Nested Control of Assistive Robots through Human Intent Inference

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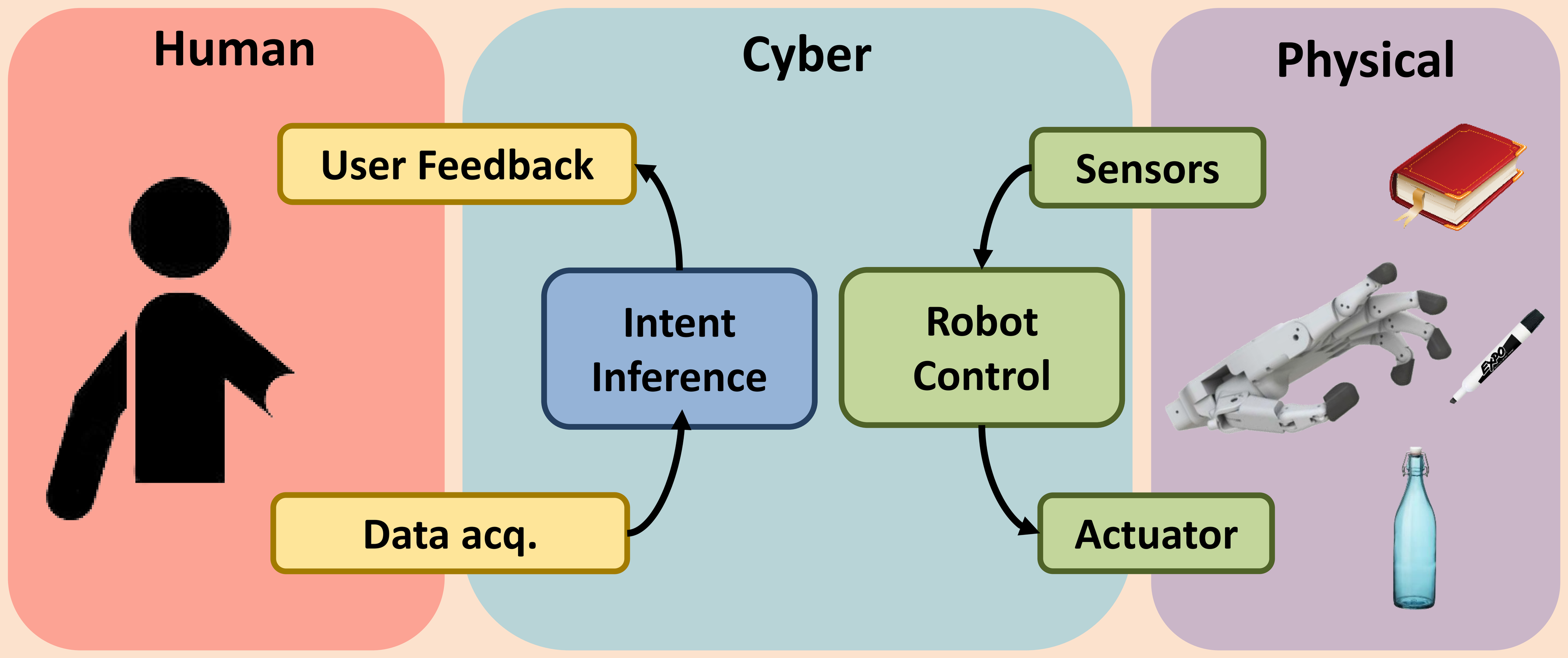
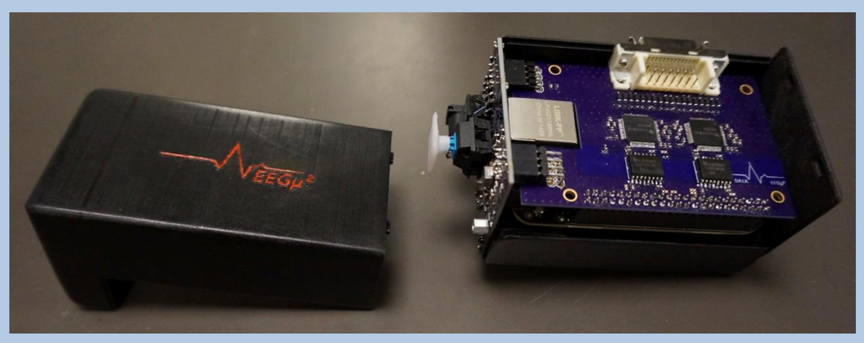
Motivation and Goal:

- Robotics has shown its great potential for restoring or augmenting the upper limb ability of people with upper-limb motor impairments.
- 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.
- Our goal: to 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 naturally control a robotic hand prosthesis.



Intent Inference:

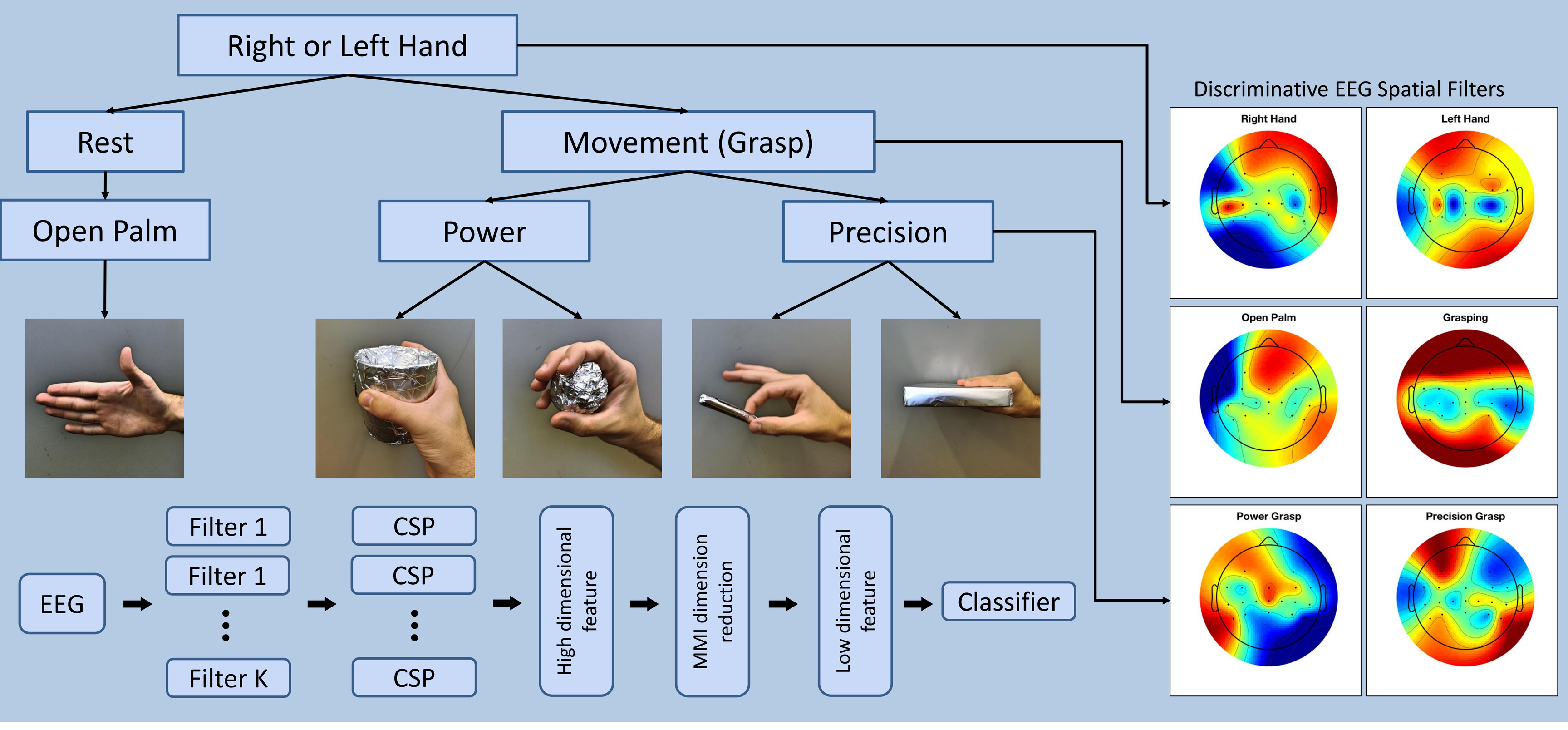
- Focus on high level human intent inference, leaving lower level details to the intelligent robotics module.



- **EEGu2**:
  - Acquisition: 16 channel EEG front-end, 24bit A/D
  - Input referred noise: 1.83uV
  - Real-time Processing: BeagleBone Black with ARM Cortex-A8 1GHz
  - Dual-chip solution
  - Allow implementation of faster control loops
  - EEG and EMG DAQ

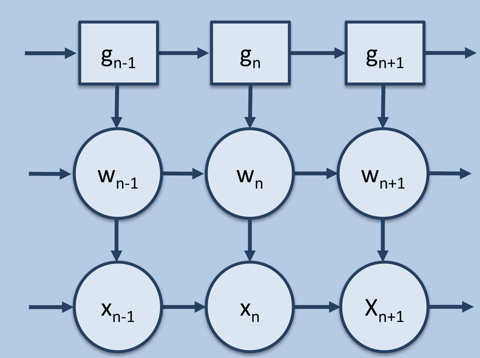
EEG

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



EMG

- Continuous EMG classification using switched dynamical system.



- Grasp g ~ prior grasp distribution p(g)

$$x_t = A_t x_{t-1} + v_t$$

$$v_t \sim N(0, Q_t) \quad Q_t = Q[g_t] \quad A_t = A[g_t]$$

$$p(g_t = i | g_{t-1} = j) = Z_{ij} \quad p(x_1|g_1) = N(x_1; \mu_1, \Sigma_1) \quad p(g_1 = i) = \pi_i$$

- Switched VAR model
- No voluntary movement that can produced by only one muscle.
- All actions are controlled by co-activation of muscles.

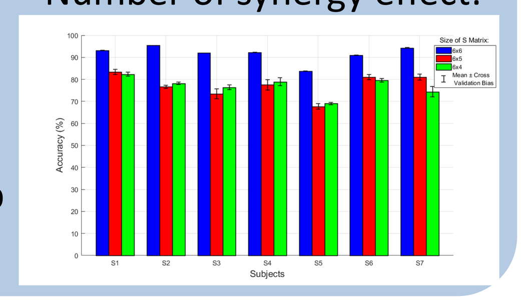
$$\min_{W,S} \frac{1}{2} \|\hat{A} - SW\|_F^2 \quad \text{subject to } W \geq 0 \text{ and } S \geq 0 \quad \Rightarrow \text{NNMF}$$

$$A = SW = \begin{pmatrix} | & | & & | \\ s_1 & s_2 & \ldots & s_K \\ | & | & & | \end{pmatrix} \begin{pmatrix} - & w_1(n) & - \\ - & w_2(n) & - \\ & \vdots & \\ - & w_K(n) & - \end{pmatrix}$$

control signal

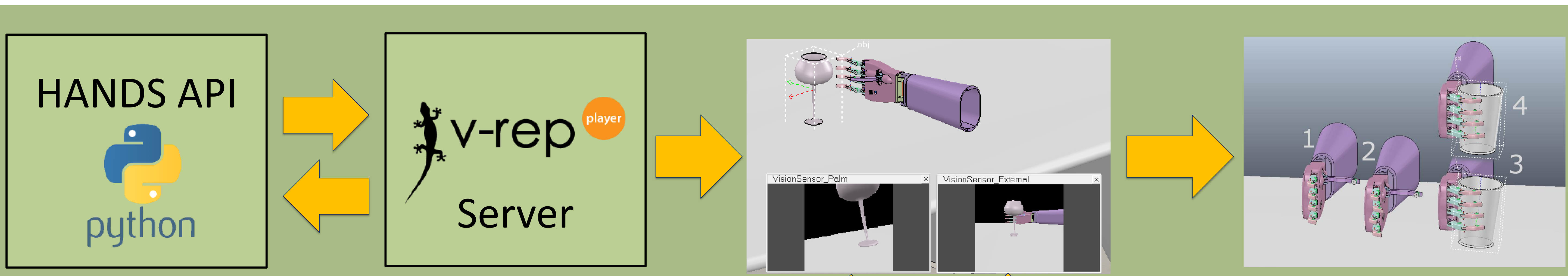
Classification accuracy of 6 muscles, 14 grasp types:

Number of synergy effect:

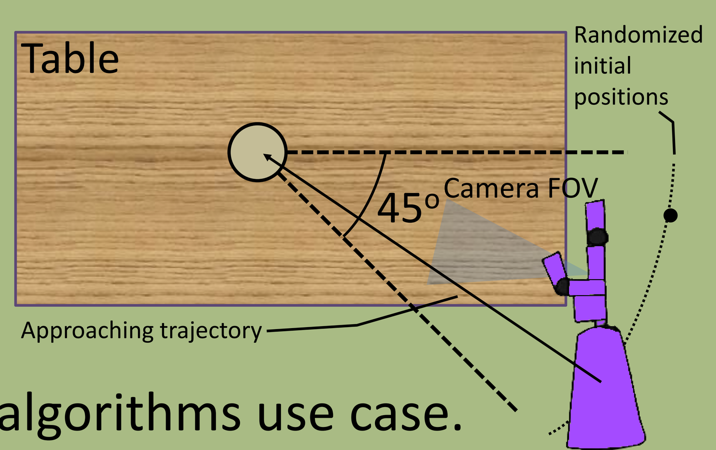


Motion Planning:

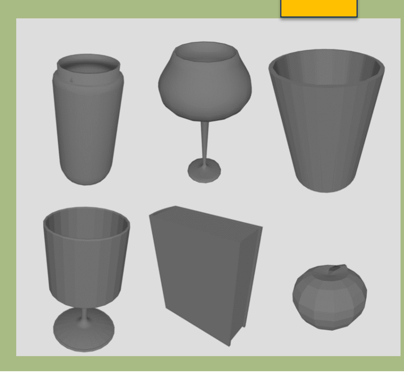
- API is used to initialize the robot environment for different objects with different positions.
- Programmer can send a command via API to control the behavior of the robot hand during simulation.



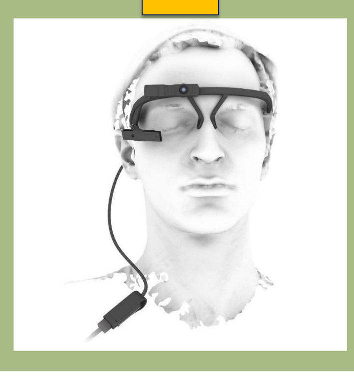
- The simulation allows engineers to rapid develop algorithms for grasping different types of objects.
- Simulation attempts to realistically model actual hardware.



- Testing motion planning algorithms use case.

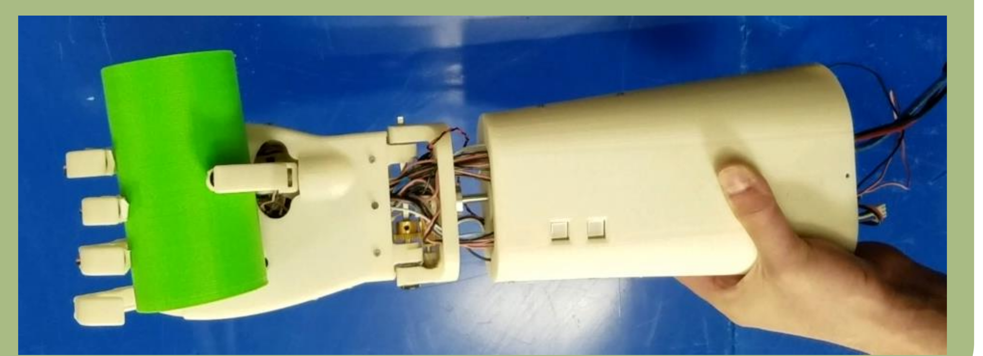


- Common objects used to prototype and test algorithms



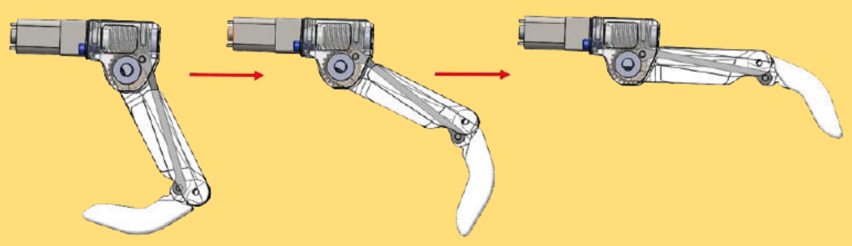
- Simulate mobile eye tracker with front facing camera for context evidence extraction.

RGB/RGBD → CNN → Obj → Grasps

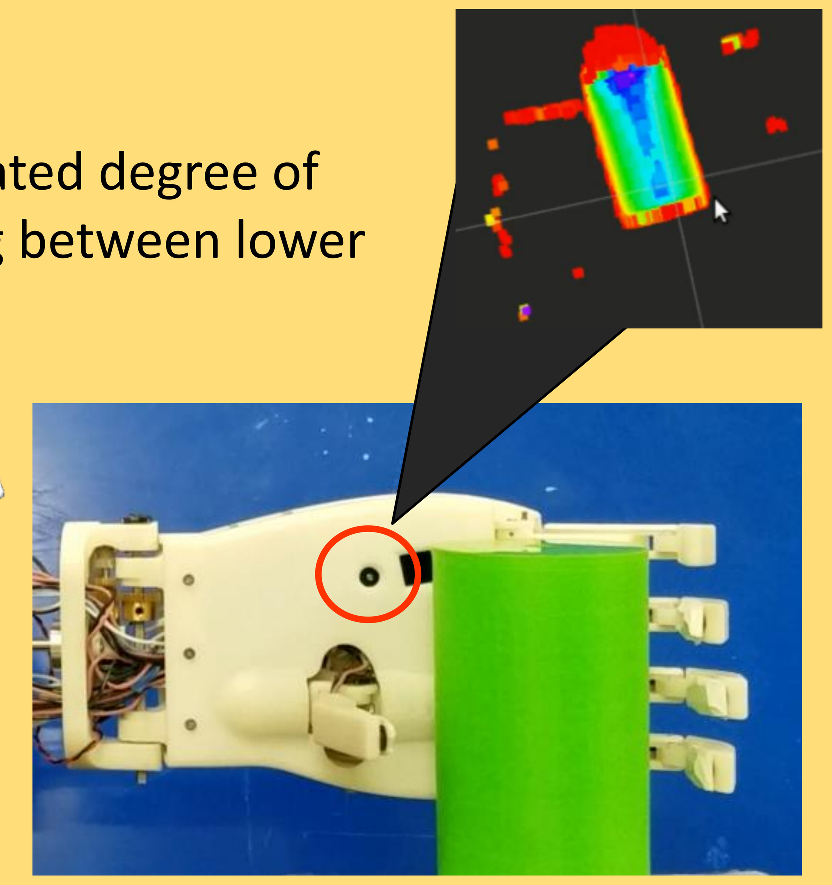


Robotic Interface:

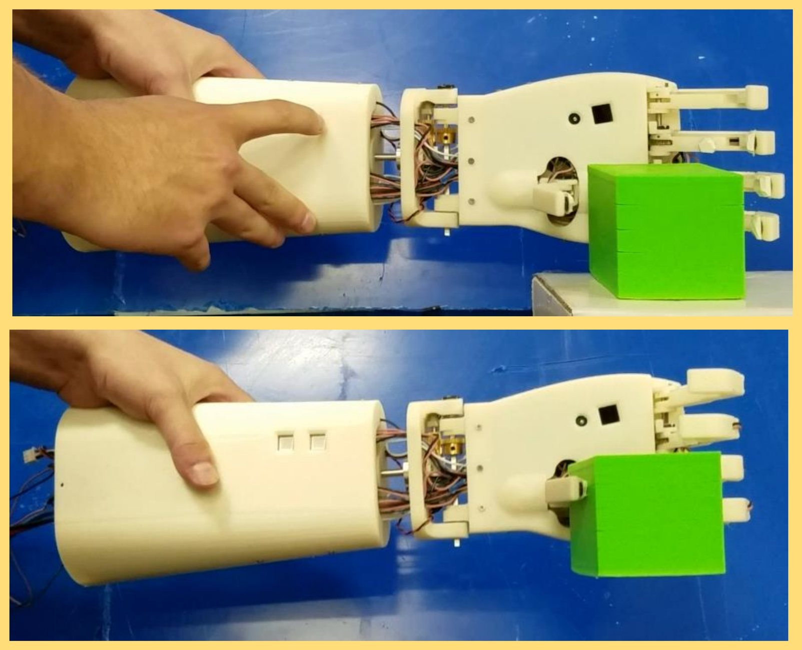
- Each digit finger has a single actuated degree of freedom and a kinematic coupling between lower and upper.

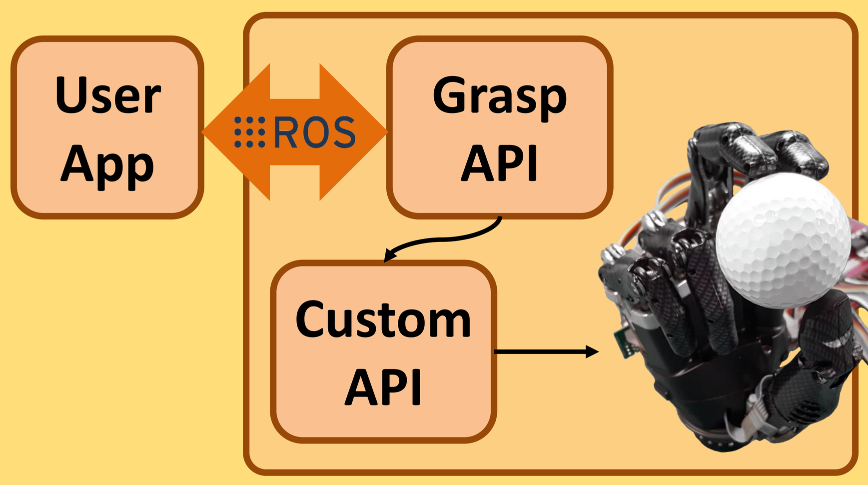


- There is a small 3D cloud camera inside the palm that obtains position and pose information of objects for improved control.



- A touch button positioned at wrist is used to initiate grasping a cube object.





- Custom programming interface for a commercial robotic prosthetic hand using a high-level ROS wrapper on top of the low-level API to allow selection of parameterized grasp types.
- Workbench where fiducial markers are used to localize objects and hand
- Main controller decides when to do the grasping when it is assumed to result in a successful grasp.