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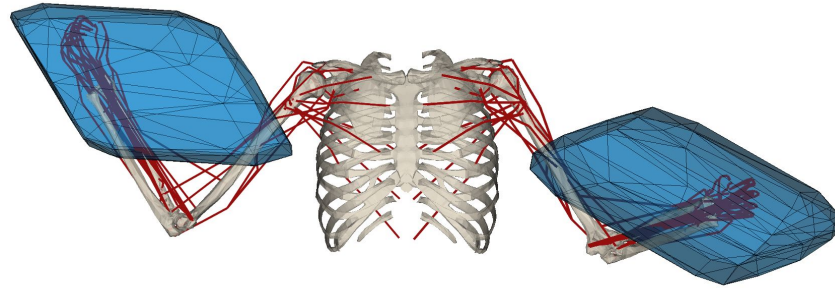
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Efficient calculation of human wrench capacity based on human musculoskeletal models

Application in collaborative robot control

Antun Skuric, Vincent Padois, Nasser Rezzoug, David Daney



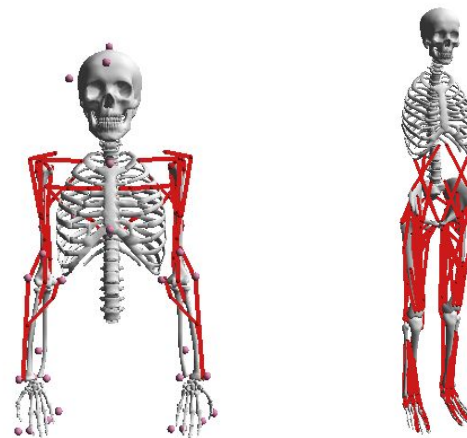
Assistive robotics perspective

- 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

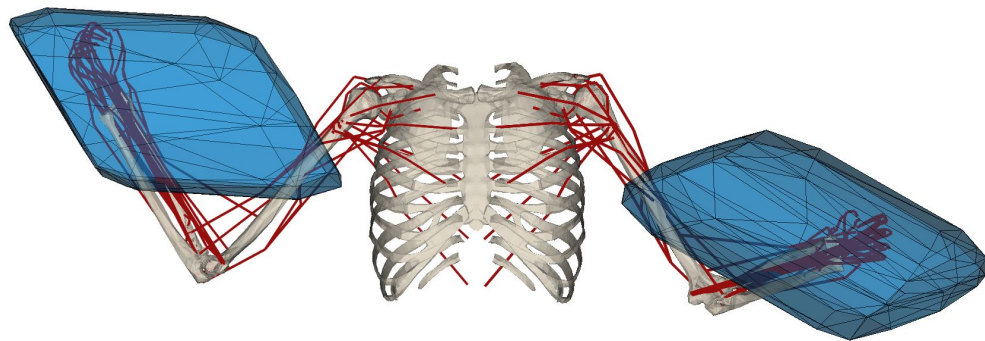
- Human-centered robot control
 - Robot constantly adapts to the **need** of the human counterpart
 - Example: Assist-as-needed paradigm
 - Exoskelts, Medical and collaborative robots
- Fundamental challenge/assumption
Real-time knowledge about human performance and capacity metrics
- Musculoskeletal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



Wrench capacity of human musculoskeletal models

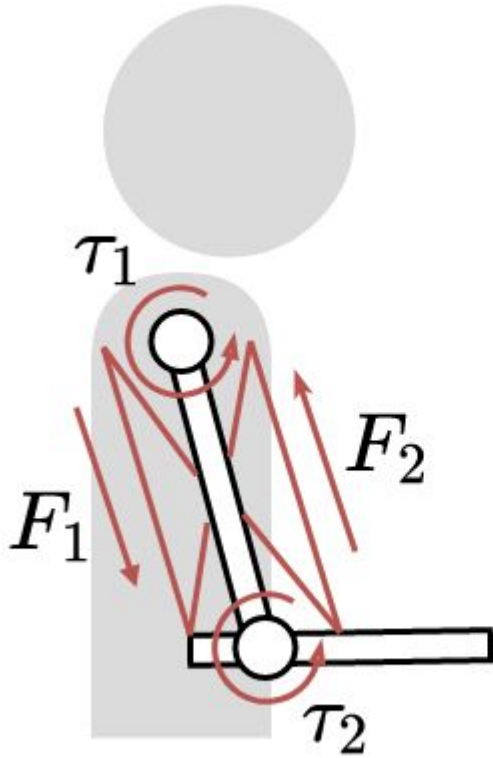
- “Ability to resist and apply forces and moments in arbitrary directions.”
 - Important for performance and safety analysis
- Ellipsoids
 - Efficient to calculate - online capable
 - Approximative measure
- ***Polytopes***
 - Exact solution
 - More complete metric
 - Computationally intensive

So far not real-time capable



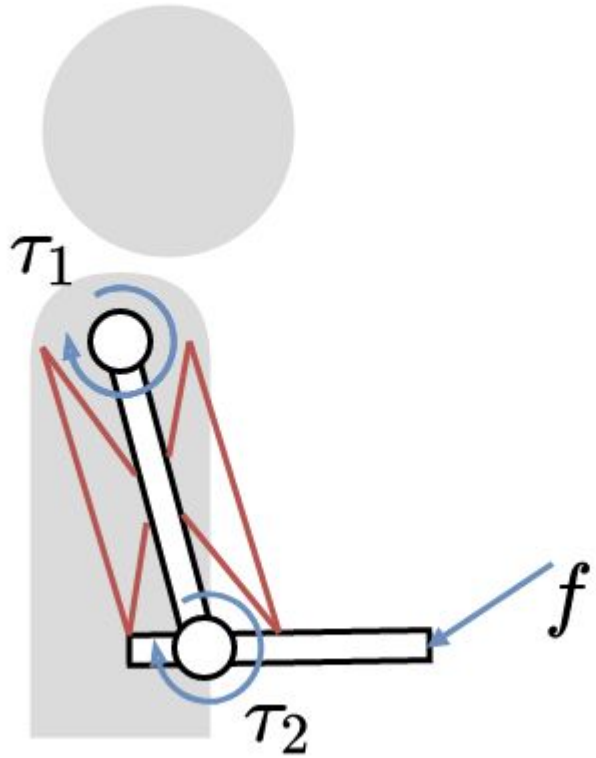
Problem geometry: 6 muscle 2 dof planar example

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



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

Problem geometry: 6 muscle 2 dof planar example

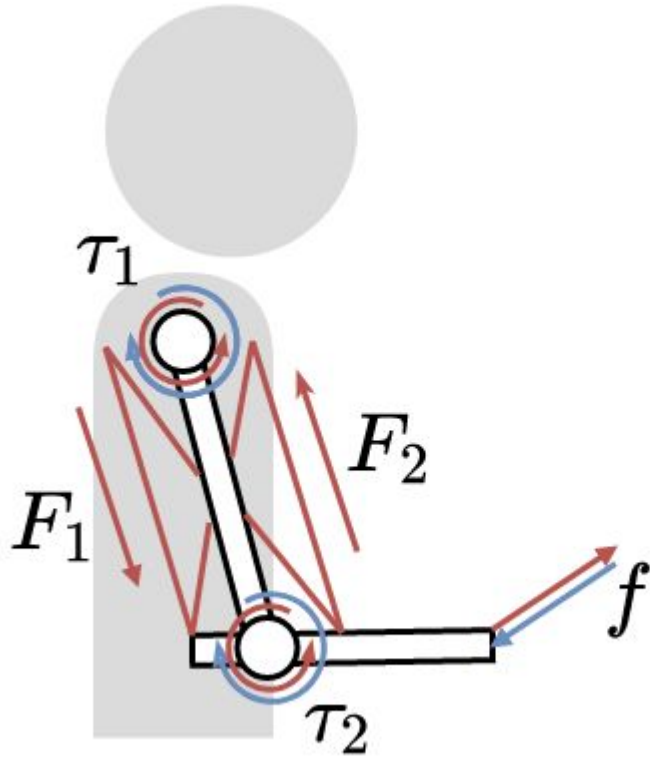


$$q = \begin{bmatrix} q_1 \\ q_2 \end{bmatrix} \quad F = \begin{bmatrix} F_1 \\ F_2 \\ \dots \end{bmatrix} \quad F \in [\underline{F}, \overline{F}]$$

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

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

Problem geometry: 6 muscle 2 dof planar example

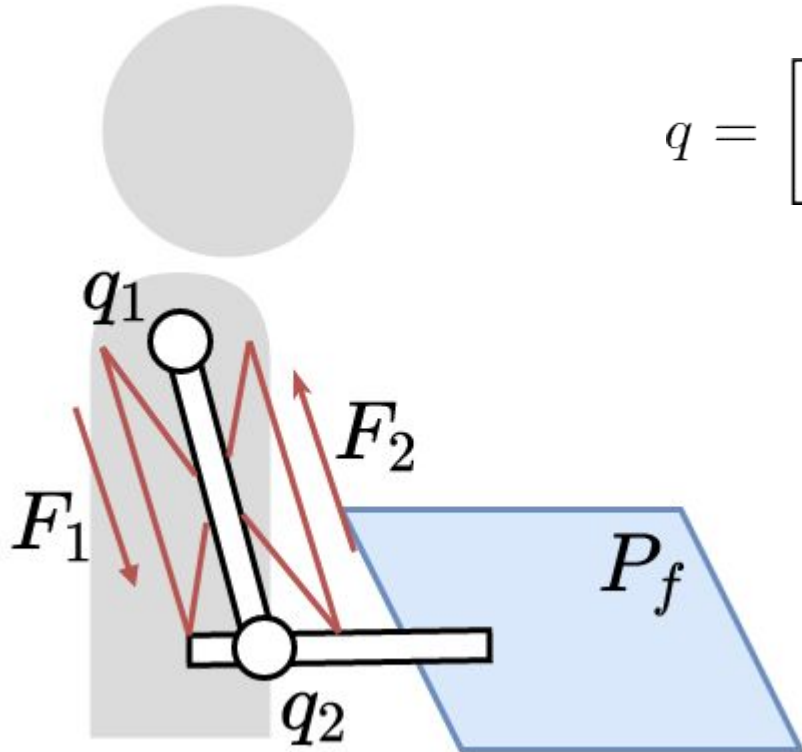


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$$J^T(q)f = N(q)F$$

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

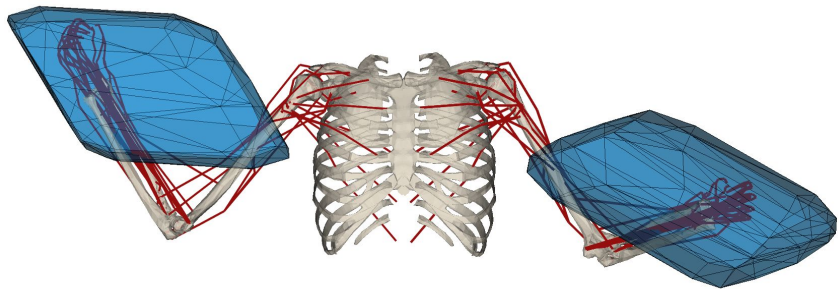
$$J^T(q)f = N(q)F \quad \underline{F} \leq F \leq \overline{F}$$

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

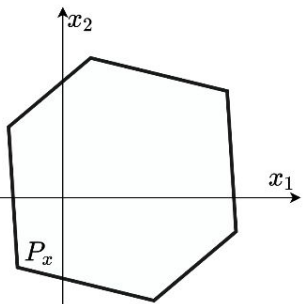
$$Ax = By \quad \underline{y} \leq y \leq \bar{y}$$

- Enables polytope approximation with user defined precision ϵ
- Near-linear execution time
 - With respect to the number of muscles
 - With respect to the precision ϵ
- 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

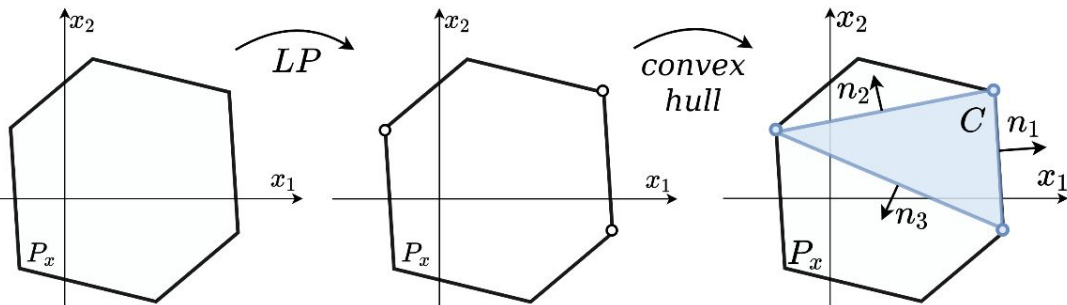
Geometric interpretation:



Proposed Algorithm

- Iterative method
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 - *Convex hull algorithm* to group them
- Successively augmenting the precision of the approximation

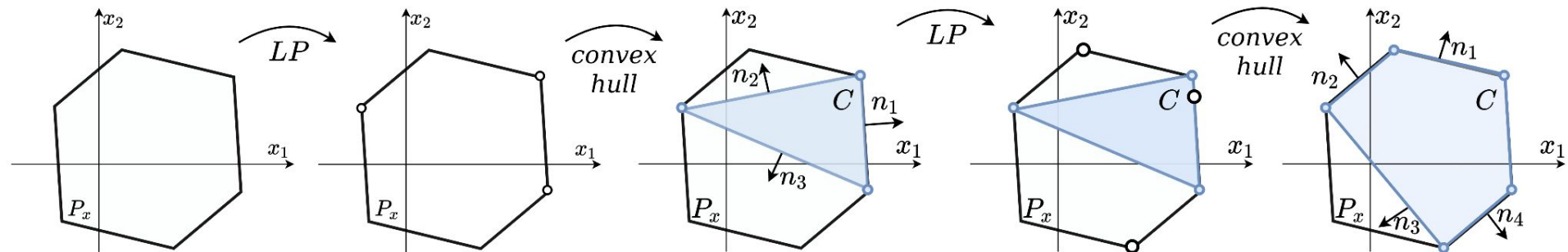
Geometric interpretation:



Proposed Algorithm

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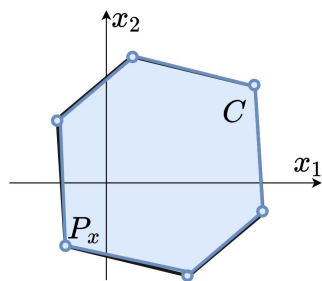
Geometric interpretation:



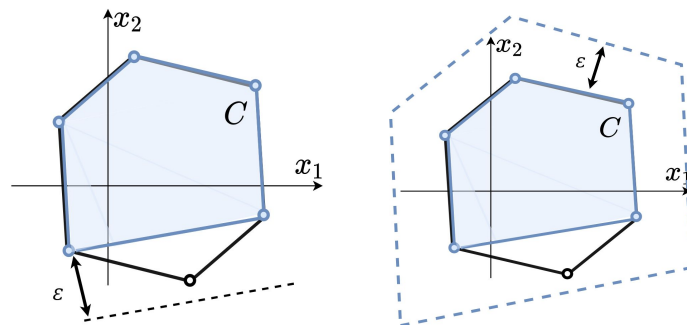
Proposed Algorithm

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

Stopping condition:



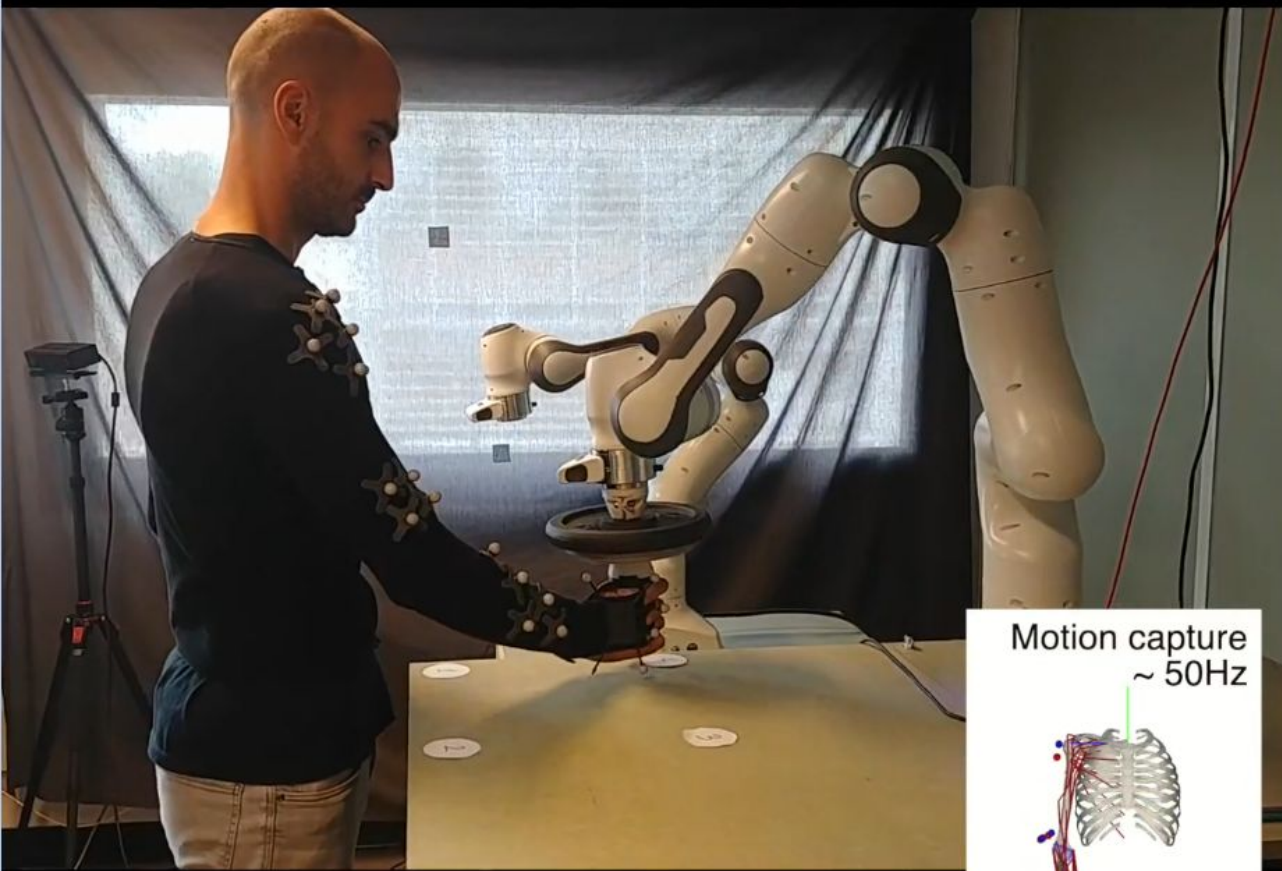
Exact solution found



Precision ϵ satisfied

Experiment

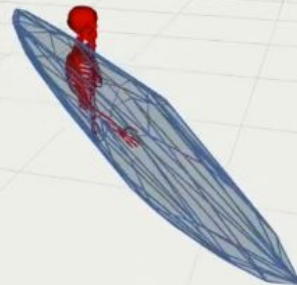
Collaborative carrying task



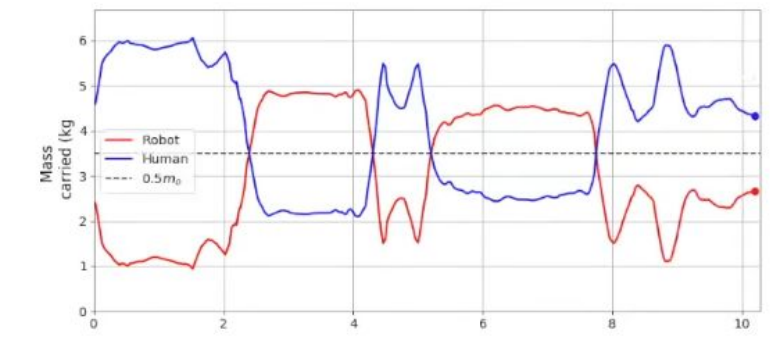
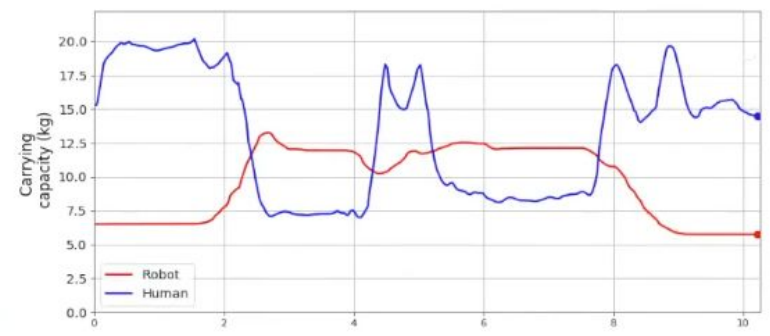
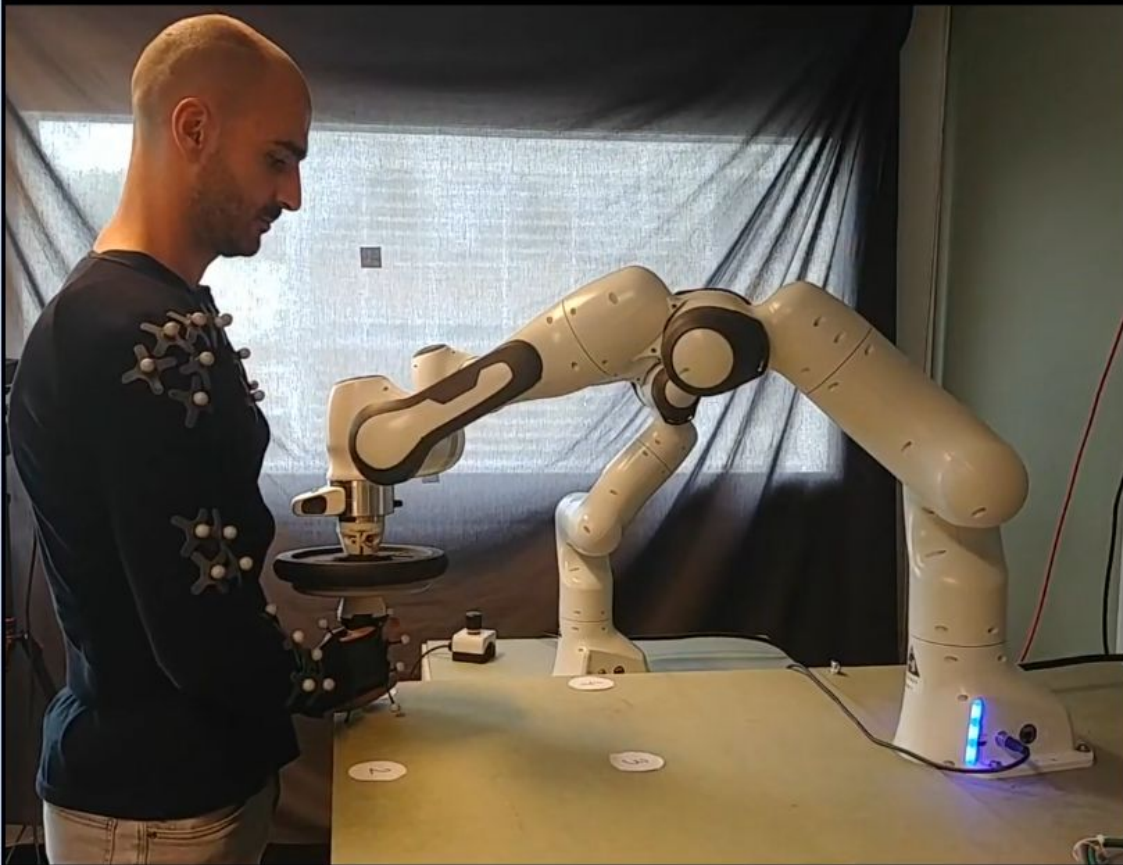
Motion capture
~ 50Hz



Force polytope
execution time
~ 200ms
~ 5Hz



Scale
1m:1000N



Conclusion

- Novel polytope evaluation algorithm for class of problems $Ax = By$
- Efficient human wrench polytope calculation
 - Enables polytope approximation with user defined precision ϵ
 - 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

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

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