AI- and Robotics-enabled systems, a forward leap into real life applications

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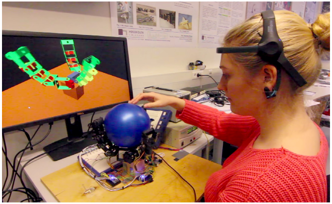
September 7, 2023

Summary

Human-robot collaboration (HRC): challenges



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Challenges:

- robots for pHRI are advancing from being simple stand-alone manipulators passing tools or parts to human collaborators to becoming **autonomous co-workers**;
- it is challenging to **extend robot capabilities in sensing human motions and behaviour**;
- there is a gap between the desire for humans and robots to work closely together and share control of operations, and **how robustly we can measure and predict human motions and intentions** in pHRI operations.

⇒ trade-off between control and mechanical/software design

[8] Filippo Sanfilippo, Houxiang Zhang, and Kristin Ytterstad Pettersen. "The New Architecture of ModGrasp for Mind-Controlled Low-Cost Sensorised Modular Hands". In: *Proc. of the IEEE International Conference on Industrial Technology (ICIT2015), Seville, Spain.* 2015, pp. 524–529.

Bio-inspired robotic hands and modular grasping

Mimicking the human hand's ability, one of the most challenging problem in bio-inspired robotics:

- large gap in terms of performances.

Classical approach, analysis of the kinematic behavior of the human hand:

- simplified human hand models with minimum and optimal degrees of freedom[9].

Modular grasping, a promising solution:

- minimum number of degrees of freedom necessary to accomplish the desired task.

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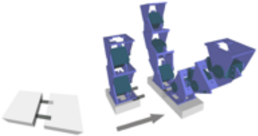
[9] S. Cobos, M. Ferre, and R. Aracil. "Simplified human hand models based on grasping analysis". In: *Proc. of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. 2010, pp. 610–615.

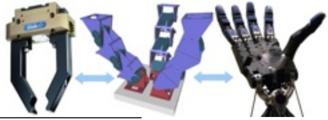
Modular grasping



- A trade off between a simple gripper and more complex human like manipulators.
- *Principle of minimalism*: choose the simplest mechanical structure, the minimum number of actuators, the simplest set of sensors, etc.

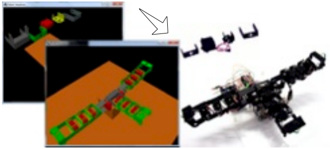
Modular grasping:

- identical modules are used to build linkages to realise the grasping functions. The modular grasping meets the requirements of standardisation, modularisation, extendibility and low cost[10].



[10] Filippo Sanfilippo et al. "Efficient modular grasping: an iterative approach". In: *Proc. of the 4th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob), Rome, Italy.* 2012, pp. 1281–1286.

ModGrasp: a rapid-prototyping framework for designing modular hands



ModGrasp:

- Modular Mechanics;
- Modular Hardware;
- Modular Software.

ModGrasp, a rapid-prototyping framework for low-cost sensorised modular hands:

- real-time one-to-one correspondence between virtual and physical prototypes;
- on-board, low-cost torque sensors, 3-D visualisation environment;

ModGrasp, not only an engineering tool but mostly a scientific tool:

- a framework that can be used to discover new ways of controlling modular hands.

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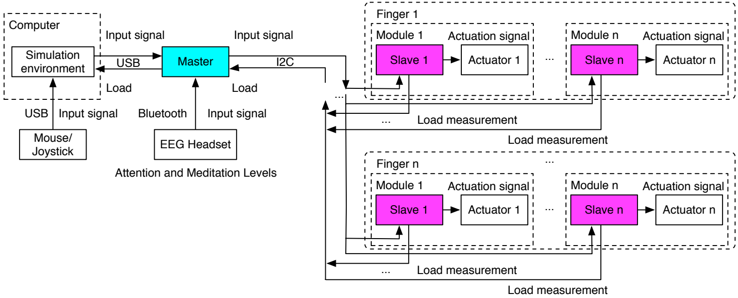
[11] Filippo Sanfilippo et al. "Modgrasp: an open-source rapid-prototyping framework for designing low-cost sensorised modular hands". In: *Proc. of the 5th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob)*. IEEE. 2014, pp. 951–957.

ModGrasp architecture



- Master-slave communication. Each module is controlled by a slave controller board, which communicates with a master controller board. The controlled manipulators are simulated in a 3-D visualisation environment that communicates with the master controller.
- Extremely robust to hardware failures. If one or more modules break or are disassembled from a prototype, the manipulator keeps working with the remaining functioning joints.

Controller boards

Controller boards, open hardware with Arduino:

- an *Arduino Uno* board based on the *ATmega328* micro-controller is used as the master, while one *Arduino Nano* board is used as a slave to control each finger joint;
- easy maintenance, reliability and extensibility.

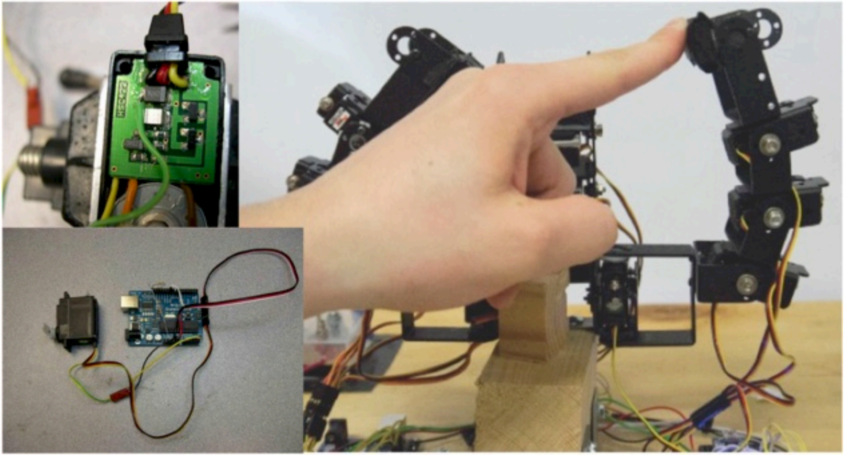
Support for different input devices:

- directly controlled from the simulator environment by means of a computer mouse/joystick or work stand-alone and be controlled by means of a set of potentiometer shafts that are used as input controllers.

Communication protocol:

- the standard I^2C is used as a communication protocol. The physical manipulator models communicate with the simulation environment through the serial interface.

Low-cost torque sensing and joint compliance



Control approach

[12]

[12] M. Santello, M. Flanders, and J. F. Soechting. "Postural hand synergies for tool use". In: *The Journal of Neuroscience* 18.23 (1998), pp. 10105–10115.

A three-fingered modular manipulator

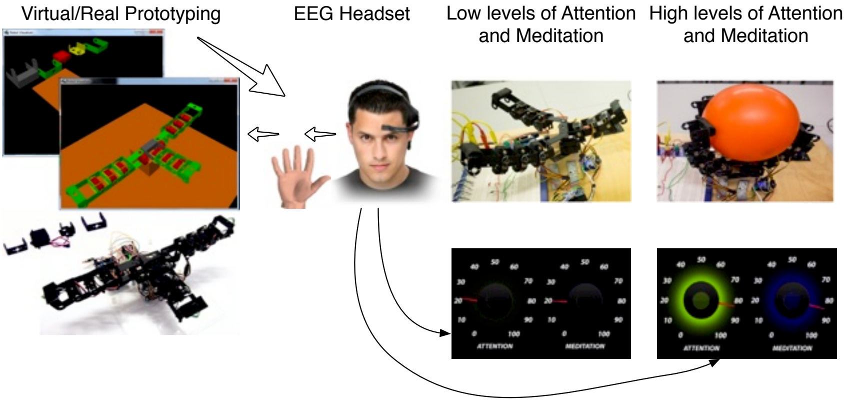
Let $q_h \in \Re^{n_{q_h}}$, with n_{q_h} representing the number of actuated joints. The subspace of all configurations can be represented by an input vector $z \in \Re^{n_z}$ (with n_z denoting the number of inputs and $n_z \leq n_{q_h}$) which parameterises the motion of the joint variables along the *synergies*:

$$\dot{q}_h = S_h \dot{z}, \tag{6}$$

being $S_h \in \Re^{n_{q_h} \times n_z}$ the synergy matrix.

$$S_h = \begin{bmatrix} -0.7 & 0 \\ -0.2 & 0 \\ -0.1 & 0 \\ 0 & -1.6 \\ -0.7 & 0 \\ -0.2 & 0 \\ -0.1 & 0 \\ 0 & 1.6 \\ -0.7 & 0 \\ -0.2 & 0 \\ -0.1 & 0 \end{bmatrix} \begin{array}{l} \left.\begin{array}{c} \\ \\ \\ \end{array}\right\} \textit{Thumb} \\ \left.\begin{array}{c} \\ \\ \\ \\ \\ \end{array}\right\} \textit{Finger1}. \\ \left.\begin{array}{c} \\ \\ \\ \\ \end{array}\right\} \textit{Finger2} \end{array} \tag{7}$$

Control objective idea



Experimental results

Closing the loop with haptic feedback

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Mixed reality (MR)

[13]

[13] Filippo Sanfilippo et al. "Mixed reality (MR) Enabled Proprio and Teleoperation of a Humanoid Robot for Paraplegic Patients". In: *Proc. of the 5th International Conference on Information and Computer Technologies (ICICT), New York City (virtual), United States*. 2022.

Thank you for your attention

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