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Design and Development of a Cybernetic Rehabilitative Hand-Wrist Exoskeleton

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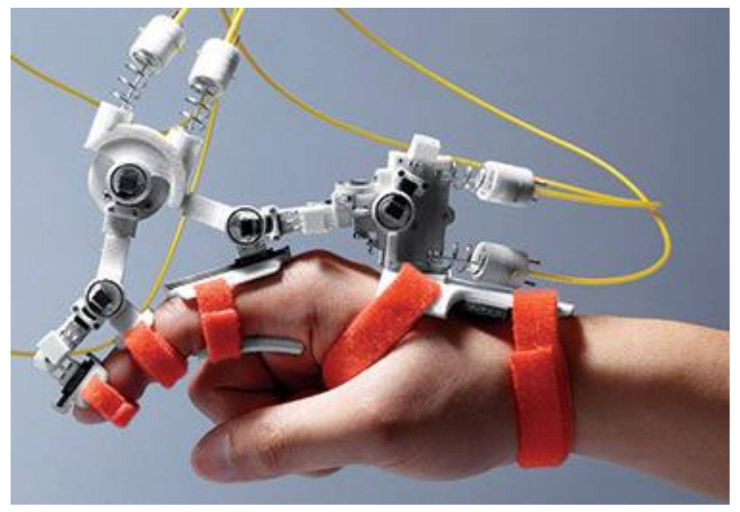
Objective: To design and develop a torque-controlled hand-wrist exoskeleton prototype for rehabilitation.

Design

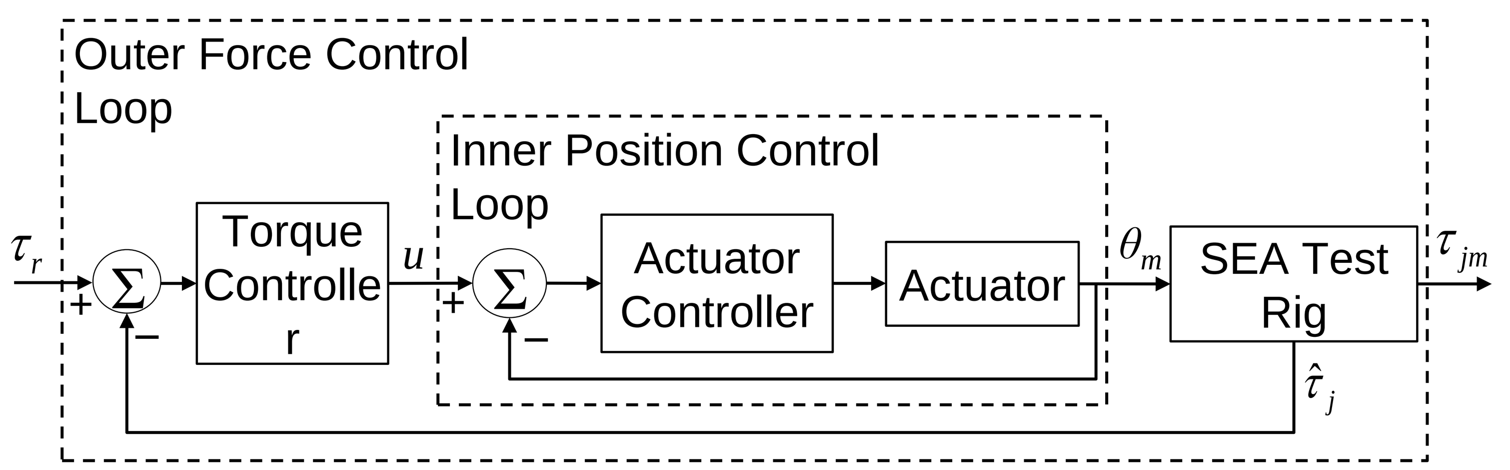
Series Elastic Actuation (SEA)



Thumb Connection Interface

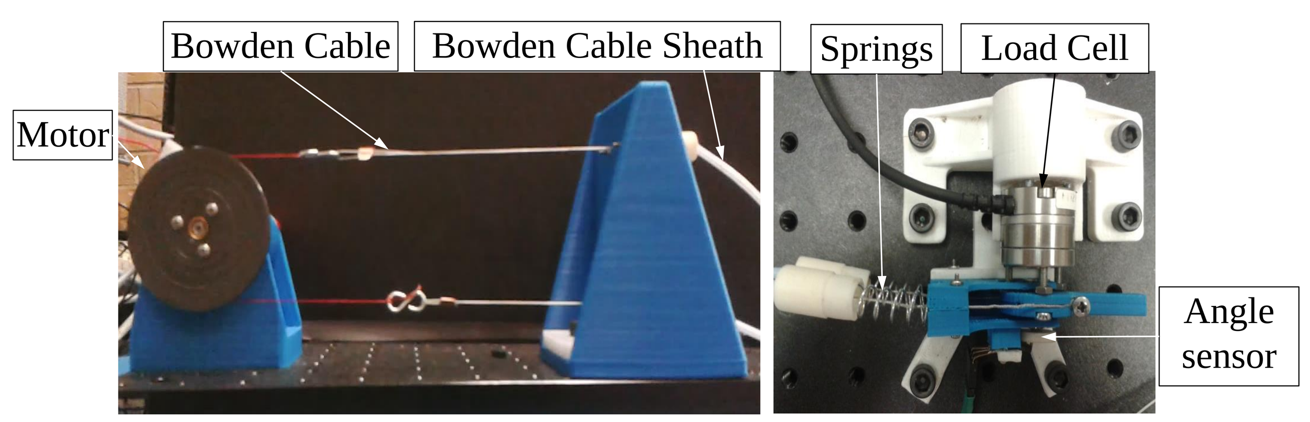
- SEA allows for accurate and stable force control
- Compliance provides comfortable and safe interaction
- Ergonomic wire-form structure transfers load to the metacarpal bone
- Slider rail position adjusts as per subject

Control Overview



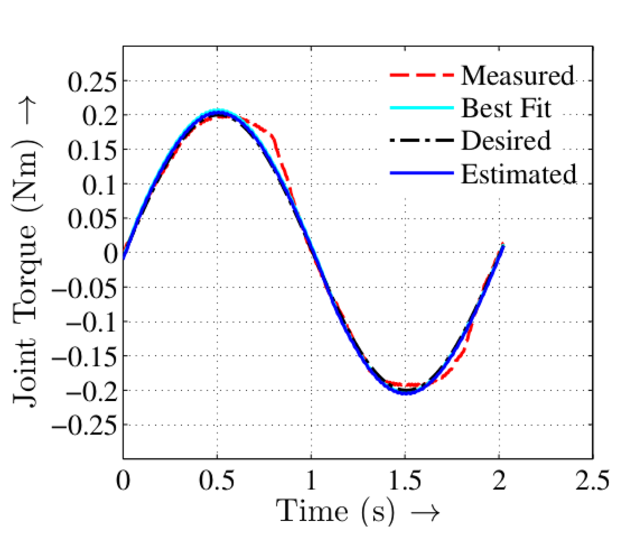
- Control scheme consists of inner position control loop + outer force control loop
- SEA spring deflections are used to estimate applied torque

SEA Torque Validation



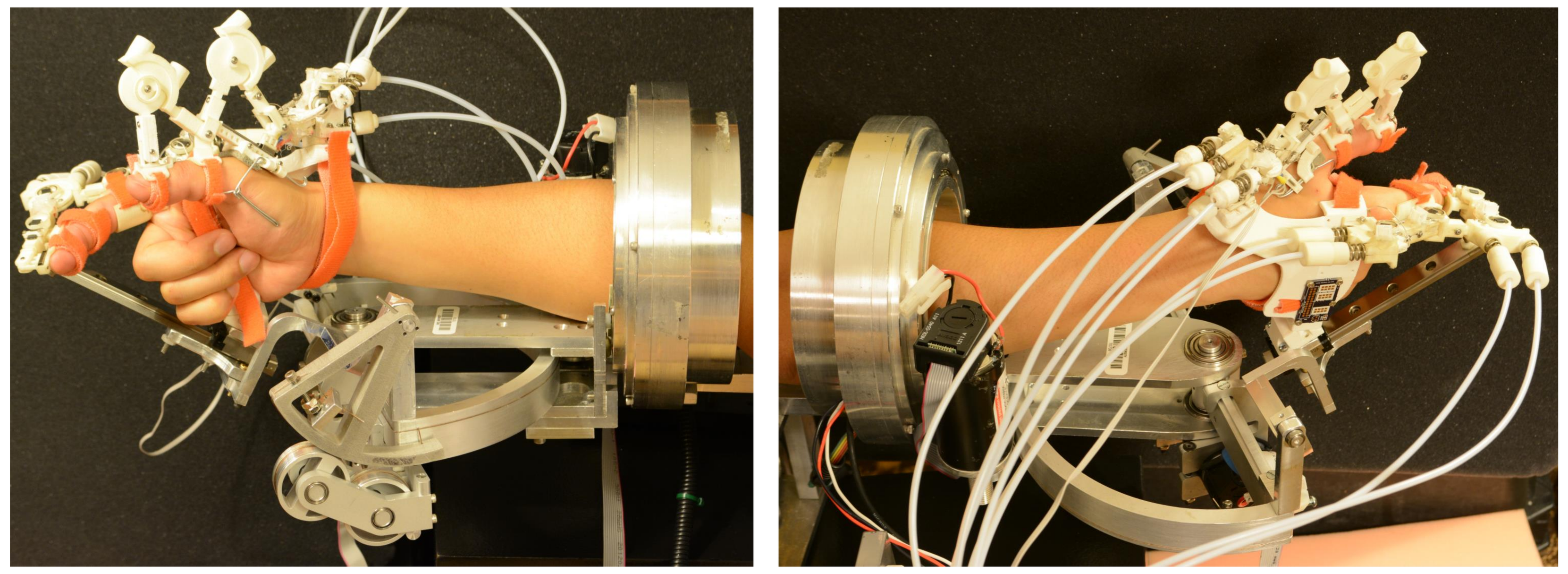
Motor Side (front view) Joint Side (top view)

- Developed test rig enables validation of torque tracking performance of designed SEA
- 6-axis load cell mounted on joint accurately measures the output torque
- Buckling of the spring results in minimal deviation of measured torque trajectory from the estimated one



Good torque tracking performance is observed!

Hand-Wrist Exoskeleton Prototype



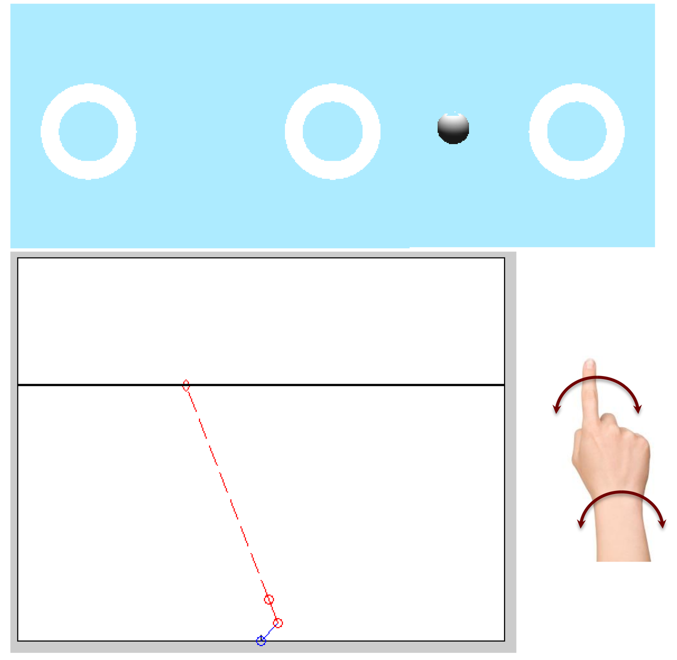
Effects of kinematic constraints on wrist-finger movements

Goals:

- Establish standard for coordinated movement in pointing tasks involving finger MCP flexion-extension and wrist flexion-extension
- Determine device transparency
- Investigate effects of device constraints on movement while backdriving exoskeleton (kinematic constraints, friction, inertia)

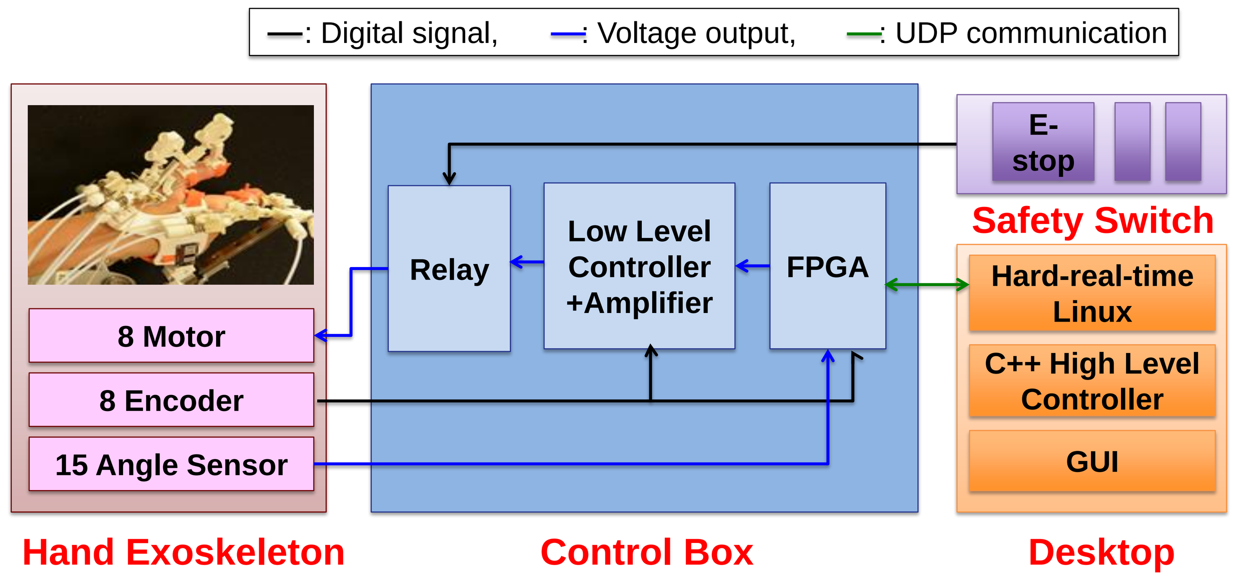
Experimental Design:

- Use optical motion capture to establish human kinematic standard
- Repeat experiment using UT-Rice hand-wrist exoskeleton



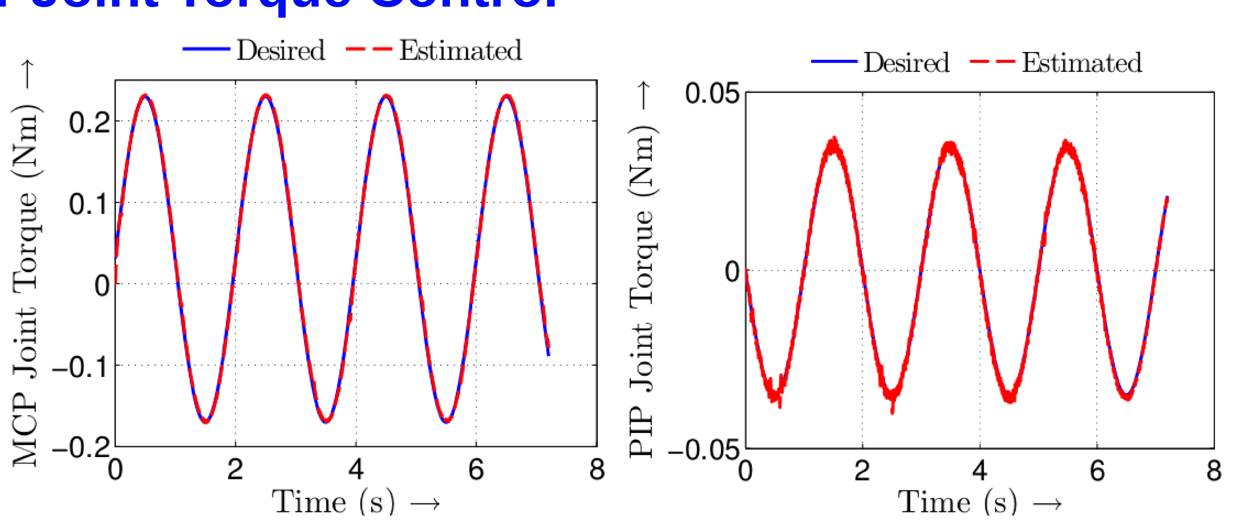
Graphical display for pointing task, motion capture results, and desired pointing movements

Hand Exoskeleton Mechatronic System Overview



- Hard-real-time control framework
- C++ based flexible programming
- Multiple E-stops to ensure safety
- Fast communication interface via FPGA

Finger Joint Torque Control



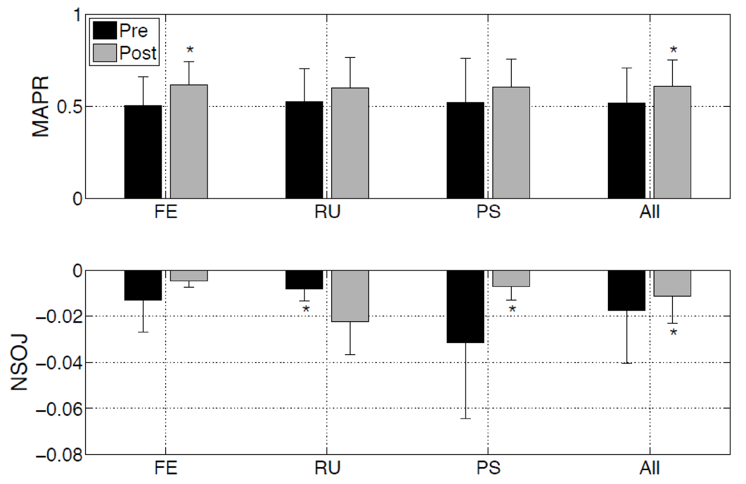
SEA leads to safe and effective torque control of the device!

Experiments with RiceWrist-S

- Clinical efficacy is evaluated with a single subject with incomplete SCI
- Jebsen-Taylor Hand Function Test (JTHFT) and Action Research Arm Test (ARAT) metrics are used for clinical assessment
- Movement-Arrest-Period-Ratio (MAPR) and Normalized sum-of-jerk (NSOJ) metrics were used to assess movement smoothness for each DOF (flexion-extension of wrist, radial-ulnar deviation, and forearm pronation-supination)

Test	Baseline	Post-treatment
ASIA UEMS	15	15
JTHFT (seconds)	99.1	93.8
Flipping cards	15	15.2
Picking up small objects	27	28.3
Simulated feeding	12.4	11.7
Lifting big objects (light)	12.3	13
Lifting big objects (heavy)	20.8	14.6
ARAT (0-57)	29	31
Grasp (0-18)	12	12
Grip (0-12)	7	7
Pinch (0-18)	4	6
Gross Movement (0-9)	6	6
Pinch Force (kgf)	3	2.8
Grip Force (kgf)	11	14

Outcomes of clinical evaluation show improvements in JTFHT scores, increases in ARAT attributed to pinch, and increases in grip strength after treatment

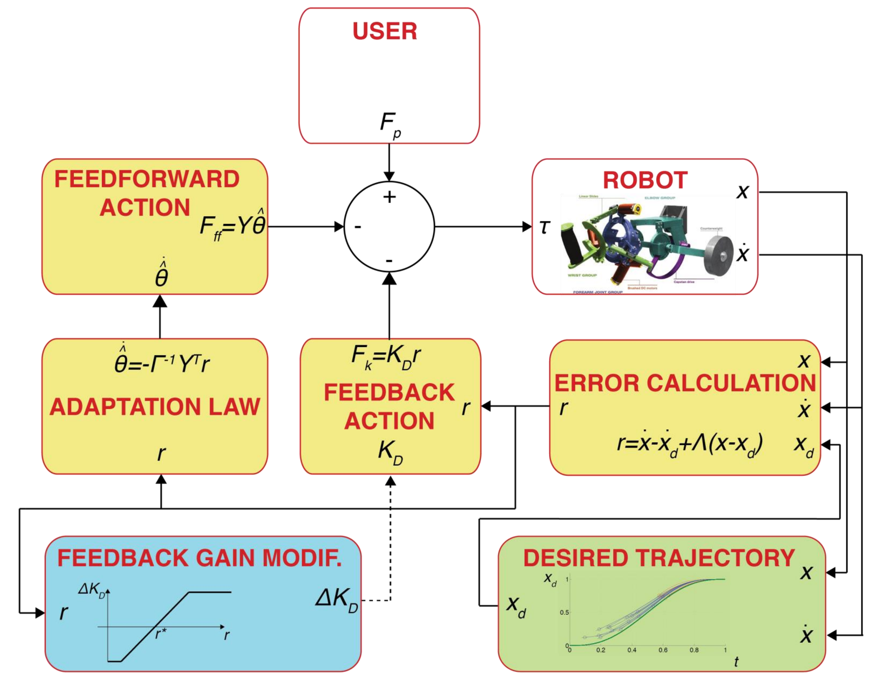


Two measures of smoothness computed during the first (Pre) and last (Post) session of therapy for each DOF of assessment. An asterisk indicates significant differences (α = 0.05). Results indicate increases in movement smoothness and quality as a result of robotic rehabilitation treatment

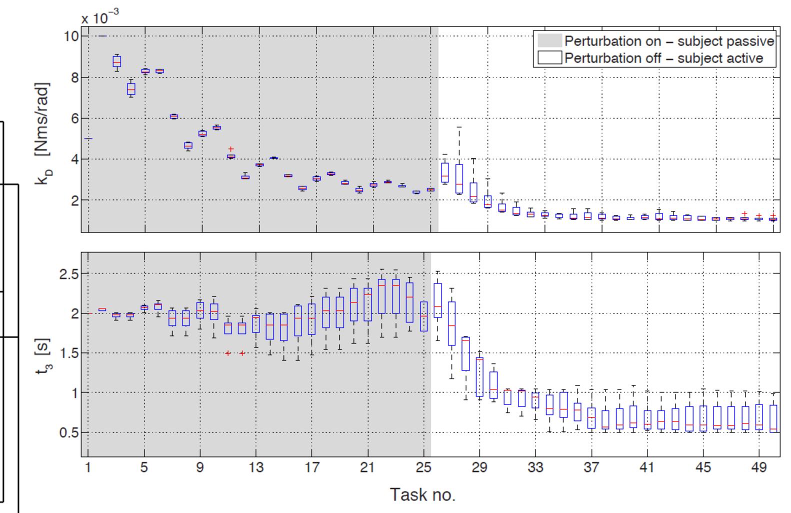
Functional scores before and after therapy with RiceWrist-S show improvements!

Subject Adaptive Controller Development and Testing

- Models the subject's input and assists only as much as needed
- Challenges the subject by regulating the allowable error and recalculating allocated time for task completion based on performance
- Controller is tested with five healthy subjects in which subjects change their engagement strategy from passive to active



Subject adaptive controller block diagram



Top: Feedback gain value during each trial
Bottom: Total allocated time for each trial (computed at the beginning of each trial)

Results show that the controller contribution decreases as user contribution increases!

Acknowledgement

The authors gratefully acknowledge the support of the National Science Foundation through grants NSF-CPS-1135949/1135916

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