Nested Control of Assistive Robots through Human Intent Inference

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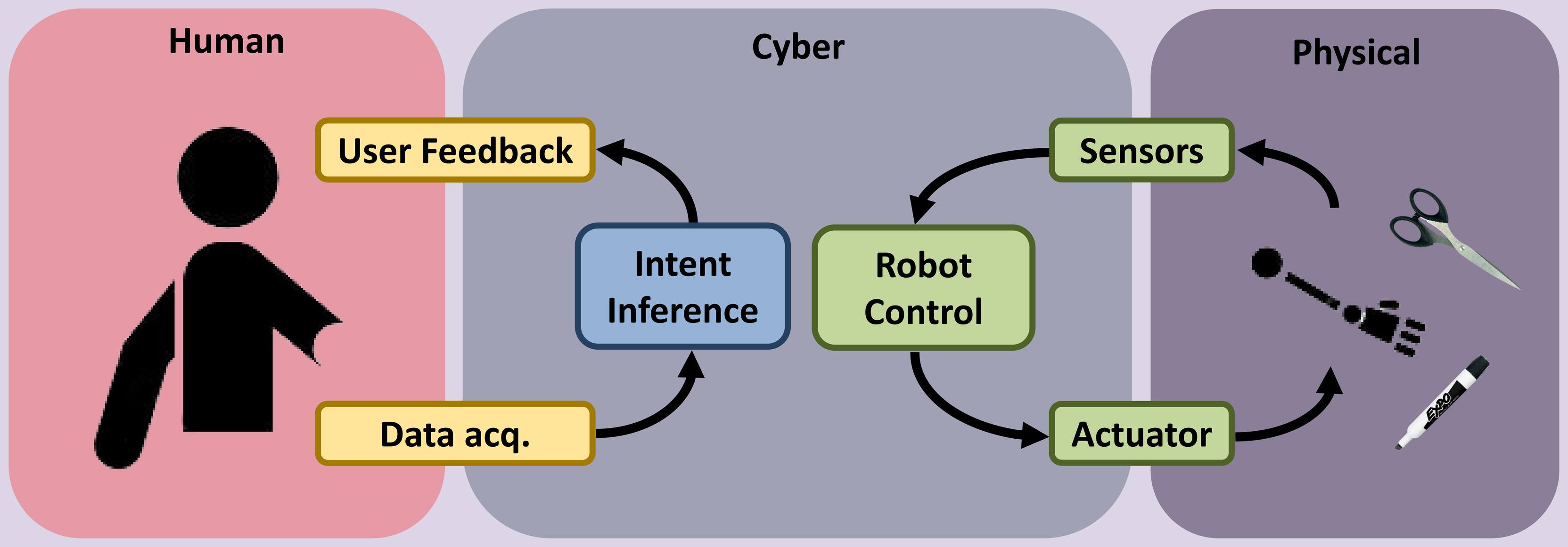
Motivation:

- Addressing upper-limb motor impairments and functional limitations is a major focus of rehabilitation interventions.
- Robotics has shown its great potential for restoring or augmenting the upper limb ability of individuals.
- Intracortical arrays and peripheral nerve interfaces have been used by researchers to control these robotic systems.
- Only a relatively small portion of the individuals with upper limb motor impairments can benefit from invasive neural interfaces due to other physical problems like immune system dysfunction.
- Electroencephalographic (EEG) recordings and surface electromyographic (EMG) recordings provide a noninvasive alternative to intracortical arrays and peripheral nerve interfaces.
- The solution needs to be a natural noninvasive physiological intent communication channel between the human and the prosthesis.

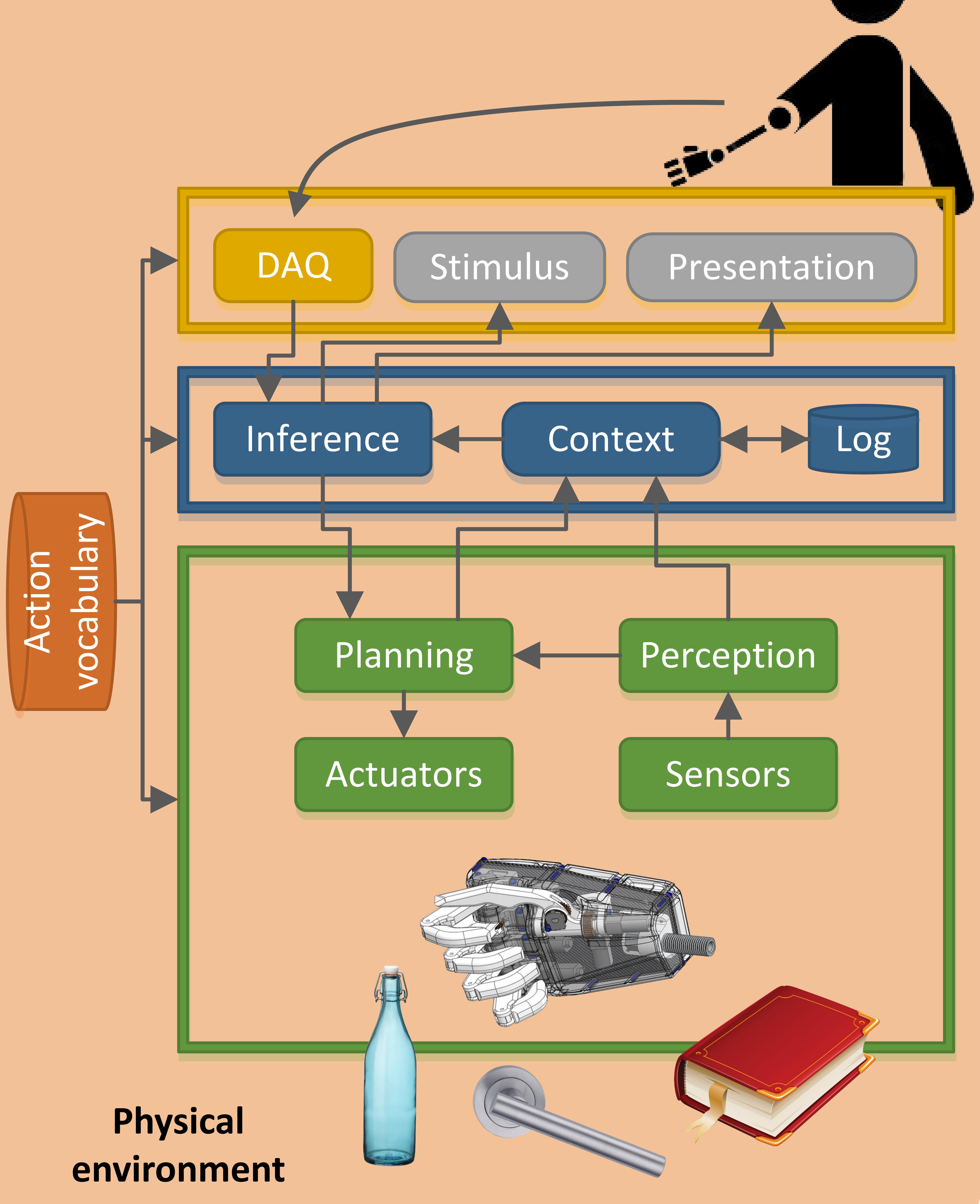
Goal:

- Design and build an **EEG-EMG-context fusion** approach for **human intent inference** that tightly integrates with an **intelligent physical interface** to allow users to control a robotic hand prosthesis.



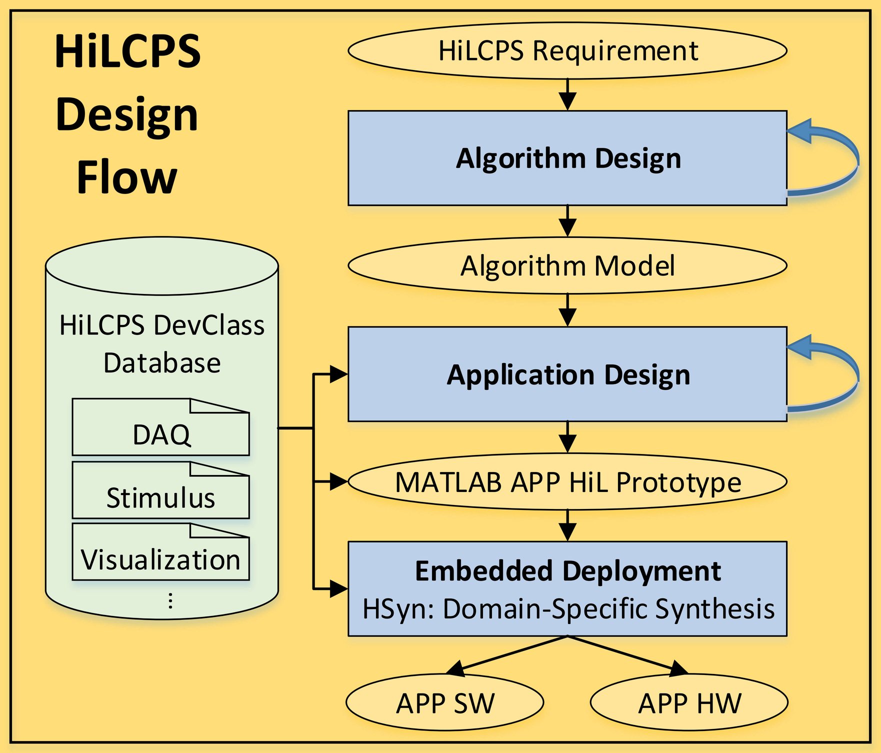
Design:

- Limited communication bandwidth offered by interfaces that exploit physiological signals.
- Focus on high level human intent inference, leaving lower level details to the intelligent robotics module.
- Defined basic hand postures that are most relevant to common tasks
- **2-level Control Loop**:
  - Outer loop: human perception (measurement feedback), human intent (true reference), and inferred intent with physiology+context.
  - Inner loop: actuators, sensors, and physical world.



Embedded Design:

- **Holistic framework for rapid system prototyping**
- **Computational Model-Based Design**
  - Hardware abstraction for hardware type and location transparent access.
  - Automatic path from high-level algorithm design to embedded implementation.
  - Tight time synchronization, and time-triggered events using OpenDDS for communication.



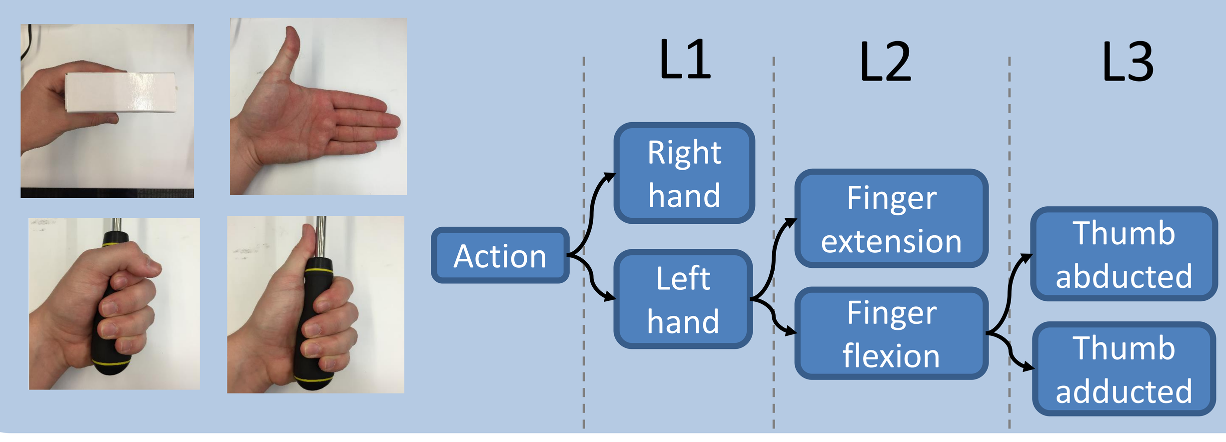
- **EEGu2**:
  - Acquisition: 16 channel EEG front-end (dual ADC), 24bit A/D
  - Signal-to-noise ratio (SNR) : 25dB
  - Input referred noise: 1.83uV
  - Real-time Processing: BeagleBone Black with ARM Cortex-A8 1GHz
  - Dynamic range ±187.5mV for EEG and EMG DAQ

Intent detection:

- **Probabilistic classification:** optimally fuse context information with physiological evidence to infer desired action

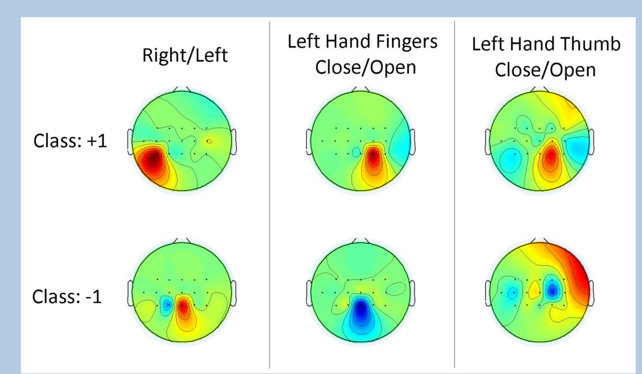
$$p(c_s = c|\mathbf{X},\omega) = \frac{\prod_i p(\mathbf{x}_i|c_s = c)p(c_s = c|\omega)}{p(\mathbf{x}|\omega)}$$

Phys. evidence: $\mathbf{X} = [\mathbf{x}_1, \mathbf{x}_2, ..., \mathbf{x}_N]$ — ω context information



EEG

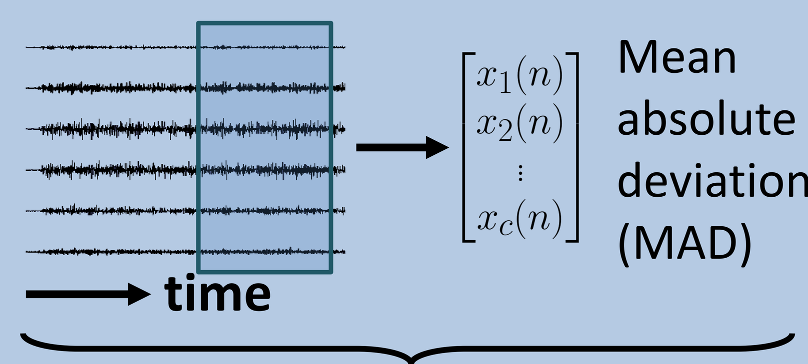
- Hierarchical log-quadratic dimension reduction method (CSP)
- Discriminative features from (de)synchronization in motor cortex



Hierarchical CSP for 3 levels

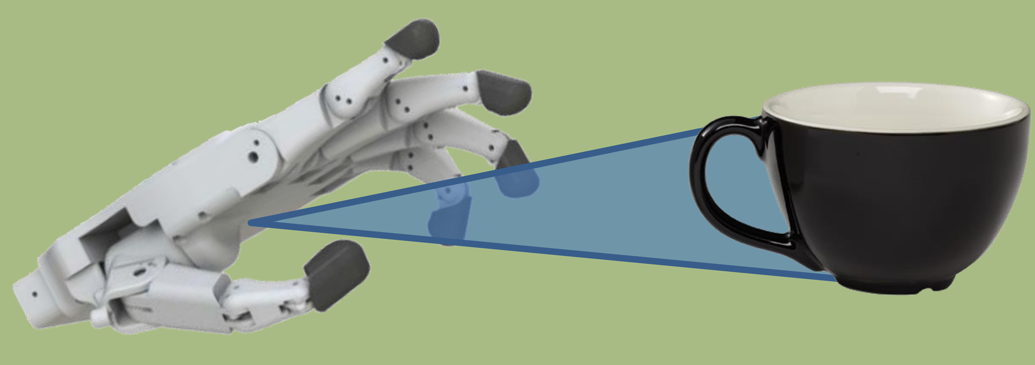
EMG

- Time-domain feature extraction

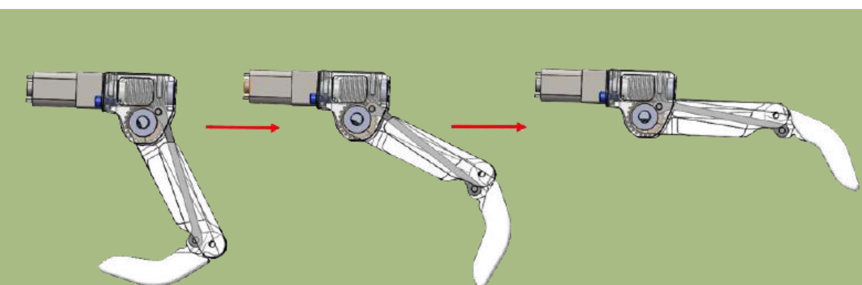


- 8 chan. EMG from upper forearm
- Gram matrix embedding in Riemannian manifold
- Avg. 95% accuracy across 7 subjects and 14 gestures

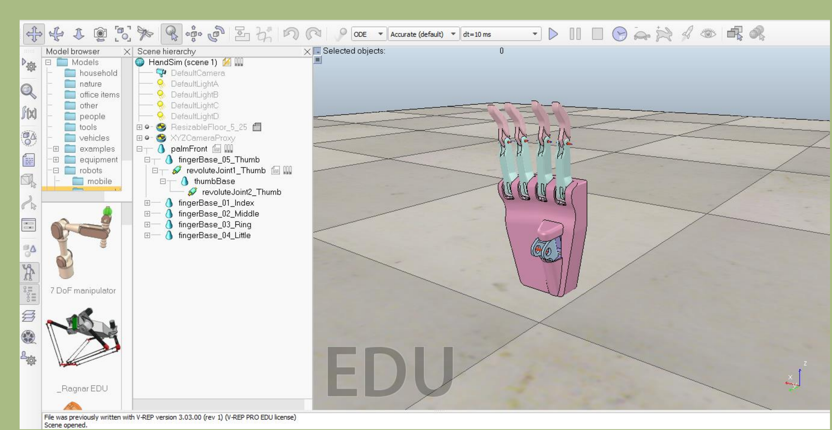
Prosthetic Robot Hand:



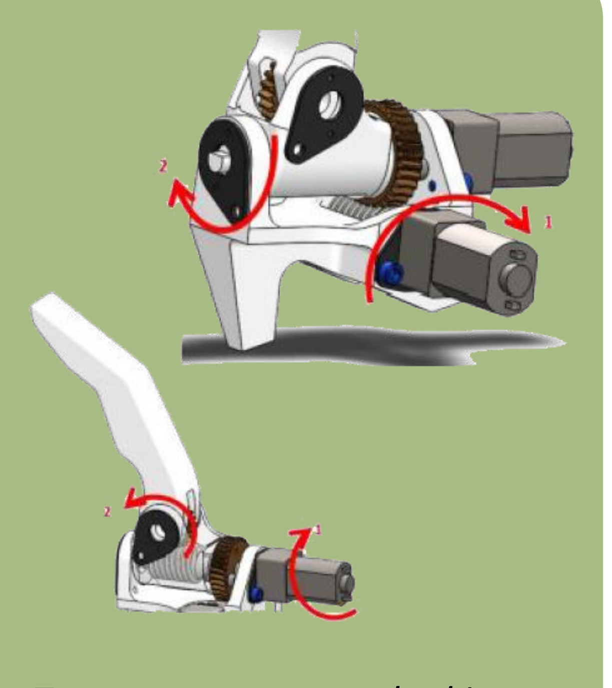
- Each digit finger has a single actuated degree of freedom and a kinematic coupling between lower and upper parts. The thumb has two actuated degrees of freedom at the base and its moves as a single rigid body.
- Each actuated joint is equipped with a potentiometer and it is driven by a DC motor.
- RGB-D camera, an IMU and an IR sensor are embedded at the palm.
- Joint reference angles can be tracked using PID at actuated joints.



Motion is generated by activating the DC motor attached to the digit finger



Realistic simulation with V-Rep as the dynamics engine and a Matlab-based communication interface



Two motors are attached in a setting where their axes are perpendicular to each other to realize anthropomorphic movement patterns