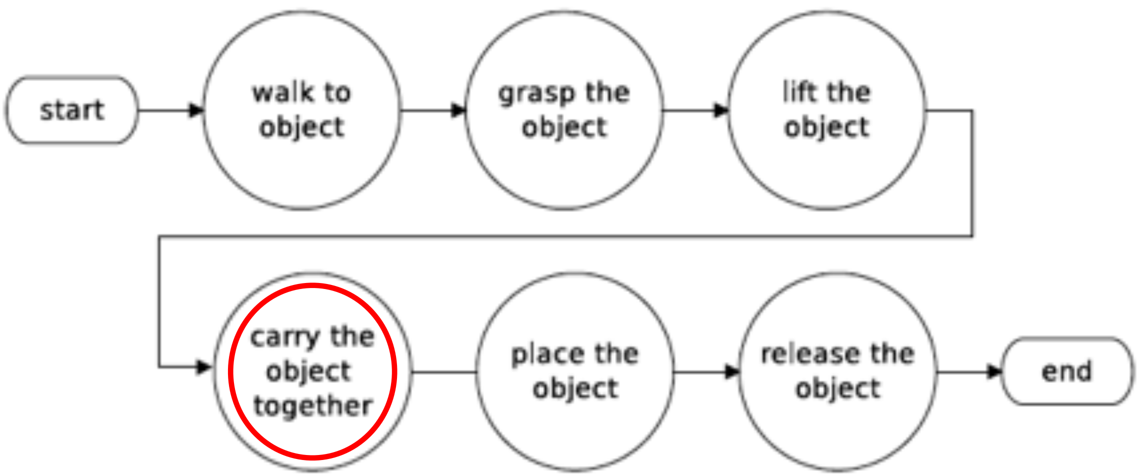
$$\begin{cases} x_{zmp} = x_{com} + \dfrac{z_{com}f_x + n_y}{mg - f_z} - \dfrac{z_{com}}{g - f_z/m}\ddot{x}_{com} \\ y_{zmp} = y_{com} + \dfrac{z_{com}f_x - n_x}{mg - f_z} - \dfrac{z_{com}}{g - f_z/m}\ddot{y}_{com} \end{cases}$$

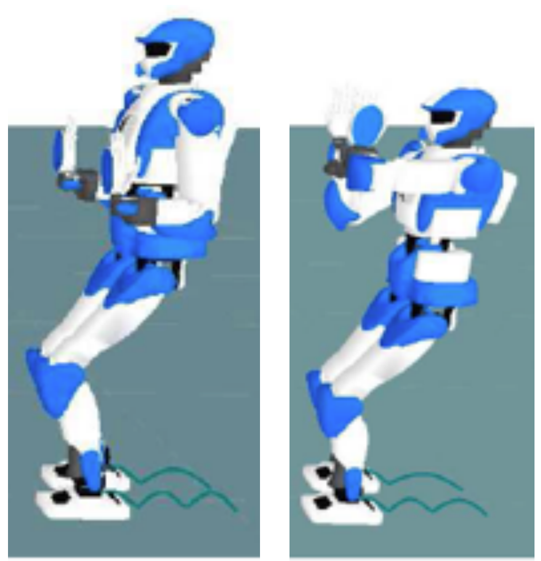



➔ Model predictive control to determine center of mass jerk and footsteps

# Whole-body control for collaborative carrying





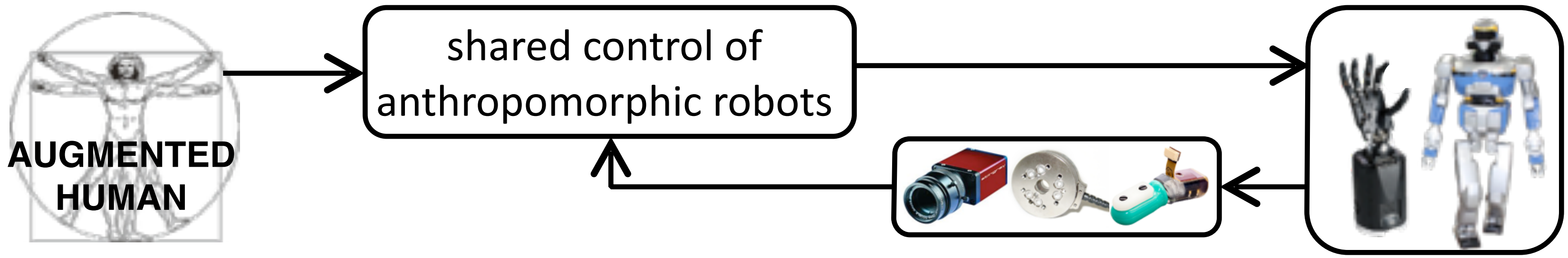
$$\underset{x}{\operatorname{argmin}} \sum_i w_i \left( x^{\mathrm{T}} \mathrm{Q}_i x + c_i^{\mathrm{T}} x \right)$$

$$\text{subject to: } \mathrm{A}x \le b$$

Both leader and follower behaviors are designed

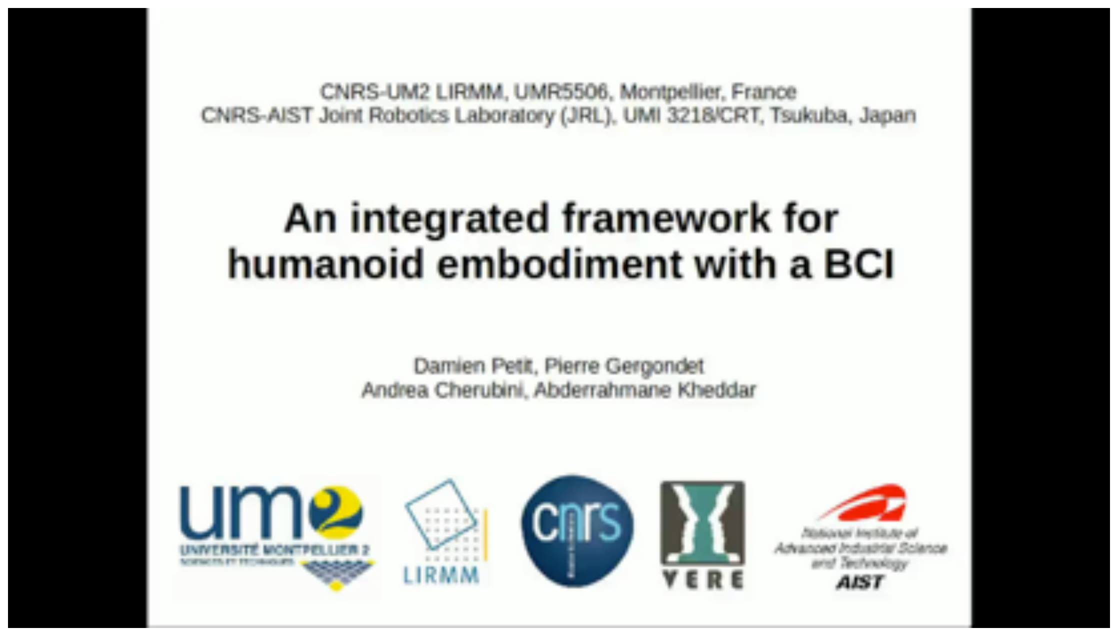
# Collaborative carrying framework

# Shared robot control




## MOTIVATION

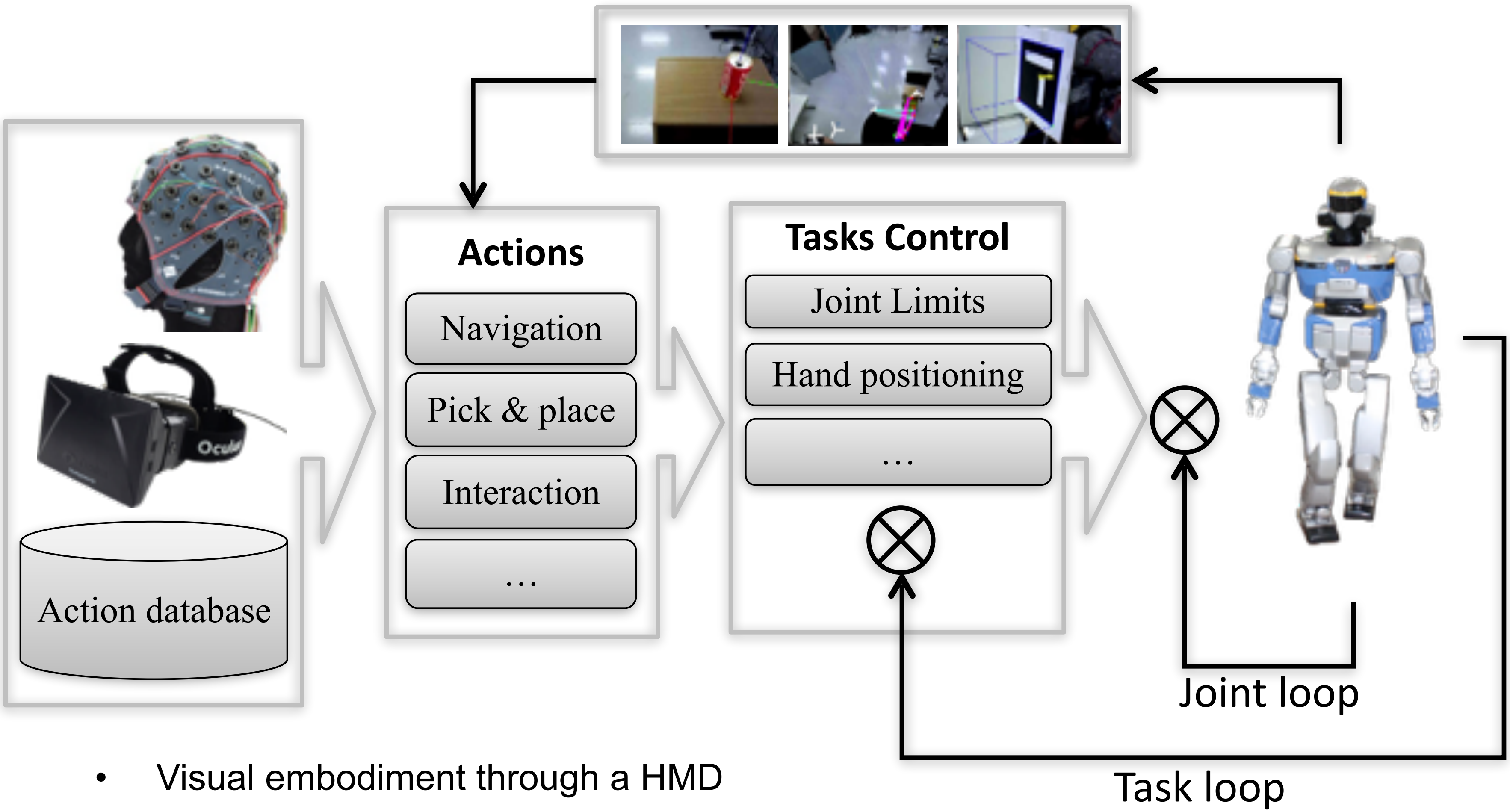
- augment human capabilities
- assistive and rescue applications




## SCIENTIFIC CHALLENGES

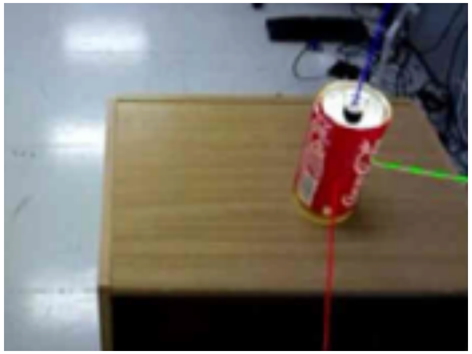
- embodiment in a robotic system
- transparent control from the user viewpoint

# Human-humanoid embodiment

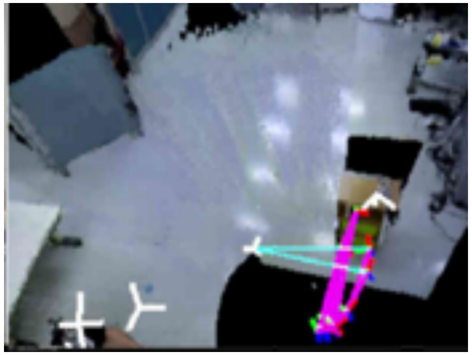



- Visual embodiment through a HMD
- Actions determined via a Brain Computer Interface
- Kinematic task control to move the robot
- Problem: BCI low frequency + high level actions
  - ➔ image processing and vision to aid shared control

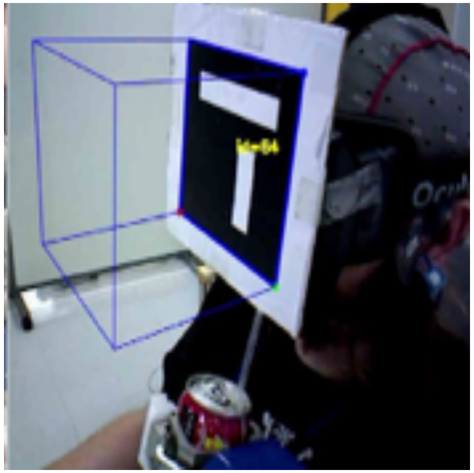
# Visual solutions aiding human control



object recognition and pose tracking [BLORT Vision Toolbox]

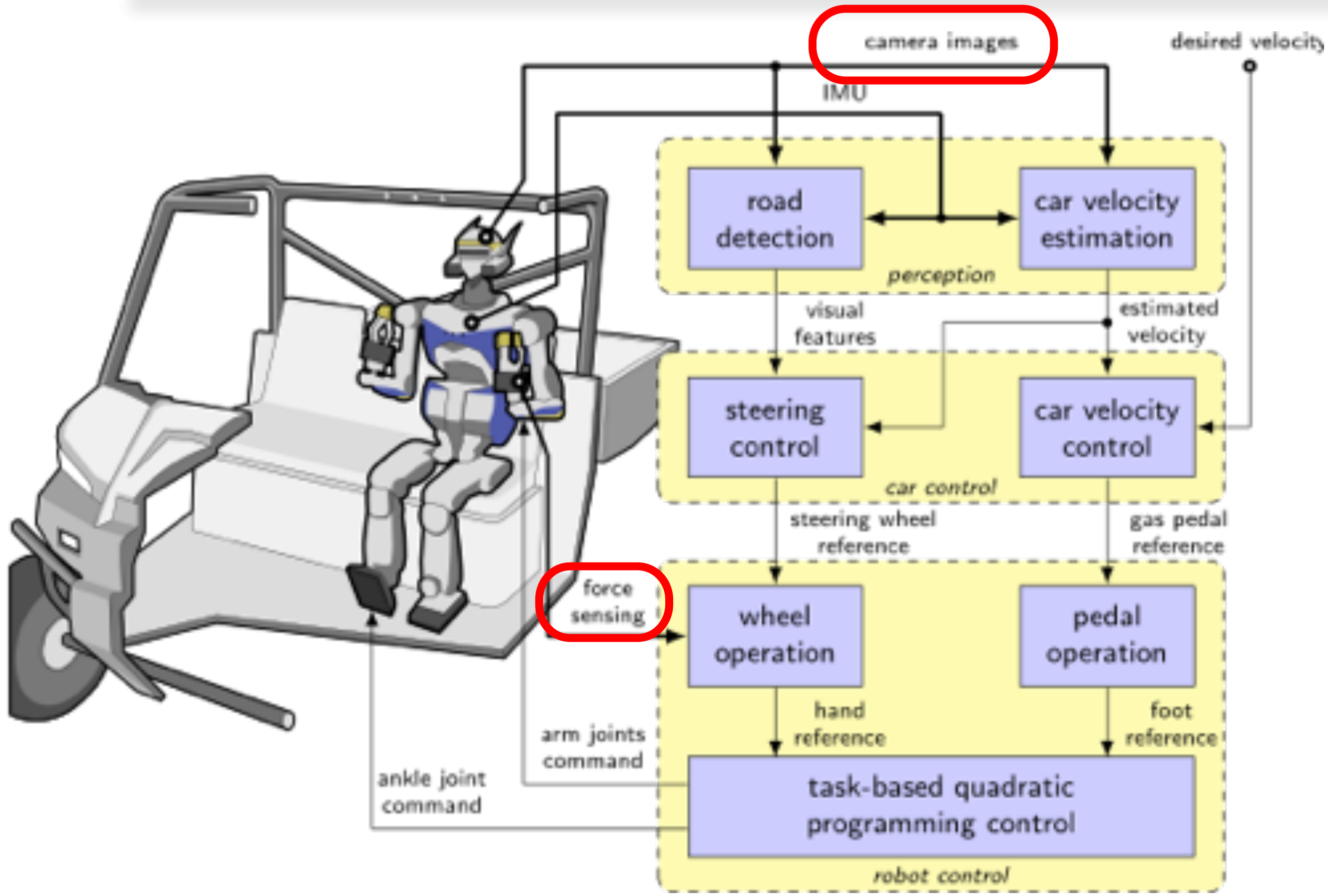


localization based on D6DSlam [Meilland, Comport, 2013]



precise positioning with ARUCO fiducial markers [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

## Autonomous car driving by a humanoid robot

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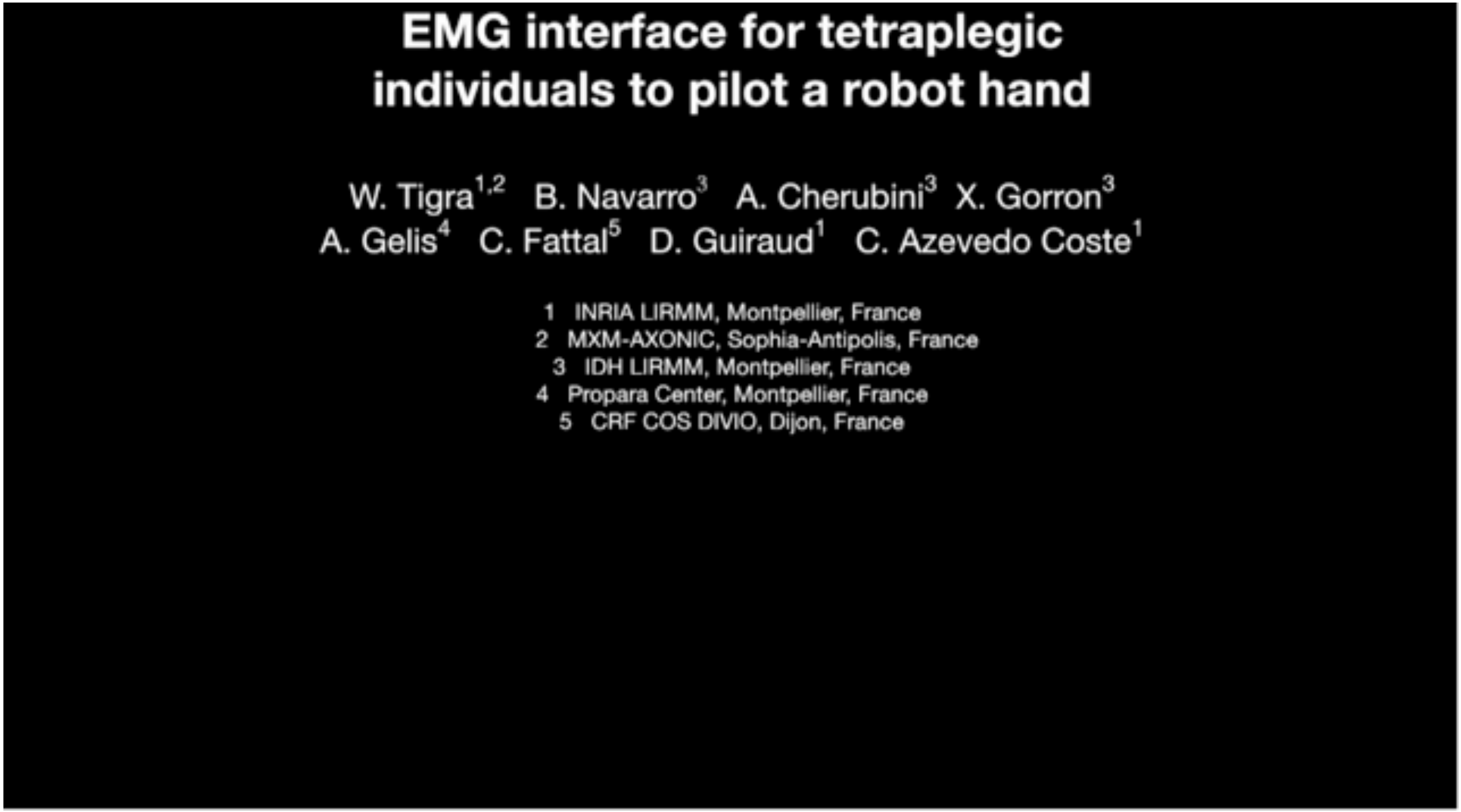
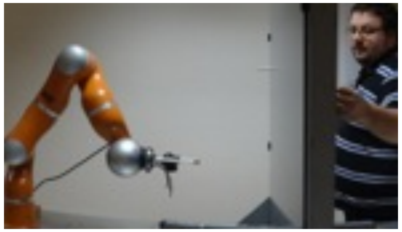
January 2016

# EMG to pilot a robotic hand




Touch used to stop grasping action

# Contributions



- generalization of the multimodal framework

- whole-body sensor-based control

- sensor-based control for inner feedback loop

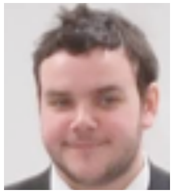
# EU H2020 Versatile Project (2017-2020)

| Parti | t Name | Country |
|---|---|---|
| 1 (Co | NALIA | Spain |
| 2 | | France |
| 3 | BUS | Spain |
| 4 | | Greece |
| 5 | IAU | Italy |
| 6 | I | Spain |
| 7 | ERMODALICS | Belgium |
| 8 | | Greece |
| 9 | LIRMM | France |

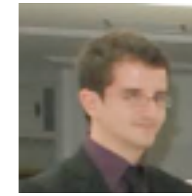
- Automotive pilot case

- Aerospace pilot case

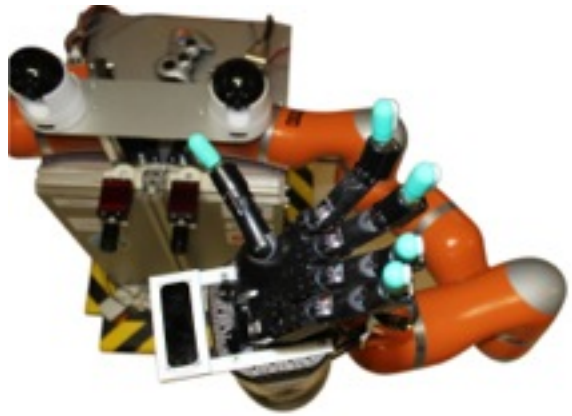
- Consumer good pilot










*Thank you!!*