THE HAND EMBODIED

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THE – The Hand Embodied

THE Hand Embodied refers to the "hand" as both a cognitive entity, standing for the sense of active touch, and as the physical embodiment of such sense, the organ, comprised of actuators and sensors that ultimately realize the link between perception and action.

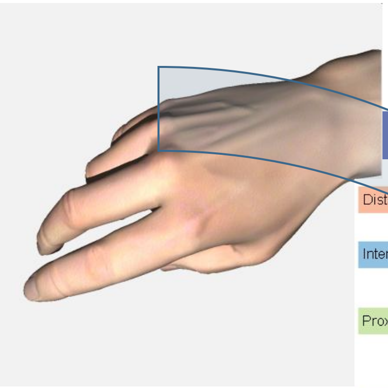
The general idea is to study how the embodied characteristics of the human hand and its sensors, the sensorimotor transformations, and the very constraints they impose, affect and determine the learning and control strategies we use for such fundamental cognitive functions as exploring, grasping and manipulating.

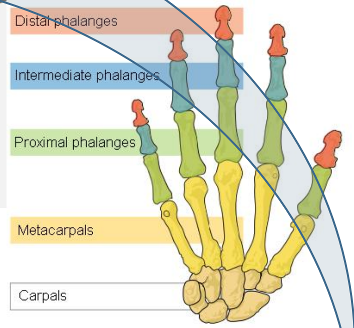
The project is supported by the European Commission under the 7th Framework Programme

THE Objectives

- the study of the organization of haptic action in motor synergies for the human hand;
- the study of the organization of haptic perception in multi-cue and multi-modal synergies for integration of percepts in the human cognitive system for active touch;
- the extraction of the conceptual organization and the geometric structures of links between the hand embodiment and the learning and adaptation capabilities of manipulation and haptic perception in humans;
- the improved design and control of robot hands;
- the application of the new understanding of sensorimotor synergies to the design of radically new and improved control architectures for haptic interfaces, both at the micro (cutaneous) and macro (whole-hand) level, and
- the advancement of the state-of-the-art in neuro-prosthetic devices by providing seamless sensorimotor bidirectional information flow and adaptability to environmental constraints.

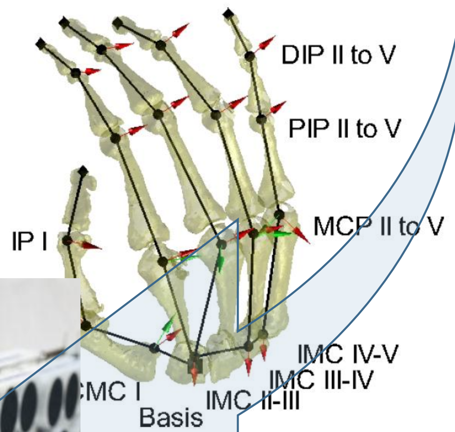
Modeling the manipulating hand

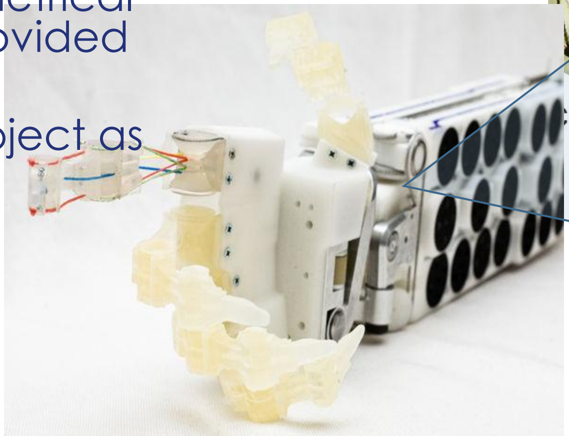




Innovation

- **Accurate kinematic and dynamic model of the human hand**:
  - model parameters evaluated by means of advanced imaging techniques, as computed tomography and magnetic resonance
  - development of a *toolbox* of functions with a modular structure making its use easy and effective for users involved in other WPs, and extended to the analysis of kineto-statics and dynamics.
- **Synergies:**
  - characterization of synergies,
  - mathematical description of new geometrical insight in grasping and manipulation provided by synergies,
  - study the motion of the manipulated object as a function of the elemental controlled variables.



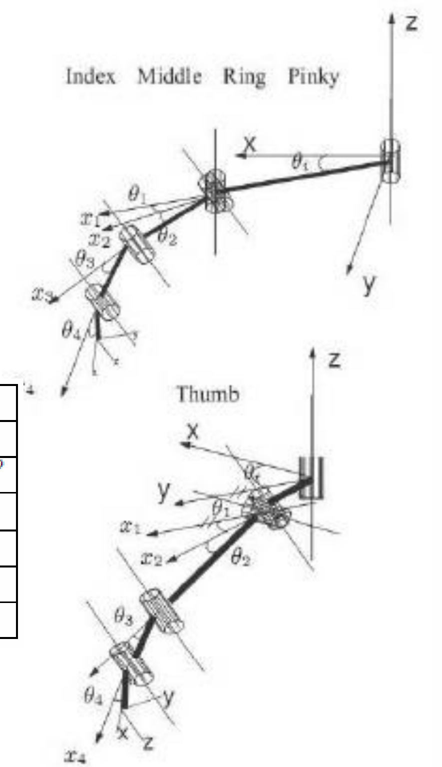


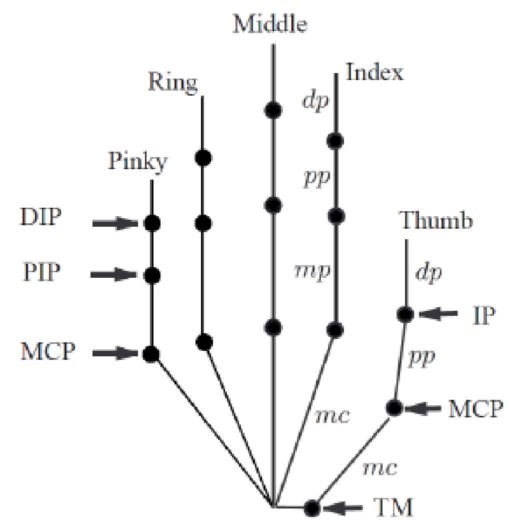
UNISI model of hand kinematics

Kinematic and dynamic model of the human hand

[G. Baud-Bovy and D. Prattichizzo and N. Brogi, 2005]

Each finger is identified by means of Denavit-Hartenberg (DH) parameters relative to each link





Thumb			
a_i	α_i	d_i	q_i
a_o	0	d_1	-51^o
0	90^o	0	q_0
mc_T	90^o	0	q_1
pp_T	0	0	q_2
dp_T	0	0	q_3

Index			
a_i	α_i	d_i	q_i
mc_I	0	0	-22^o
0	-90^o	0	q_4
pp_I	0	0	q_5
mp_I	0	0	q_6
dp_I	0	0	q_7

Grasp modeling with synergies

The objective of a synergy based hand is to achieve a trade-off between simplicity, gained through synergy based control, and its versatility.

First of all, we have to analyse how a synergy based control influence grasping properties.

For instance the number and types of synergies should be related to the possibility of controlling contact forces and object motion in grasping and manipulation tasks.

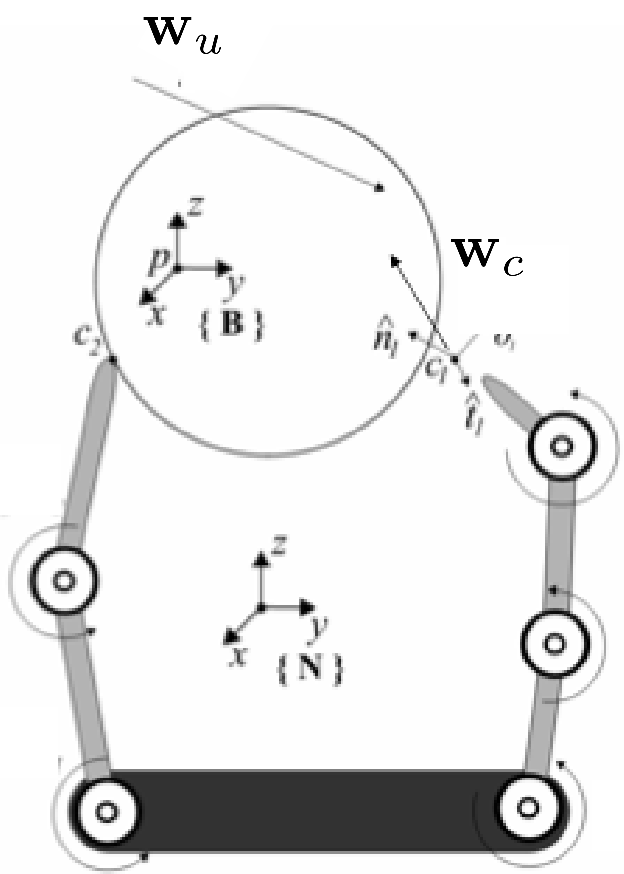
Grasp modeling with synergies

Some of the main questions to answer when interpreting the motion and force control in the light of synergies are:

- how many synergies have to be involved for a given grasp?
- which are the contact forces which result to be controllable when acting on synergies instead of each single actuator, independently?
- is a synergy based actuation of the robotic hand sufficient to guarantee a stable and efficient grasp?
- what kind of force feedback information is needed to implement the feedback controller based on synergy?

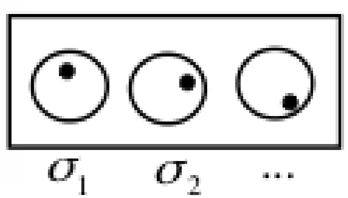
Model, Notation and Synergies

[Prattichizzo, Malvezzi, Bicchi, 2010 (submitted)]



$q = S\sigma$

Notation	Definition
n_q	number of joints of the hand
$\tau_q \in \mathbb{R}^n_q$	non-contact joint loads
n_s	number of postural synergies
$\boldsymbol{\tau}_s \in \mathbb{R}^{n_s}$	synergy generalized forces
n_l	number of contact force and velocities
$\mathbf{w}_c \in \mathbb{R}^{n_l}$	contact forces (and moments)
$\mathbf{w}_u \in \mathbb{R}^6$	non-contact object wrench
$\mathbf{J} \in \mathbb{R}^{n_l \times n_q}$	hand jacobian matrix
$\mathbf{S} \in \mathbb{R}^{n_q \times n_s}$	synergy matrix
$\mathbf{G} \in \mathbb{R}^{6 \times n_l}$	grasp matrix



postural synergies can be represented as a joint displacement aggregation corresponding to a reduced dimension representation of hand movements.

Synergies

Postural Hand Synergies for Tool Use

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Table 1. List of objects used in the task

1. Apple	30. Hammer
2. Banana	31. Ice cube
3. Baseball	32. Iron
4. Beer bottle	33. Jar lid
5. Beer mug	34. Kitchen knife
6. Brick	35. Knob of a lid
7. Bucket	36. Knob of a stove
8. Calculator	37. Light bulb
9. Chalk	38. Milk carton
10. Cherry	39. Needle
11. Chinese tea cup	40. Notebook
12. Cigarette	41. Pen
13. Circular ashtray	42. Playing card
14. Coffee mug	43. Rope
15. Comb	44. Scissors
16. Compact disc	45. Screwdriver
17. Computer mouse	46. Stapler
18. Dictionary	47. Sugar cone
19. Dinner plate	48. Teaspoon
20. Dog dish	49. Telephone handset
21. Door key	50. Tennis racket
22. Door knob	51. Toothbrush
23. Drawer handle	52. Toothpick
24. Egg	53. Turtle
25. Espresso cup	54. Umbrella
26. Fishing rod	55. Wafer
27. Frisbee	56. Wrench
28. Frying pan	57. Zipper
29. Hair dryer	

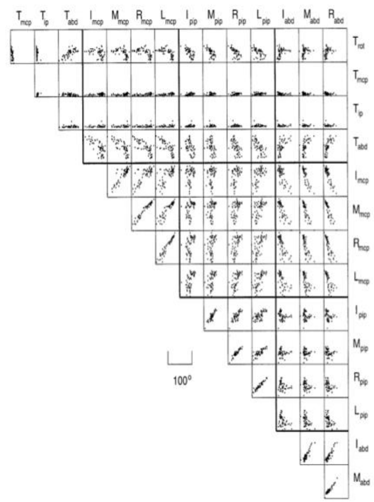

Table 2. Percent variance accounted for by each principal component

Subjects	PC_1	PC_2	PC_3	PC_4
FC	52.9	24.7	8.4	4.8
GB	49.5	37.6	4.8	4.6
MF	74.8	13.0	5.4	2.9
MS	79.3	10.0	5.0	2.2
UH	62.9	17.2	8.6	5.9