HANDS.DVI

ECHORD

# A DeVice-Independent programming and control framework for robotic HANDS

dvi

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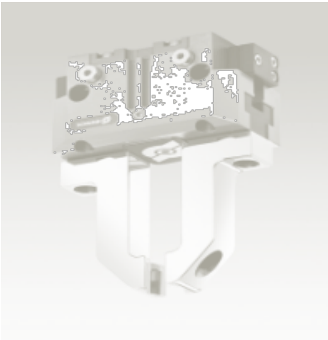
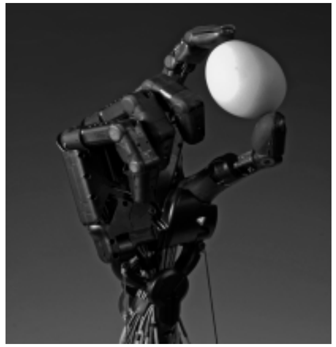
# The problem

N. of DoFs







N. of apps in industries

Why articulated hands are not so frequently used in industrial environments ?
- Too complex from a control point of view: reaching, grasping, manipulation
- They suffer from a lack of standard control approaches

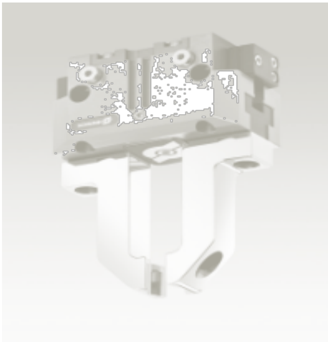
# The problem

N. of DoFs

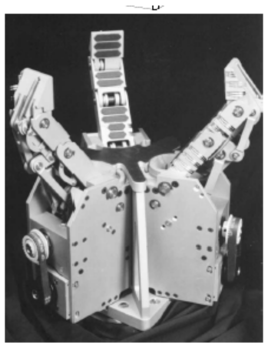
N. of apps in industries

Because of their intrinsic complexity, there is not a standard approach to the control of grasping and manipulation tasks. Borrowing the terminology of software engineering, there is a need for middleware solutions for manipulation and grasping tasks to seamlessly integrate robotic hands in flexible cells.

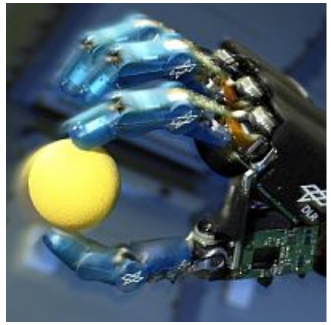
# We want to simplify but how ?



DoF = 1
DoA= 1
DoC =1



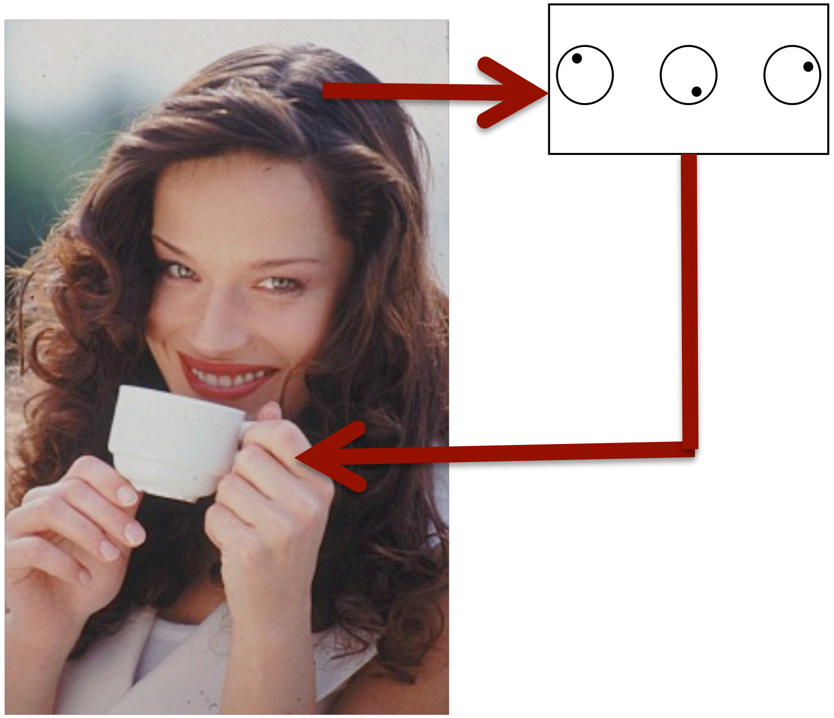
DoF = 12
DoA= 6
DoC =6
[Gosselin et al.]

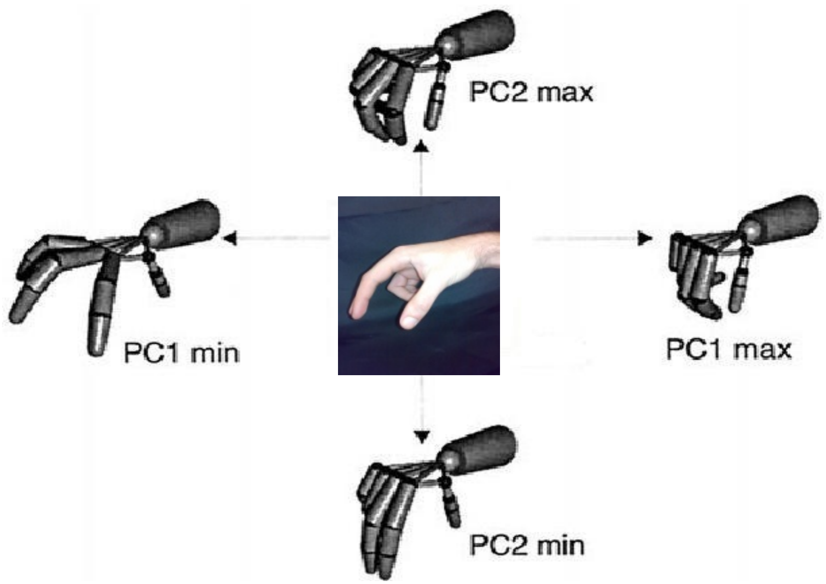


DoF = 12+1
DoA= 12+1
<u>DoC = **?**</u>
[DLR Hand II]

Degree of Freedom [DoF]
Degree of Actuation [DoA]
Degree of Control [DoC]

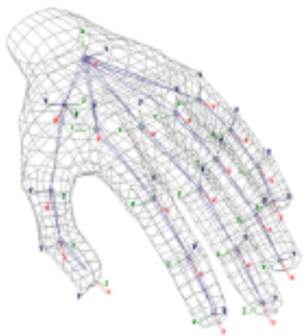
# DoC inspired by sensorimotor synergies



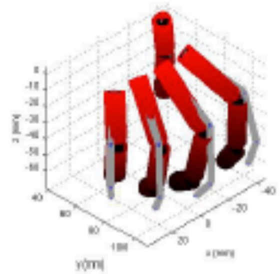



Recent results on the organization of the human hand in grasping and manipulation are the inspiration for this project proposal: these results have demonstrated that, notwithstanding the complexity of the human hand, *a few variables are able to account for most of the variance in the patterns of human hands configuration* and movement.

# Synergies as constraints on DoFs



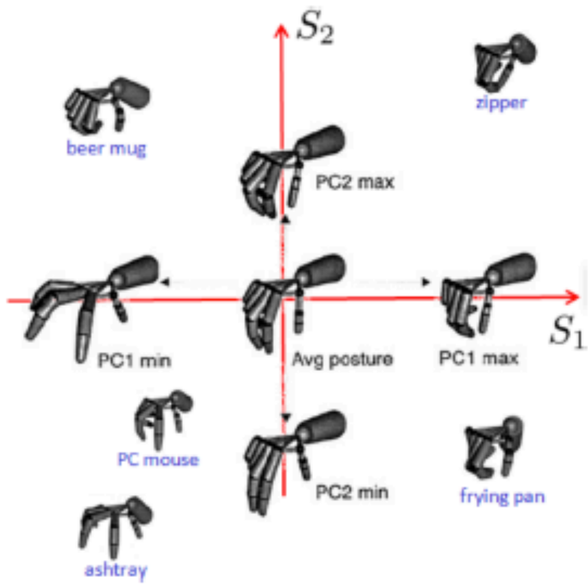
$q = [S_1] z_1$ with $z_1$ scalar



- These constraints do not limit performance rather allow the brain to deal with the huge redundancy of sensory and motor apparatuses
- Extensive neuroscientific evidence for the existence of sensorimotor synergies and constraints Babinski, Bernstein, Bizzi, Arbib, Jeannerod, Wolpert, Latash, Flanagan, Soechting, Sperry, ...
- Quantitative work on hand postural synergies dates back a decade only

# Postural synergies

Santello et al. [1998, 2002] investigated the hypothesis that "learning to select appropriate grasps is applied to a series of inner representations of the hand of increasing complexity, which varies with experience and degree of accuracy required."




- 5 subjects were asked to shape their hands in order to mime grasps for a large set (57) of familiar objects
- Joint values were recorded with a CyberGlove;
- Principal Components Analysis (PCA) of these data revealed that the first two Principal Components or postural synergies account for $\sim 84\%$ of the variance, first three $\sim 90\%$
- PCs (eigenvectors $S_i$ of the Covariance Matrix) can be used to define a basis for a subspace of the joint space

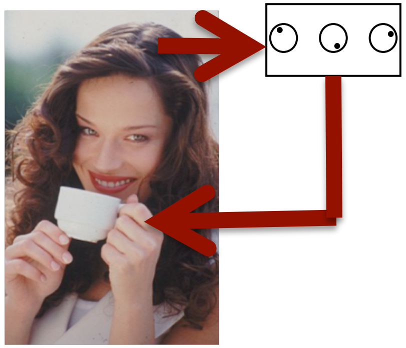
# Synergistic motions $q(t) = Sz(t)$

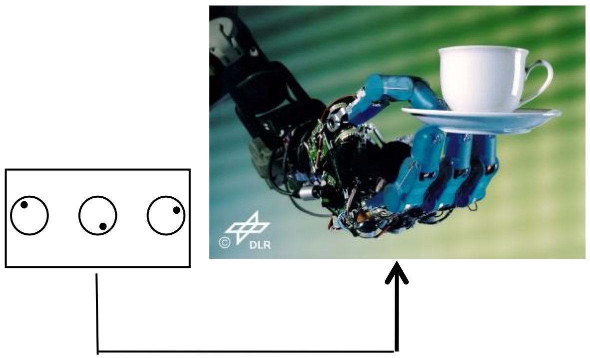
$$S = \left[ \begin{array}{cccccc} \vdots & \vdots & \vdots & \vdots & \dots & \vdots \end{array} \right] \in \mathbb{R}^{20\times 20}$$

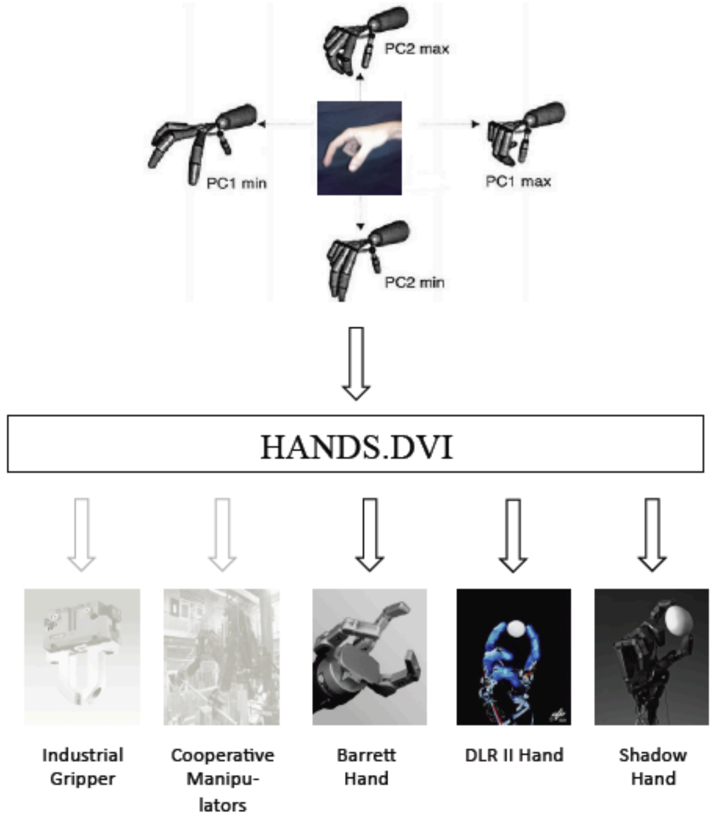
The first three components, i.e. columns $S_1, S_2$ and $S_3$ account for the 90% of the data.

$$q = S_1 z_1 \qquad q = S_2 z_2 \qquad q = S_3 z_3$$

# A few knobs for the abstraction layer for most of the artificial hands





# The main points

The paradigmatic hand

``A trade–off between the complexity of the human hand model accounting for the synergistic organization of the sensorimotor system and the simplicity of the models of robotic hands available on the market."

Synergies

``The paradigmatic hand will be developed to define a basis of synergies that will allow to design simplified strategies for the control of grasping forces. Here, the number and the structures of the force synergies will be defined."

Projecting synergies to the robotic hands with dissimilar kinematics

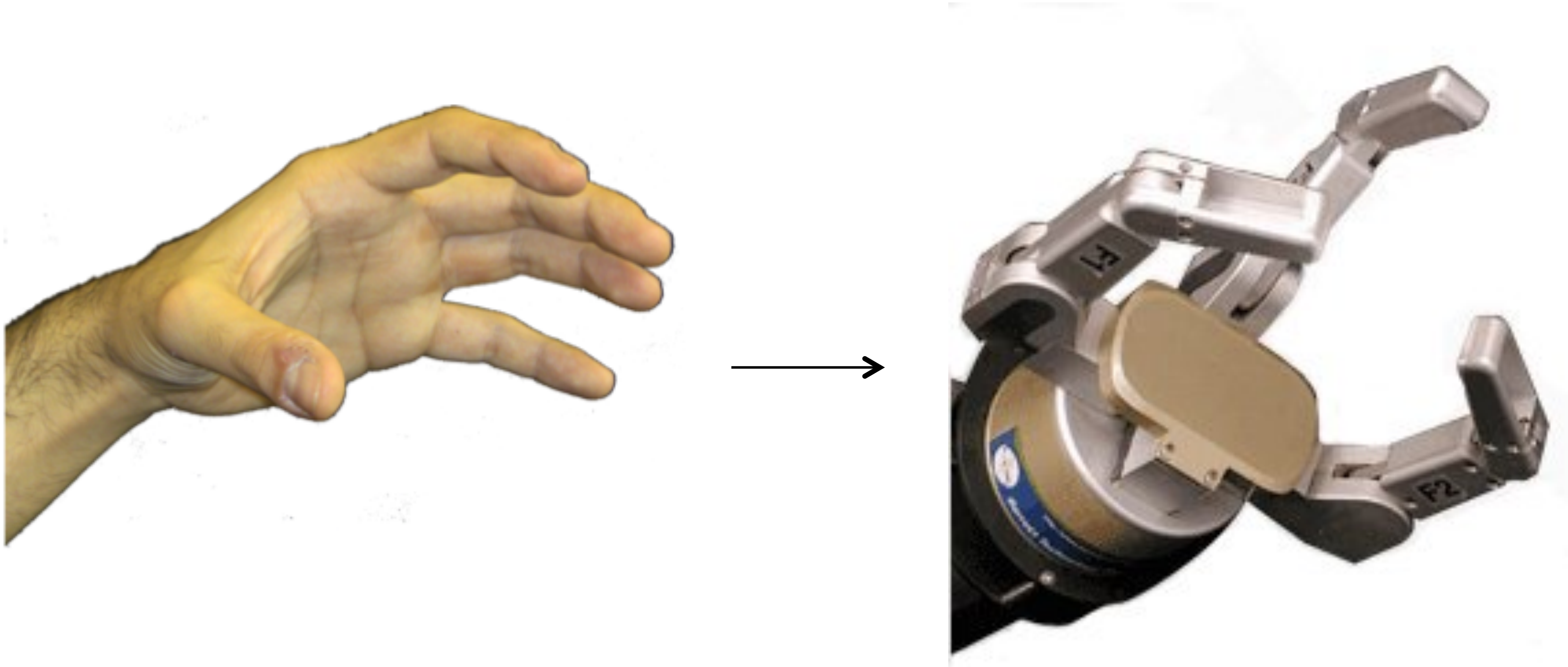
``Theoretical tools to design a suitable mapping function of the control action (decomposed in its elemental action, synergies) from the paradigmatic hand domain onto the articulated hand co-domain.

The definition of this mapping is the core of HANDS.DVI.

Experiments

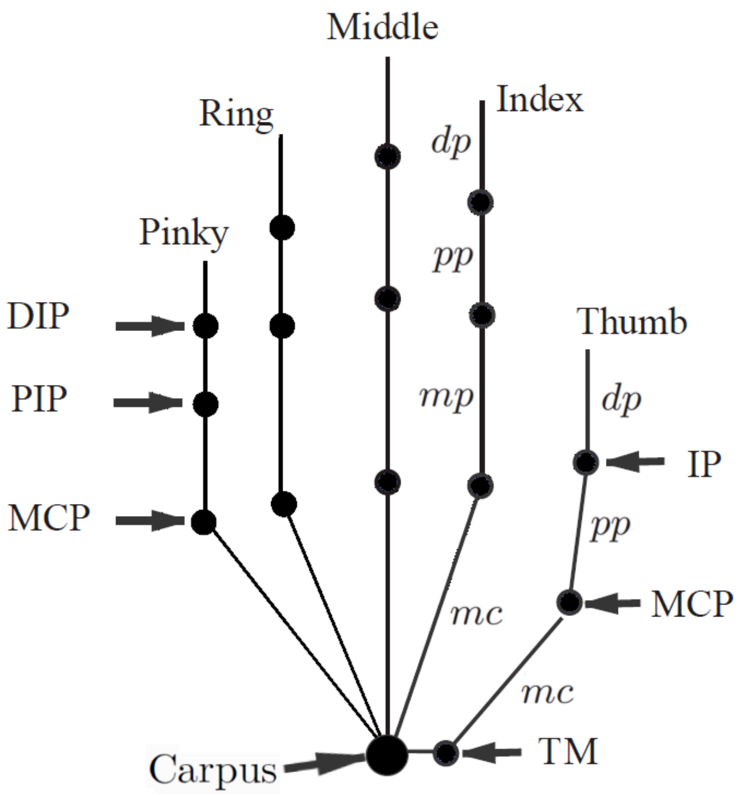
``The experiment consists of 3 robotic hands."

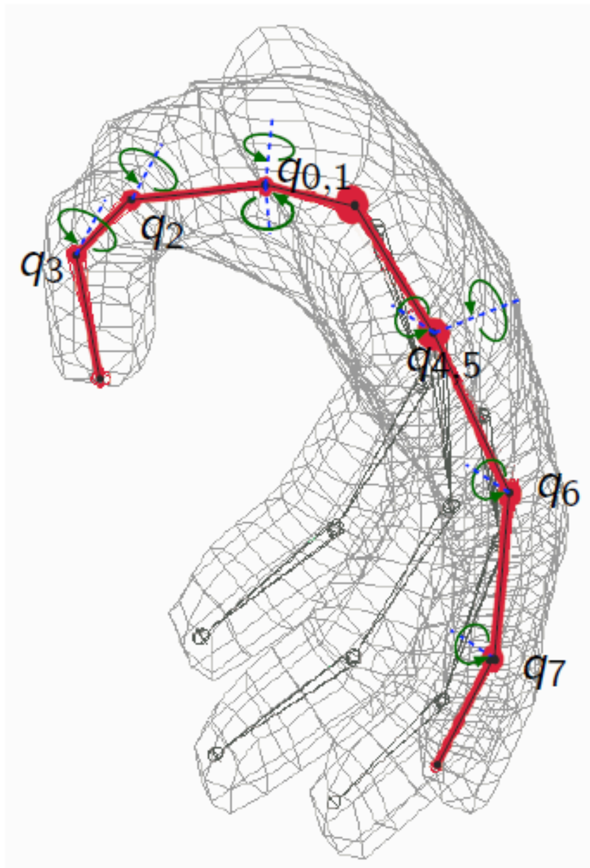
# Preliminary results UNISI



# The paradigmatic hand with synergies

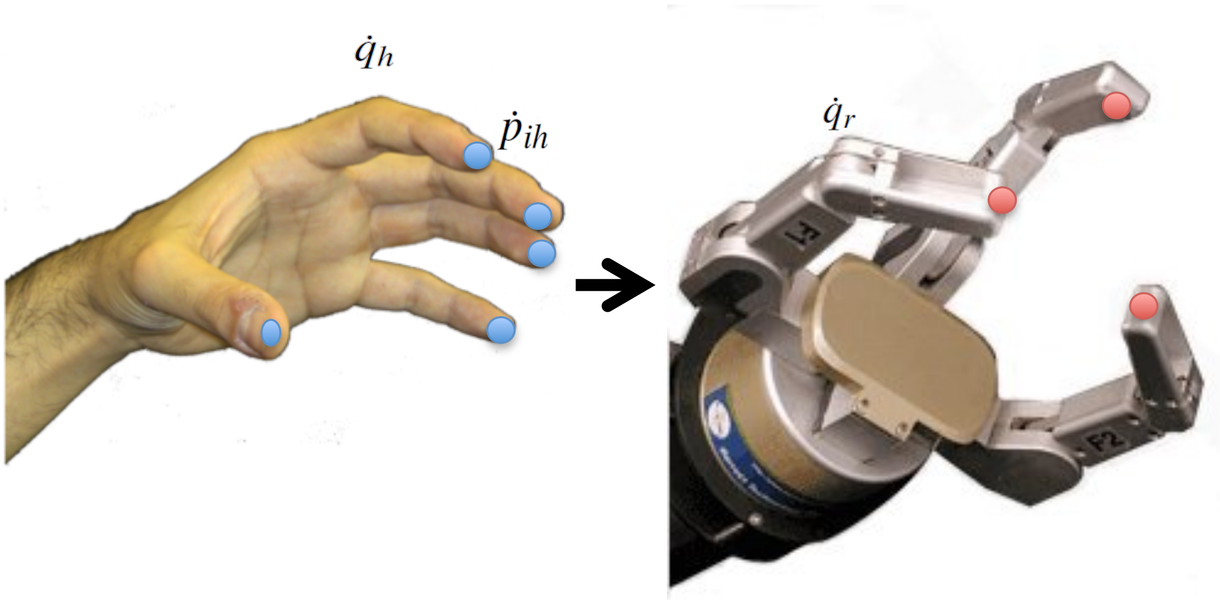
- Kinematic model of the hand @ UNISI (20 DoFs)



# Different mapping approaches

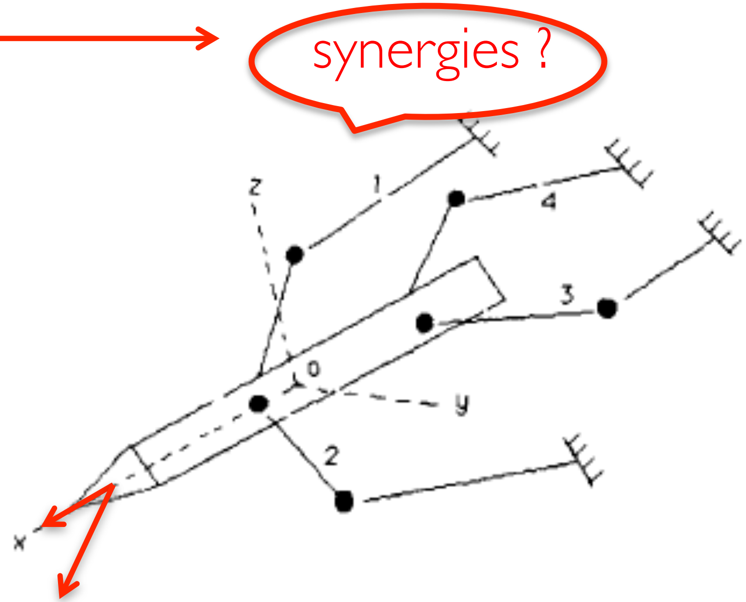
- **Joint-to-joint mapping**: joint values of human hands directly mapped into robotic joints. Empirical solutions for non-anthropomorphic hands. [M.T. Ciocarlie, P. K. Allen – 2009]
- **Fingertip mapping**: relation between different workspaces. [A. Peer, S. Einenkel, M. Buss – 2008]



# Object-space mapping for forces and motions

Middleware


Real hand

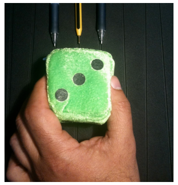
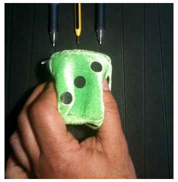


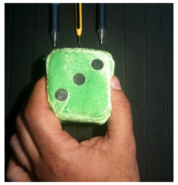
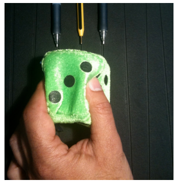

object-oriented.

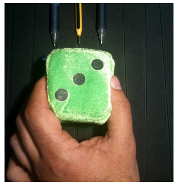
- compute the object motion associated to synergies in the paradigmatic space
- assign those ellipsoid to the same object but with the real hand
- solving an inversion problem compute the synergy mapping

A synergy mapping for a given object and a given set of contacts.

# Internal force and object motion control

$\ast$  $\Rightarrow$  Internal forces $(\mathcal{R}(E_s))$

 $\Rightarrow$  Non rigid-body motions

$\ast$  $\Rightarrow$  Rigid-body motions $(\mathcal{R}(\Gamma_{ucs}))$

What about controlling together (jointly and coordinately) both object motions and internal forces (and redundancies) via synergies?

Both internal forces and rigid-body object motions.

# Main result on force and motion control

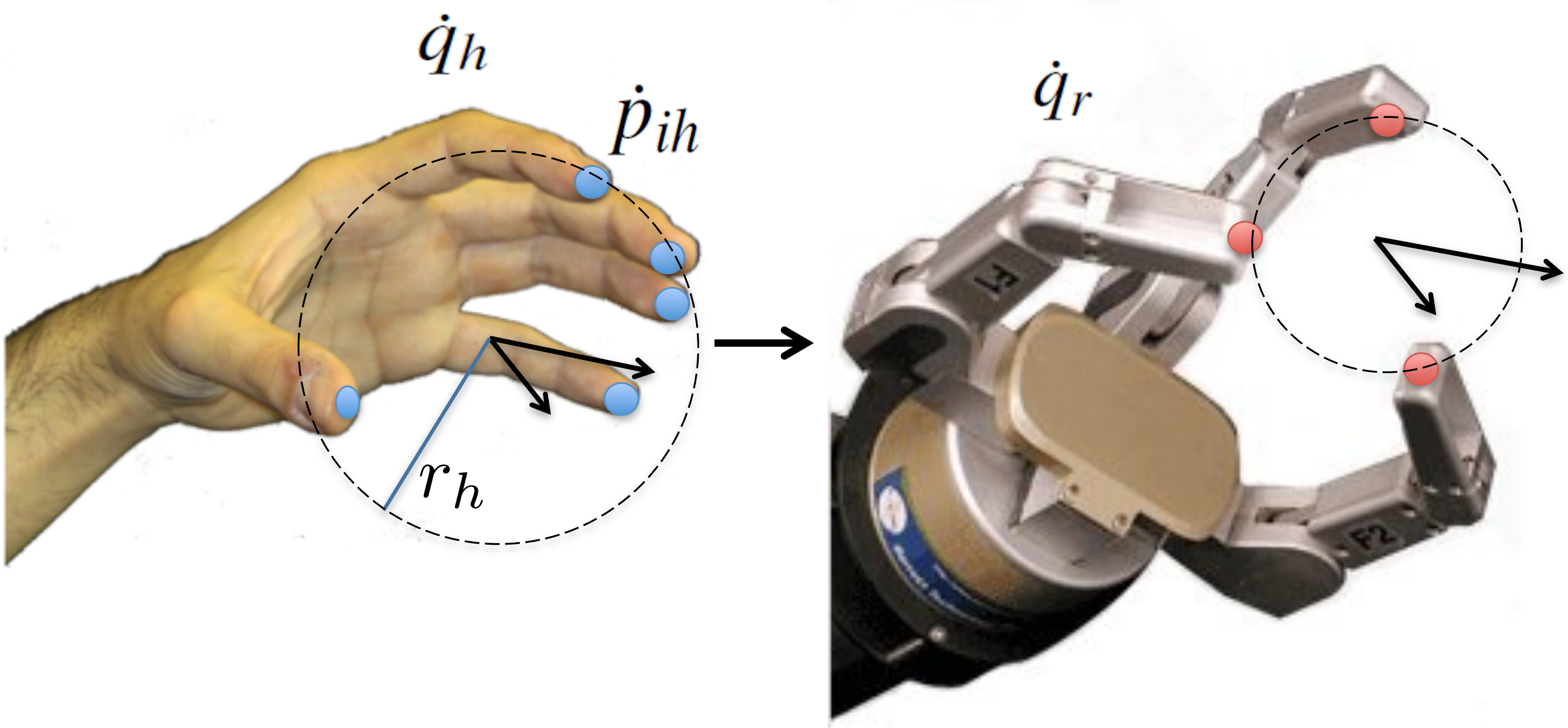
- It is always possible to control, jointly but independently, the controllable internal forces, the rigid–body object motions and redundancy with the control input as synergy displacement $\Delta z_r$.
- Algebraically, this corresponds to state that for any $\alpha$, $\beta$ and $\gamma$, there always exists a $\Delta z_r$ solving the linear system of equations

$$\begin{bmatrix} E_s\alpha \\ \Gamma_{ucs}\beta \\ \Gamma_{zr}\gamma \end{bmatrix} = \begin{bmatrix} (I - KG^T(GKG^T)^{-1}G)KJS \\ (GKG^T)^{-1}GKJS \\ I \end{bmatrix} \Delta z_r$$

- Moreover, solution for $\Delta z_r$ is unique and the number of synergies $n_z$ is equal to the sum of the dimensions of the controlled output subspaces:

$$n_z = \dim(E_s) + \dim(\Gamma_{ucs}) + \dim(\Gamma_{zr})$$

# Virtual sphere algorithm

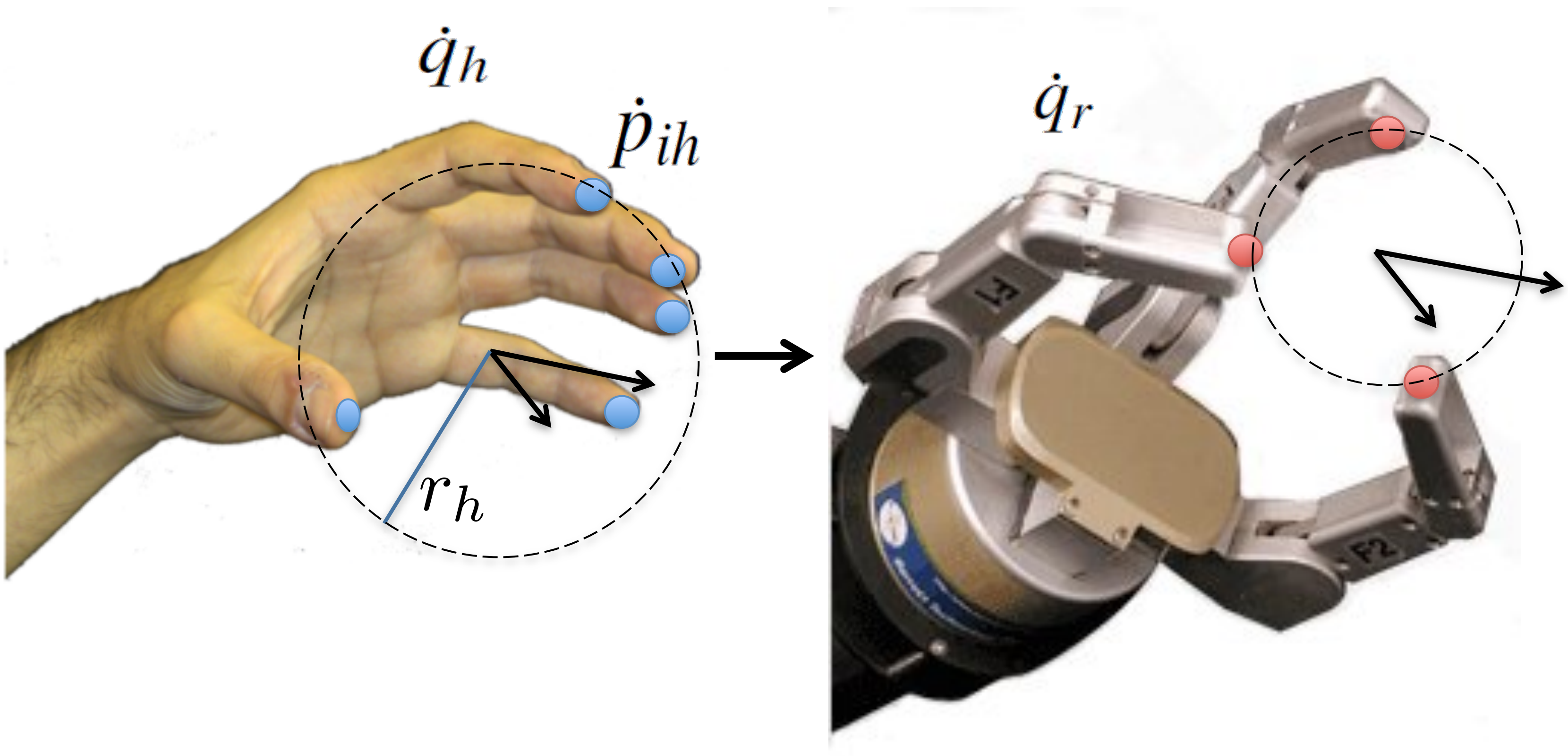



- A set of *reference points* are chosen on the human hand model (paradigmatic hand) in a given configuration
- The virtual sphere is the minimum volume sphere
- <u>Best map between sphere twist and radius changes</u>
- Inspired by [Cutckosky et al. 2000]

# Motion and 'squeezing force' equivalence

We impose:

$$\begin{bmatrix} \dot{o}_r \\ \omega_r \\ \dot{r}_r \end{bmatrix} = K_c \begin{bmatrix} \dot{o}_h \\ \omega_h \\ \dot{r}_h \end{bmatrix}$$



# Virtual sphere algorithm

- Robotic reference points velocities are then related to virtual sphere parameters by:

$$\dot{p}_r = A_r \begin{bmatrix} \dot{o}_r \\ \omega_r \\ \dot{r}_r \end{bmatrix} \longrightarrow \dot{p}_r = A_r K_c A_h^{\#} J_h S_h \dot{z}$$

- Considering the robotic hand differential kinematics we find:

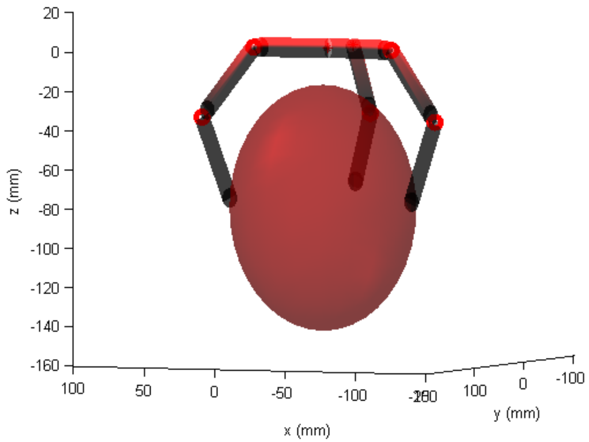
$$\dot{q}_r = J_r^{\#} A_r K_c A_h^{\#} J_h S_h \dot{z}$$

- And thus the mapping function between the two *synergy matrices*:

$$\boxed{S_r} = J_r^{\#} A_r K_c A_h^{\#} J_h \boxed{S_h}$$

# Performance evaluation

- The algorithm was validated with a spherical and a cubic object




- Joint-to-joint mapping and fingertip mapping were compared with the virtual sphere mapping

- Grasp quality and object motion directions were considered

# Performance Analysis - grasp quality

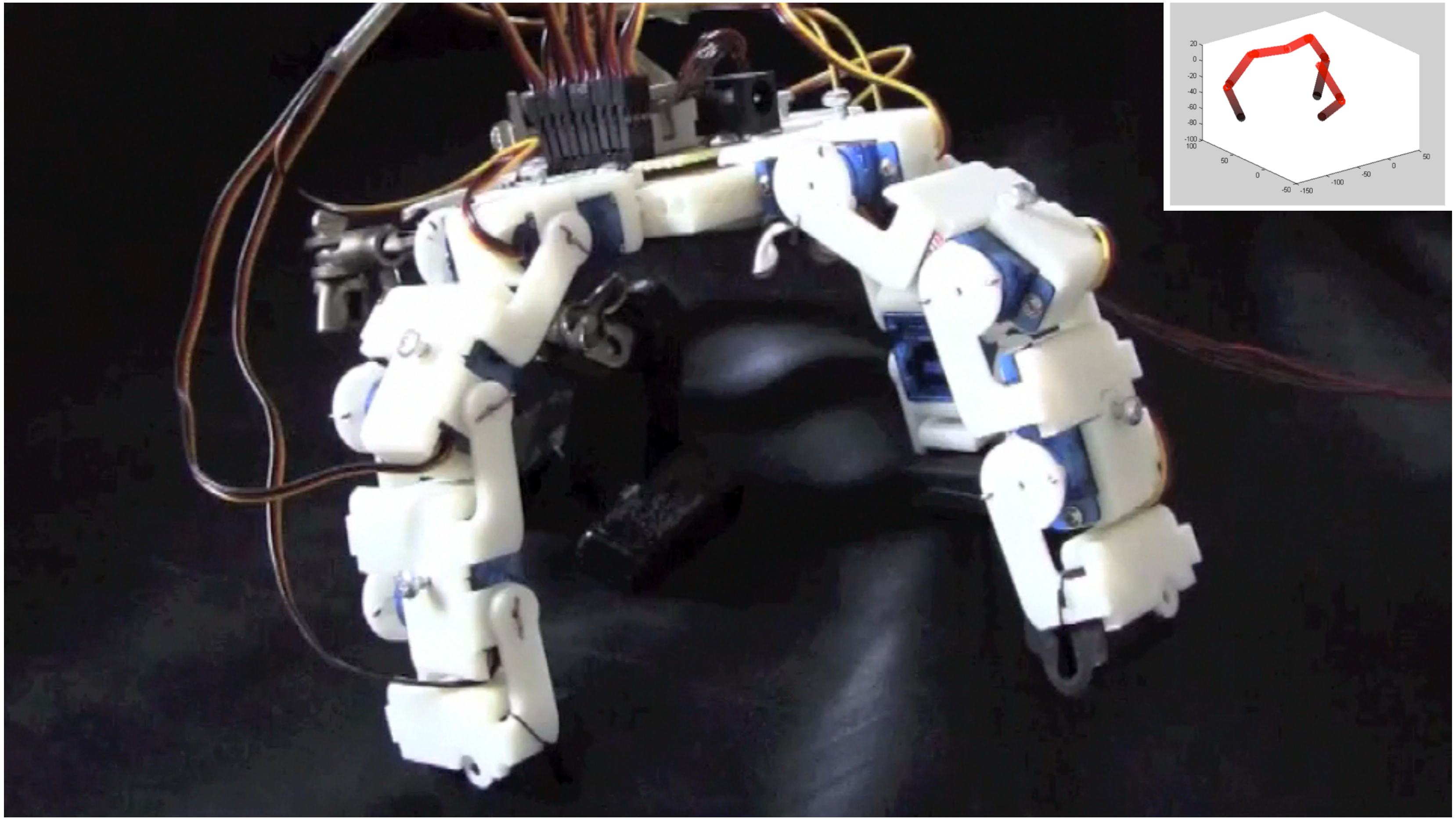
- Spherical object:

| Synergies | Human H | Virtual Sphere | Joint-to-joint | Fingertip |
|---|---|---|---|---|
| Syn 1 | 0.2 | 0.12 | 26.48 | 0.37 |
| Syn 2 | – | – | 0.09 | – |
| Syn 3 | – | 0.36 | – | – |
| Syn [1-2] | 0.14 | 0.08 | 0.09 | 0.11 |
| Syn [1-3] | 0.09 | 0.08 | 0.08 | 0.07 |

- Cubic object:

| Synergies | Human H | Virtual Sphere | Joint-to-joint | Fingertip |
|---|---|---|---|---|
| Syn 1 | 0.2 | 0.12 | 26.48 | – |
| Syn 2 | – | – | 0.10 | – |
| Syn 3 | – | 0.37 | – | – |
| Syn [1-2] | 0.20 | 0.08 | 0.09 | – |
| Syn [1-3] | 0.14 | 0.08 | 0.08 | 0.08 |

# The modular hand @UNISI



The UNISI team: M. Malvezzi, G. Salvietti, F. Chinello, G. Gioioso, D. Prattichizzo

# Promising results but …

Results are preliminary

The proposed mapping algorithm is a non-linear mapping. It depends on:

- Initial hand configurations
- Reference points
- Joint variables

Limits of the approach:

[G. Gioioso, G. Salvietti, M. Malvezzi and D. Prattichizzo, ICRA 2011]

Which and how many synergies ?

[M. Gabiccini, M. Malvezzi, D. Prattichizzo, A. Bicchi, Autonomous Robots, cond. accepted 2011]