Design and Development of a Cybernetic Rehabilitative Hand-Wrist Exoskeleton

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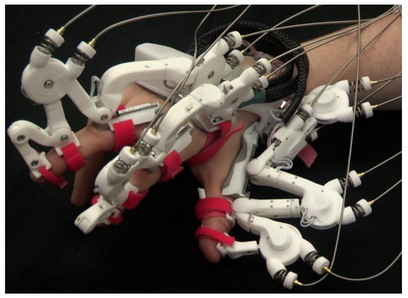
Objective: To design and develop a torque-controlled hand-wrist exoskeleton prototype for rehabilitation.

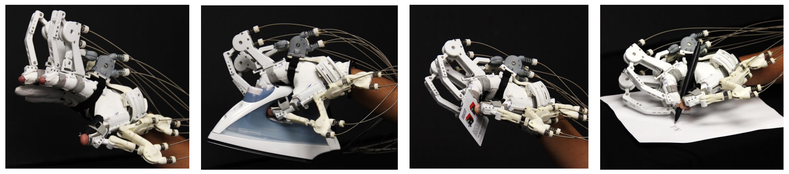
Maestro



- Maestro is designed for **hand rehabilitation** and **assistance**
- It consists of **thumb, index, and middle finger** modules
- It allows for **large range of motion** and **assists individual joints** of each digit
- It **controls joint torque** using Bowden-cable-based **series-elastic actuators**

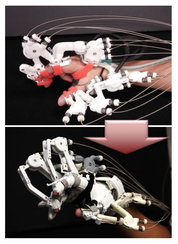
Assistive hand exoskeleton

- Maestro is used to assist hand function of Spinal Cord Injury (SCI) subjects in activities of daily living.
- It is capable of performing four distinct common hand pose categories
- It is operated by an intention recognition method based on EMG sensors
- It is tested on SCI subjects with C5, C6 and C7 injury levels
- Its effectiveness has been evaluated by Sollerman hand function test
- Results show improved hand function with the exoskeleton



Improved Design and Interface

- Addition of the glove results in more comfortable interface and shorter don and doff time
- Fixing links to the glove prevents relative motion between links and fingers
- Change in linkage design increased finger range of motion and resulted in precise grasp
- Sensation is retained on fingertips for object interaction

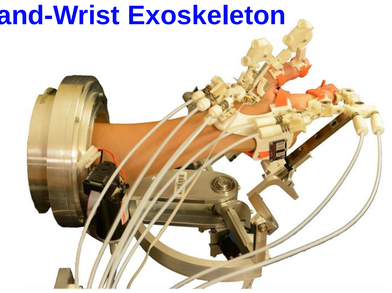


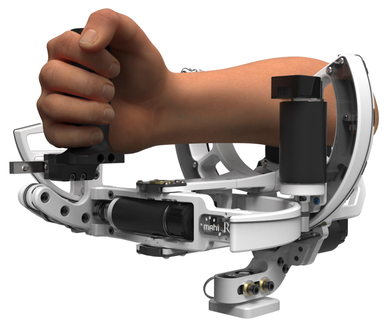
Intention Recognition

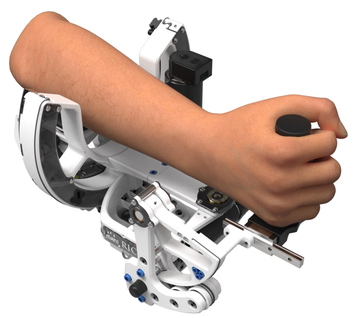
- Three EMG sensors are attached to subject's forearm and palm to measure their muscle activity
- Subject's muscle activity is classified into one of 4 grasp modes using a pattern recognition method
- A probabilistic approach is used to ensure reliable operation of assistive device

Redesign of Wrist Module of Hand-Wrist Exoskeleton

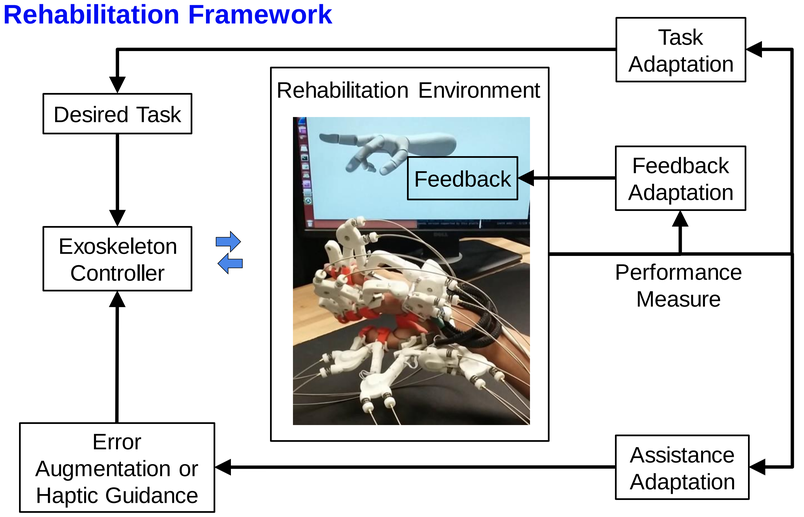
- **Open** pronation/supination DOF significantly improves **ingress/egress**
- Improved interface with Maestro: relocated to dorsal side, increasing ulnar deviation ROM and facilitating grasping tasks.
- Ergonomics and user comfort improved by telescoping elbow rest
- **Doubled torque output** from redesigned Pronation/supination DOF
- **Modular design** and upgraded tensioning mechanisms allow for quick **ambidextrous** configurations.
- Polymer-ceramic coating compatible for **EMG control** and **motion capture**
- **Decreased inertia** by 10% (FE) and 40% (RU) via motor placement, upgraded aluminum alloys, and routing of electrical cables though joint axes







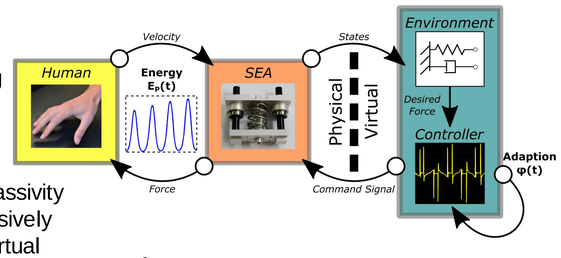
Rehabilitation Framework

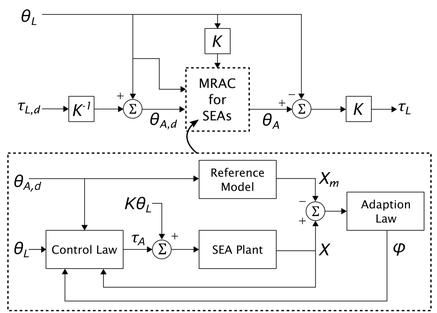


Our framework allows for simultaneous adaptation of task, assistance and feedback based on performance on the task

Time-Domain Approach to Control of Series Elastic Actuators

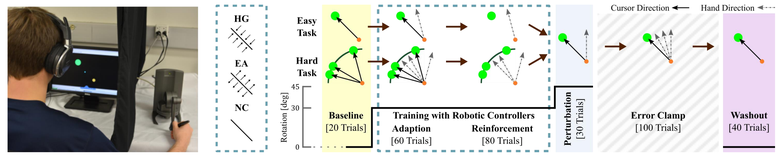
- Reduced the amount of parameter identification necessary by introducing an adaptive torque controller for series elastic actuators (SEAs)
- Used the time-domain passivity approach in order to passively couple arbitrary stable virtual environments and torque controllers
- By changing the virtual environment in response to the amount of dissipated energy, we could render stiffnesses greater than the stiffness of the SEA



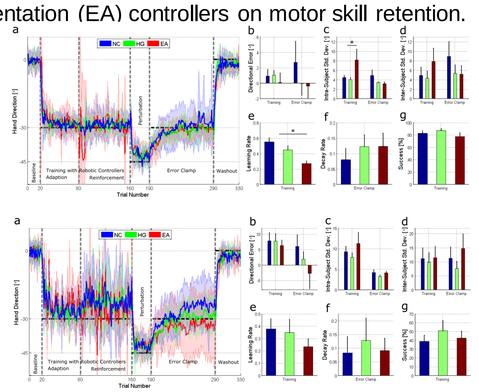


Time-Domain techniques can ensure safety while increasing performance

Improving Motor Skill Retention w/ Reward-Based Reinforcement



- Investigated the effect of combining reward-based reinforcement with haptic guidance (HG) and error augmentation (EA) controllers on motor skill retention.
- User operates a haptic device while observing visual feedback on a screen (Left). Subjects assigned either Easy or Hard reaching tasks while training with HG, EA, or No Controller (NC) (330 total trials conducted) (Right).



With reward based feedback, haptic guidance and error augmentation lead to better retention

Acknowledgement

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3. D. P. Losey, L. H. Blumenschein, and M. K. O'Malley. "Improving the retention of motor skills after reward-based reinforcement by incorporating haptic guidance and error augmentation." *6th IEEE International Conference on Biomedical Robotics and Biomechatronics (BioRob)*. June 2016.