Manipulation systems

Gionata Salvietti

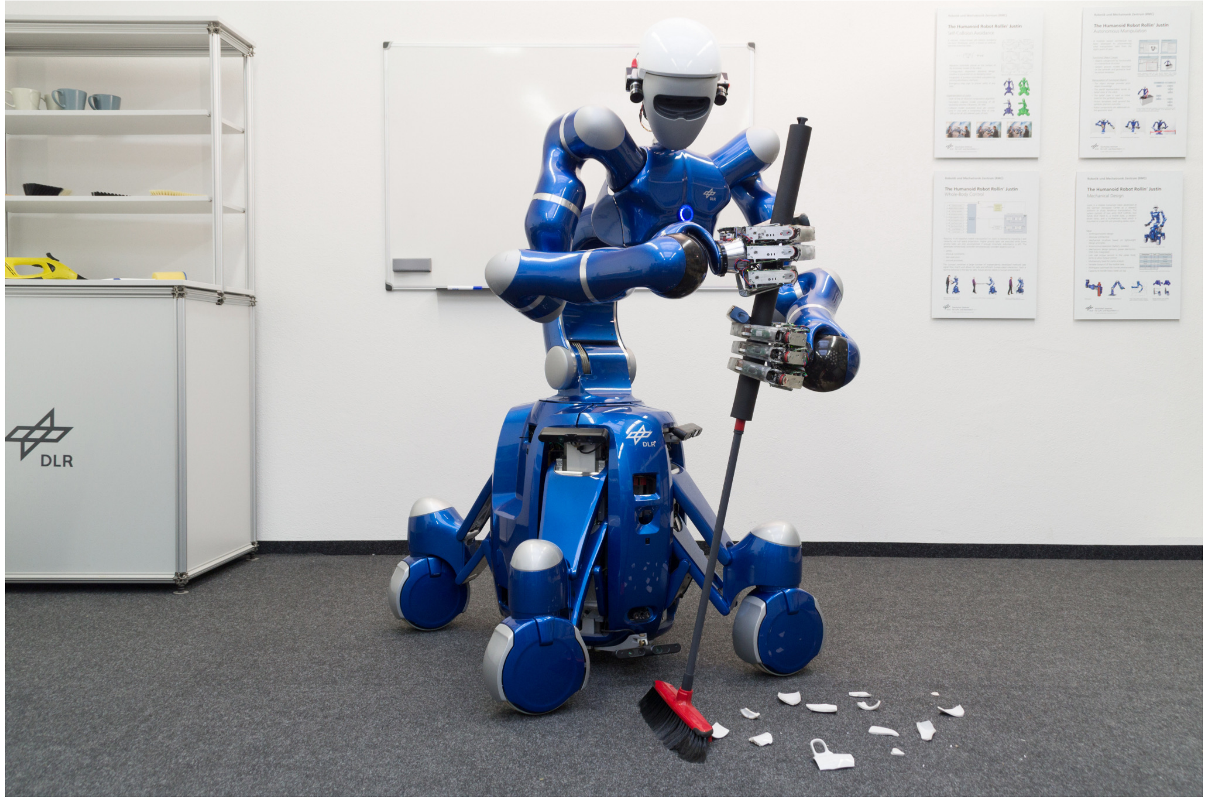
ROBOTIC MANIPULATION

Robotic Manipulation

1997- IBM supercomputer, Deep Blue became Chess World Champion

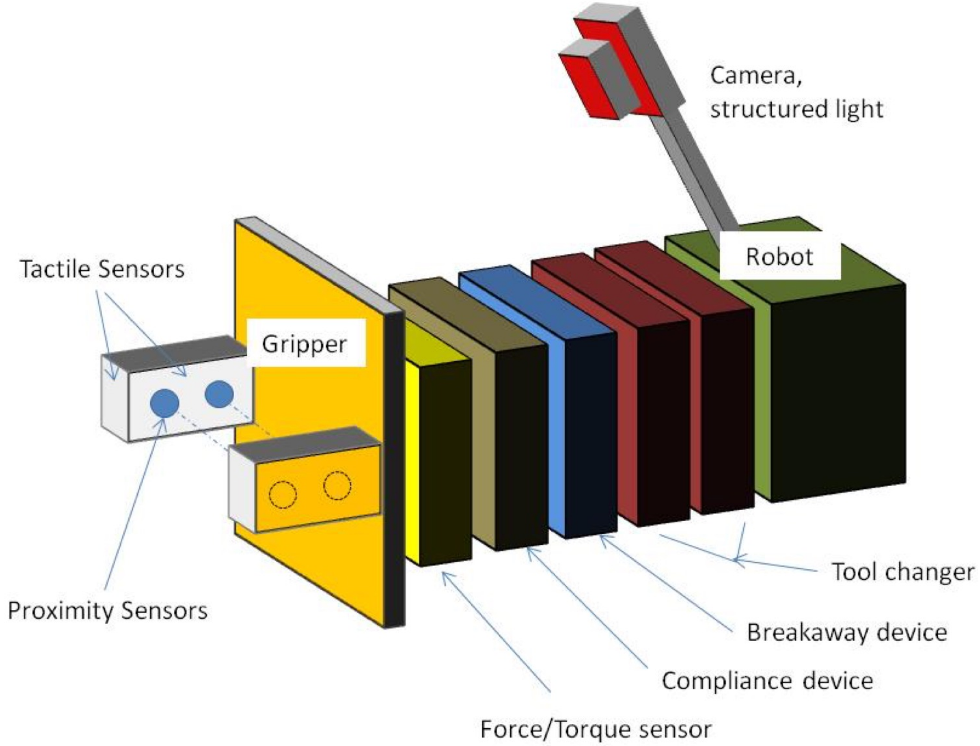
Rolling Justin @ DLR

https://youtu.be/SLqXZ3aFVQA



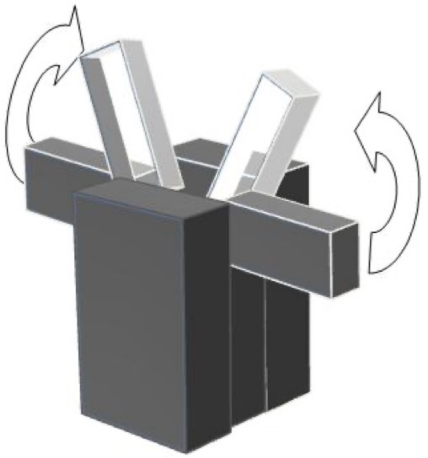
Manipulation technology

Robot end-effector



Bostelman, R. and Falco, J. (2012), Survey of Industrial Manipulation Technologies for Autonomous Assembly Applications, NIST Interagency/Internal Report (NISTIR), National Institute of Standards and Technology, Gaithersburg, MD, [online], https://doi.org/10.6028/NIST.IR.7844

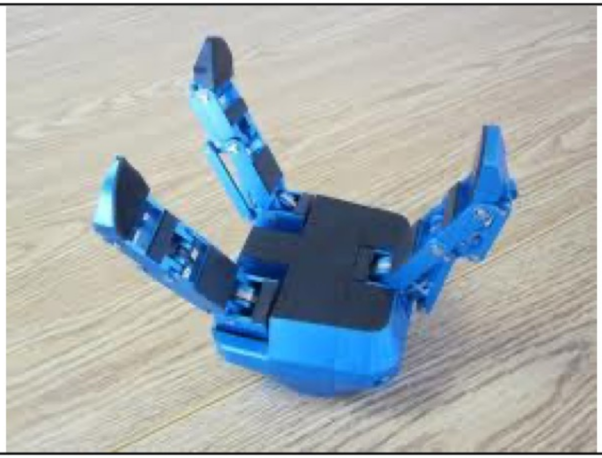
End-effectors with fixed shape fingers

Gripper Class Example	Brief Description
 	<u>Two fingers - Revolute (angular) and translational pairs:</u> (left) Rotational or angular and (right) translational (www.schunk.com) two fingered grippers. The translational gripper shows the universal adapter (bottom tabs) ready for attaching custom fingers as in the extended jaw case that follows. *[photo-use permission granted by Schunk]*

End-effectors with fixed shape fingers

	Two Fingers - Extended jaws: Translational two fingered gripper with extended jaws for grasping square or round parts. (www.schunk.com) *[photo-use permission granted by Schunk]*
	Three fingers - Grasp at three points: Three fingered concentric, long stroke, belt-drive gripper (www.schunk.com) *[photo-use permission granted by Schunk]*

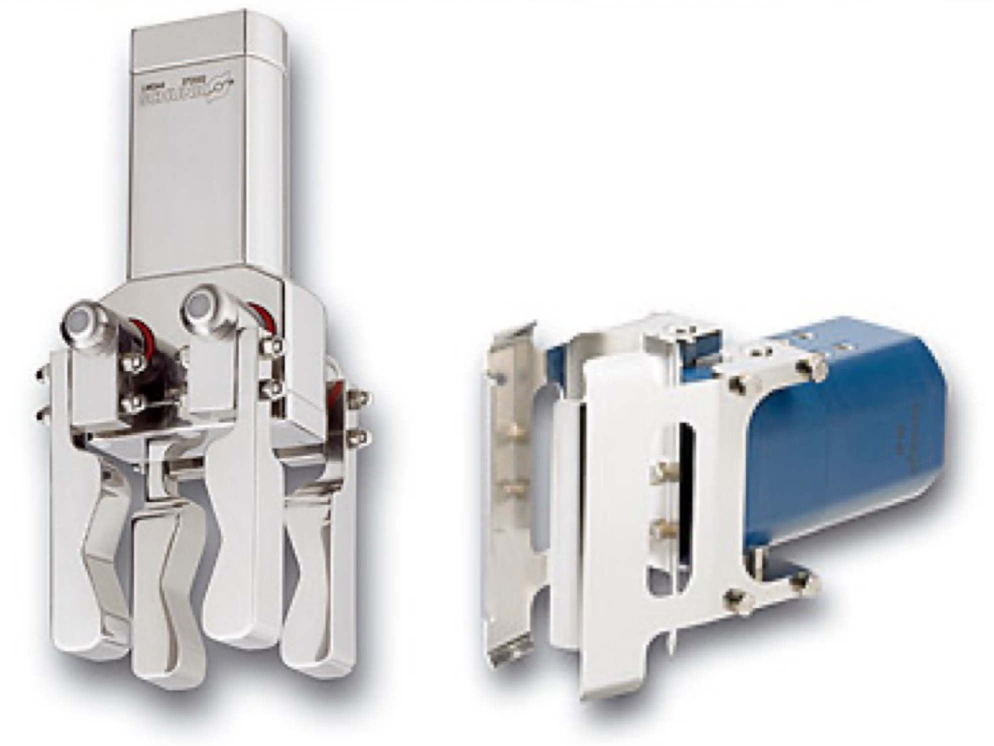
End-effectors with fixed shape fingers



Spherical objects of differing size maintaining center:
Three fingered gripper (www.robotiq.com)

[photo-use permission granted by Robotiq]

End-effectors with fixed shape fingers

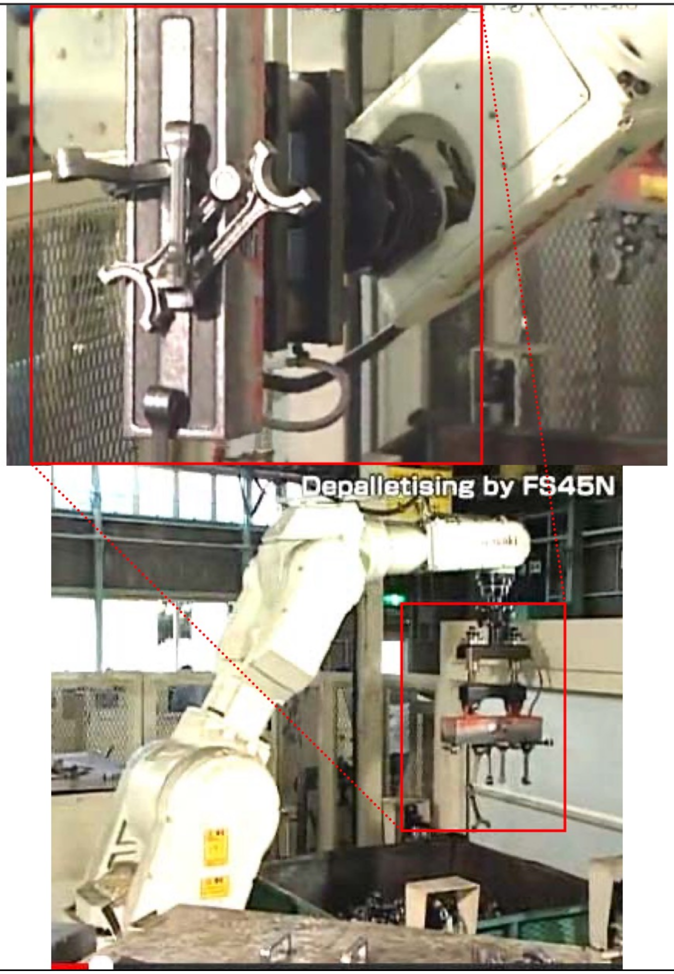


Special purpose grippers:
(top left) angular gripper with hygienic design and (top right) stacking gripper, both for the food processing industry (www.schunk.com) ; (bottom left) bagged product gripper and (bottom right) universal warehousing gripper that can handle bags, bundles, cases, etc. (www.fanucrobotics.com)

[photo-use permission granted by Schunk and Fanuc Robotics]

End-effectors with fixed shape fingers

Special purpose end-effectors

	Electromagnetic gripper: Magnetic gripper handling piston rods (Kawasaki Robotics - http://www.youtube.com/watch?v=eGPne8_sR4c)

Multipurpose end-effectors

DLR-HIT Hand II

Universal Gripper

Gripper vs Hands

- Structured environments
- Reliable
- Simple
- Low cost


- Unstructured environments
- Adaptable
- Complex
- Expensive



Gripper vs Hands

N. of DoFs

N. of apps in industries

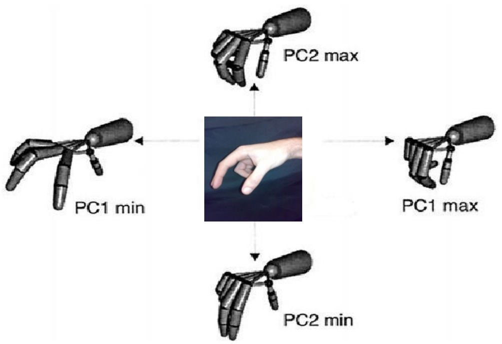
Why articulated hands are not so frequently used in industrial environment?

- Too complex from a control point of view: reaching, grasping, manipulation
- They suffer from a lack of standard control approaches that uses few parameters in spite of the mechanical complexity
- Simplify a complex control problem and analogies with industrial PID

G. Salvietti, Frontiers on Neurorobotics, 2018.

SIMPLIFICATION BY CONTROL

A simplified control framework



Task planning using human postural synergies

Object-based Mapping

Mapping

Control of robotic hands with different kinematics

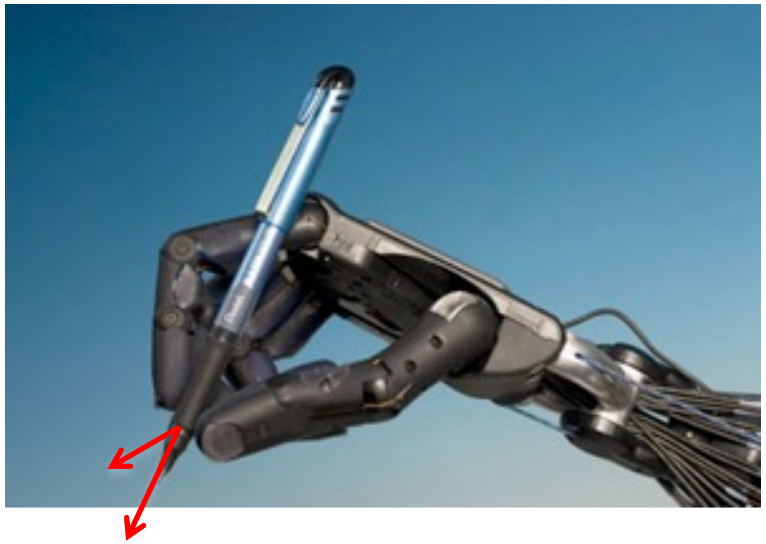
Use synergies to decrease the complexity of control algorithm for robotic hands

The basic idea is to <u>plan the task with a paradigmatic hand</u> and <u>map the obtained movements onto the robotic hands</u>

Object-based mapping for forces and motions

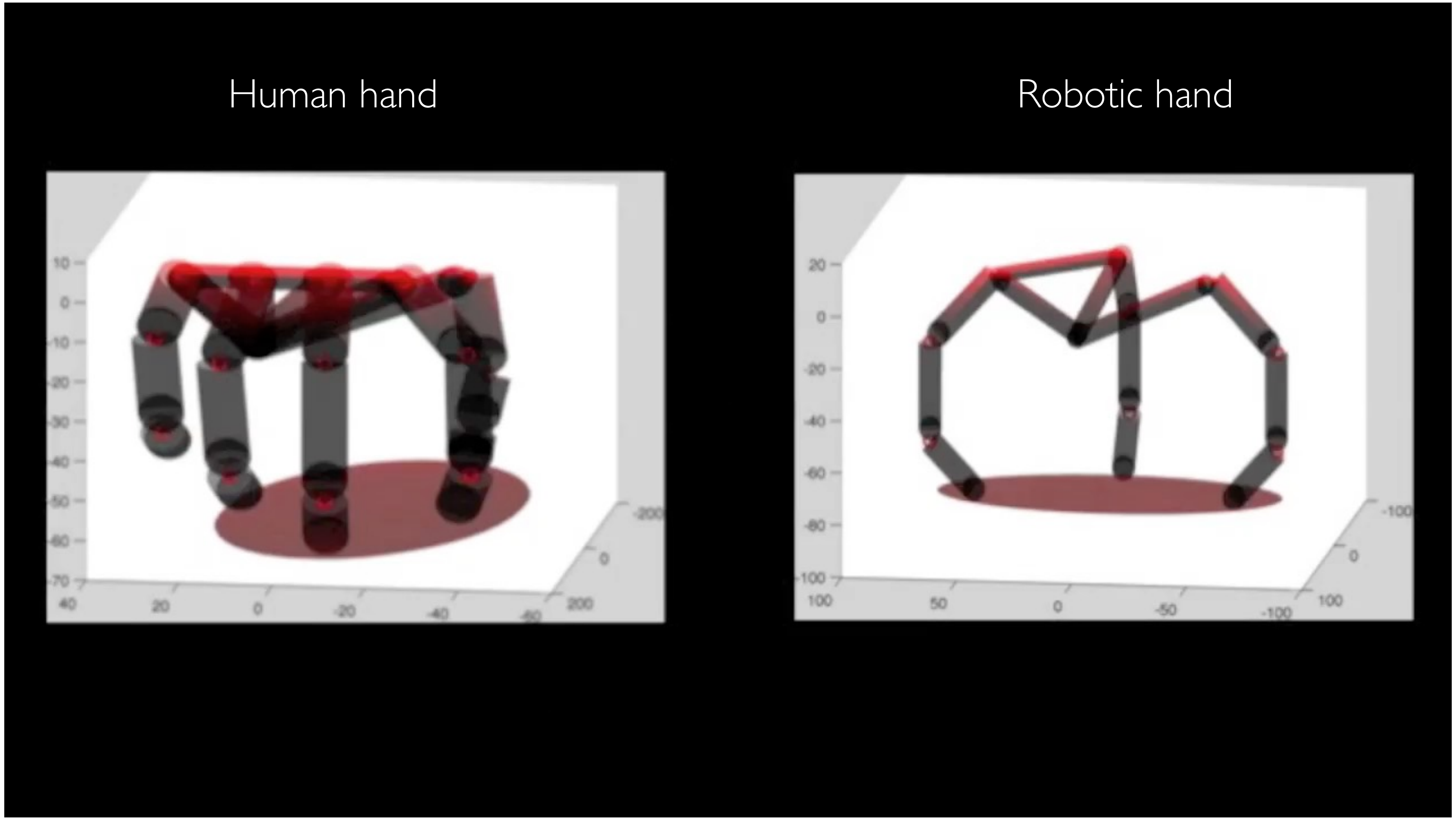
Human hand

Robotic hand



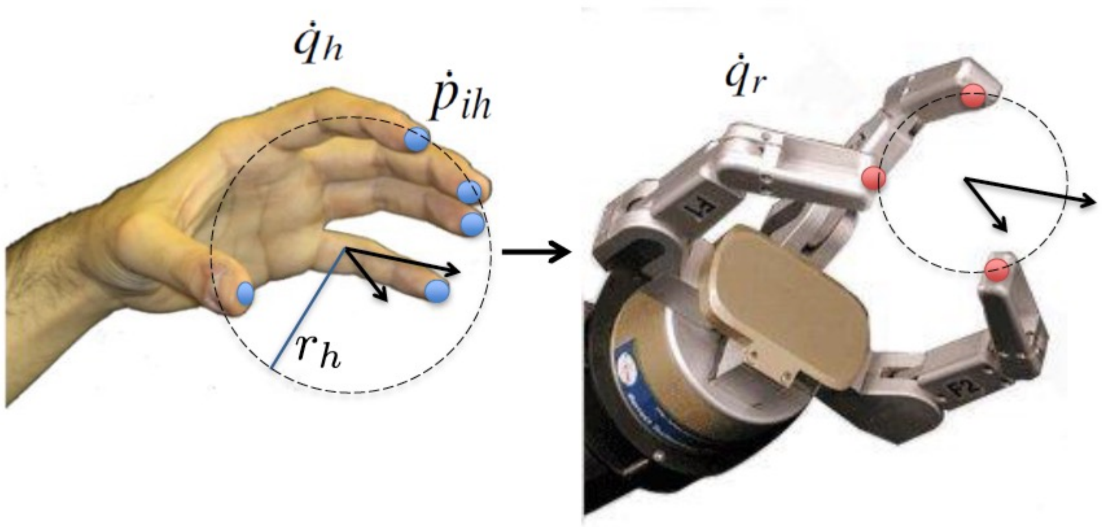
Object-based
- compute the object motion associated to a motion on the human hand
- assign that motion to the same object but with the robotic hand
- solving an inversion problem to compute the slave motion

Object-based abstraction for simplification



Simulation with Syngrasp toolbox

A virtual sphere



A set of *reference points* are chosen on the hand model in a given starting configuration

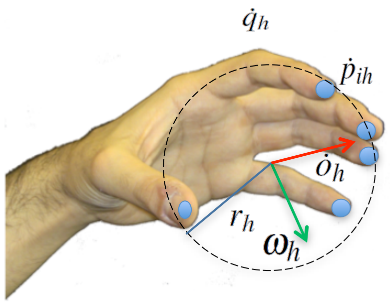
The virtual sphere is the minimum volume sphere containing the reference points

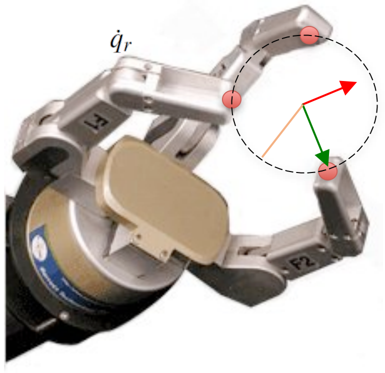
Rigid-body motion and radial deformation for the virtual sphere

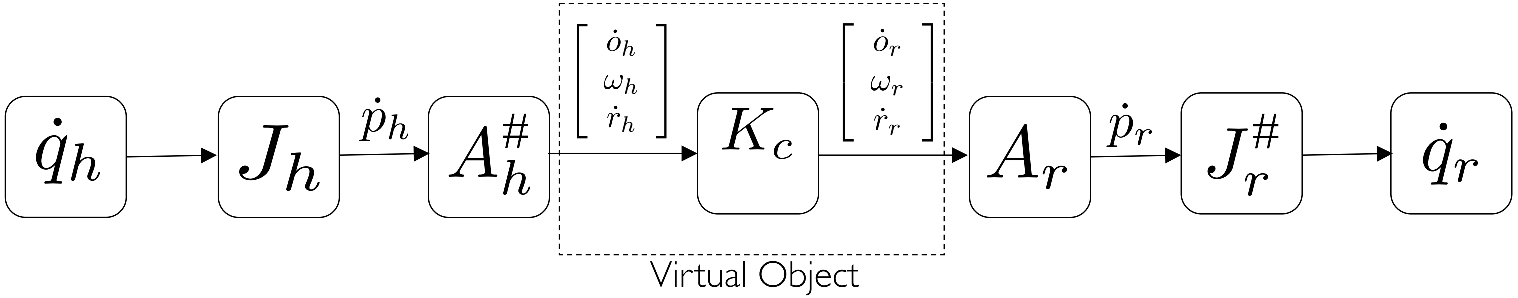
G. Gioioso, G. Salvietti, M. Malvezzi, D. Prattichizzo. Mapping Synergies from Human to Robotic Hands with Dissimilar Kinematics: an Approach in the Object Domain. IEEE Trans. on Robotics, 2013.

Virtual sphere mapping algorithm

Reference points on the fingertips







J_h, J_r Jacobian matrix

K_c scaling matrix

Reference point velocity

$$\dot{p}_{ih} = \dot{o}_h + \omega_h \times (p_{ih} - o_h) + \dot{r}_h (p_{ih} - o_h)$$

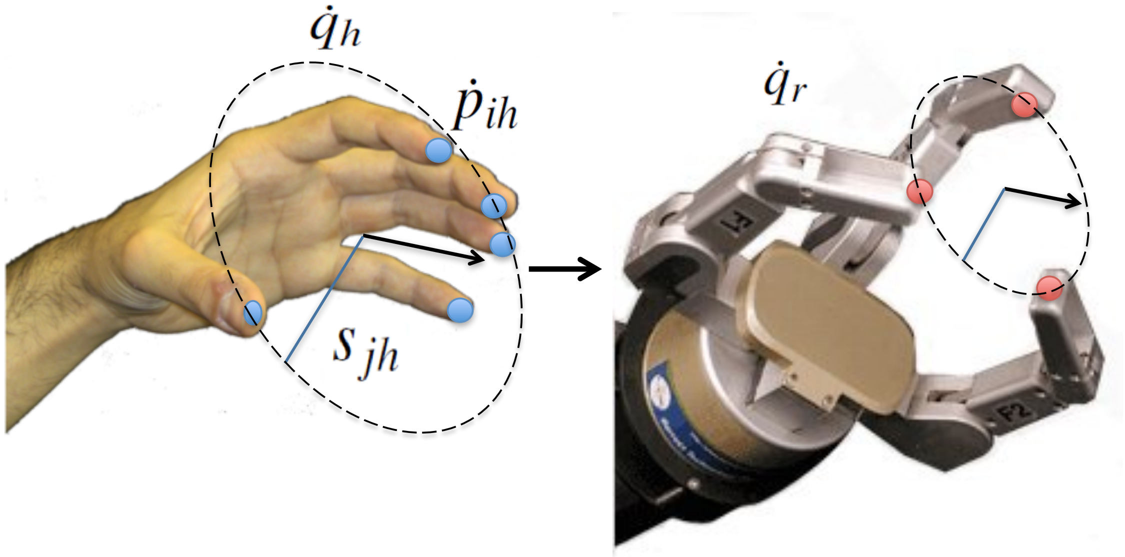
Extended Grasp matrix

$$A_h = \begin{bmatrix} I & -[p_{1h} - o_h]_\times & (p_{1h} - o_h) \\ \cdots & \cdots & \cdots \\ I & -[p_{ih} - o_h]_\times & (p_{ih} - o_h) \\ \cdots & \cdots & \cdots \end{bmatrix}$$

More information: a virtual ellipsoid

G. Gioioso, G. Salvietti, M. Malvezzi, D. Prattichizzo. An Object-Based Approach to Map Human Hand Synergies onto Robotic Hands with Dissimilar Kinematics. In Robotics: Science and Systems VIII, 2013

Virtual ellipsoid mapping

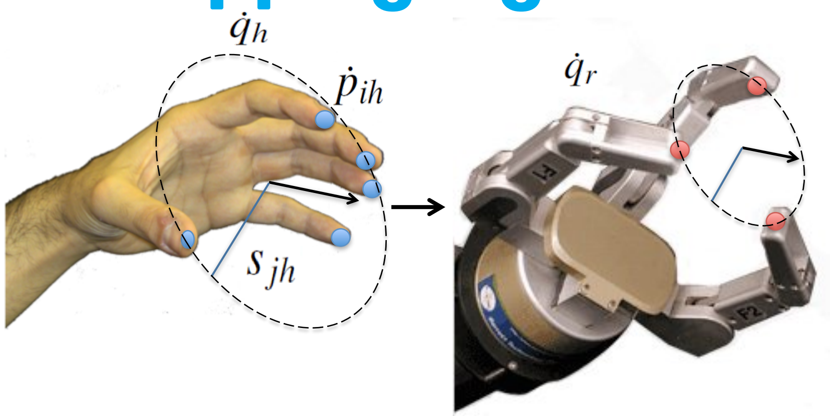


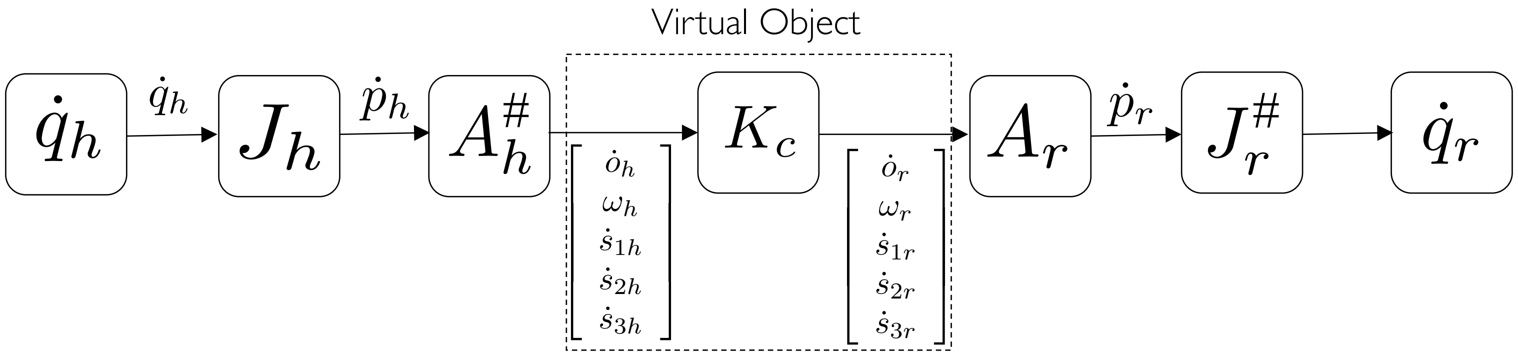
The virtual ellipsoid is the minimum volume ellipsoid

Rigid-body motion and semi-axes deformations for the virtual ellipsoids

More accuracy but more parameters

Virtual ellipsoid mapping algorithm





J_h, J_r Jacobian matrix

K_c scaling matrix

Reference point velocity

$$\dot{p}_{ih} = \dot{o}_h + \omega_h \times (p_{ih} - o_h) + \sum_{j=1}^{3} \dot{s}_{jh} \left[(p_{ih} - o_h)^\top \hat{s}_{jh} \right] \hat{s}_{jh}$$

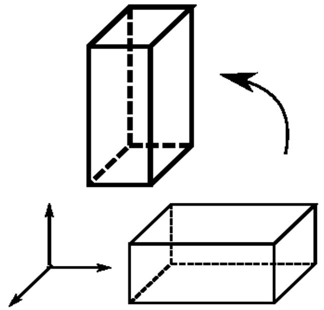
Extended Grasp matrix

$$A_h = \begin{bmatrix} I & -S(p_{1h} - o_h) & \left[(p_{1h} - o_h)^\top \hat{s}_{1h} \right] \hat{s}_{1h} & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ I & -S(p_{ih} - o_h) & \left[(p_{ih} - o_h)^\top \hat{s}_{1h} \right] \hat{s}_{1h} & \cdots \\ \cdots & \cdots & \cdots & \cdots \end{bmatrix}$$

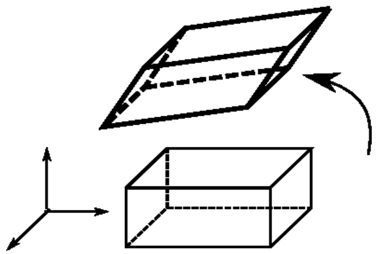
Homogeneous transformation

G. Salvietti, M. Malvezzi, G. Gioioso, D. Prattichizzo. On the Use of Homogeneous Transformations to Map Human Hand Movements onto Robotic Hands., ICRA, 2014.

$$\mathbf{T} = \prod_{i=1}^{n_t} \mathbf{T}_{p,i}$$



$$\mathbf{T}_{rb} = \begin{bmatrix} \mathbf{R} & \mathbf{p} \\ 0 & 1 \end{bmatrix}$$



$$\mathbf{T}_{def} = \begin{bmatrix} 1 & \mathrm{h}_{xy} & \mathrm{h}_{xz} & 0 \\ \mathrm{h}_{yx} & 1 & \mathrm{h}_{yz} & 0 \\ \mathrm{h}_{zx} & \mathrm{h}_{zy} & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

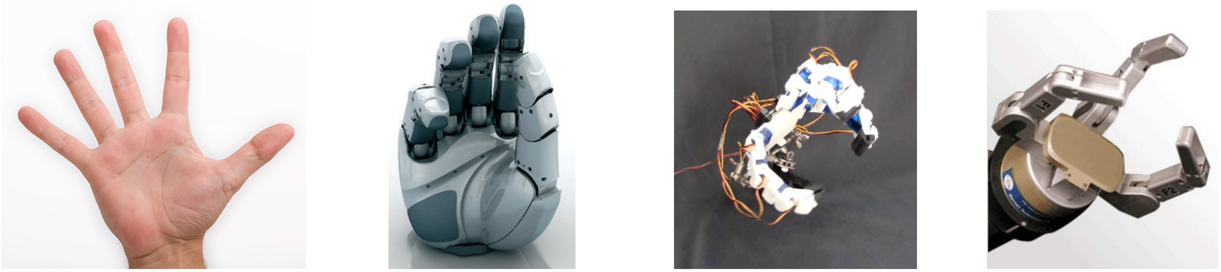
Rigid body motion: the distance between points and angles between vectors is preserved (rotation + translation).

Isotropic and non-isotropic transformations modify the object size by scaling factors in x, y, and z.

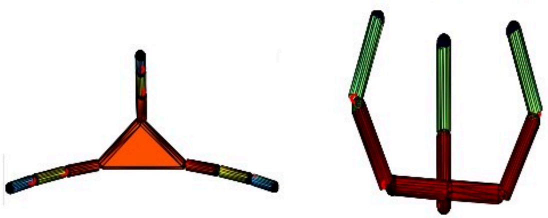
Shear transformations displace each point in fixed direction by an amount proportional to its signed distance from a line that is parallel to that direction.

M. Malvezzi, G. Gioioso, G. Salvietti, D. Prattichizzo. SynGrasp: A Matlab Toolbox for Underactuated and Compliant Hands. Robotics Automation Magazine, IEEE, 2015.

The SynGrasp Toolbox



Paradigmatic hand | DLR-HIT II hand | ModHa39p hand | Barrett hand



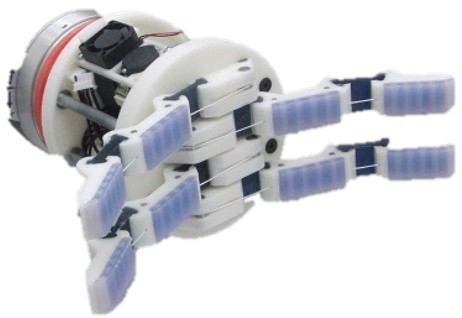
Syngrasp is a Matlab Toolbox for the analysis of grasping, suitable both for robotic and human hands. Available at http://syngrasp.dii.unisi.it - More than 7500 downloads

The hand modeling allows to define compliance at the contacts and joints level

Controllable forces and object movement, manipulability analysis, grasp quality measures, easy graphical representation of the hands

SIMPLIFICATION BY DESIGN

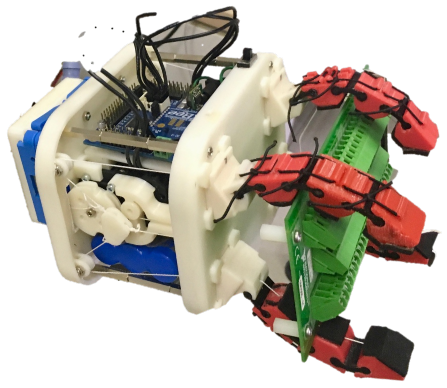
Robotic soft hands and grippers



Dollar et al.

Brock et al.

Bicchi et al.



Salvietti et al.

Intrinsically compliant – Safe interaction

Underactuation

Tendon driven/pneumatic actuation

Robust

Interaction with the environment

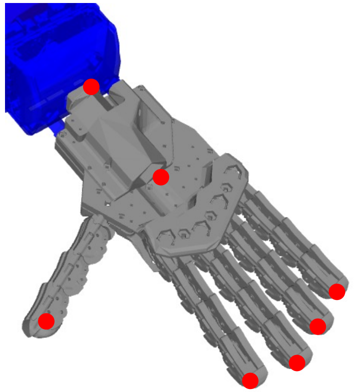
Soft Hands EU project SOMA

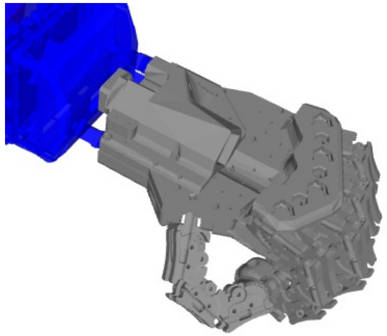
https://www.youtube.com/watch?v=b9pFjNNPtnA

soma SOFT MANIPULATION

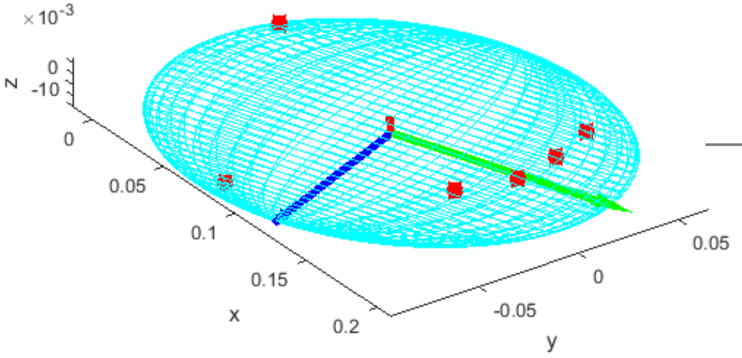
Modeling: Closure signature

Track the reference points during free-hand closing motion



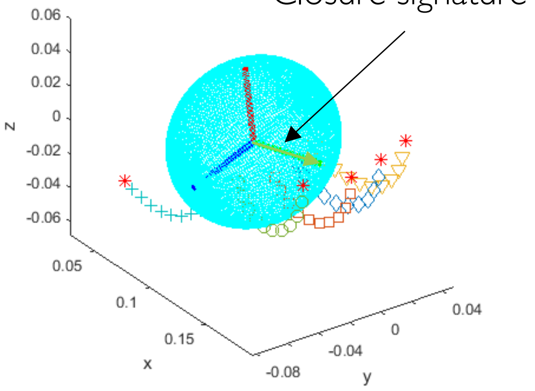


Compute ellipsoid transformation due to hand motion



Initial ellipsoid

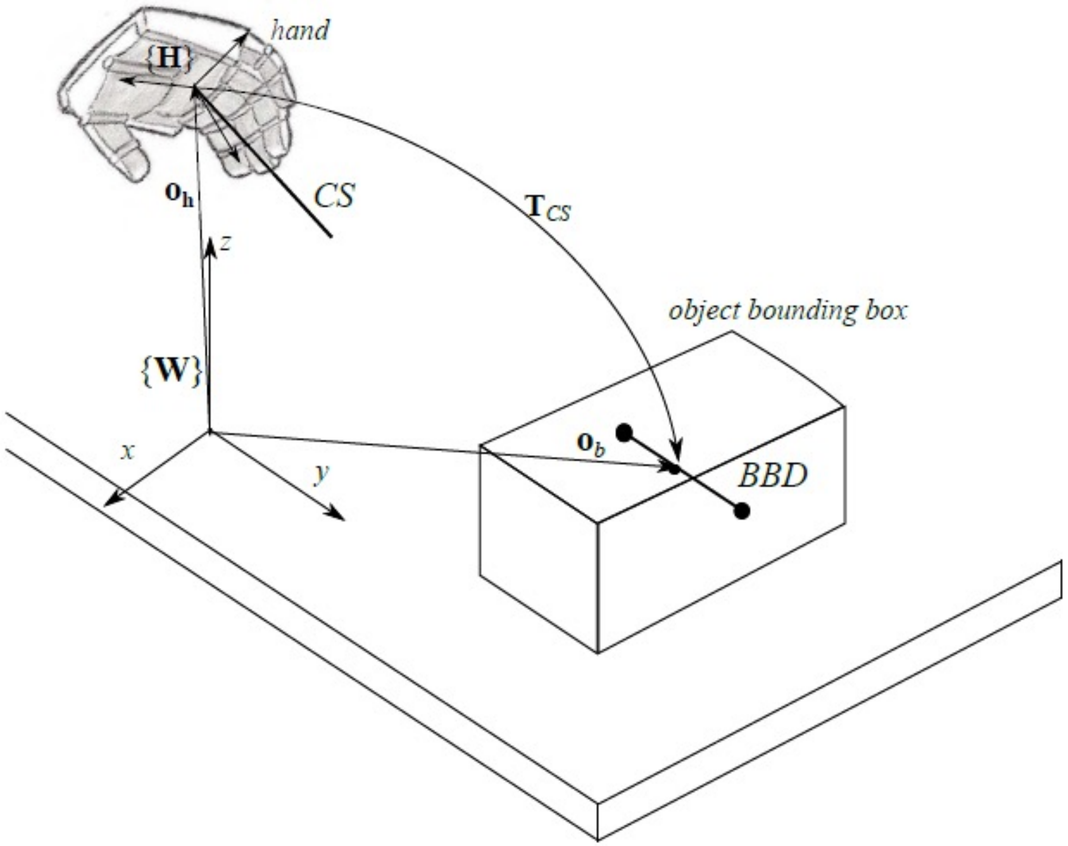
Closure signature



Final ellipsoid

Planning

Top grasps exploiting the CS

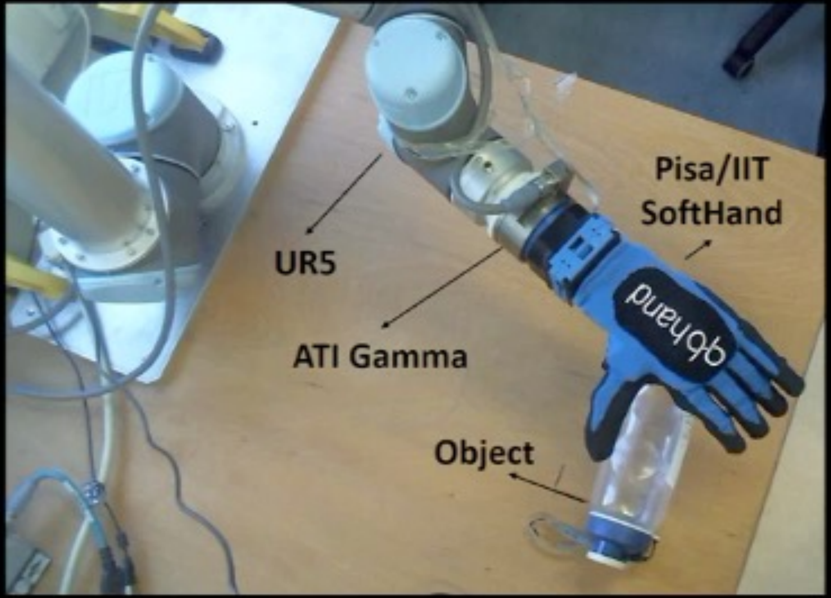


M. Pozzi, G.Salvietti et al., RAL 18

Closure signature – Experimental validation

Experimental Setup

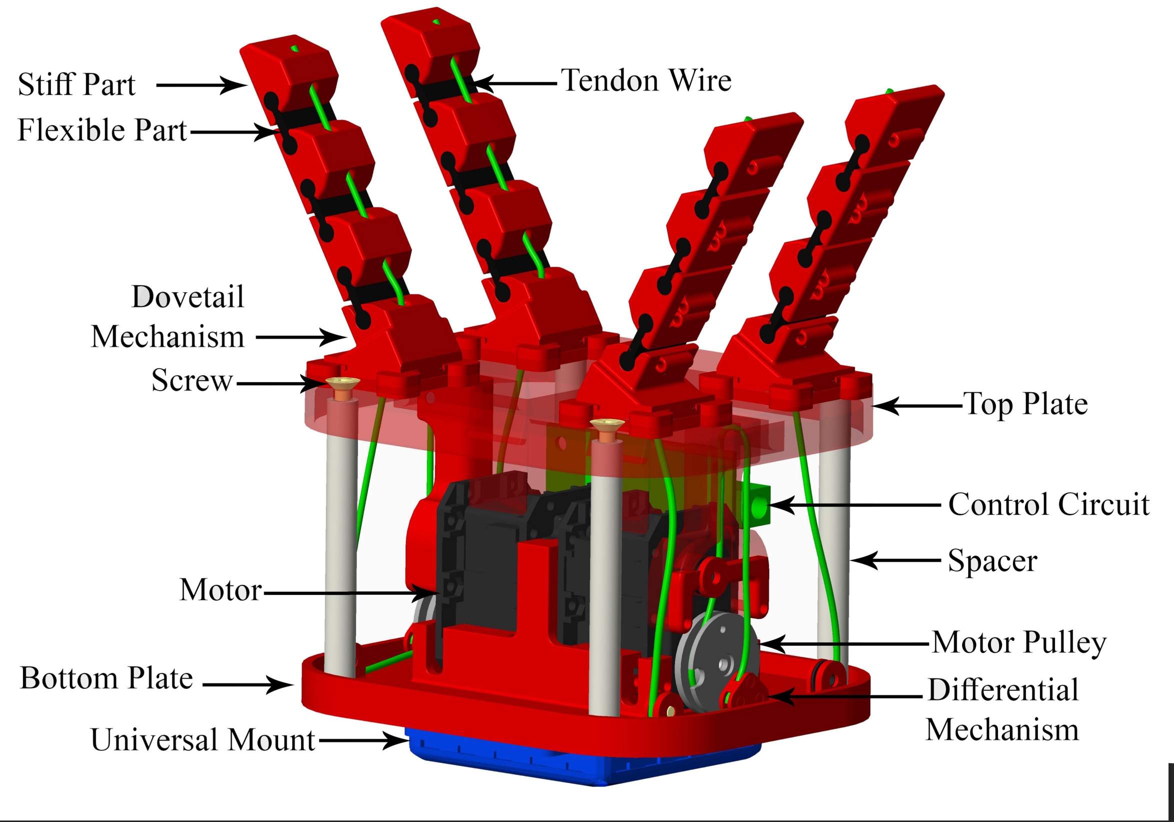
- UR5 robot arm
- ATI force/torque sensor at the wrist
- Pisa/IIT SoftHand
- Xtion PRO depth camera

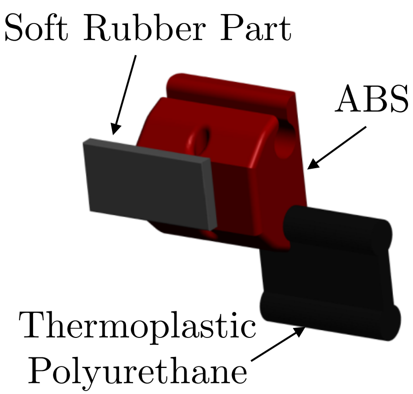


SOFT-RIGID GRIPPER DESIGN

Intrinsically safe and adaptability

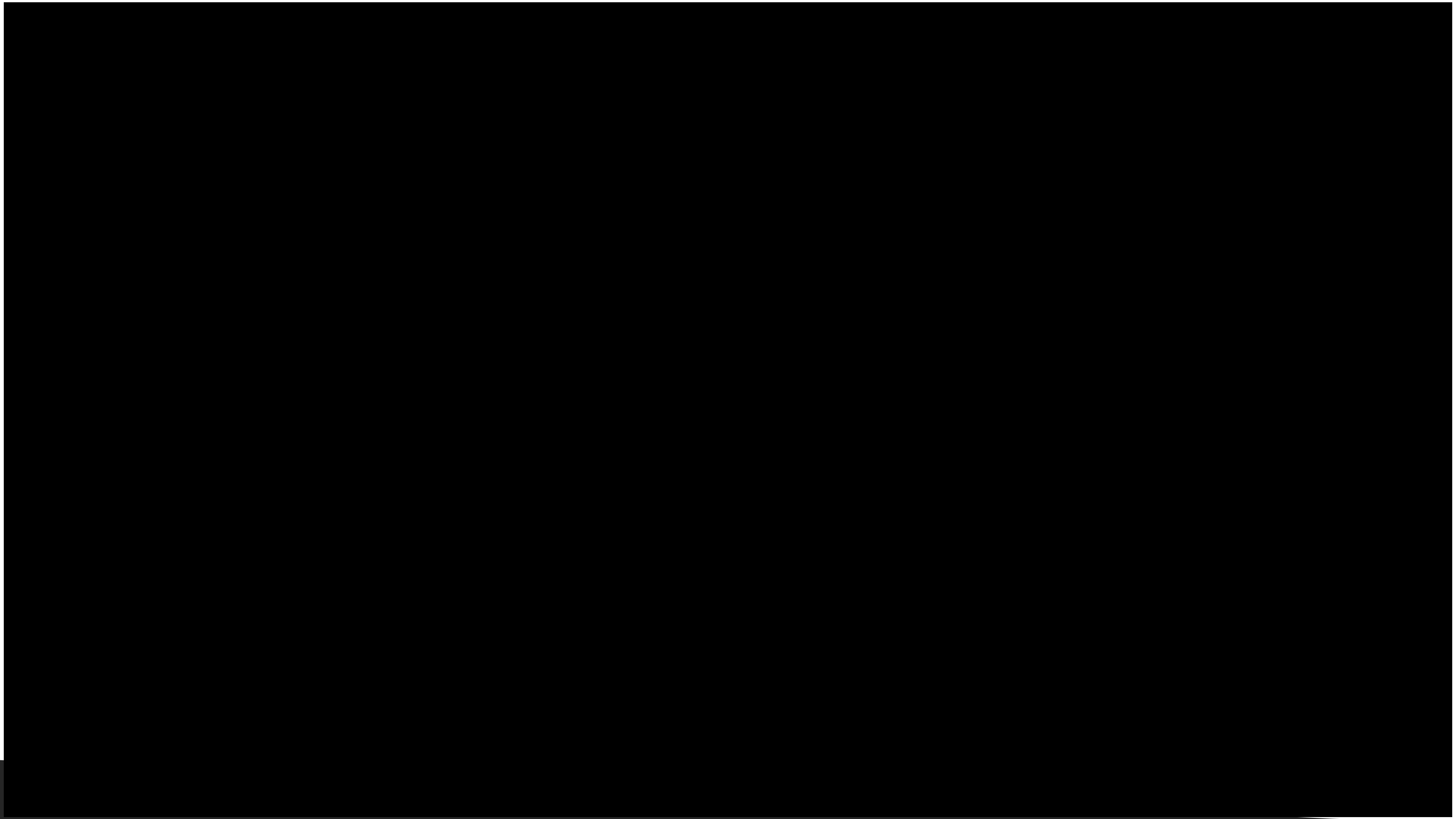
Softness for safety and adaptability





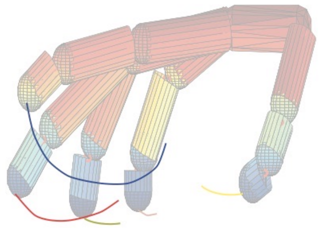
Modular fingers

The Co-Gripper

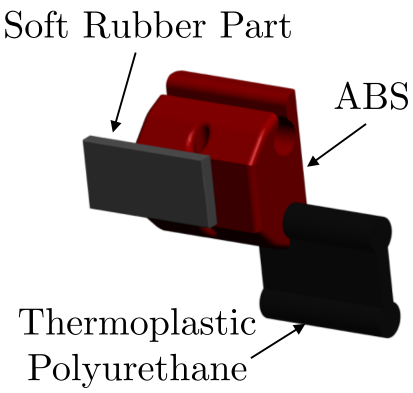


Salvietti G. et al,. IROS 2018

Fingertip trajectory design



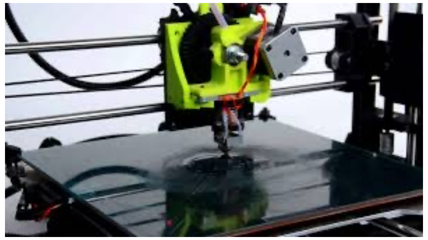
Design/select fingertip trajectories



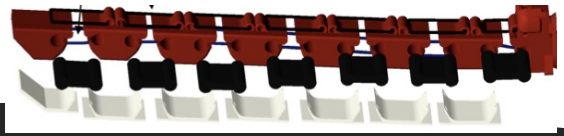
Modular fingers

$$\mathbf{k}_{q_k} = \mathbf{Q}_k^{-1}\mathbf{T}_k^{\mathrm{T}}\delta\mathbf{f}_k$$

Compute relative joint stiffness ratio



Built the soft module with the K computed

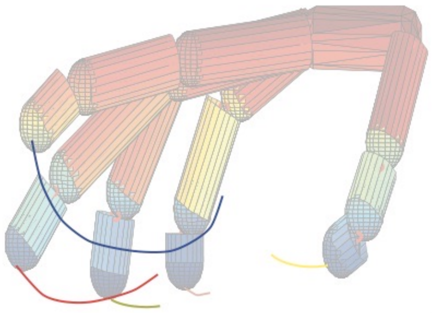


assemble the fingers

G. Salvietti et al. RAL 16, TNSRE 17, IJRR 17, RAS 17, RAL 16. - F. Sanfilippo et al. BIOROB 12, 14

From trajectory to stiffness ratio

Relation between tendon applied force f and the torques at joints $\boldsymbol{\tau} = \mathbf{T}^{\mathrm{T}}\mathbf{f}$



where $\mathbf{T} \in R^{n_t \times n_q}$ is a transformation matrix whose elements depend on finger pulleys' sizes and tendon routing topology and we assume independent from hand posture

We assume that the torque actuated by the motor τ_a balances the torque generated by the deformation of elastic elements in the soft joints

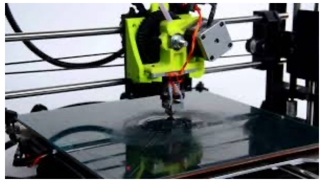
$$\delta\boldsymbol{\tau}_a = \mathbf{K}_q(\mathbf{q})\delta\mathbf{q}$$

At time instant k, the joint stiffness necessary to move di hand joints of δq_k applying a force $\delta\mathbf{f_k}$ is computed as

$$\mathbf{k}_{q_k} = \mathbf{Q}_k^{-1}\mathbf{T}_k^{\mathrm{T}}\delta\mathbf{f}_k$$

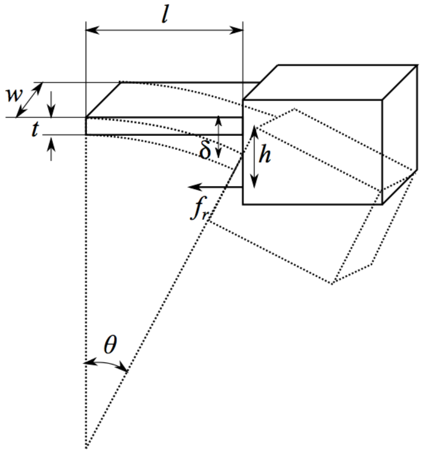
where $\mathbf{Q}_k \in R^{n_q \times n_q}, \mathbf{Q}_k = diag(\delta q_k)$

From stiffness to module design



From beam Theory

$$\delta_i = \frac{-f_{rj} h l^2}{2 E_i I}$$



$$\theta_i = \frac{-f_{rj} h l_i}{E_i I_i}$$

Second moment of area

$$I_i = \frac{w_i t_i^3}{12}$$

Infill density $\rho\%$	E (MPa)
10	1.07
30	1.38
50	2.07
70	6.53
90	9.45
100	10.50

Thermoelastic Polyurethane

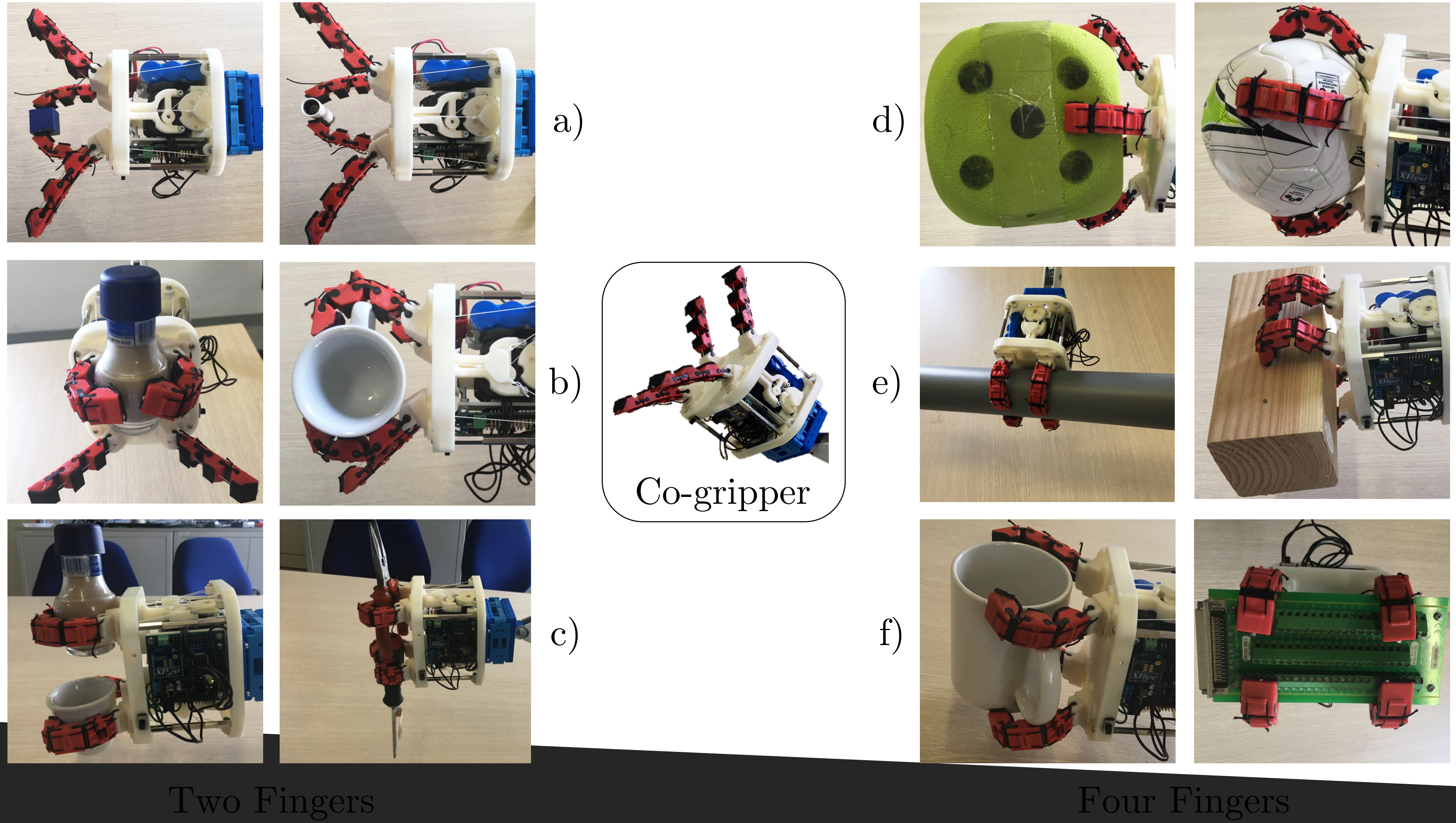
$$k_i = \frac{E_i I}{l}$$

E Young's modulus

$$k_i = f(\rho_i)$$

infill percentage density ρ

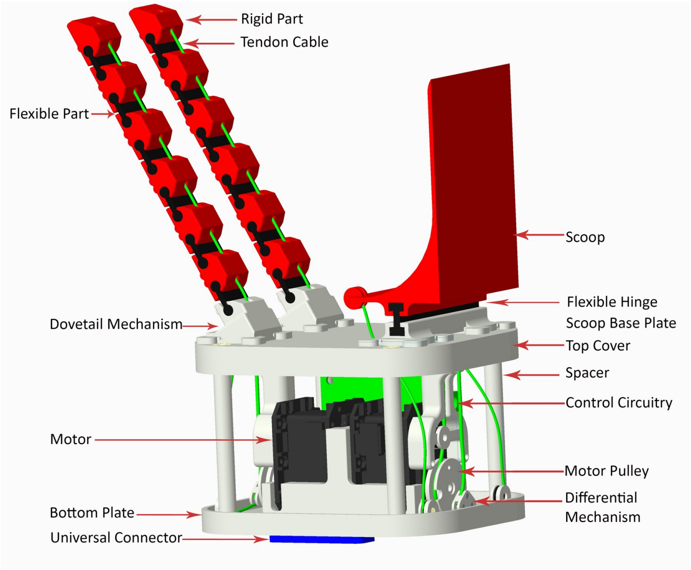
Possible grasps

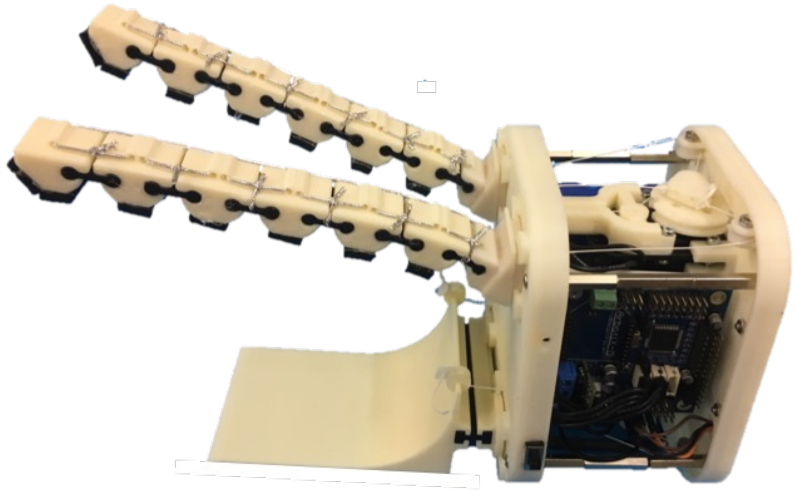


How soft hand can exploit rigid constraints?

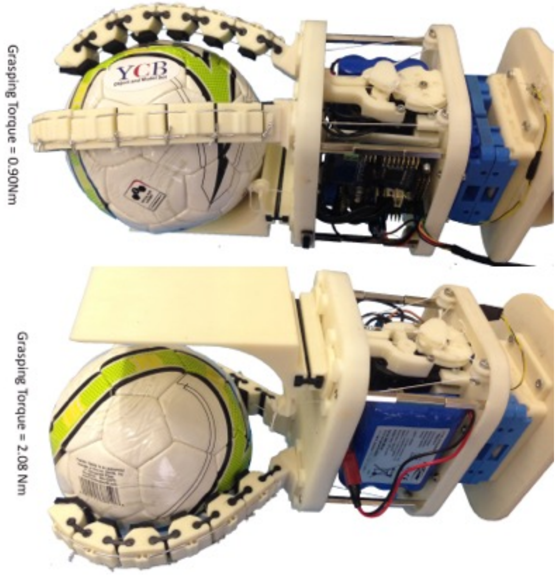
The idea

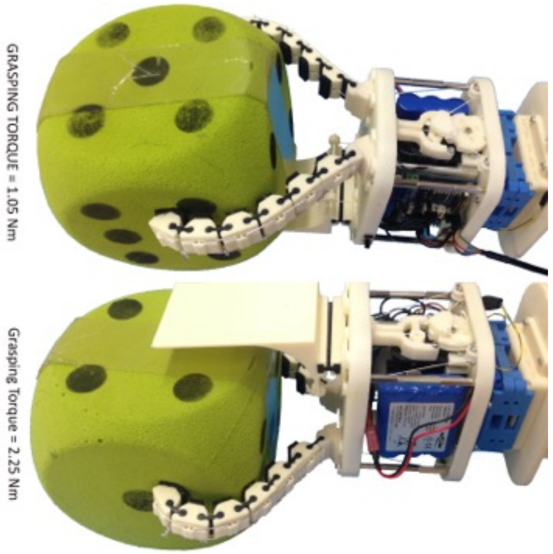
The design


Rigid Part
Tendon Cable
Flexible Part
Scoop
Flexible Hinge
Scoop Base Plate
Dovetail Mechanism
Top Cover
Spacer
Control Circuitry
Motor
Motor Pulley
Differential
Mechanism
Bottom Plate
Universal Connector



Reduction of grasp force

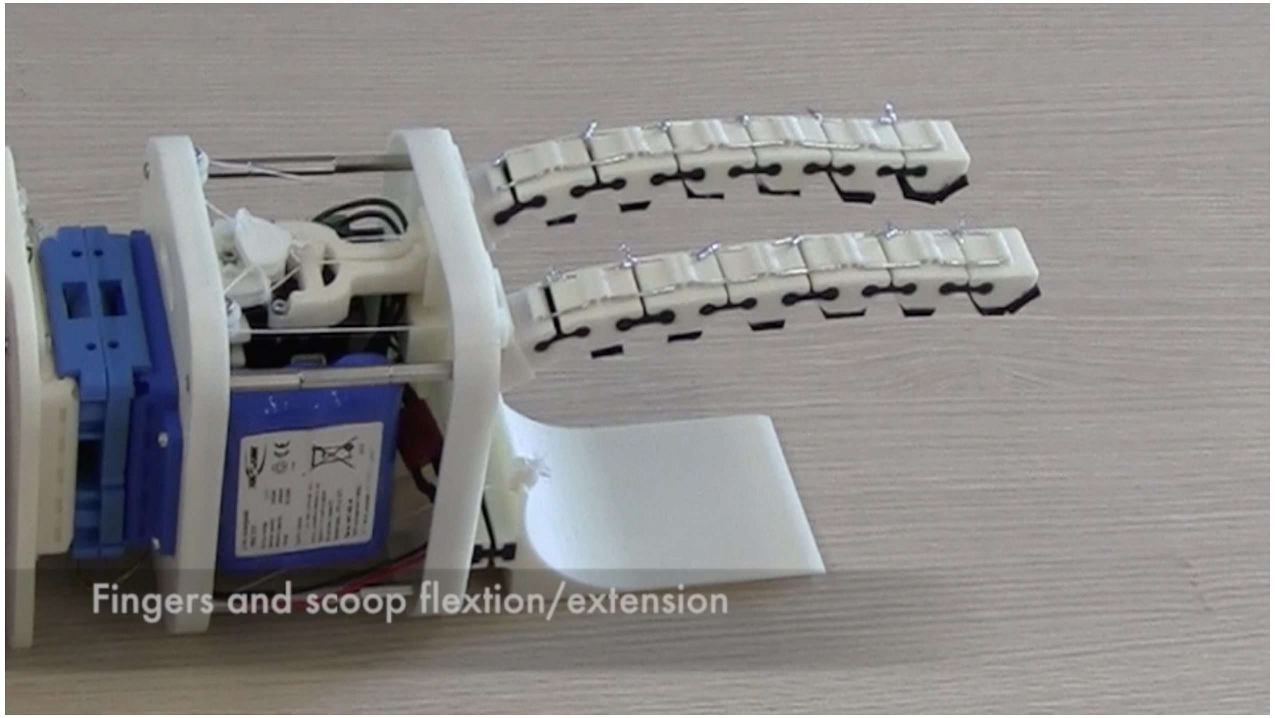




Grasping strategies

(a) (b) (c) (d)

ScoopGripper

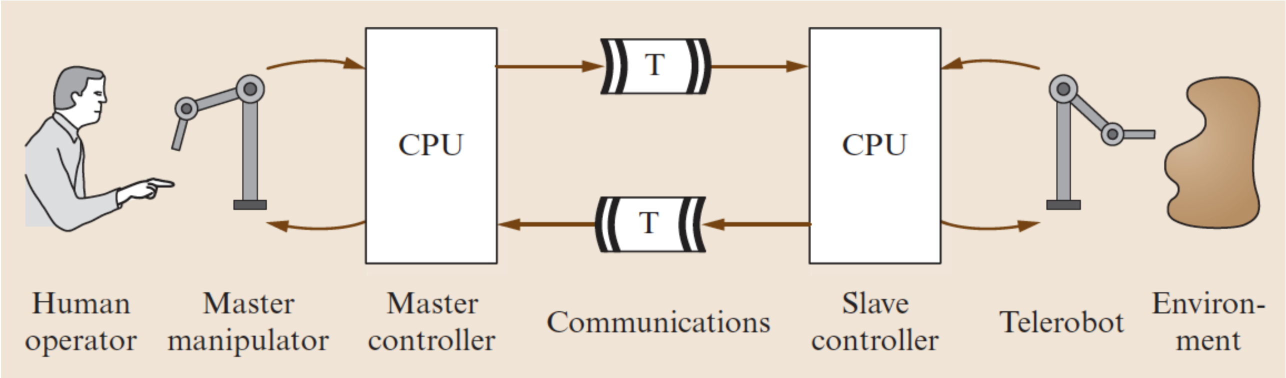


Salvietti et al., ICRA 2019

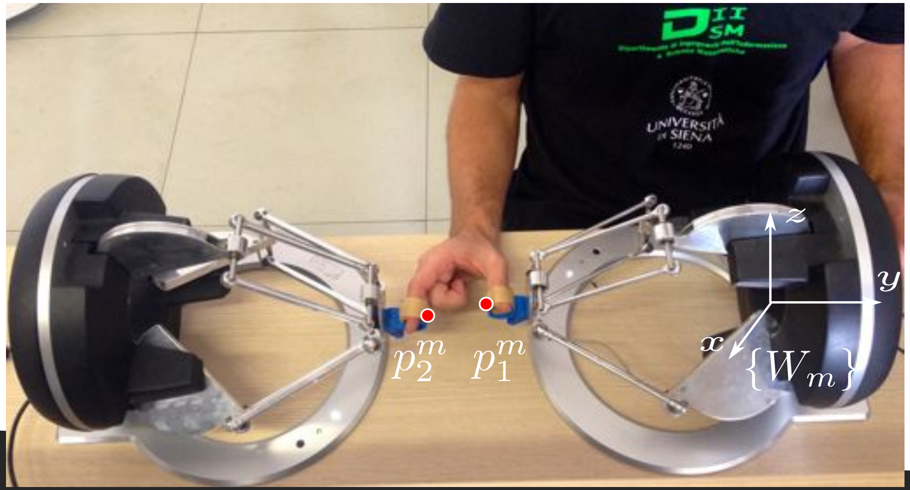
ROBOTIC TELEOPERATION

Telemanipolazione bilaterale con multi-contatto

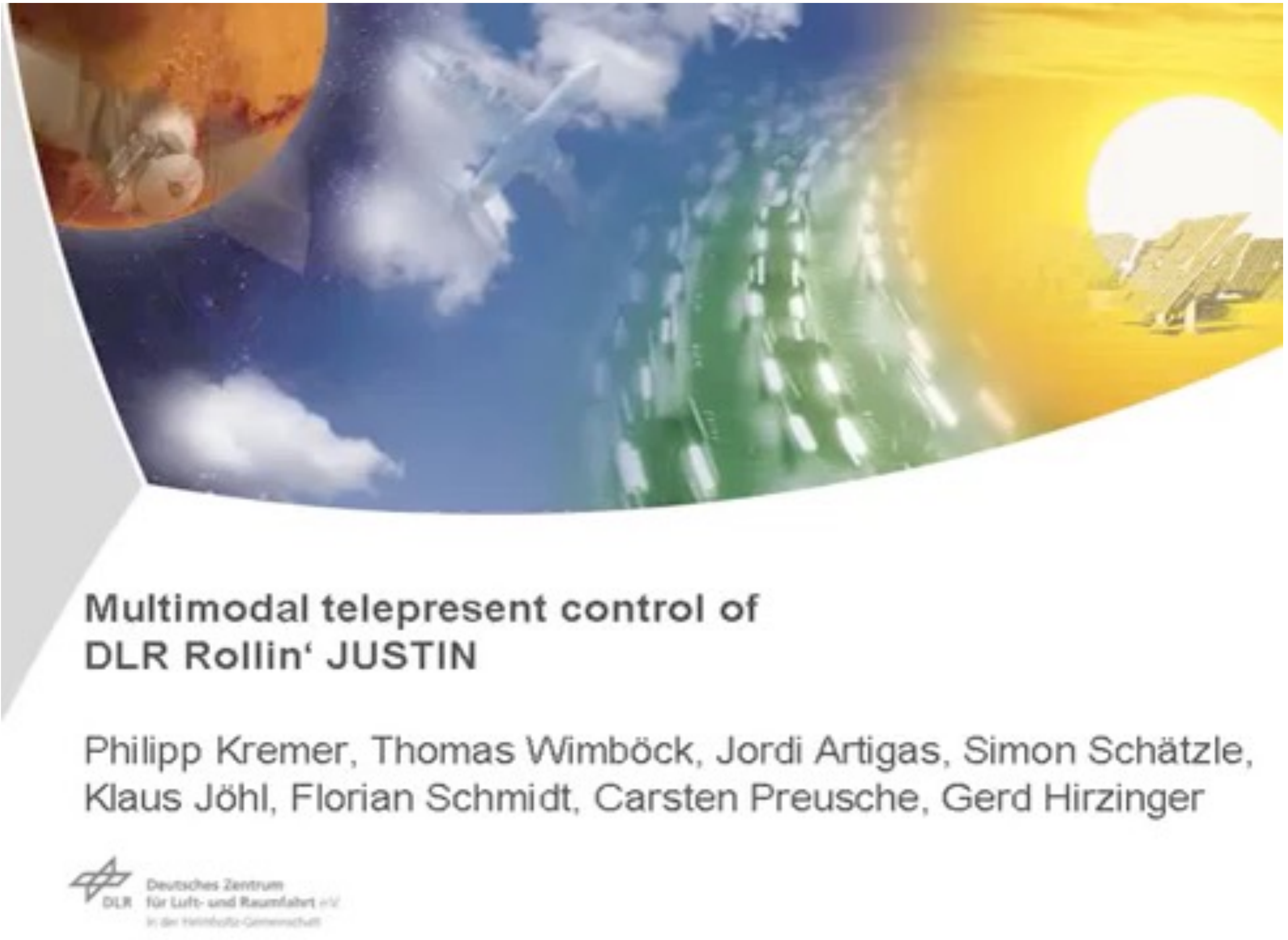
Bilateral teleoperation with similar master/slave robots



Niemeyer et al., Chapter on Telerobotics, Handbook of Robotics



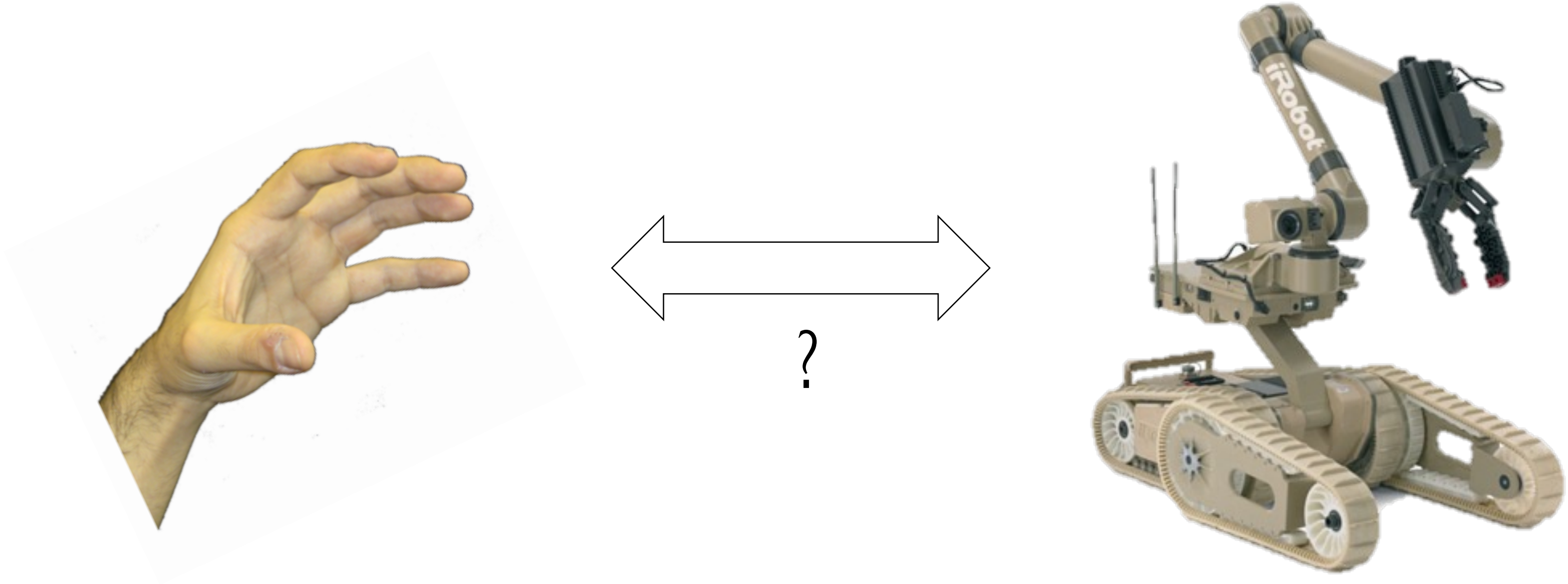
Robot Simili



Dissimilar Kinematics

Very dissimilar kinematic structure are typically put in correspondence

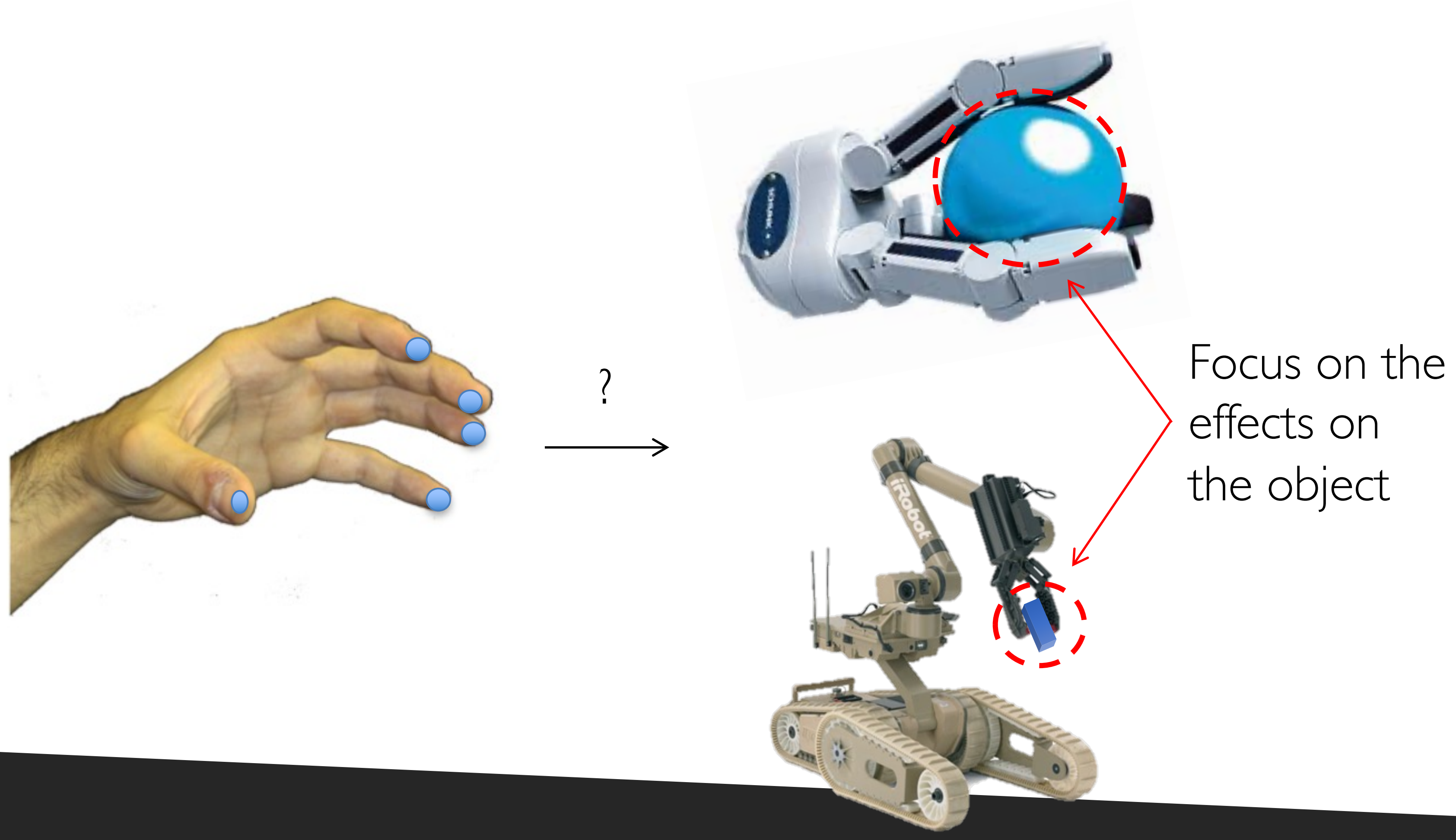
Different number of contact points between master and slave



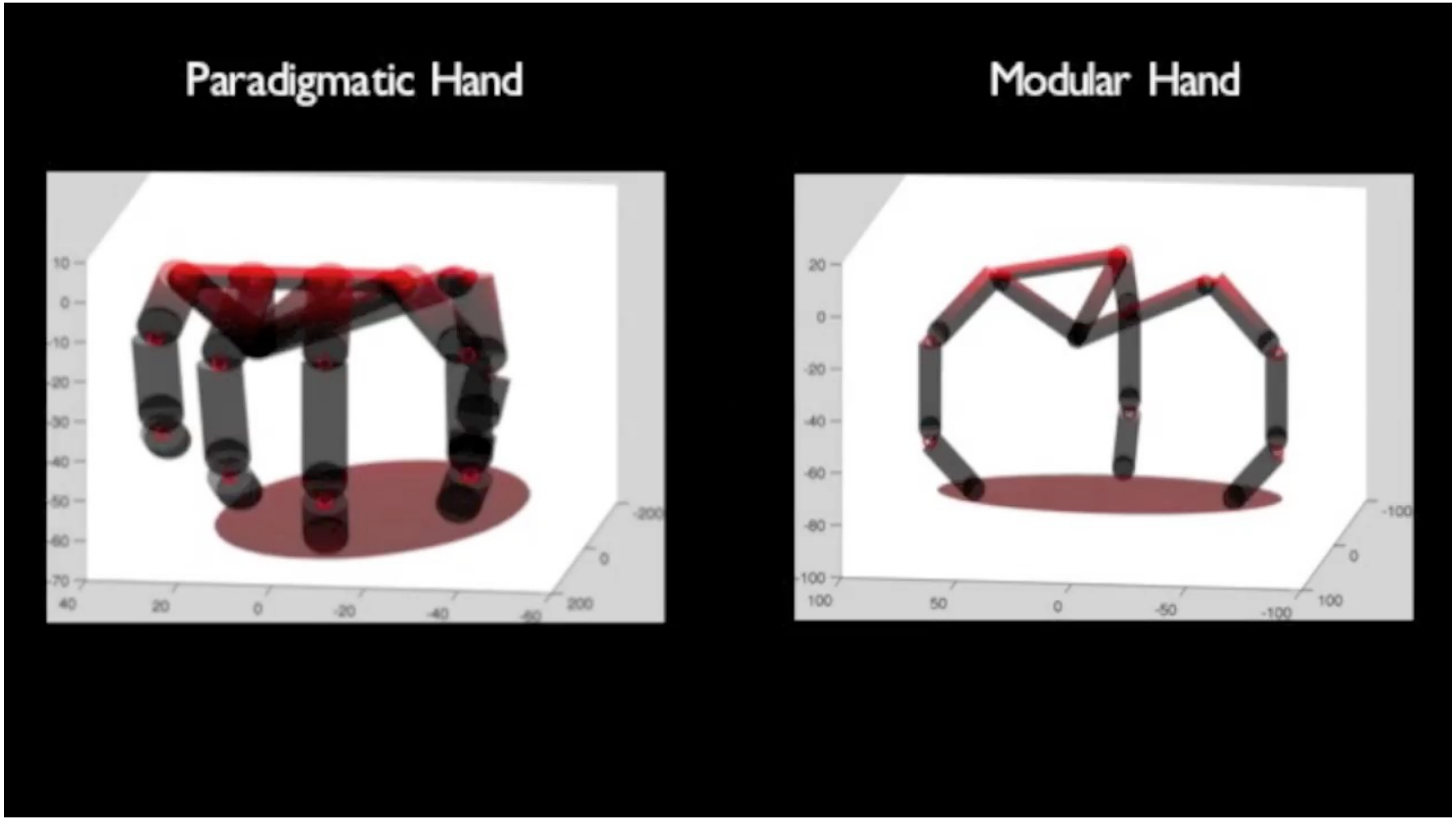
Robot 710 Warrior from iRobot

Focus on the object motion

Human hand motions have to be replicated by robotic devices with a dissimilar structure

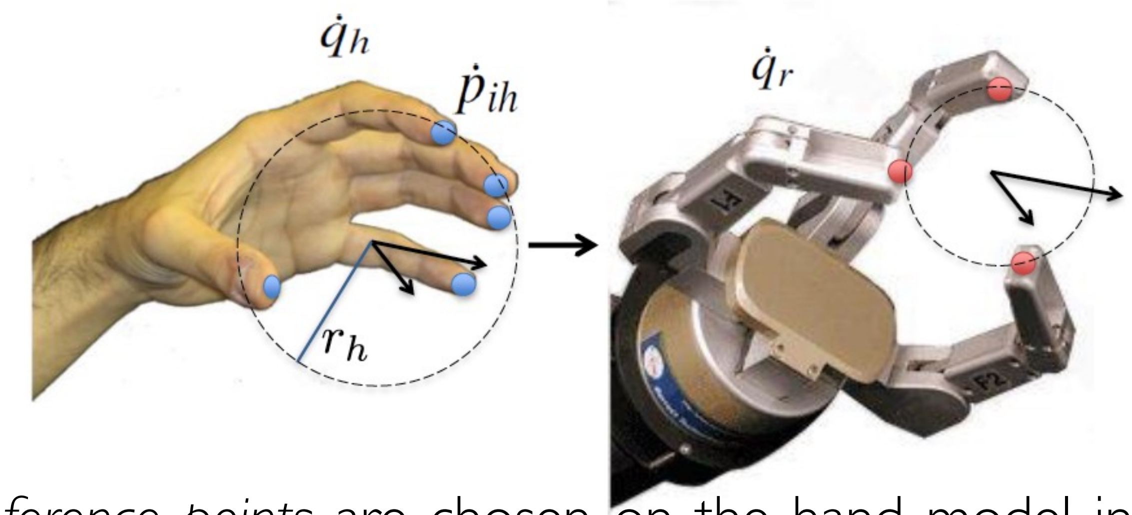


From human hand to robotic hands



A virtual sphere

Virtual sphere mapping



A set of *reference points* are chosen on the hand model in a given starting configuration

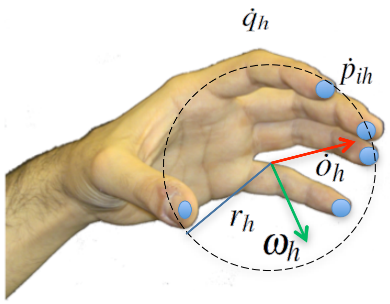
The virtual sphere is the minimum volume sphere containing the reference points

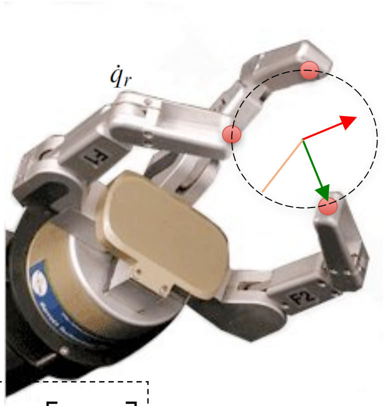
Rigid-body motion and radial deformation for the virtual sphere

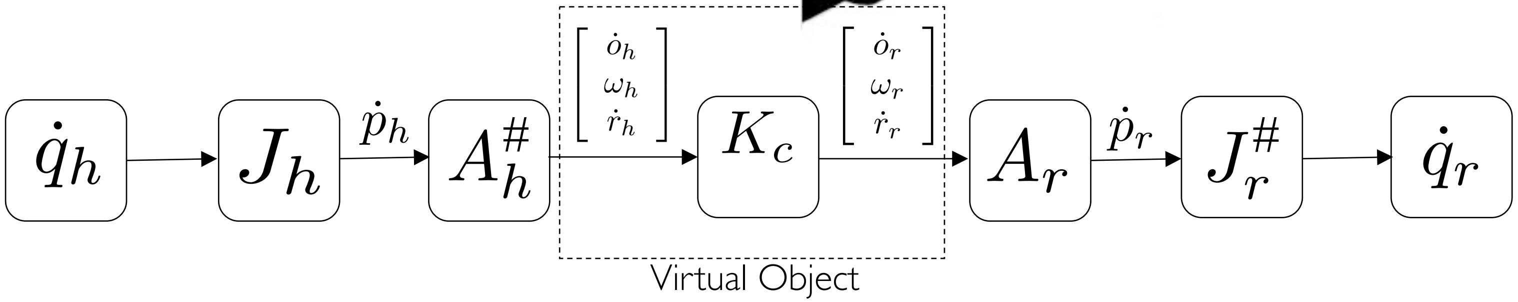
G. Gioioso, G. Salvietti, M. Malvezzi, D. Prattichizzo. Mapping Synergies from Human to Robotic Hands with Dissimilar Kinematics: an Approach in the Object Domain. IEEE Trans. on Robotics, 2013.

Virtual sphere mapping algorithm

Reference points on the fingertips







J_h, J_r Jacobian matrix

K_c scaling matrix

Reference point velocity

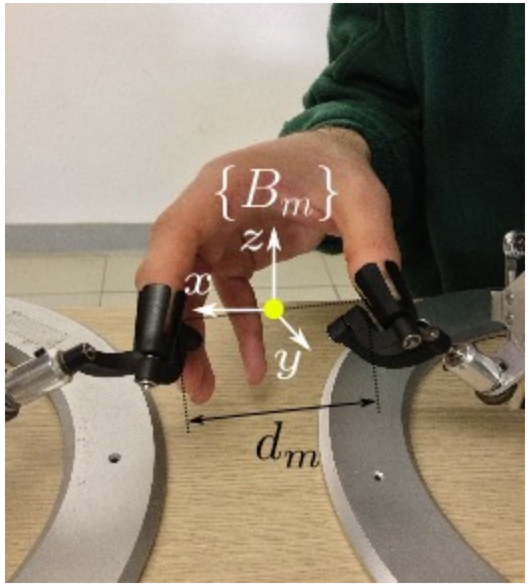
$$\dot{p}_{ih} = \dot{o}_h + \omega_h \times (p_{ih} - o_h) + \dot{r}_h \, (p_{ih} - o_h)$$

Extended Grasp matrix

$$A_h = \begin{bmatrix} I & -[p_{1h} - o_h]_\times & (p_{1h} - o_h) \\ \cdots & \cdots & \cdots \\ I & -[p_{ih} - o_h]_\times & (p_{ih} - o_h) \\ \cdots & \cdots & \cdots \end{bmatrix}$$

From robotic hands to human hand

Master



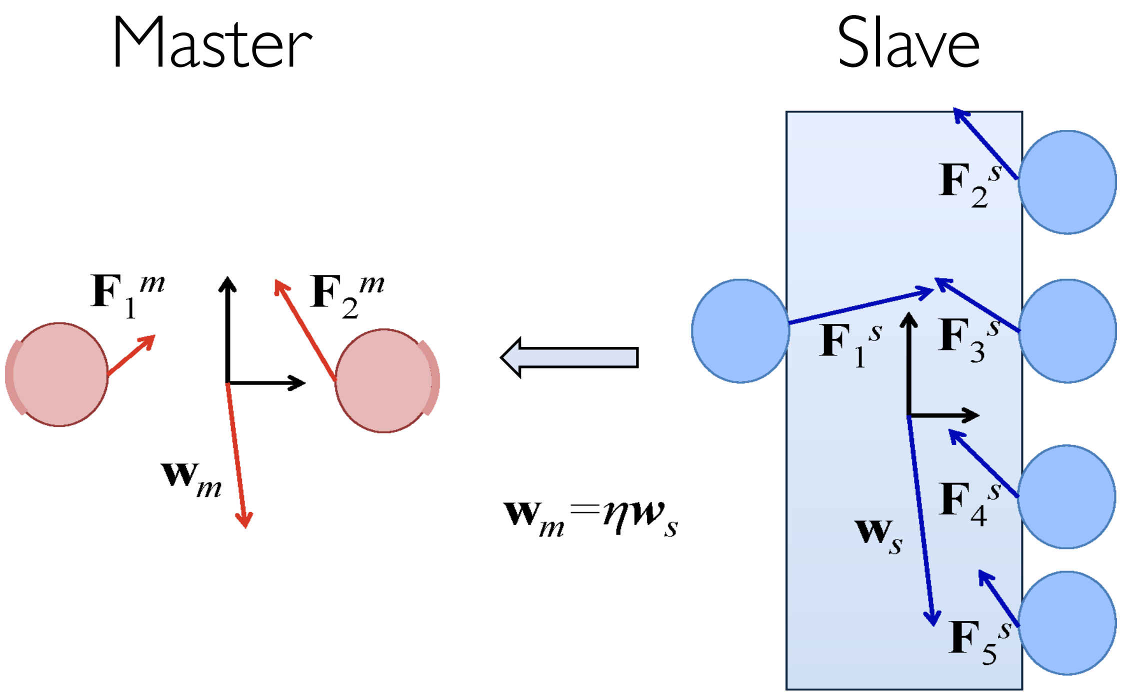
2 contact points

Slave

more contact points

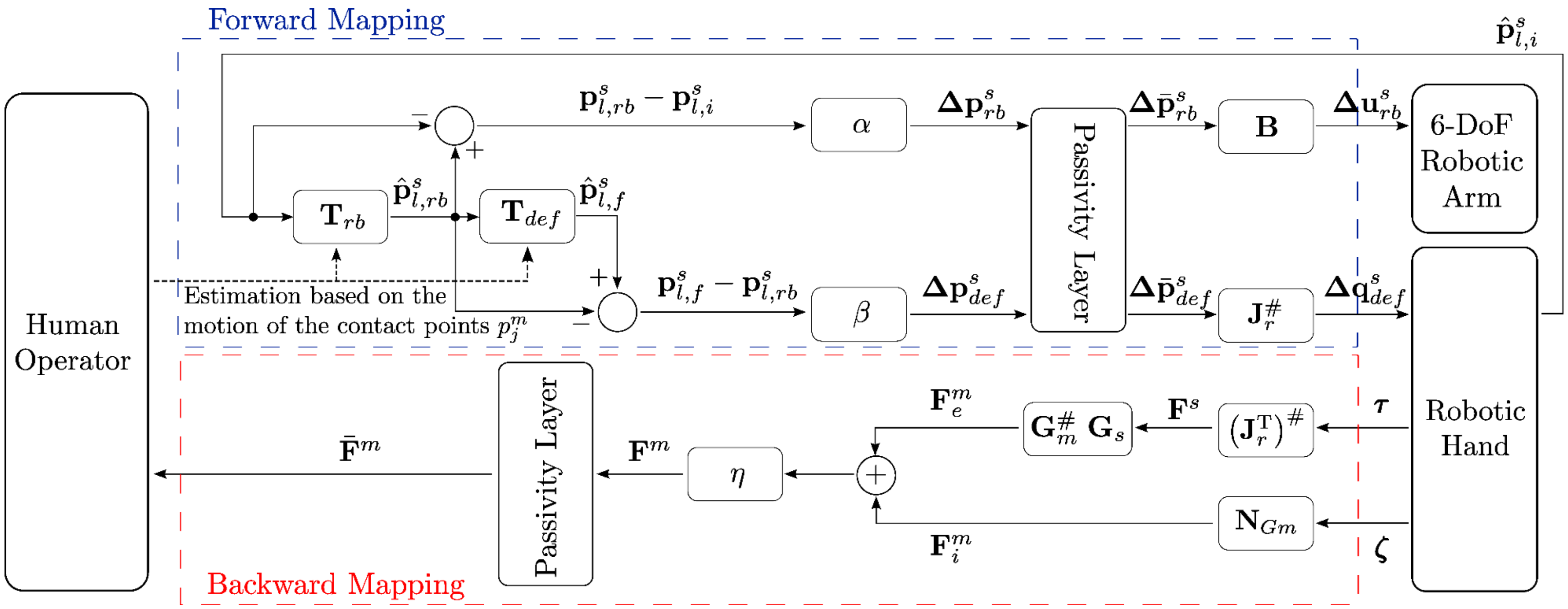
Backward mapping

How to evaluate forces to be rendered on the master side ?

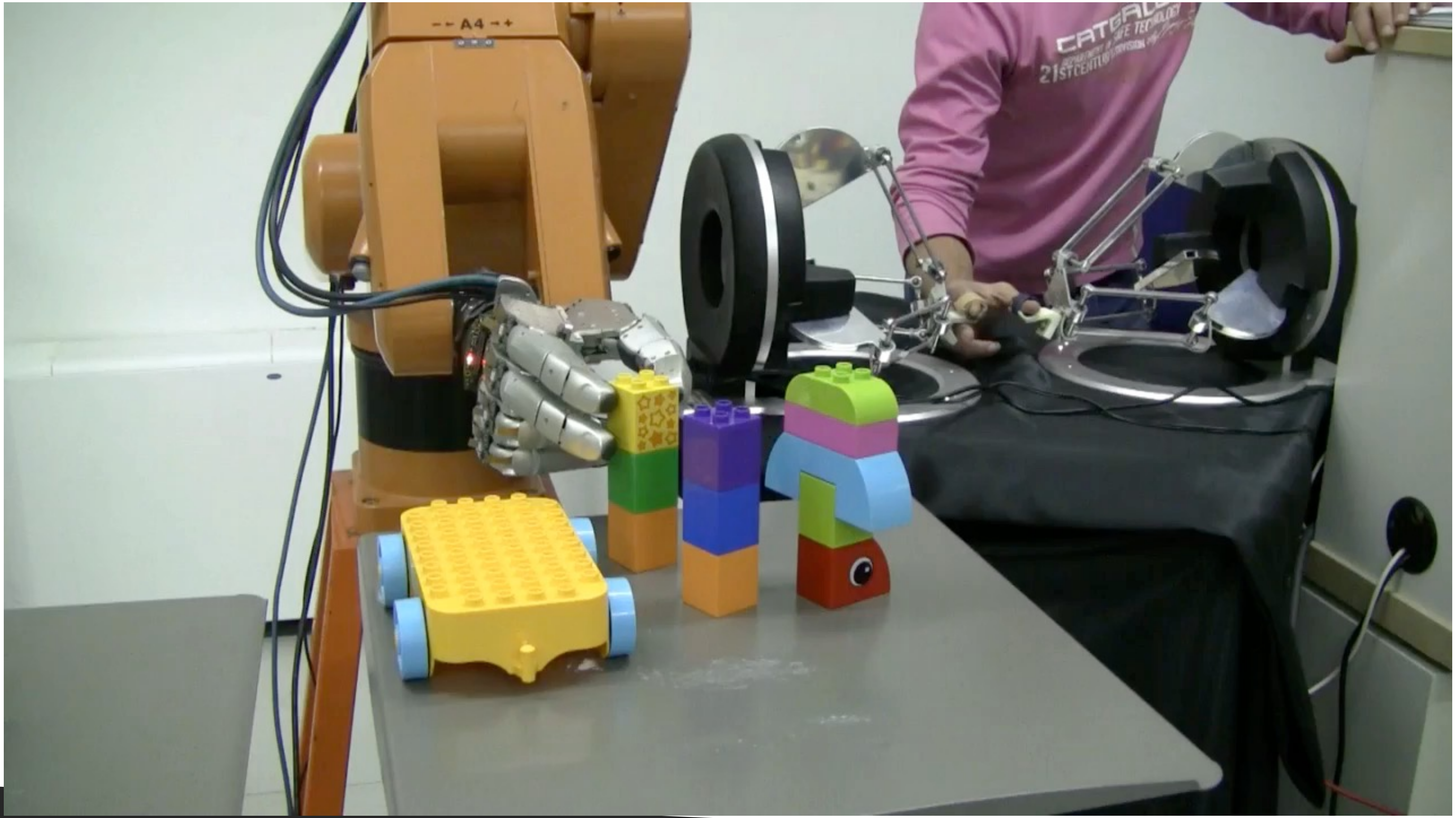


We impose that the same wrench is applied on the master virtual object

Schematic overview of the bilateral telemanipulation framework



Experiments

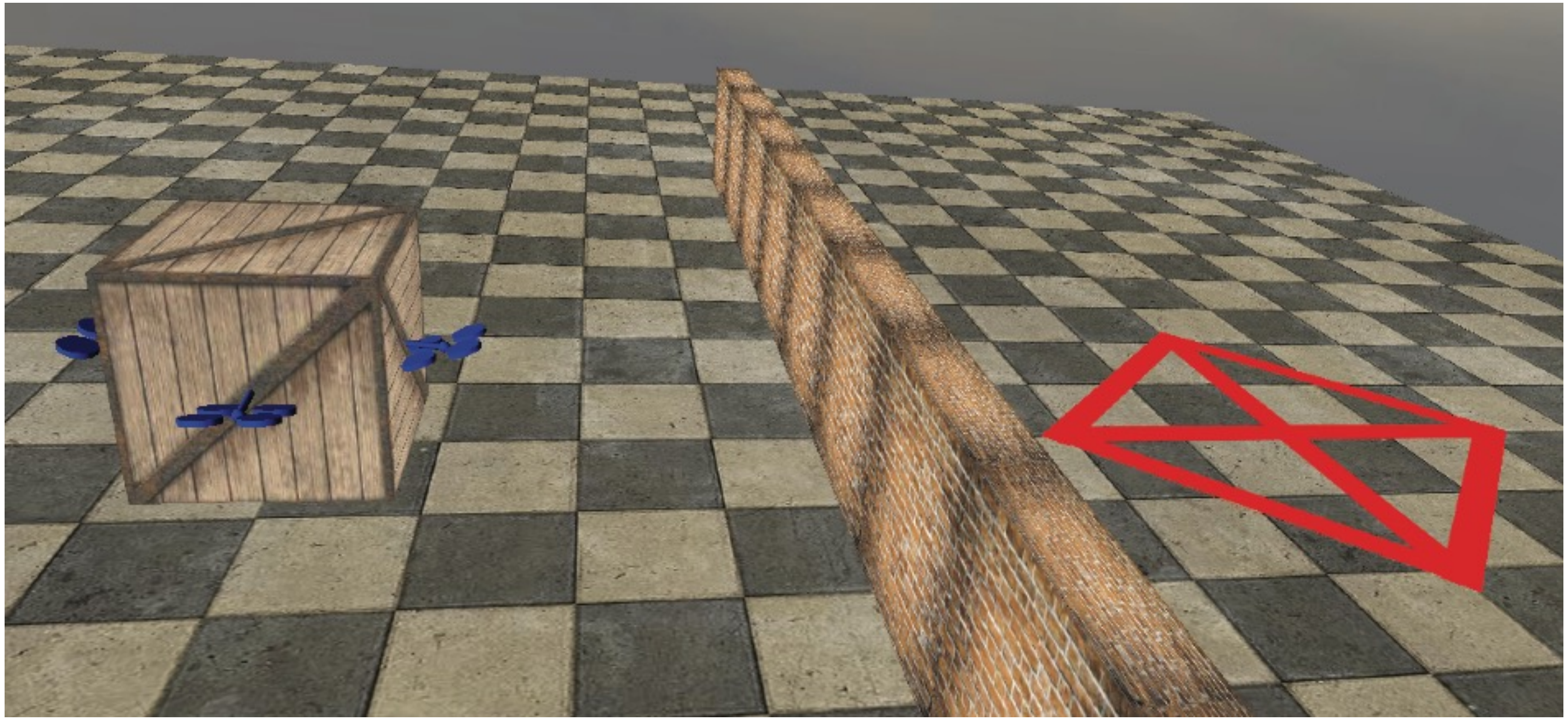


G. Salvietti, L. Meli, G. Gioioso, M. Malvezzi, D. Prattichizzo. **Multi-Contact Bilateral Telemanipulation with Kinematic Asymmetries**. *IEEE/ASME Transaction on Mechatronics*, 2017.

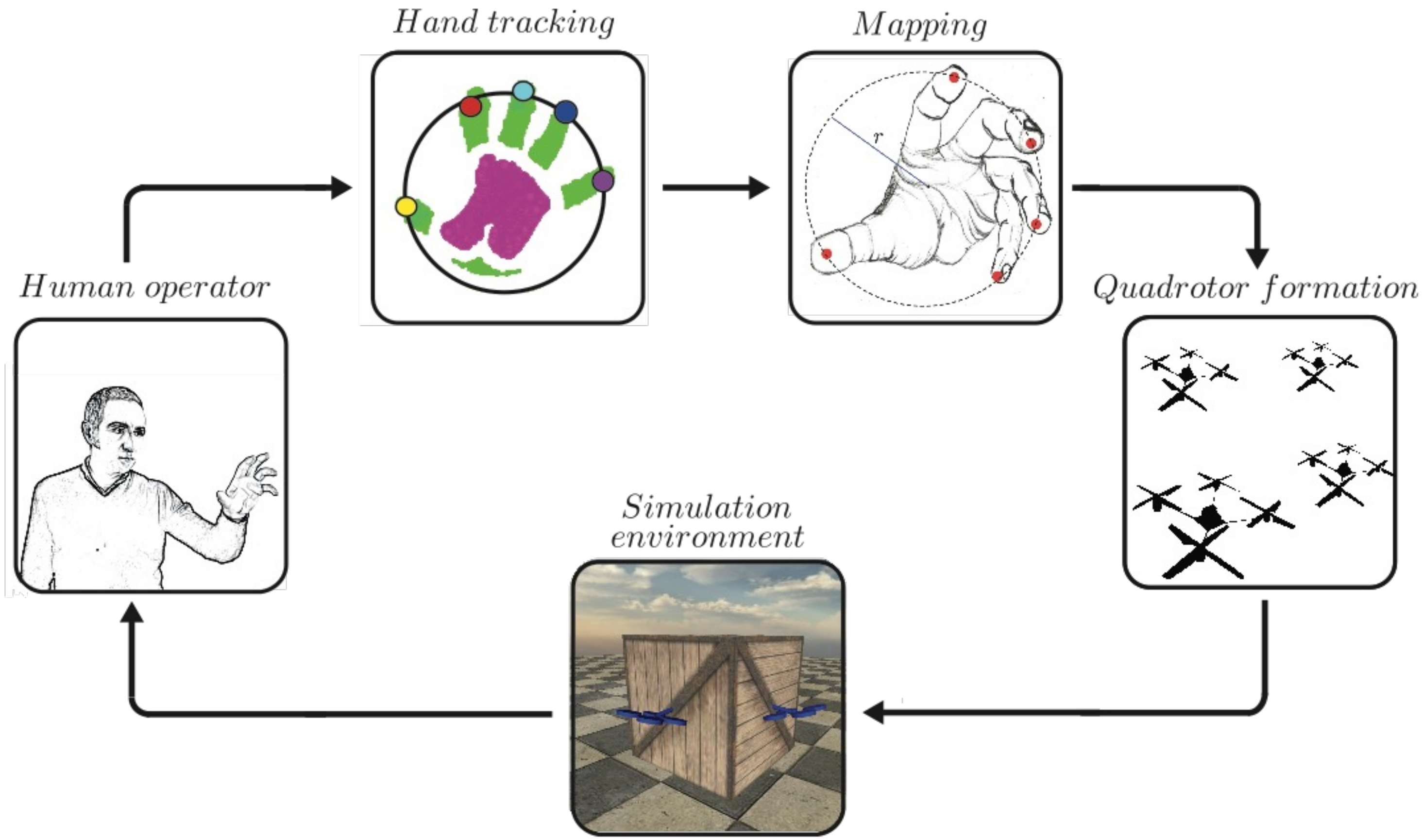
Going wearable…

L. Meli, G. Salvietti, G. Gioioso, M. Malvezzi, D. Prattichizzo. **Multi-Contact Bilateral Telemanipulation using Wearable Haptics**. In *Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Systems*, *To appear*, Korea, 2016.

The flying hand: an UAV formation to cooperatively grasp and carry objects

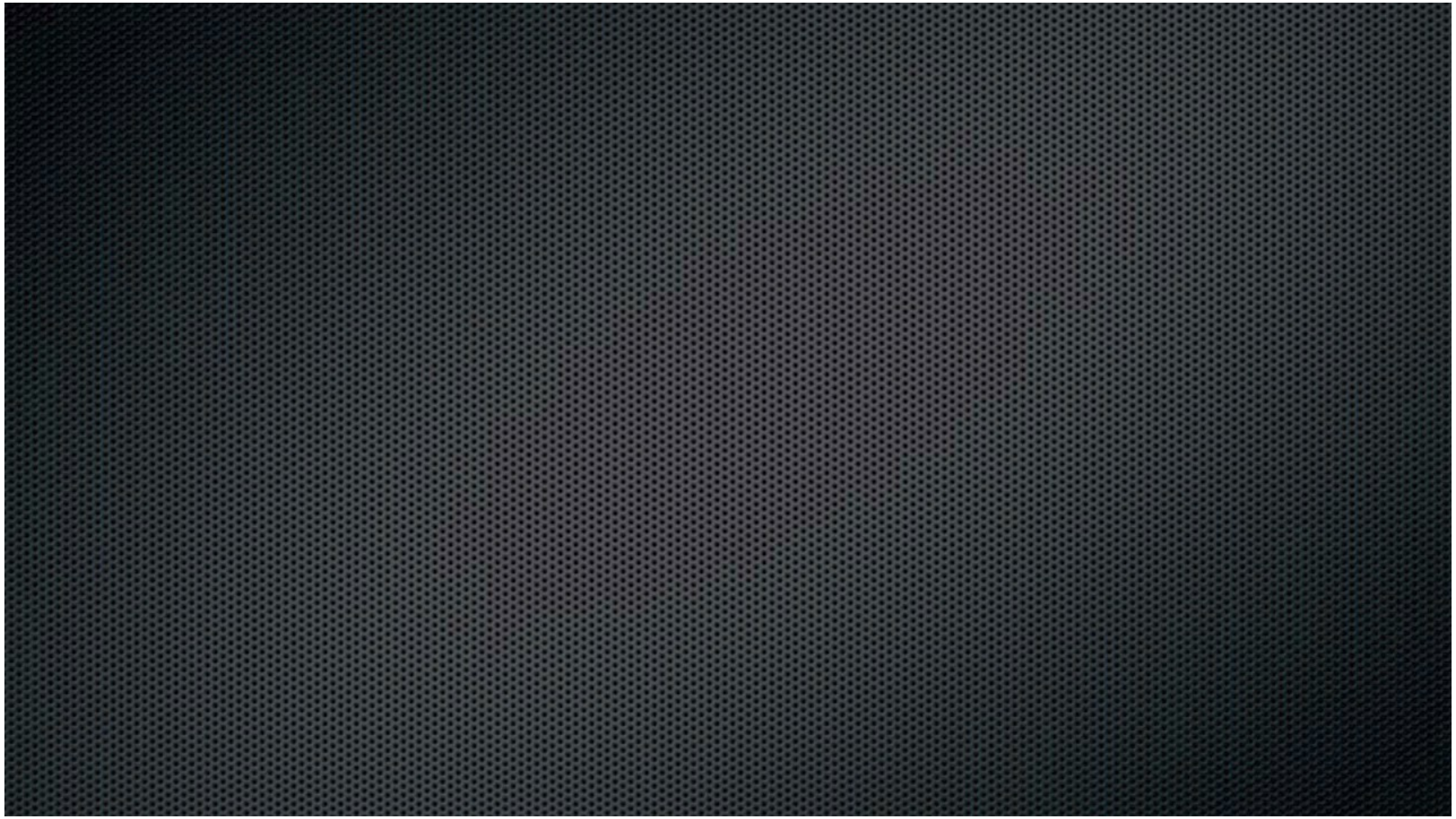


Mapping from hand onto formations



Cooperative Robot Grasping

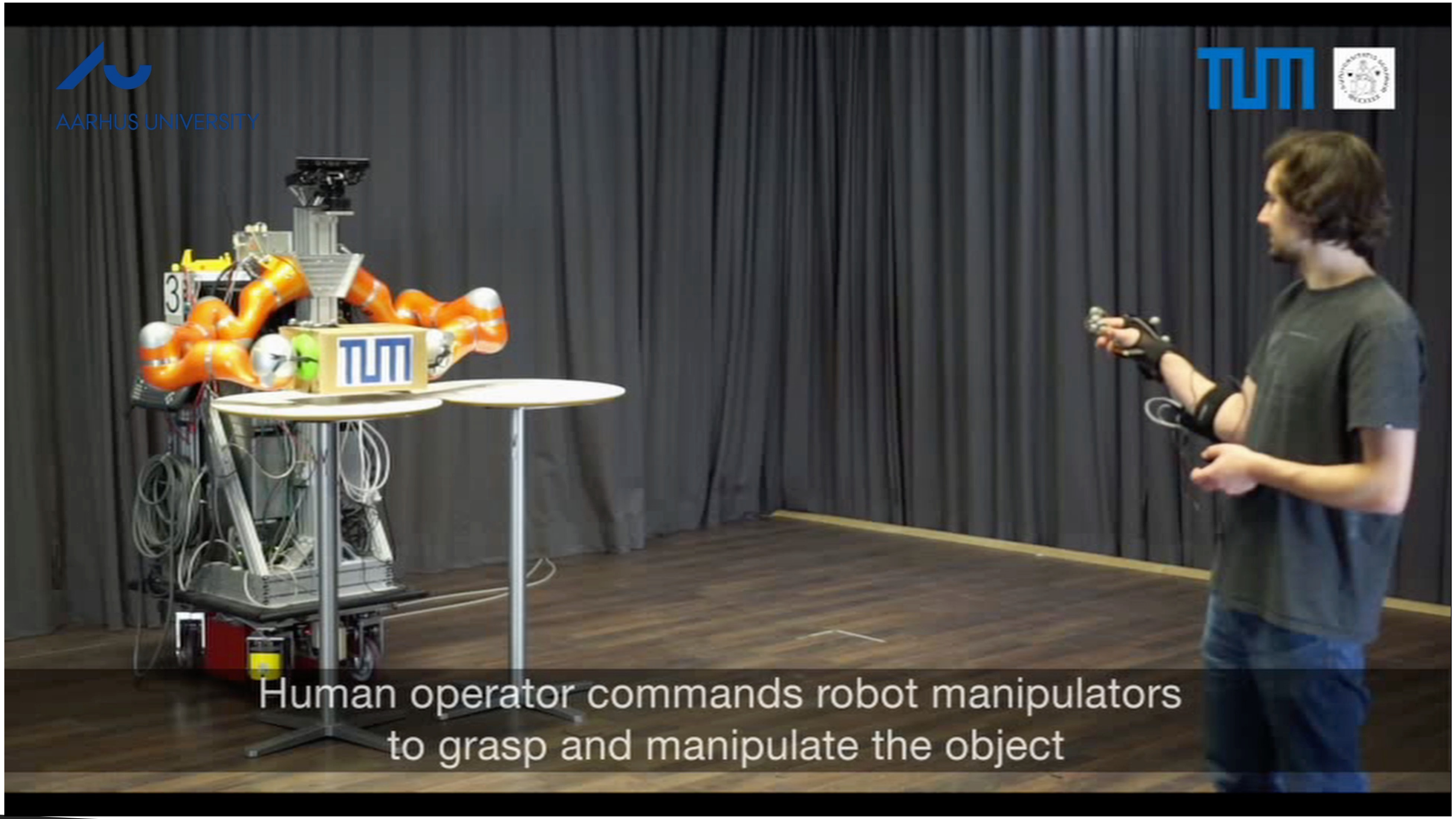
The flying hand – cooperation with Antonio Franchi CNRS



G. Gioioso, A. Franchi, G. Salvietti, S. Scheggi and D. Prattichizzo “The Flying hand: a Formation of UAVs for Cooperative Aerial Tele-Manipulation”, ICRA 14,

Cooperative Robot Grasping

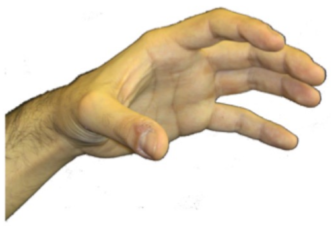
Haptic feedback in case of cooperative grasp – cooperation with TUM



S. Music, G. Salvietti, et al. “Human-Multi-Robot Teleoperation for Cooperative Manipulation Tasks using Wearable Haptic Devices”, IROS 17, in review ToH 18.

The Sixth Finger: Mapping from domain to codomain

domain: human hand



codomain: robot hand

[IEEE TRO, 2013]

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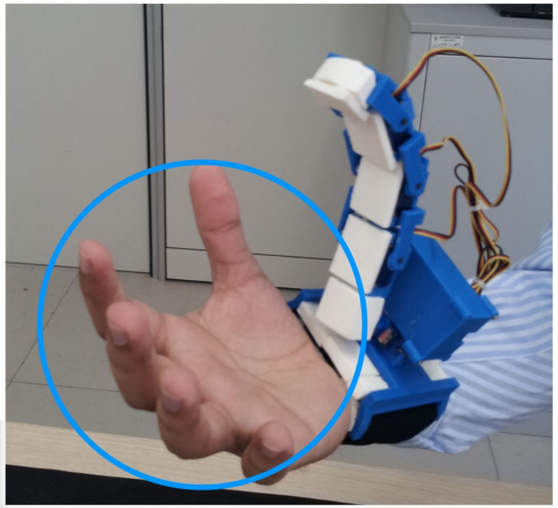
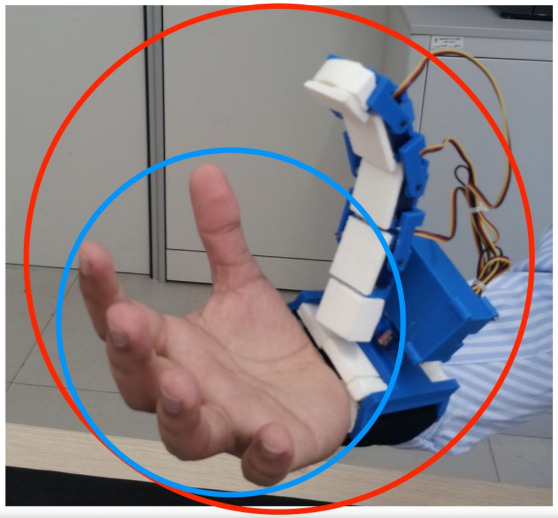
domain: human hand



codomain: human hand + robot

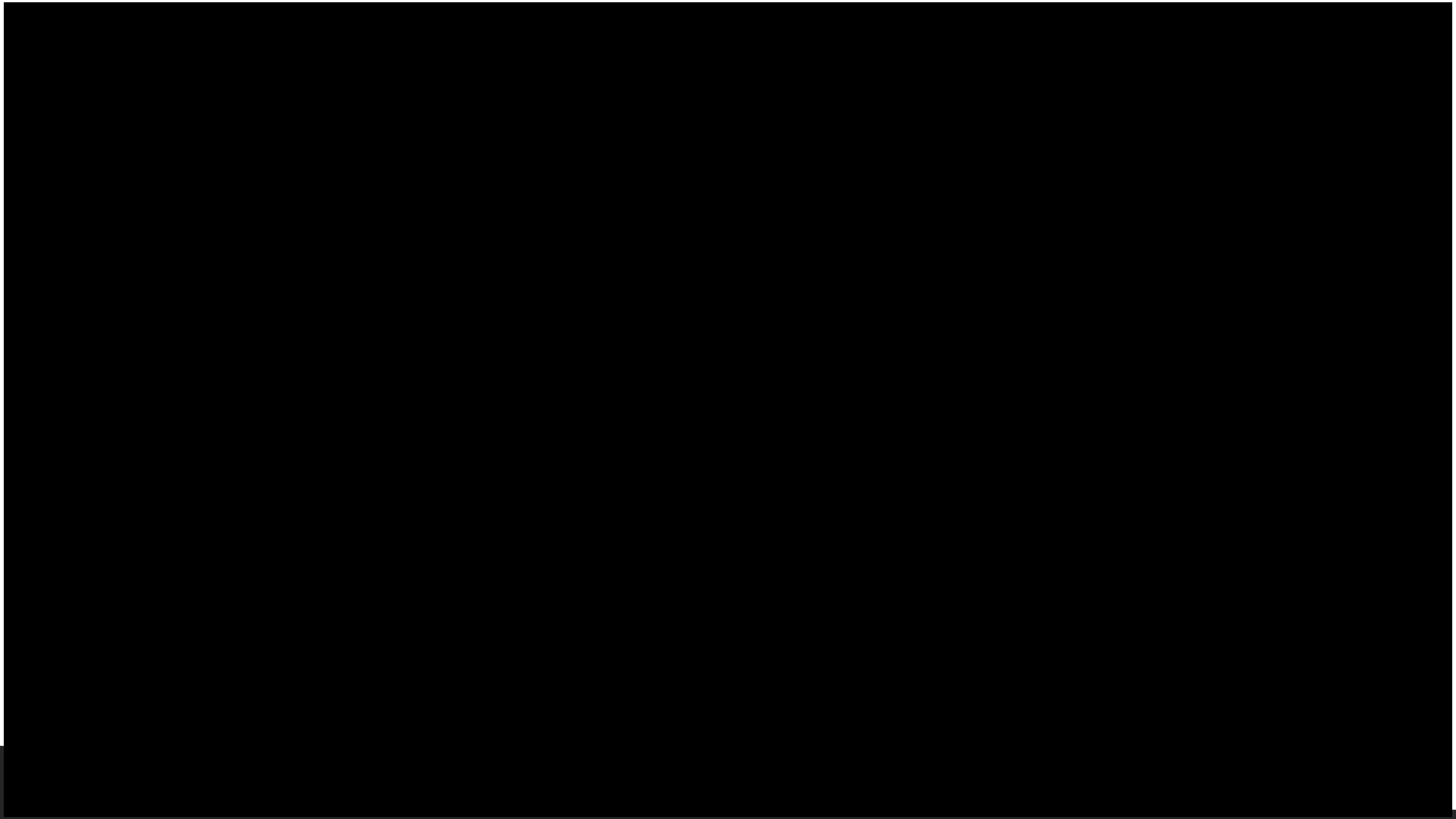


[AIM, 2014]

The Robotic Sixth Finger

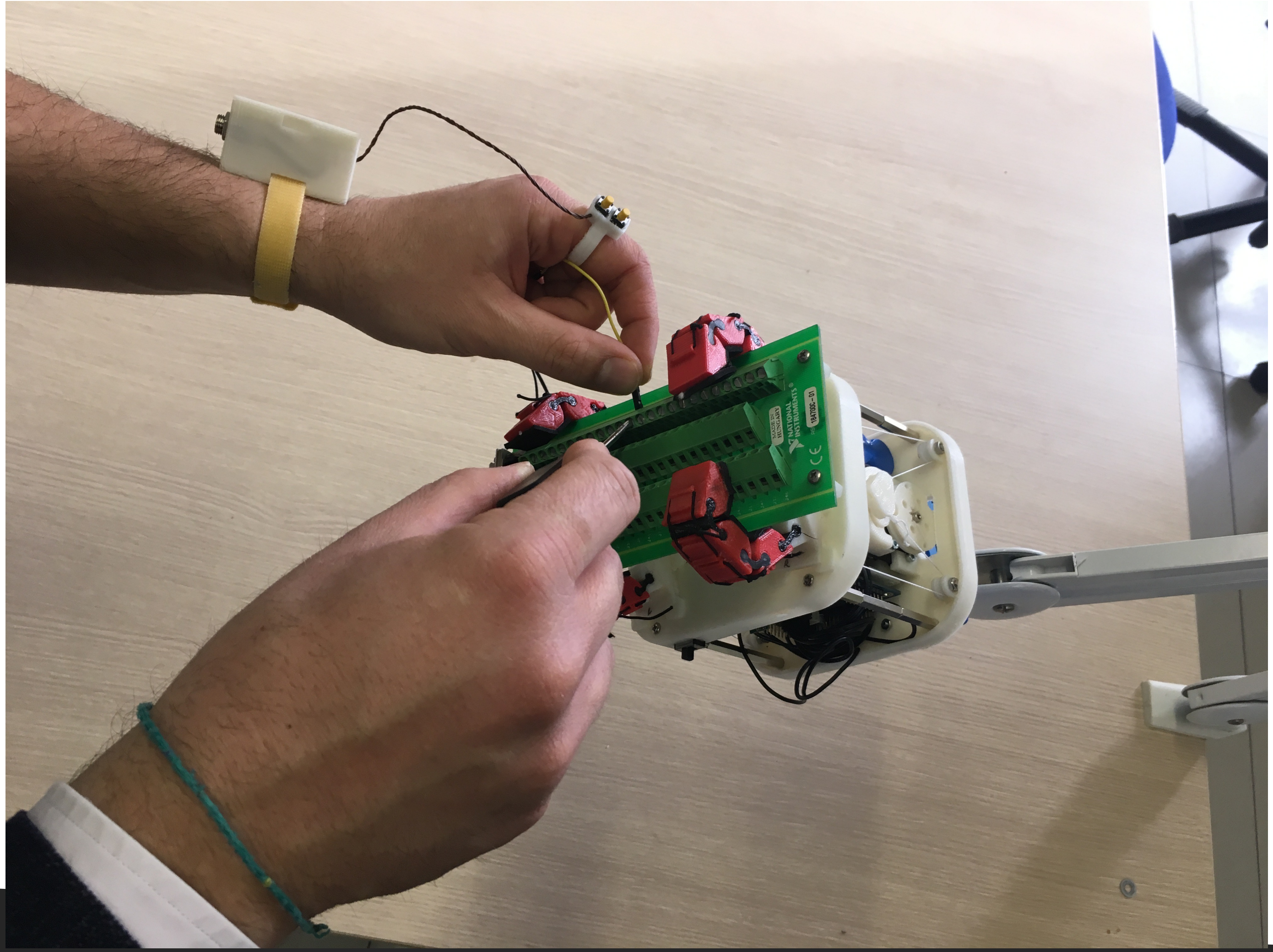
G. Salvietti, I. Hussain, M. Malvezzi, D. Prattichizzo, ICORR 15, WHC 15, AIM 14, ROMAN 14

Il Sixth Finger per i pazienti di ICTUS

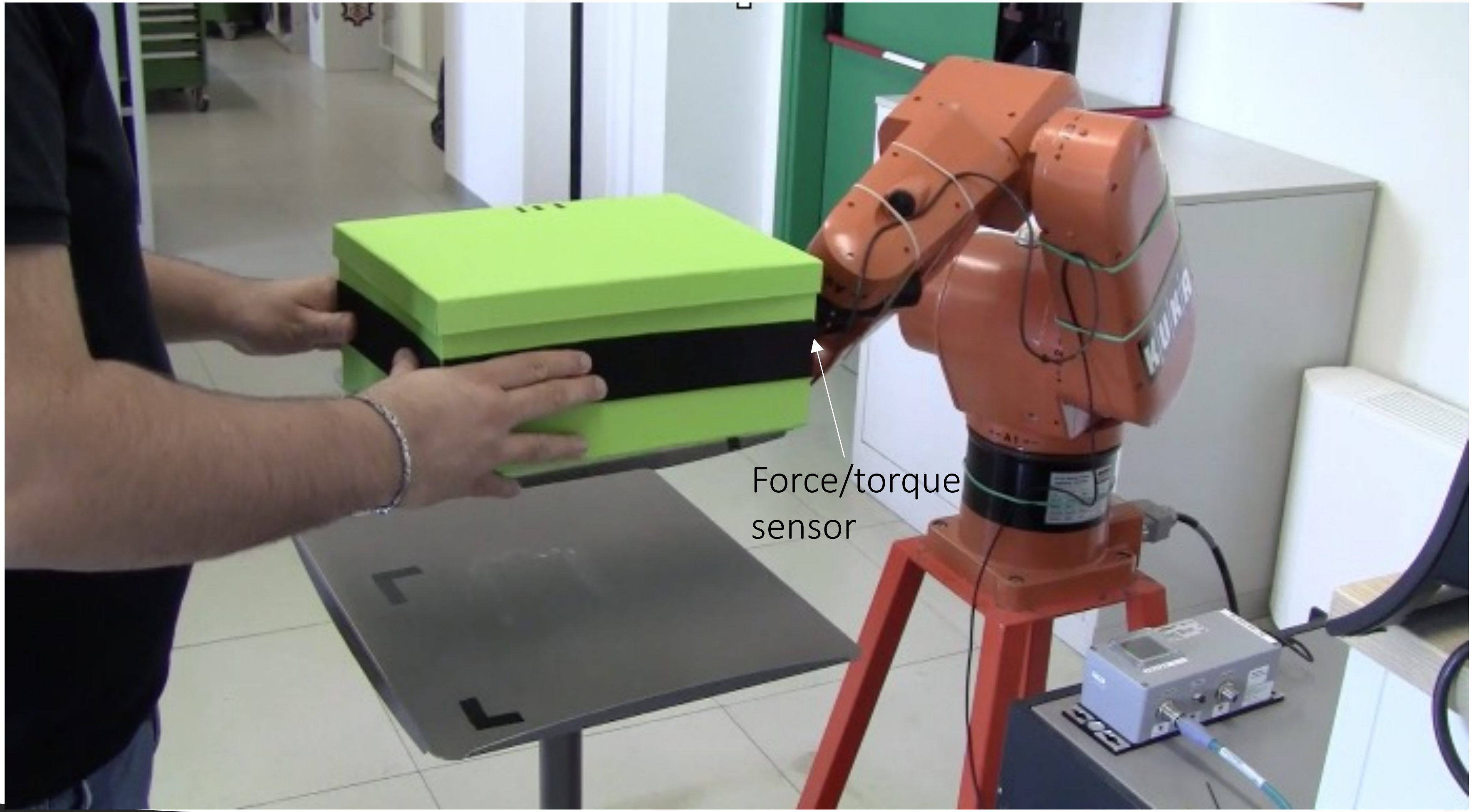


HUMAN CENTRED ROBOTICS

Cooperative manipulation



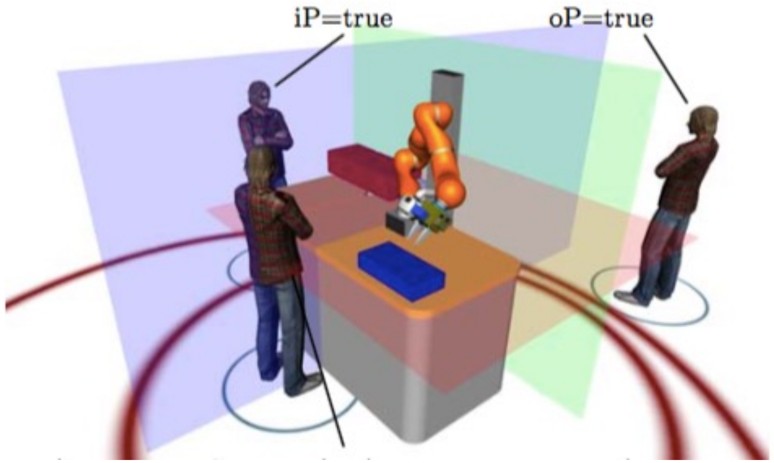
Cooperative manipulation

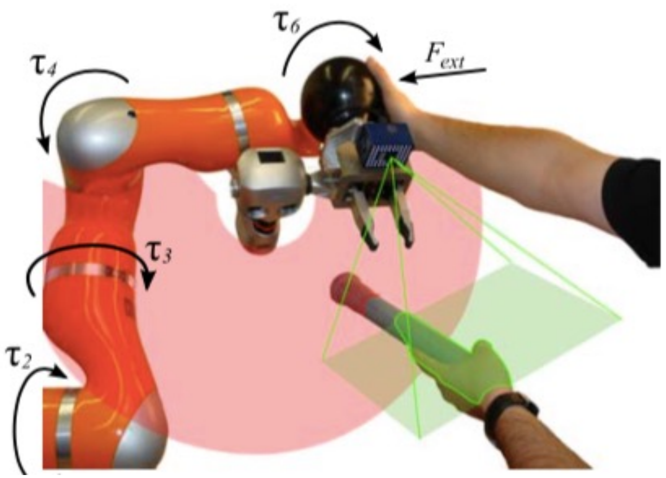


Human intention recognition

Perception

- Cameras, e.g., Leapmotion, Kinect
- Contact interaction, tactile sensors, F/T sensors





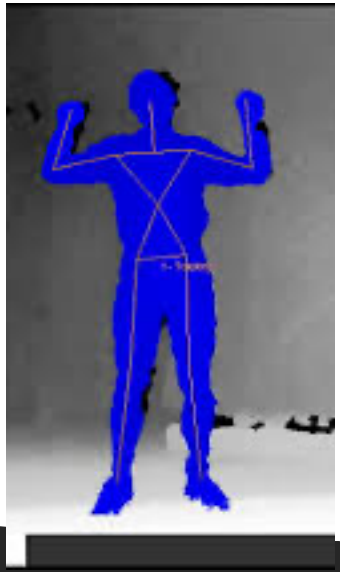
from Haddadin et al. 2009

Human intention recognition

Artificial intelligence and machine learning techniques to let robots generalize across the actions captured from humans

In a workplace scenario the set of actions are reduced and could be classified

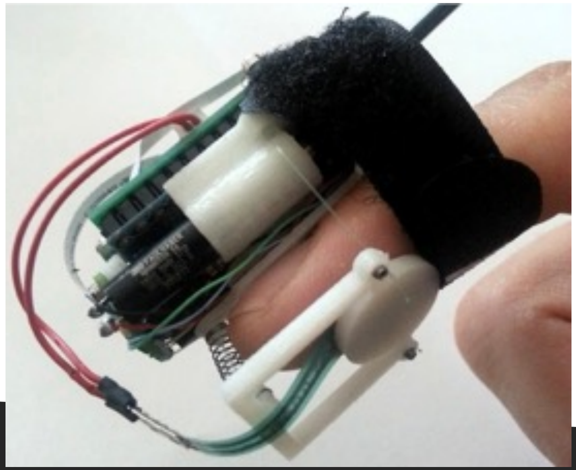
Implicit vs explicit control

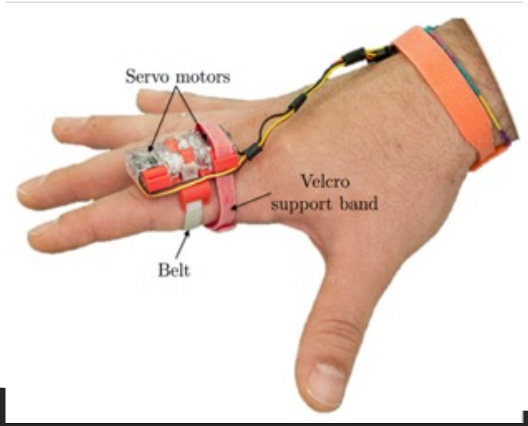


Sensorimotor interfaces

The robot can communicate with the worker through the sense of touch

- robust communication
- wearability and portability
- awareness



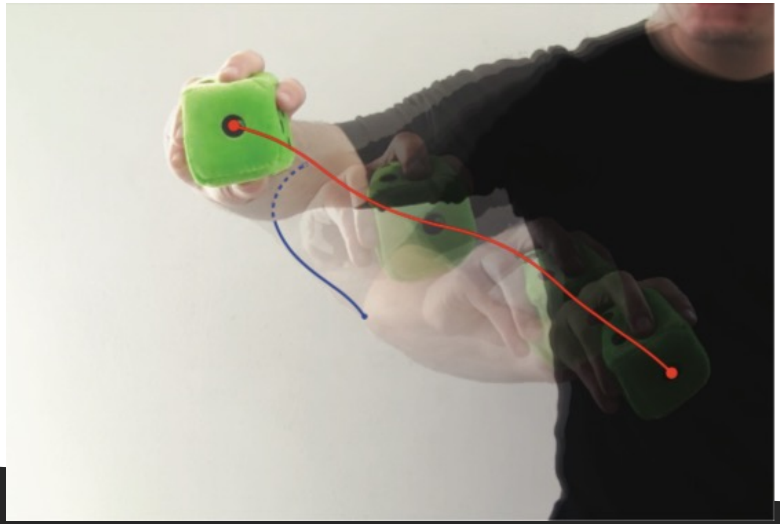


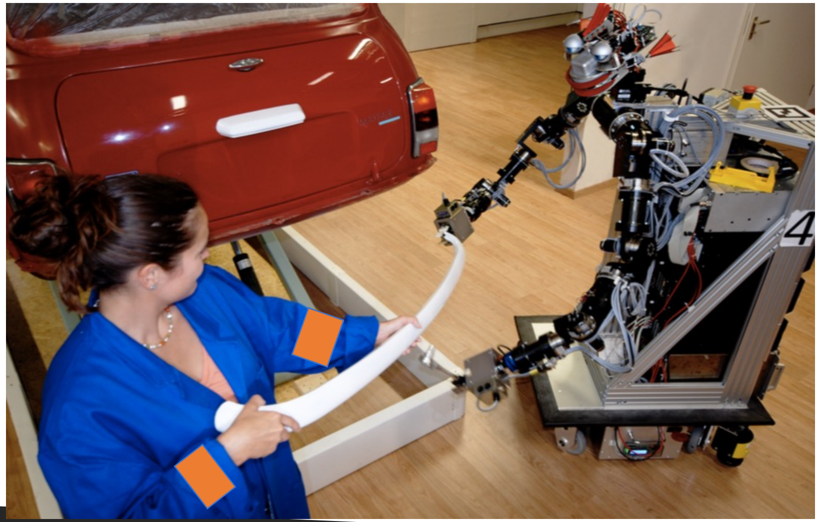
Use of interfaces

Guidance

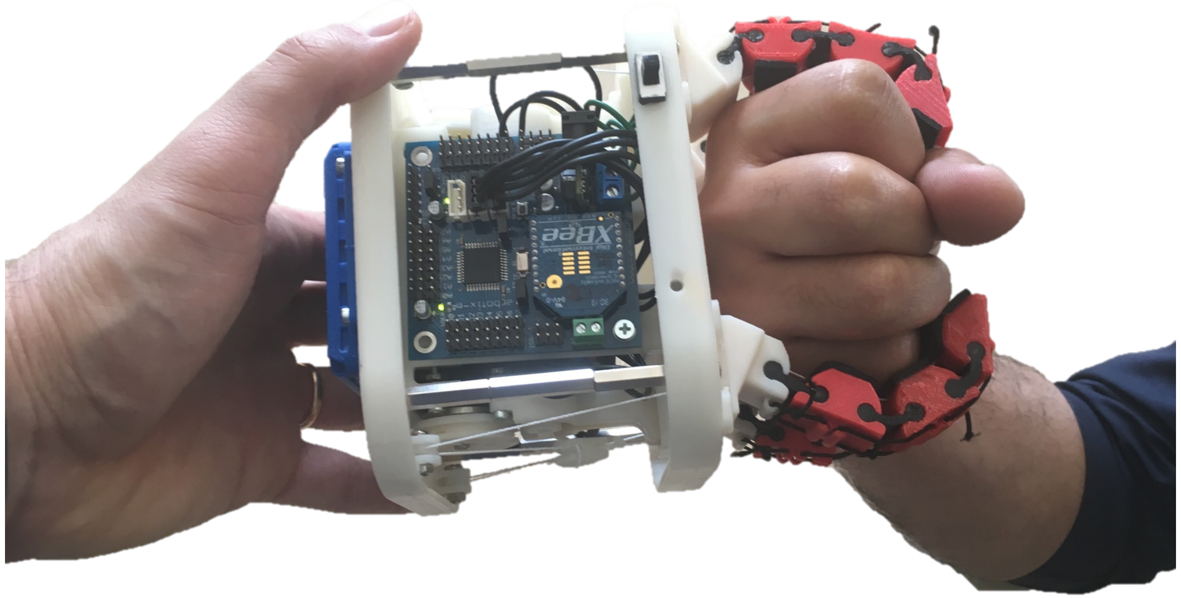
Alert

Force feedback in teleoperation





Design of a novel generation of cooperative grippers for smart factories



Cooperative robotics so far...

Main focus on safety and on robotic arms

Kuka LBR iiwa

Franka Emika Panda

Rethink Robotics Sawyer

Interaction with the operator

Many times at the end-effector level

Collaborative grippers

Co-act SCHUNK

RG6 ThinkBot

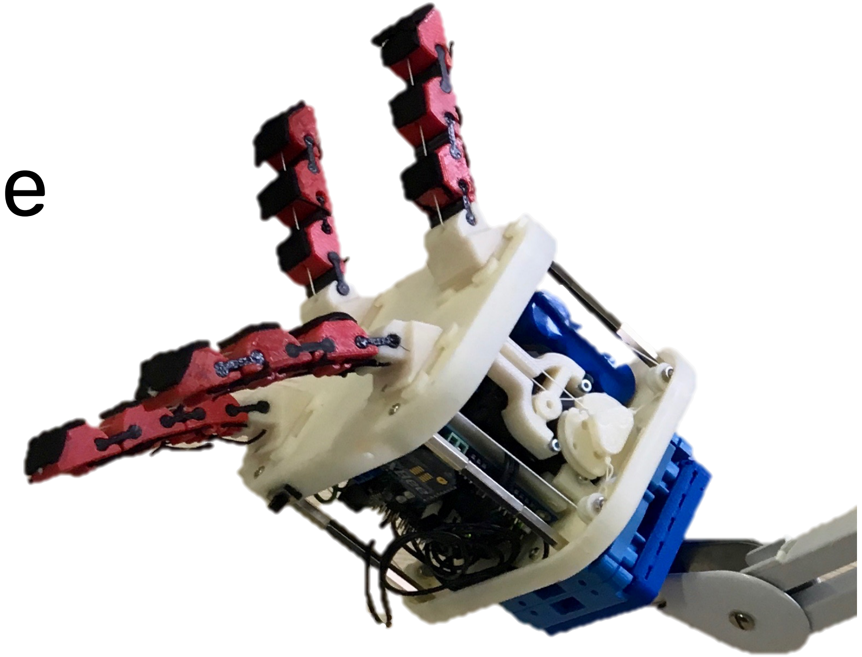
Four main guidelines for cooperative grippers

Intrinsically safe and adaptable

Ease of interface

Portability

Ease of reconfiguration



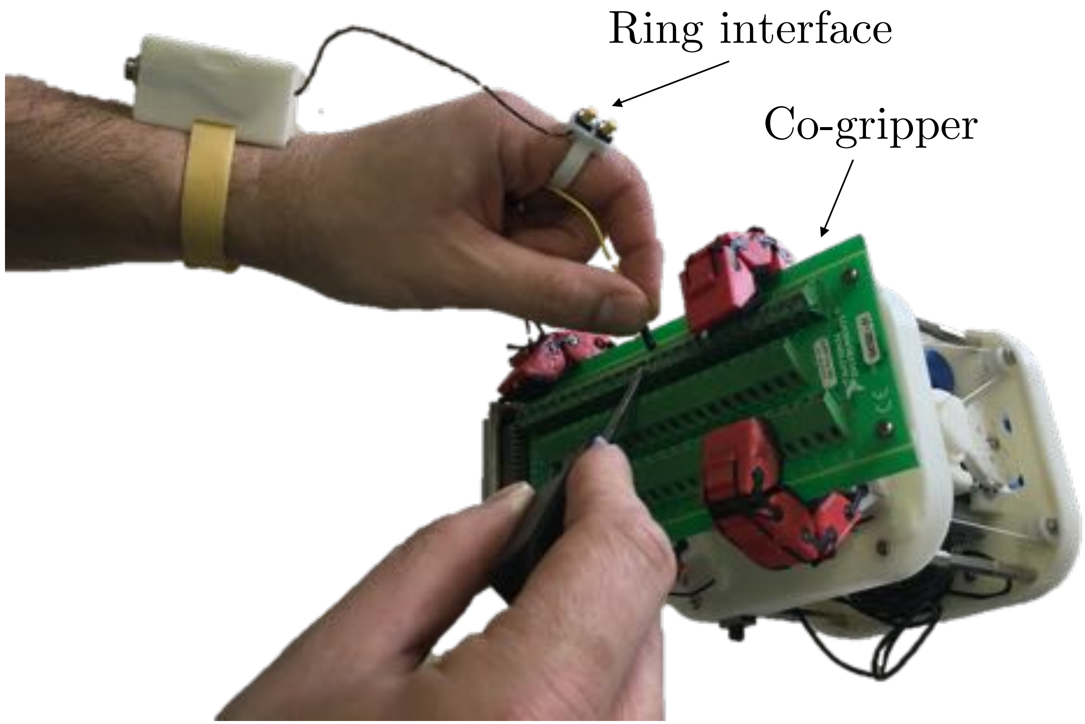
The CoGripper

G. Salvietti et al., IROS 2018

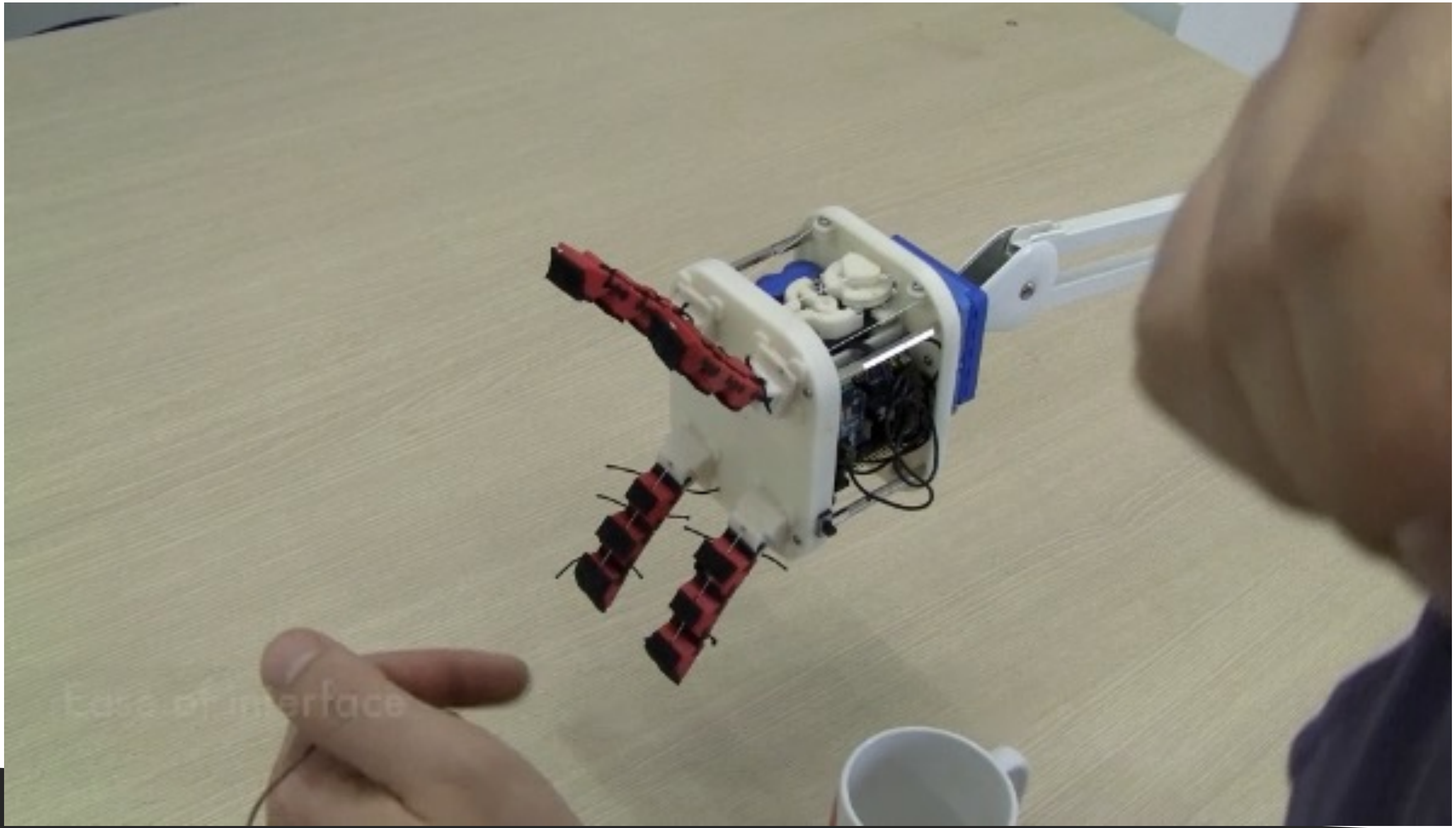
Intrinsically safe and adaptability

Ease of interface

Intuitive and simple

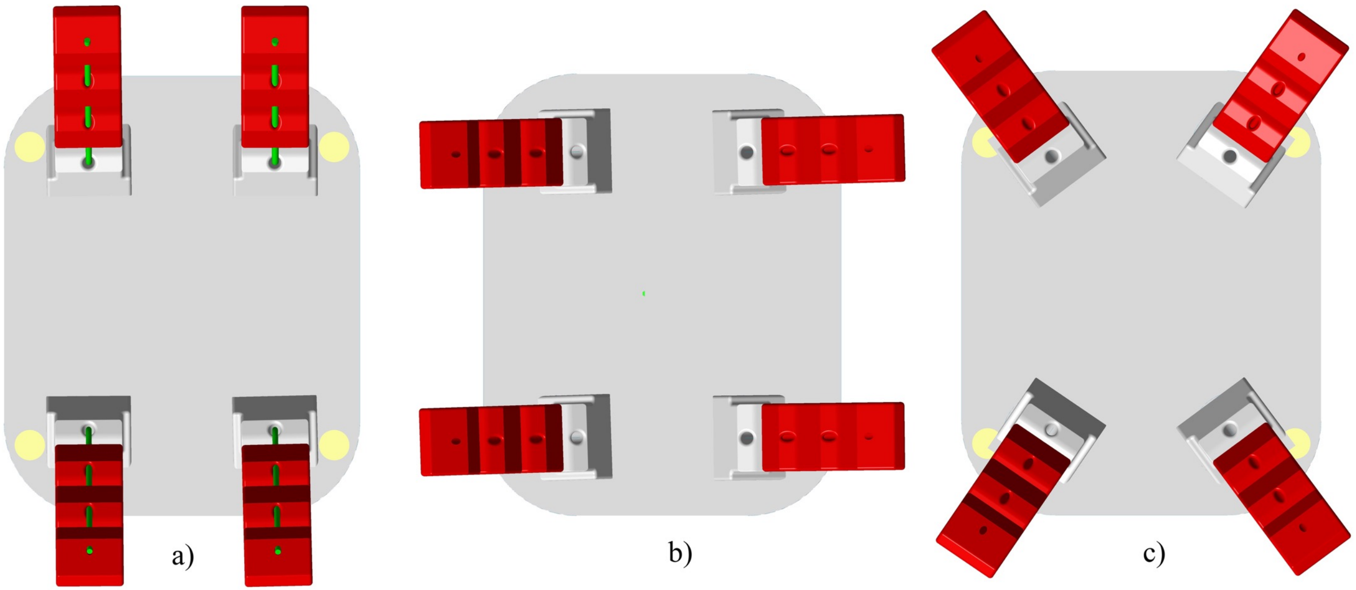


Ease of interface



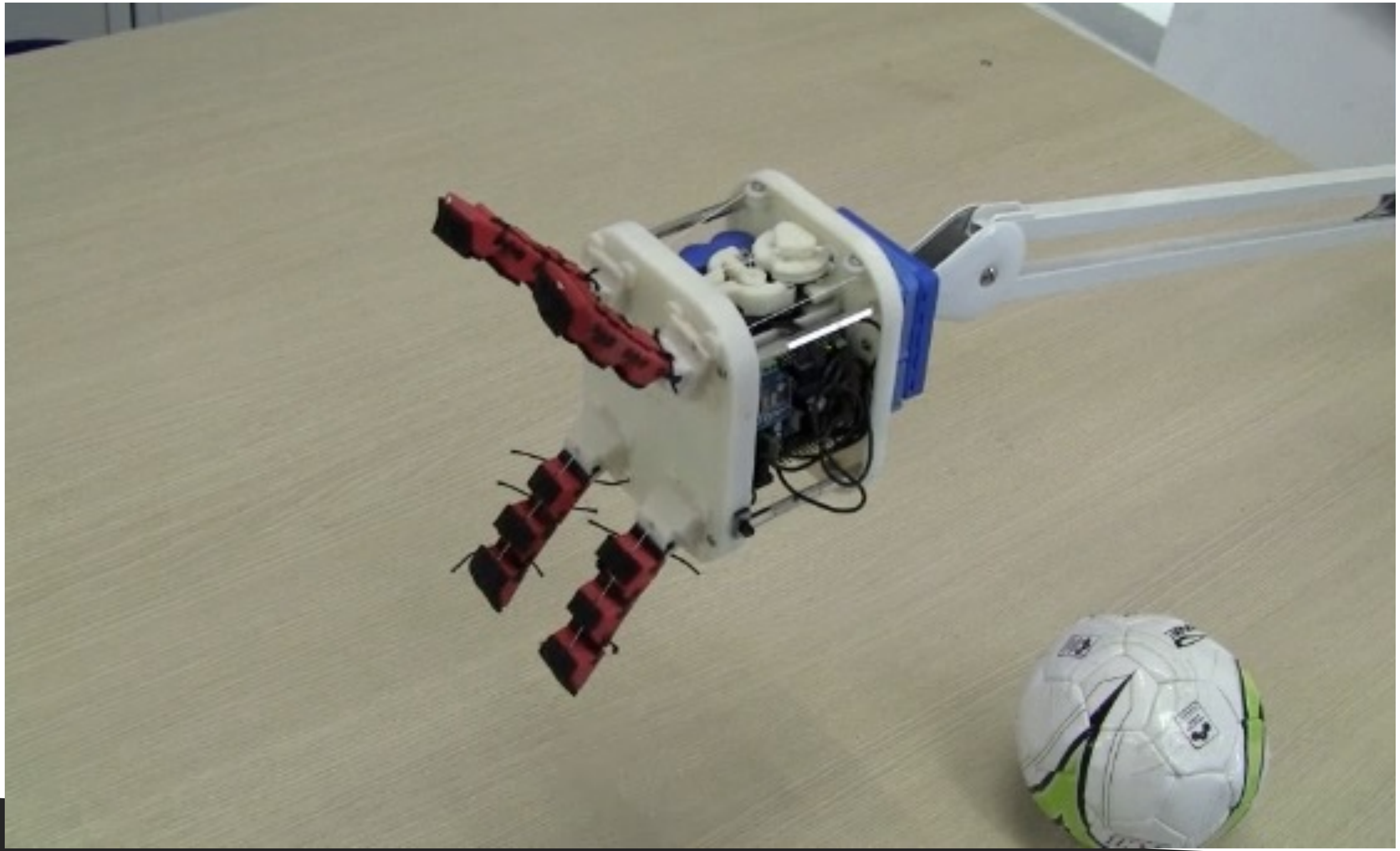
Ease of reconfiguration

Reorientation of the fingers



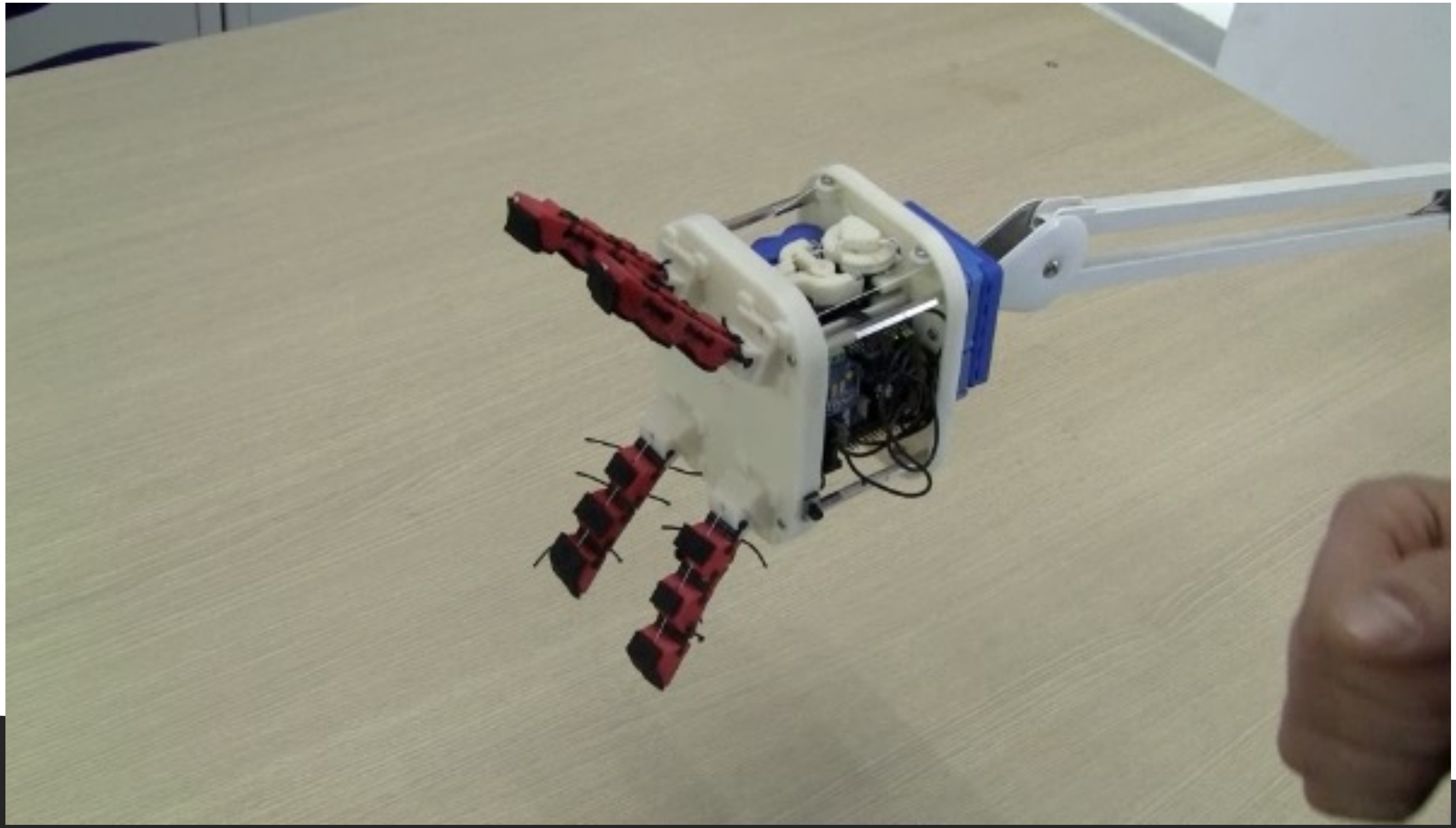
Fingers' orientation on the palm can be manually reconfigured by the operator. The combination of the modularity, possible finger trajectory design through stiffness and finger configurations meet the requirements for easy reconfigurability of the system

Ease of reconfiguration



Ease of reconfiguration

Flexion trajectories of the fingers – Power and Pinch grasps

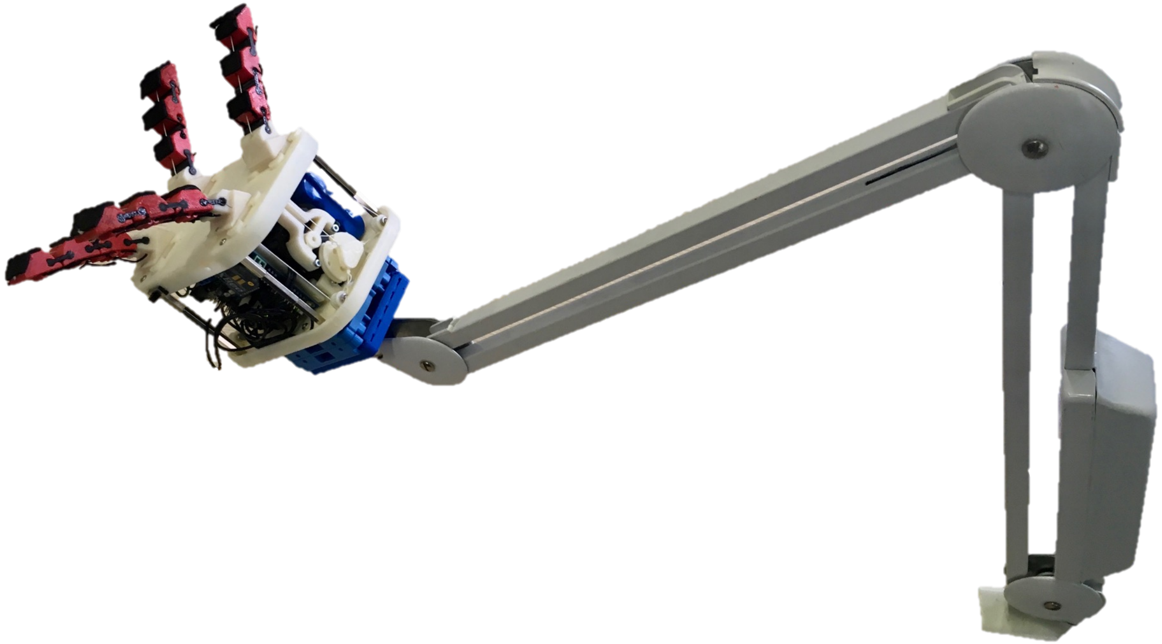


Portability

The CoGripper is wireless and can be used also with passive supports

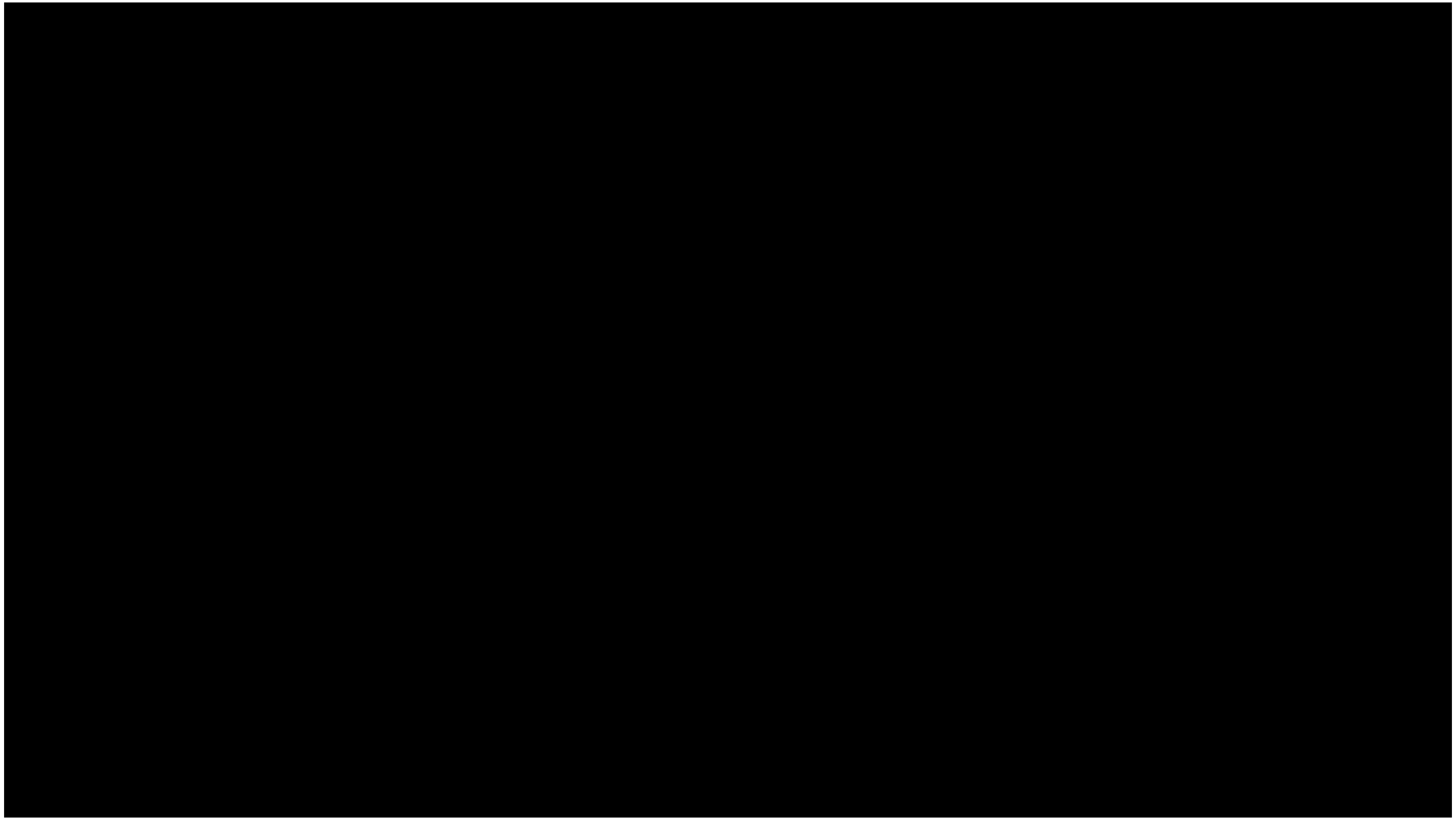
Possible to be used also without a robotic arm as support for particular processes

No re-grasp needed



Portability

Bilateral haptic collaboration for cooperative grippers

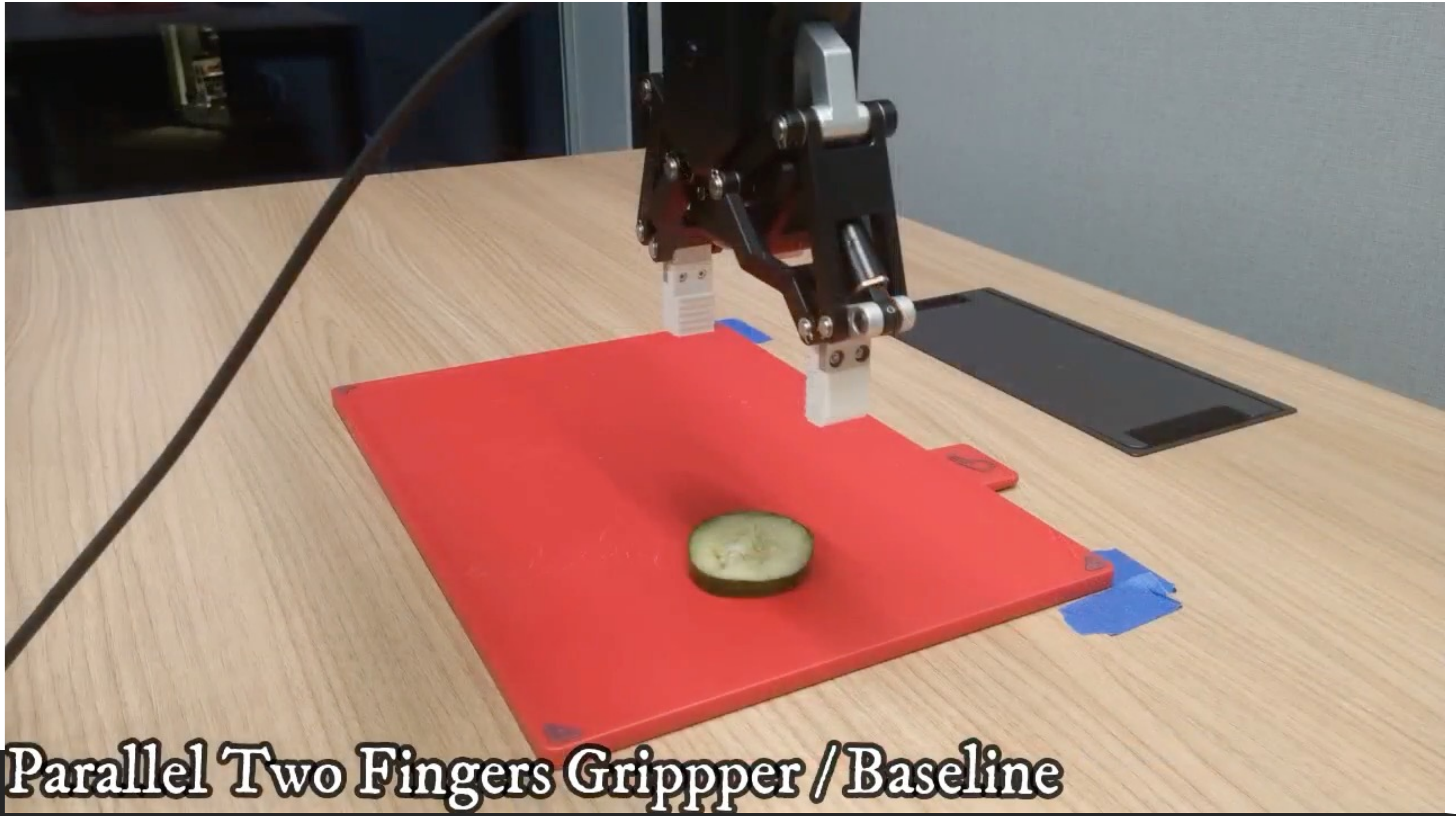


G. Salvietti, et al., ICRA 20

AN EXAMPLE

Gripper for food handling @REMYRobotics

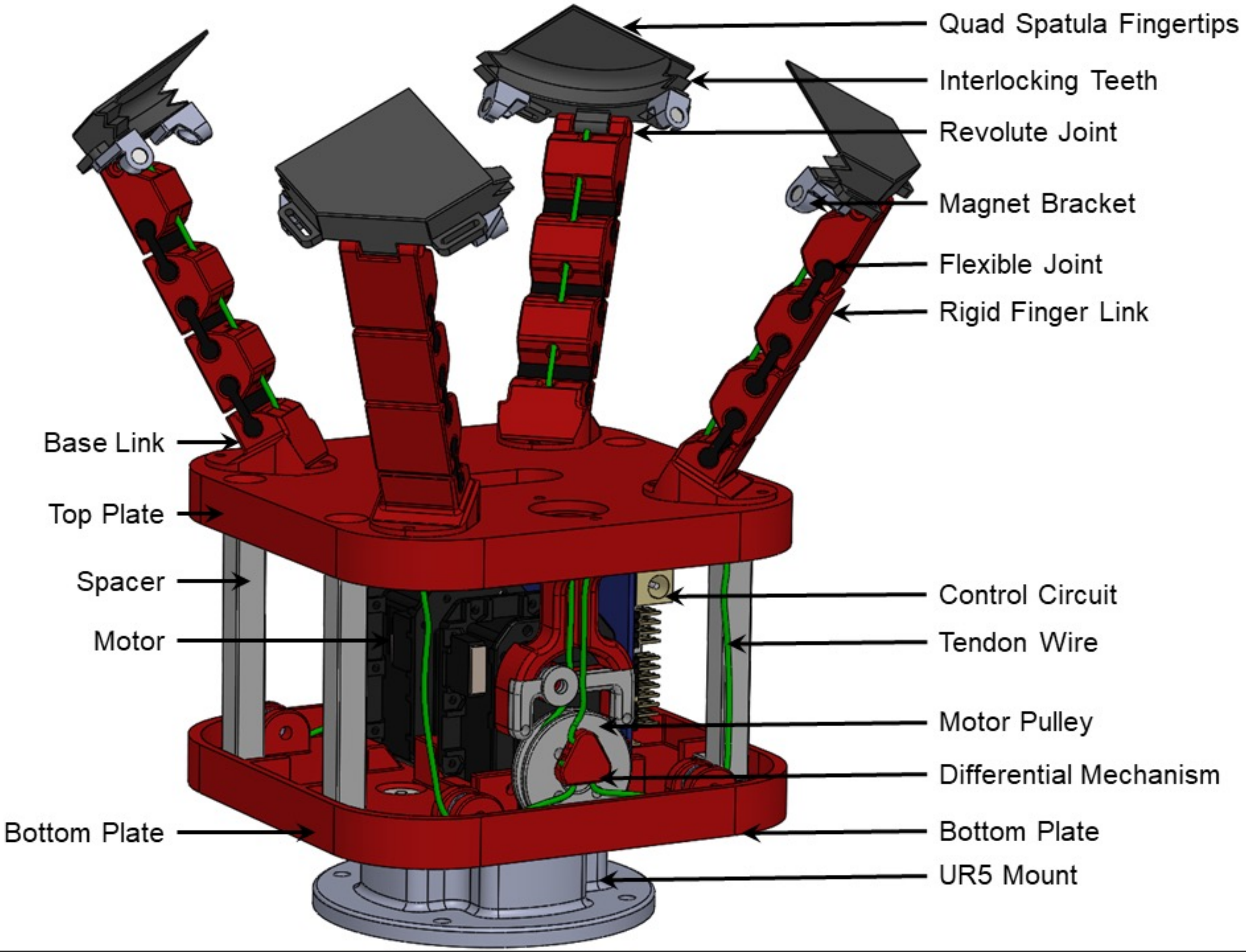
Classic two-fingers grippers

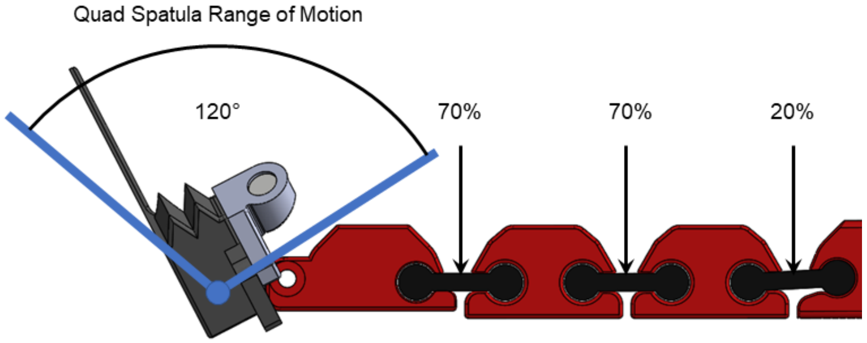


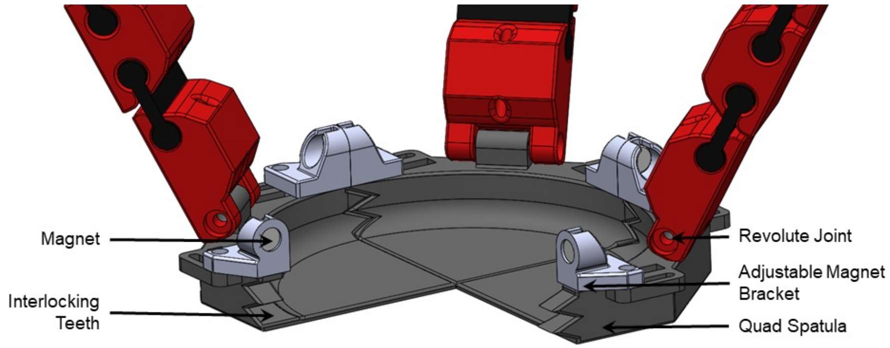
THE IDEA: SPECIALISE THE FINGERTIPS

The Quad-Spatula Gripper

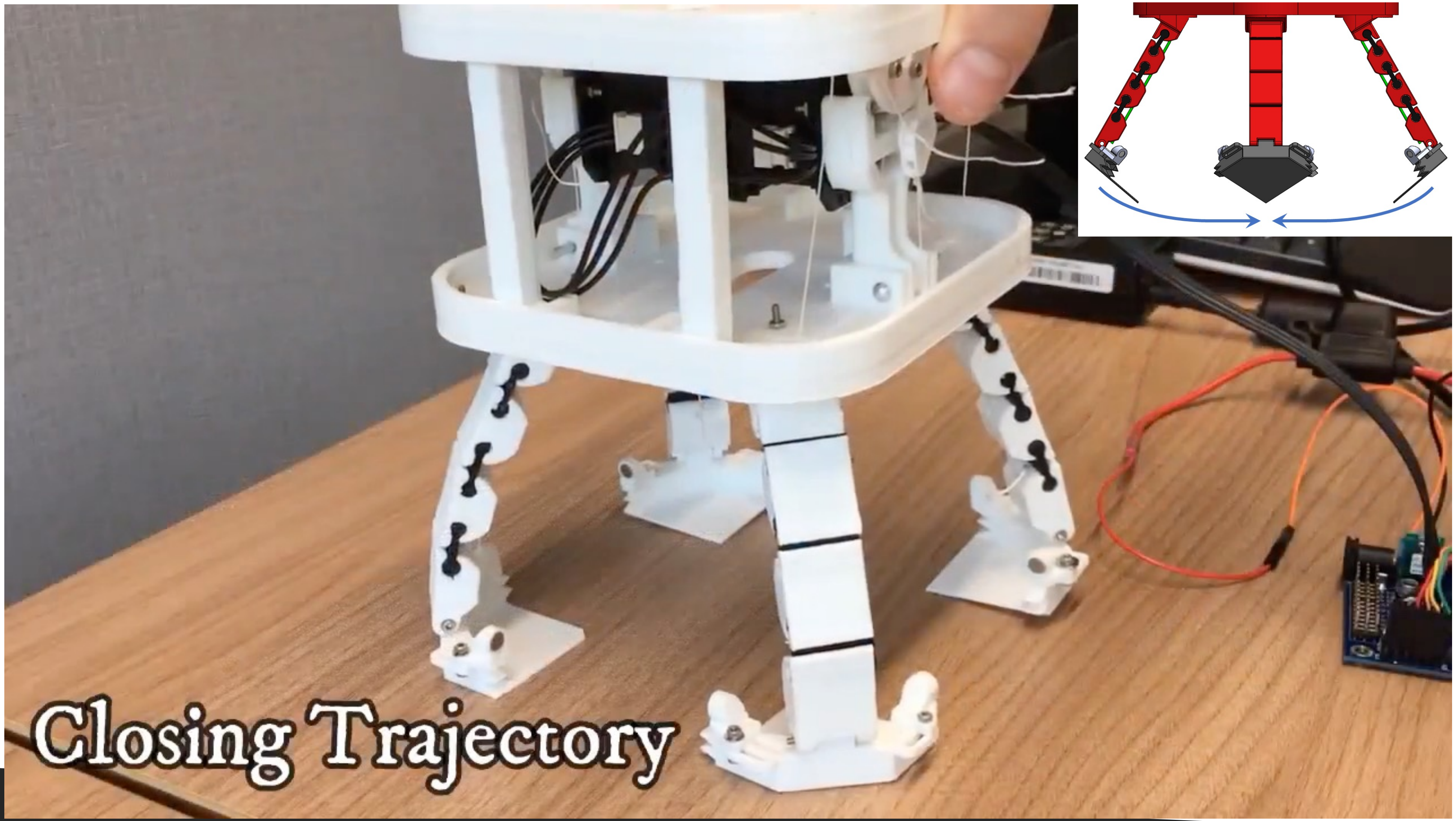
Salvietti et al., Robosoft 2020



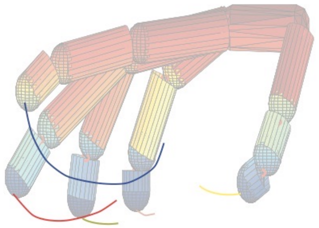




The Quad-Spatula Gripper



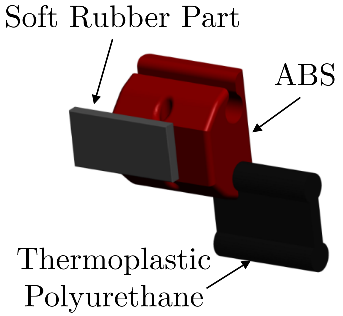
Joint stiffness design

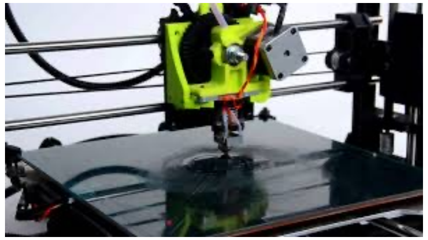


Design/select fingertip trajectories

$$\mathbf{k}_{q_k} = \mathbf{Q}_k^{-1}\mathbf{T}_k^{\mathrm{T}}\delta\mathbf{f}_k$$

Compute relative joint stiffness ratio

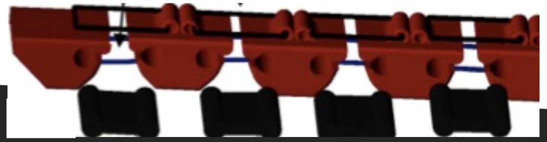




$$k_i = f(\rho_i)$$

infill percentage density ρ

Built the soft module with the K computed



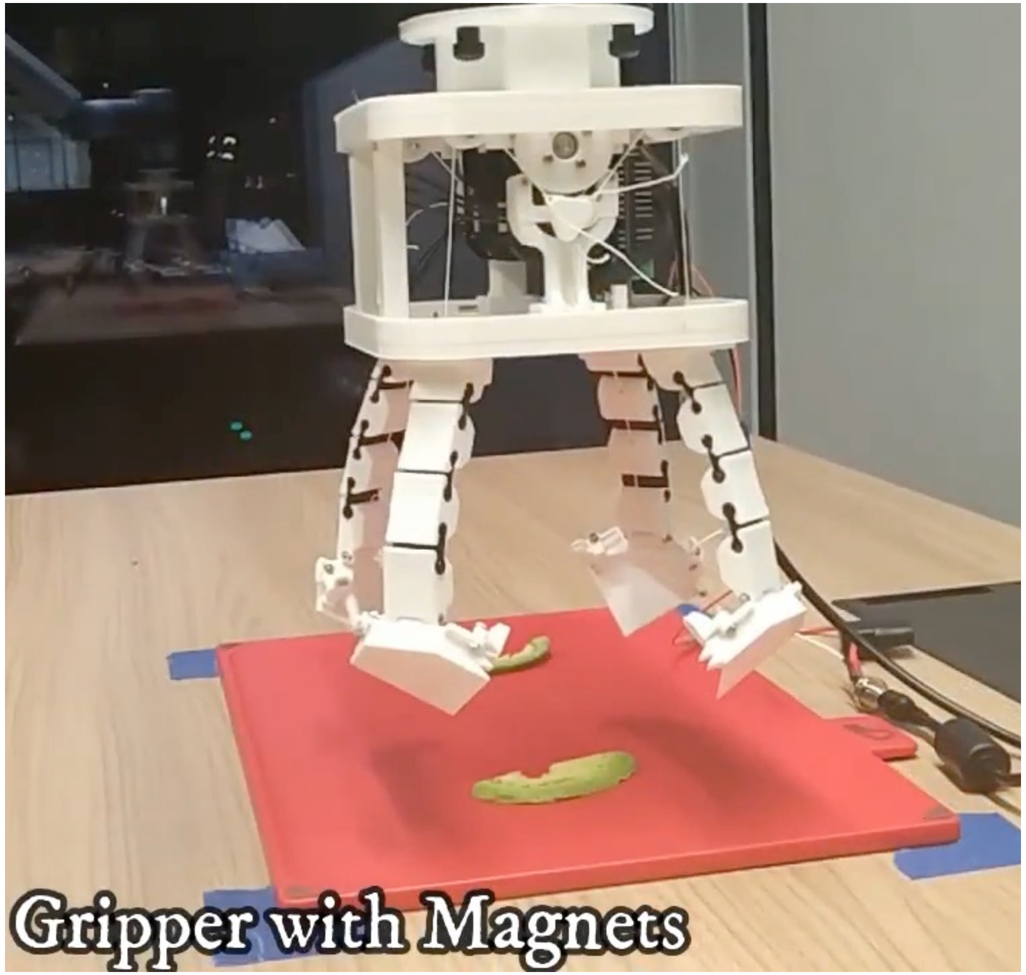
assemble the fingers

Salvietti et al., RAL 2017

EXPERIMENTS

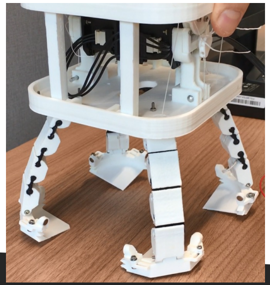
Grasping ability

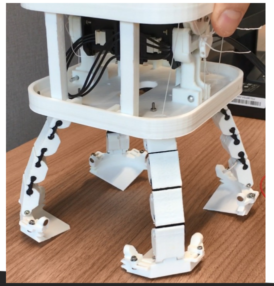
Slices	Strips	Cubes/Irregular
Tomato	Smoked Salmon	Cherry Tomato
Cucumber	Kale	Olives
Pepperoni	Avocado	Tofu Cubes
Cold-Cut Ham		Pineapple Cubes
		Chicken Cubes
		Sausages
		Chicken Nuggets
		Broccoli



Grasping ability

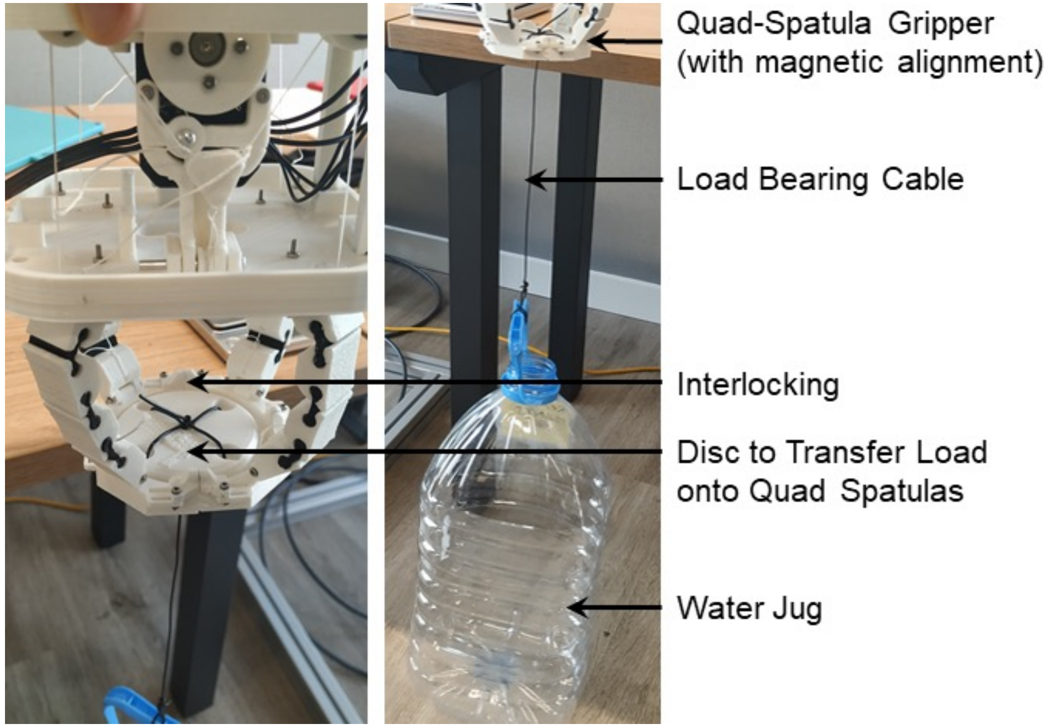
- no ingredient is identical to the other in its set
- all ingredients vary significantly by size and shape
- ingredients can possess one or a combination of properties and at different scales such as sliminess, stickiness, deformability and brittleness





Ingredient	Parallel Gripper	QS-Gripper	QS-Gripper with magnets
Cherry tomato	80%	100%	100%
Tomato slices	40%	100%	100%
Olives	100%	100%	100%
Tofu	90%	100%	100%
Pineapple cubes	90%	100%	100%
Dinosaur Kale Strips	90%	100%	100%
Cucumber slices	60%	90%	100%
Pepperoni slices	80%	100%	100%
Avocado strips	70%	100%	100%
Ham slices	70%	100%	100%
Broccoli	80%	100%	100%
Salmon Strips	70%	90%	100%
Chicken cubes	20%	60%	90%
Chicken Nuggets	90%	100%	100%
Sausage	70%	100%	100%
Total success rate	73.3%	96%	**99.3%**

Evaluation Interlocking with Magnetic Alignment in the QS

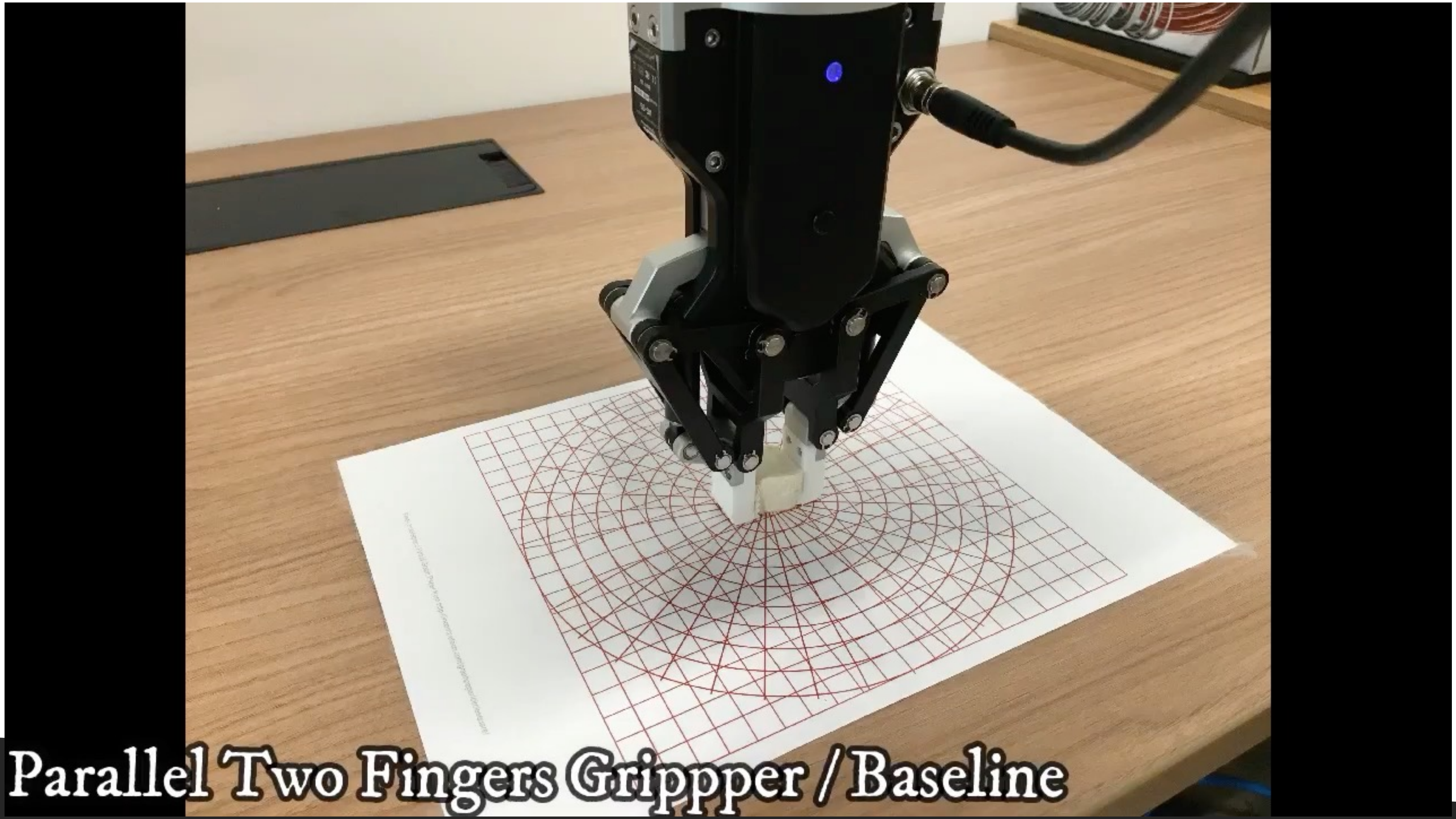


The QS-Gripper was able to achieve 58% successful interlocks without- and 80% with magnetic alignment.

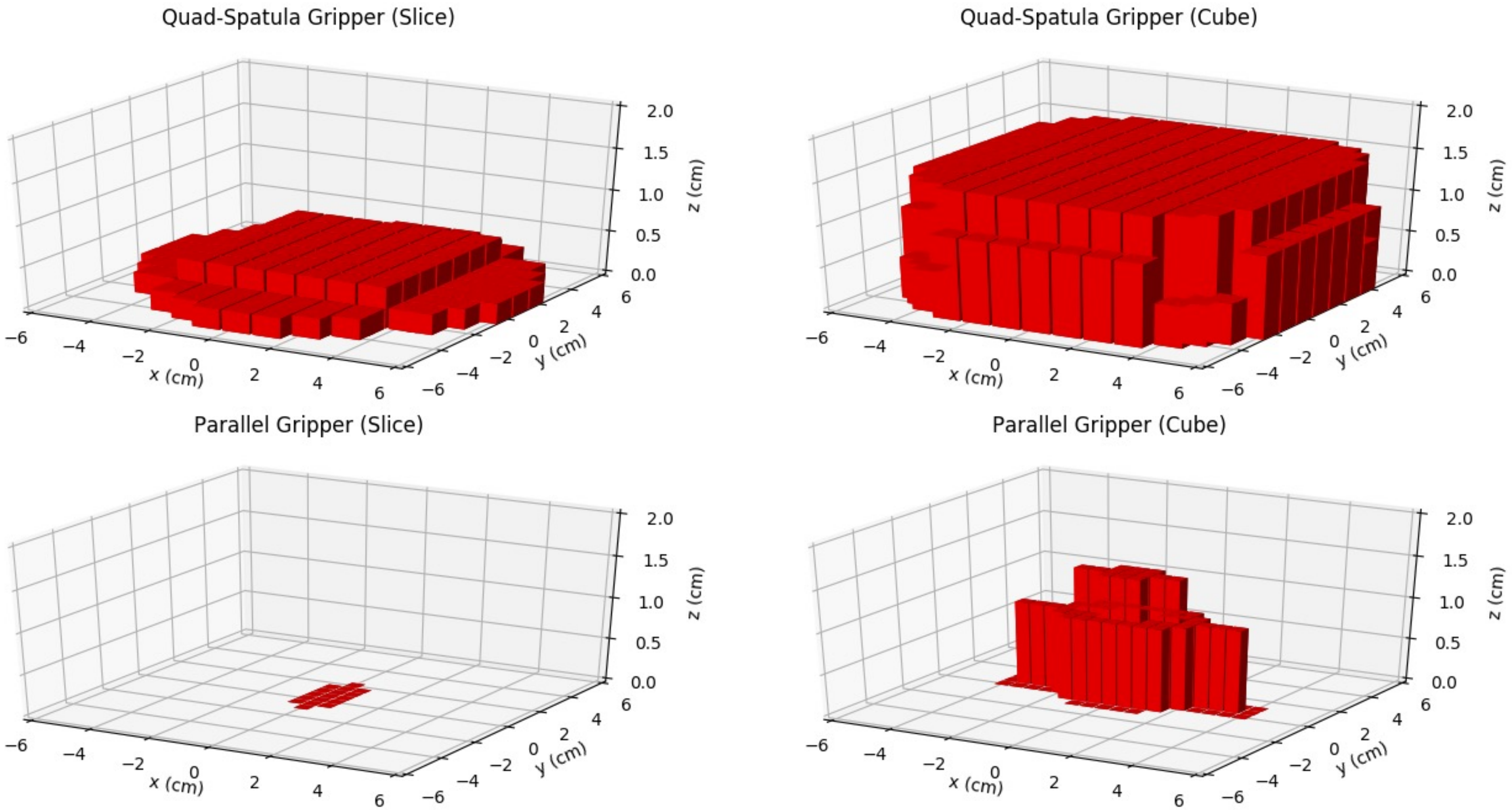
The QS-Gripper was able to hold approximately 335 grams without- and 735 grams with magnetic alignment.

50 mL increments

Evaluation of Uncertainty in Object Positioning



Evaluation of Uncertainty in Object Positioning



Grasping tolerance volume plots