ModGrasp: an Open-Source Rapid-Prototyping Framework for Designing Low-Cost Sensorised Modular Hands

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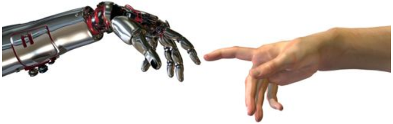
IEEE RAS & EMBS BioRob 2014

Summary

Bio-inspired robotic hands



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:

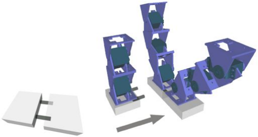
- simplified human hand models with minimum and optimal degrees of freedom[1], efficient manipulation tasks. Difficult to adapt to different grasping operations or to the grasping of objects with dissimilar size.

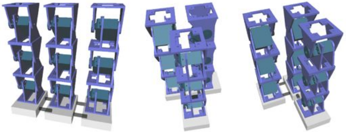
Modular grasping, a promising solution:

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

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

Modular grasping

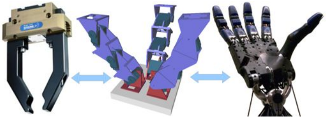




- A trade off between a simple gripper and more complex human like manipulators.
- *Principle of minimalism*: choose the simplest mechanical structure, the minimum number of actuators, the simplest set of sensors, etc.

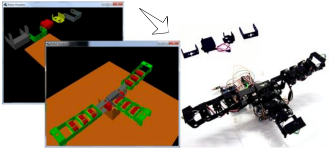
Modular grasping:

- identical modules are used to build linkages in order to realize the grasping functions. From a mechanical point of view, even if it is not the most efficient grasping approach, the modular grasping still meets the requirements of standardization, modularisation, extendibility and low cost[2].



[2] F. Sanfilippo et al. "Efficient modular grasping: An iterative approach". In: *4th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob)*. IEEE. 2012, pp. 1281–1286.

ModGrasp: a rapid-prototyping framework for designing modular hands



ModGrasp is highly modular:

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

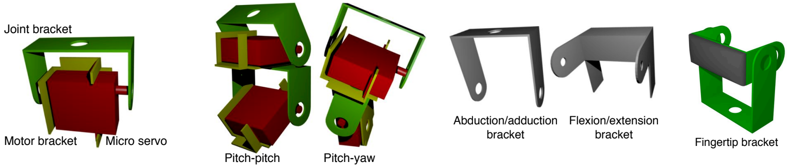
ModGrasp, a virtual and physical prototyping framework that allows for rapid-prototyping low-cost sensorised modular hands:

- a real-time one-to-one correspondence between virtual and physical prototypes;
- on-board, low-cost torque sensors provided within each module allow for evaluating the stability of the obtained grasps;
- intuitive visual feedback by means of a 3-D visualisation environment;
- both the virtual models and their physical counterparts can be controlled by using the same input device.

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

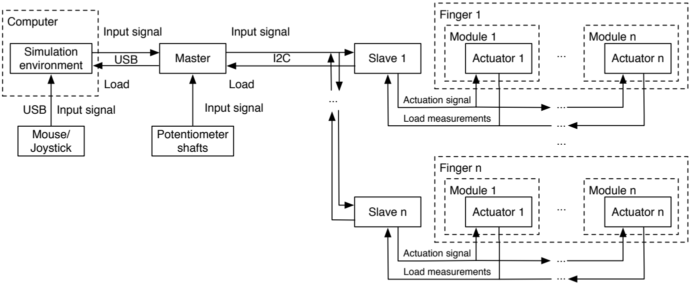
- a framework that can be used to discover new ways of controlling modular hands.

A generalised manipulator model



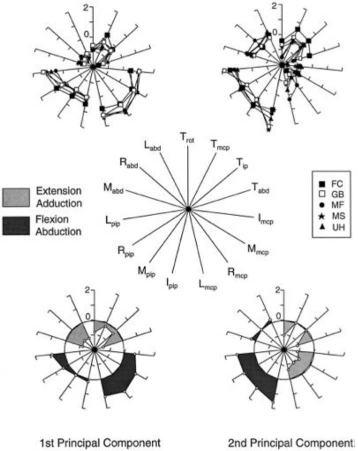
- One or more chains of identical modules fixed on a modular base. Referring to a human-like hand, each chain can be considered as a finger, each module as a phalanx and the base as a palm.
- The fundamental building module: a standard micro servo motor and two metal brackets.
- Each finger is attached to a common modular base by means of two special brackets, which make abduction/adduction and flexion/extension movements possible.
- A component, which is made by combining two joint brackets, is used for the fingertips.
- It meets the requirements of standardisation, modularisation, extendibility and low-cost.

ModGrasp architecture



- A master-slave communication pattern is used. Each finger 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.
- The resulting prototypes are extremely robust to hardware failures. For instance, if one or more modules or even one or more entire fingers break or are disassembled from a prototype, the manipulator keeps working with the remaining functioning joints.

Control approach



[4]

- When the complexity of the modular model increases or when different modular configurations must be controlled independently of their specific morphology, a highly flexible and general control algorithm is needed.
- A deeper understanding of how the brain exploits the high redundancy of human hands could be an important key in the development of such a control algorithm. Some studies demonstrate that, despite the complexity of the human hand, a few variables are able to account for most of the variance in the patterns of all the possible configurations and movements.
- The first two principal components account for most of the variability in the data, more than 80% of the variance in the hand postures.

[4] 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.

Human synergies

- The principal components were referred to as *synergies*.
- This reduction of DOFs can be used to decrease the complexity of the control algorithm for robotic hands with an anthropomorphic structure that closely copies the structure of the human hand. Nonetheless, several approaches for mapping the human hand *synergies* to differently structured robotic hands have been presented[5],[6], showing that this idea is feasible.

Let $\mathbf{q}_h \in \Re^{n_{q_h}}$, with n_{q_h} representing the number of actuated joints. We assume that the subspace of all configurations can be represented by an input vector of a lower dimension $\mathbf{z} \in \Re^{n_z}$ (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*. In terms of velocities, one gets:

$$\dot{\mathbf{q}}_h = \mathbf{S}_h \dot{\mathbf{z}}, \tag{1}$$

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

[5] G. Gioioso et al. "Mapping Synergies from Human to Robotic Hands with Dissimilar Kinematics: an Approach in the Object Domain". In: *IEEE Transactions on Robotics* 29.4 (2013), pp. 825–837.

[6] M. T. Ciocarlie and P. K. Allen. "Hand posture subspaces for dexterous robotic grasping". In: *The International Journal of Robotics Research* 28.7 (2009), pp. 851–867.

Controller boards and communication protocol

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;
- easy maintenance, reliability and extensibility.

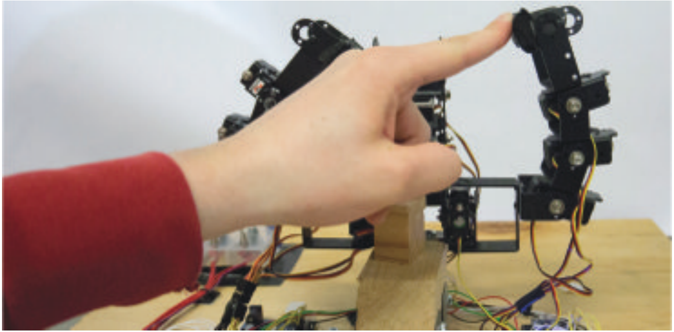
Support for different input devices:

- 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:

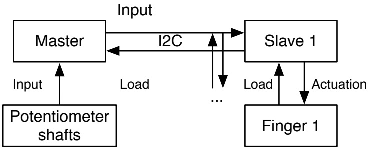
- the standard I^2C is used as a communication protocol between the master and the slaves. The physical manipulator models communicate with the simulation environment through the serial interface of the master controller board.

Low-cost torque sensing and joint compliance



- In order to monitor the load of each joint actuator, the current is continuously measured from each slave controller.
- The current sensing at the joints level allows for a more accurate grasping of objects with different stiffness without squeesing or damaging them.
- By measuring the input current to each servo motor, the servo torque can be calculated and adjusted according to the task to be performed.

Logic of the master and slave programs



Algorithm 1 Master program.

```
connect to communication network as the master
while true do
    read inputs
    send input values to slaves
    receive current loads from slaves
end while
```

Algorithm 2 Slave program.

```
define current threshold, step-back value
connect to communication network as a slave
while true do
    send current values to the master
    if input values are received from the master then
        for each joint do
            calculate actuation value
            actuate joint
            if current load ≥ current threshold then
                calculate step-back value
                actuate joint
            end if
        end for
    end if
end while
```

Case study: a three-fingered modular manipulator

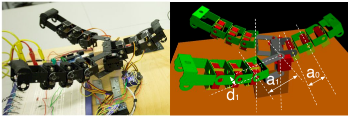


Table: D-H table of the thumb, where $a_0 = 3.2cm$

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	a_0	0	θ_1
2	0	a_0	0	θ_2
3	0	a_0	0	θ_3

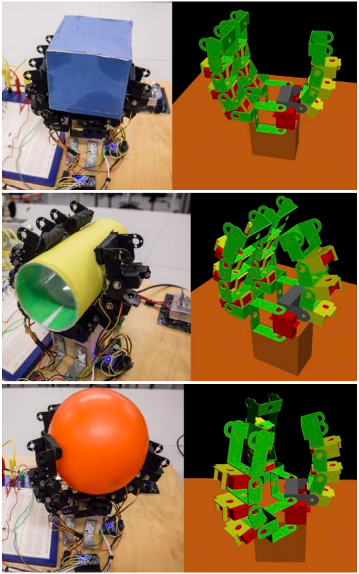
Table: D-H table of the other two fingers, where $d_1 = 1.5cm$ and $a_1 = 5.9cm$

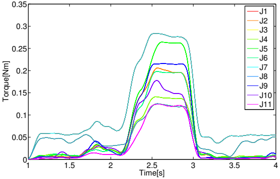
i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	d_1	θ_1
2	$\frac{\pi}{2}$	a_1	0	θ_2
3	0	a_0	0	θ_3
4	0	a_0	0	θ_4

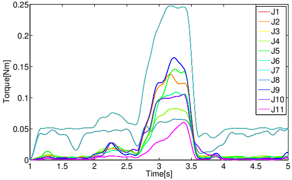
$$\mathbf{S}_h = \begin{bmatrix} -0.7 & 0 \\ -0.2 & 0 \\ -0.1 & 0 \\ 0 & -1.6 \\ -0.7 & 0 \\ -0.2 & 0 \\ -0.1 & 0 \\ 0 & 1.6 \\ -0.7 & 0 \\ -0.2 & 0 \\ -0.1 & 0 \end{bmatrix} \begin{matrix} \left.\vphantom{\begin{matrix}0\\0\\0\end{matrix}}\right\} \text{Thumb} \\ \left.\vphantom{\begin{matrix}0\\0\\0\\0\end{matrix}}\right\} \text{Finger1.} \\ \left.\vphantom{\begin{matrix}0\\0\\0\\0\end{matrix}}\right\} \text{Finger2} \end{matrix} \qquad (2)$$

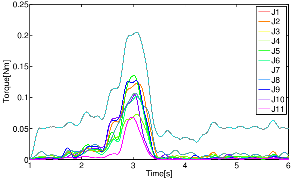
Experimental results

Experimental results









Conclusion and future work

ModGrasp potentials:

- The production cost of a simple model can be easily kept below 100 US dollars given the metal brackets, the micro servo motors, the controller boards and the resistors that are used for sensorising the physical prototypes.

Future work:

- In the future, the production cost could be even further reduced by using a 3-D printing approach or a shape deposition manufacturing (SDM) method to produce the mechanical brackets.
- It is the authors intend this work to be an open platform for the open-source research community.
- However, the simulation environment is still in the early stages of development and currently, only free-hand motions are possible. In the future, integration with a physics engine would allow for the simulation of controllable forces, object displacements, manipulability analysis and the addition of other grasp quality measures.

Thank you for your attention

ModGrasp repository and support:

- *ModGrasp* is an open-source project and it is available on-line at `https://github.com/aauc-mechlab/modgrasp`, along with several class diagrams, all the mechanics, hardware schematics and demo videos;
- F. Sanfilippo, Department of Maritime Technology and Operations, Aalesund University College, fisa@hials.no.