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# Efficient calculation of human wrench capacity based on human musculoskeletal models Application in collaborative robot control

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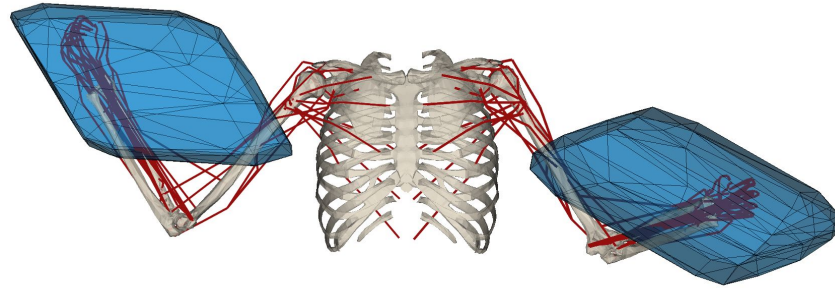
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# Efficient calculation of human wrench capacity based on human musculoskeletal models

Application in collaborative robot control

Antun Skuric, Vincent Padois, Nasser Rezzoug, David Daney



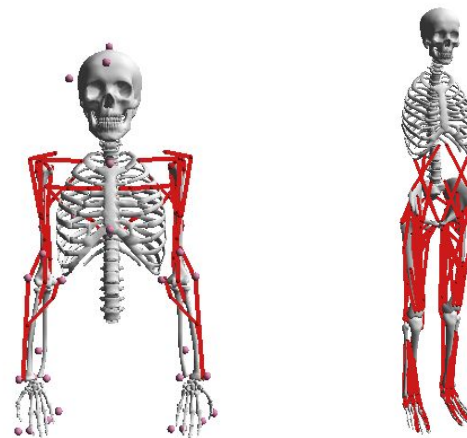
# Assistive robotics perspective

- Human-centered robot control
  - Robot constantly adapts to the **need** of the human counterpart
  - Example: Assist-as-needed paradigm
    - Exoskelts, Medical and collaborative robots
- Fundamental challenge/assumption  
***Real-time knowledge about human performance and capacity metrics***



# Assistive robotics perspective

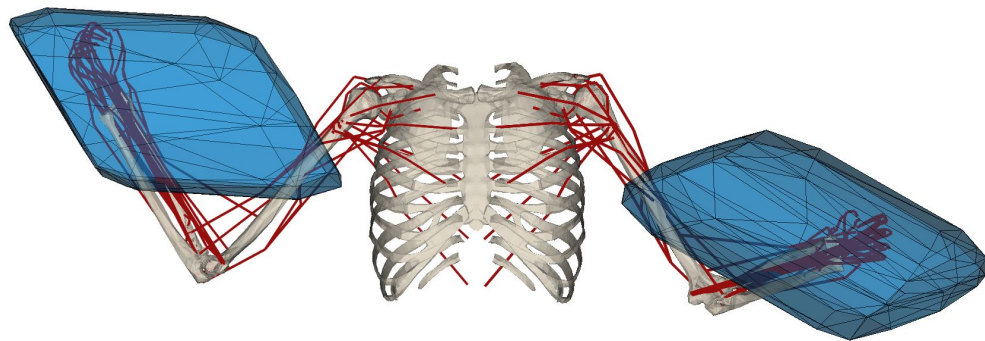
- Human-centered robot control
  - Robot constantly adapts to the **need** of the human counterpart
  - Example: Assist-as-needed paradigm
    - Exoskelts, Medical and collaborative robots
- Fundamental challenge/assumption  
***Real-time knowledge about human performance and capacity metrics***
- Musculoskeletal models
  - Most complete human body models
  - Mapping muscular dynamics to human body dynamics



# Wrench capacity of human musculoskeletal models

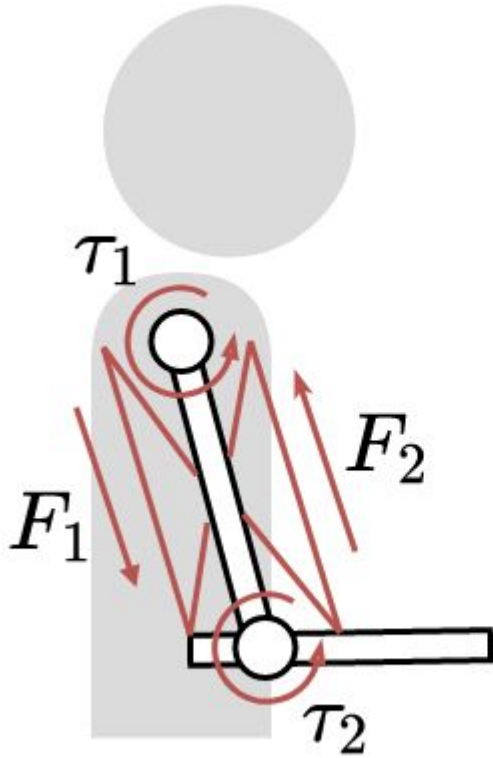
- “Ability to resist and apply forces and moments in arbitrary directions.”
  - Important for performance and safety analysis
- Ellipsoids
  - Efficient to calculate - online capable
  - Approximative measure
- ***Polytopes***
  - Exact solution
  - More complete metric
  - Computationally intensive

**So far not real-time capable**



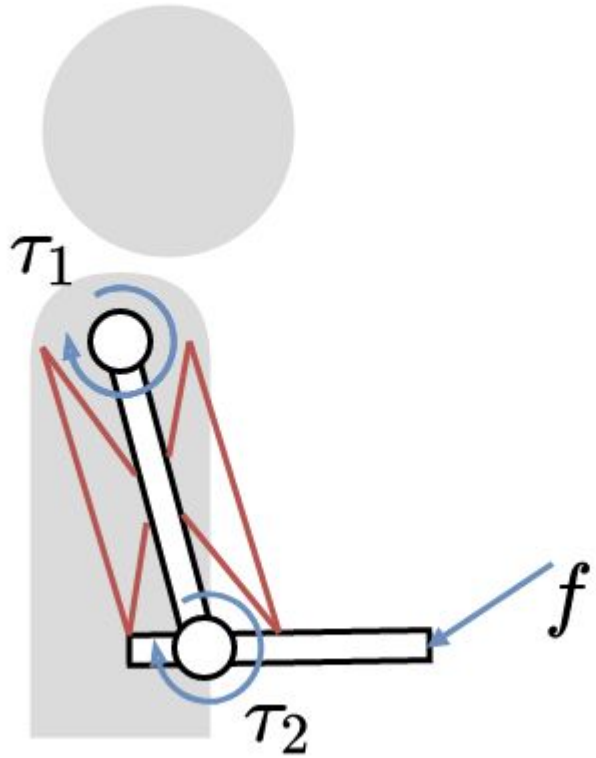
# Problem geometry: 6 muscle 2 dof planar example

$$q = \begin{bmatrix} q_1 \\ q_2 \end{bmatrix} \quad F = \begin{bmatrix} F_1 \\ F_2 \\ \dots \end{bmatrix} \quad F \in [\underline{F}, \overline{F}]$$



$$\tau = N(q)F$$

# Problem geometry: 6 muscle 2 dof planar example



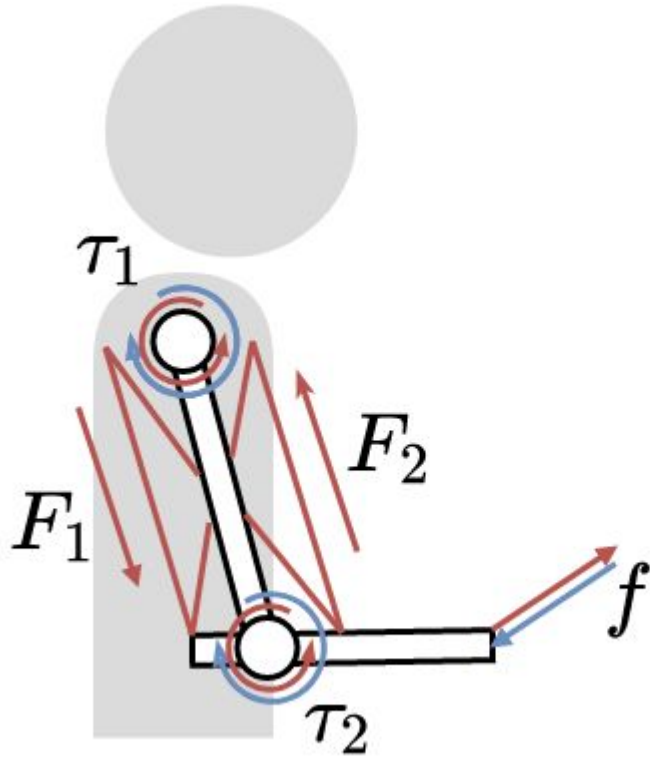
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$$\tau = N(q)F$$

$$\tau = J^T(q)f$$

Moment arm and Jacobian matrix  
Calculated using: OpenSim, Pyomeca, ...

# Problem geometry: 6 muscle 2 dof planar example



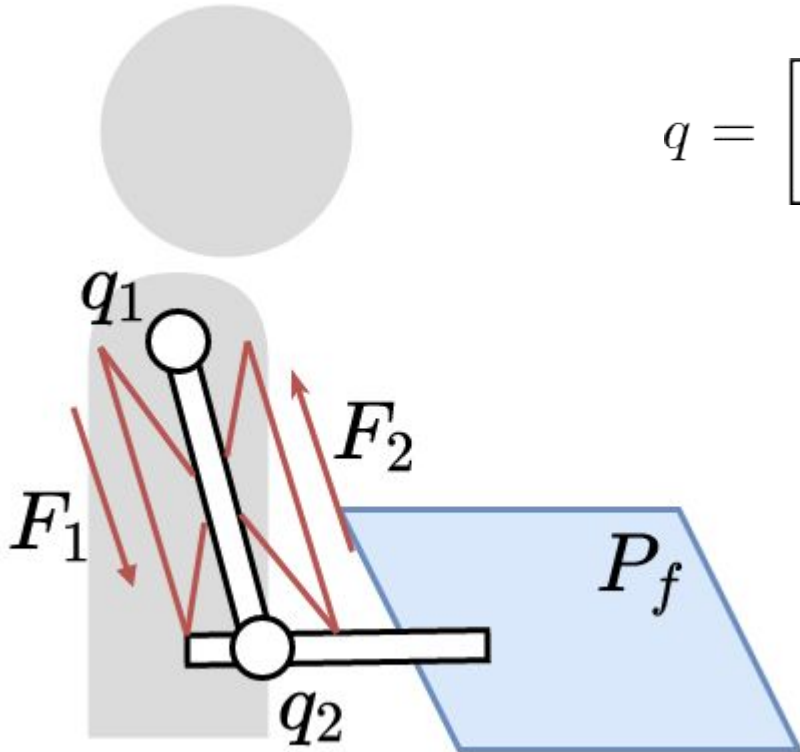
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$$J^T(q) f = N(q) F$$



# Problem geometry: 6 muscle 2 dof planar example

$$q = \begin{bmatrix} q_1 \\ q_2 \end{bmatrix} \quad F = \begin{bmatrix} F_1 \\ F_2 \\ \dots \end{bmatrix} \quad F \in [\underline{F}, \overline{F}]$$



$$J^T(q)f = N(q)F$$

$$P_f = \{f \in R^m \mid J^T f = NF, F \in [\underline{F}, \overline{F}]\}$$

# Wrench polytope calculation challenges

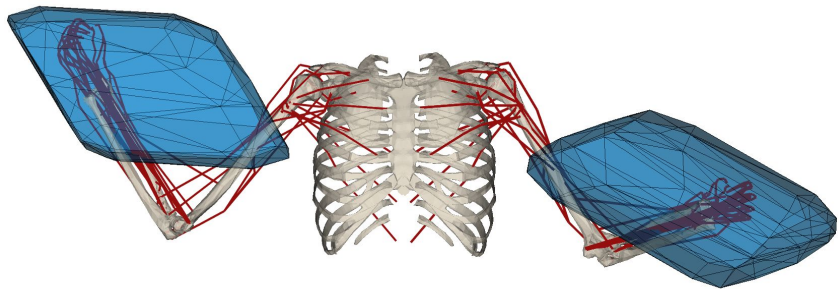
$$J^T(q)f = N(q)F \quad \underline{F} \leq F \leq \overline{F}$$

Class of problems:  $Ax = By \quad \underline{y} \leq y \leq \overline{y}$

Standard algorithms challenges:

- Implicit polytope definition
  - Combination of multiple methods necessary  $Ax \leq b$  and  $y = Ax$
- Exponential execution time with number of muscles
  - Number of muscles is usually high (ex. human arm 20-50 muscles)
- Exact polytope often impractical
  - Very high number of faces and vertices

# Proposed Algorithm



- Using implicit definition directly

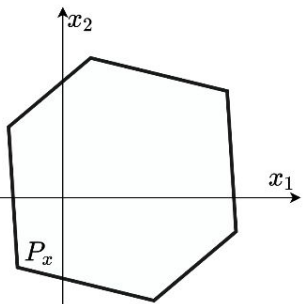
$$Ax = By \quad \underline{y} \leq y \leq \bar{y}$$

- Enables polytope approximation with user defined precision  $\epsilon$
- Near-linear execution time
  - With respect to the number of muscles
  - With respect to the precision  $\epsilon$
- Enables intuitive performance vs precision trade-off - *real-time capable*
  - Execution time: under 200ms for 50 muscle 7 dof human arm, precision  $\epsilon = 10\text{N}$
  - Execution time: under 100ms for 32 muscle 7 dof human arm, precision  $\epsilon = 10\text{N}$

# Proposed Algorithm

- Iterative method
  - *Linear programming* to find polytope vertices
  - *Convex hull algorithm* to group them
- Successively augmenting the precision of the approximation

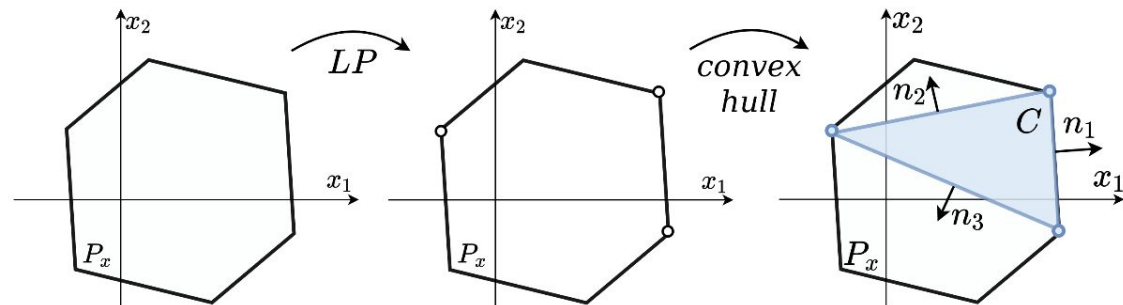
Geometric interpretation:



# Proposed Algorithm

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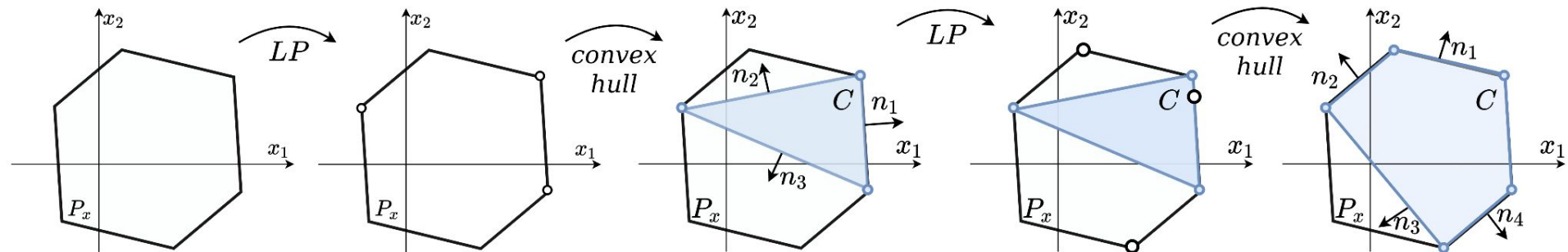
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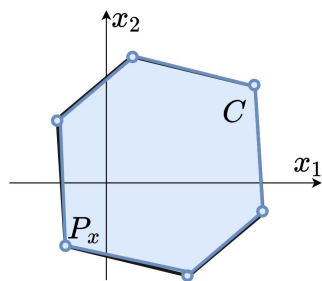
Geometric interpretation:



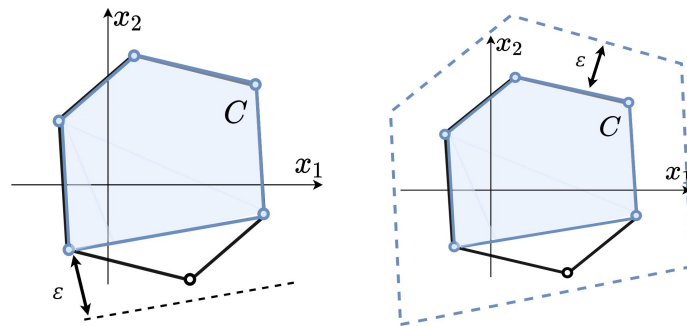
# Proposed Algorithm

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Stopping condition:



Exact solution found



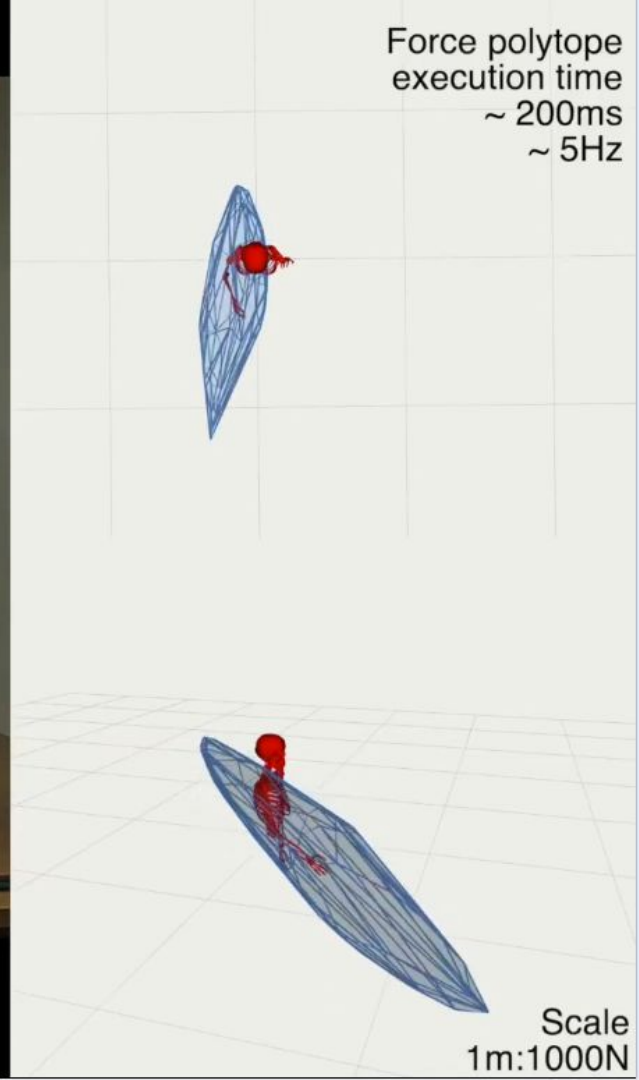
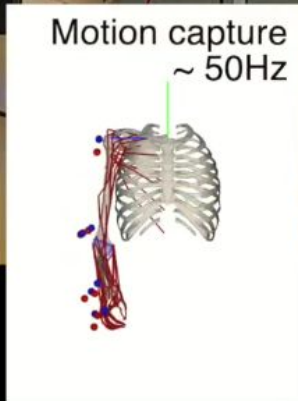
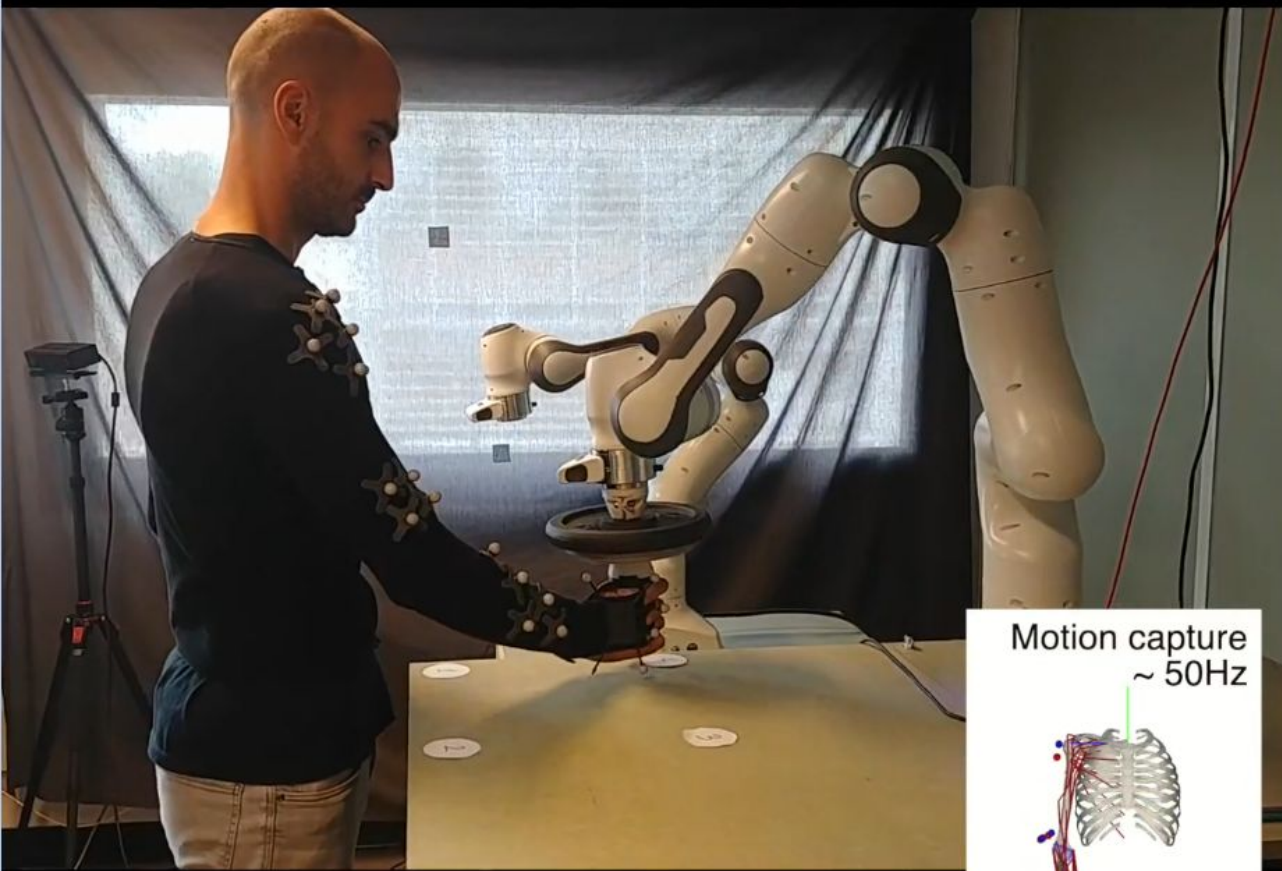
Precision  $\epsilon$  satisfied

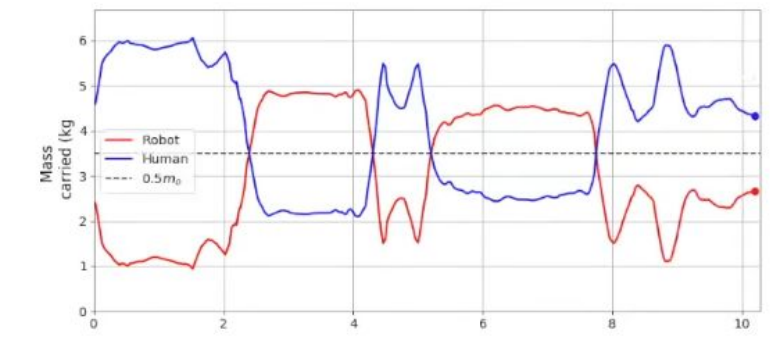
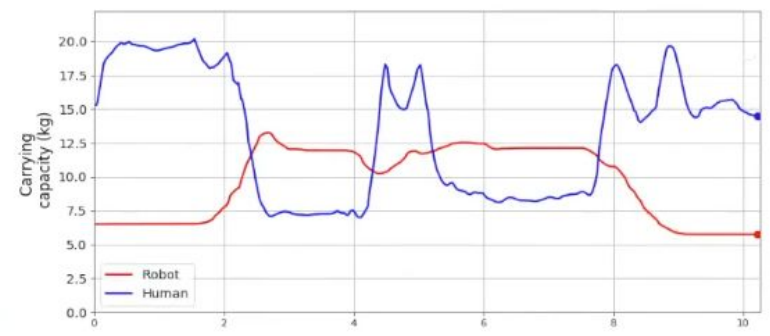
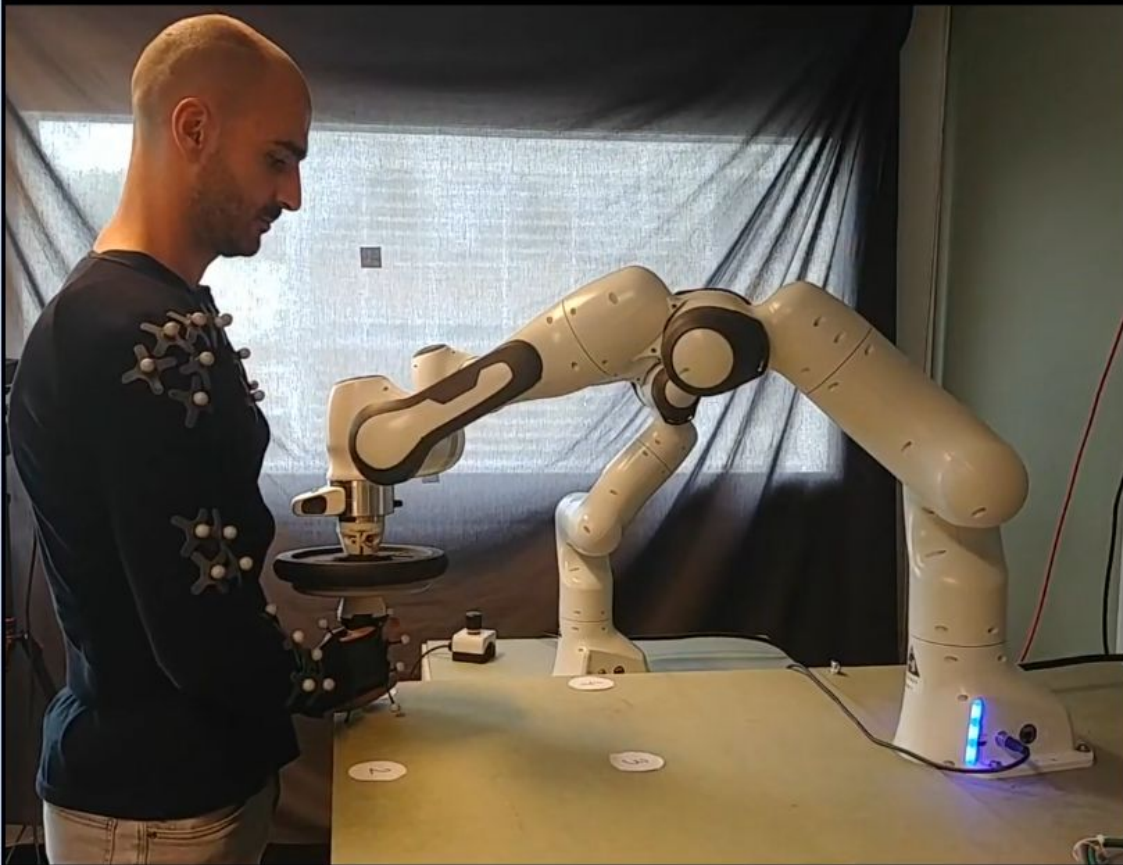
*Experiment*

*Collaborative carrying task*

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# Conclusion

- Novel polytope evaluation algorithm for class of problems  $Ax = By$
- Efficient human wrench polytope calculation
  - Enables polytope approximation with user defined precision  $\epsilon$
  - Can be used for real-time robot control - *example: Collaborative carrying task*

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**GitLab:** [https://gitlab.inria.fr/askuric/human\\_wrench\\_capacity](https://gitlab.inria.fr/askuric/human_wrench_capacity)

**HAL:** <https://hal.inria.fr/hal-03369576>

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