Abstract
Over 450,000 Americans suffer from debilitative disorders resulting in the loss of proper hand function. A lightweight, non-cumbrous, orthotic hand exoskeleton was designed to restore normal pinching and grasping finger motions. Three functional digit mechanisms were designed: a thumb, index, and grouped third digit, comprised of the middle, ring, and small fingers. Each phalange was enclosed by a series of cylindrical aluminum bands connected at the centers of rotation of each joint. Bowden cables were mounted beneath each digit to provide active flexion, mimicking the tendons in the hand. A spring extension mechanism maintained constant tension in the Bowden cables, and during relaxation, returned the actuated digits to a fully extended resting position. Individually controlled actuators mounted on a forearm assembly produced 15 N of tensile force in each cable. The orthotic hand exoskeleton will be integrated with a digital control system currently under development in this laboratory. The complete system was designed to restore hand functionality through the amplification of precision pinch and/or power grasp.

Background
Debilitative muscle disorders decrease strength and dexterity in the hand.

Solution
Orthotic hand exoskeletons may be used to amplify the remaining muscle control in the hand and facilitate pinching or grasping movements.

Current Designs and Limitations
Current designs actuate either a precision pinch or a power grasp (Fig. 1) and are bulky on the wearer’s hand.

A tendon-drive mechanism incorporating three laterally mounted cables was utilized to produce flexion of the three index finger joints in the five-fingered assistive hand designed at the University of Tsukuba [1].

A pneumatic piston driven cable system was responsible for actuating flexion of the index finger against a fixed thumb in the device designed at Carnegie Mellon University [2]. A spring mechanism enabled passive index extension. A functional pinching force was non-cumbrous in design and incorporated cables, as opposed to bulky pistons positioned atop the dorsum of the hand. The spring extensor mechanism passively controlled the return of actuated digits.

Digit Mechanism
- Cylindrical aluminum bands enclose the phalanges of all digits (Fig. 2)
- Bands are thin and accommodate internal sensors and cushioning
- Band connections create points of rotation that coincide with the centers of rotation of the natural joints
- Distal and proximal band connections fit within the intermediate band, eliminating bulk between the fingers
- Platforms reduce contact stress on fingers

Exoskeleton Construction

Active Flexion
- Rest position
  - Index and third digit extended at 0°
  - Thumb at right angle to digits
- Bowden cables
  - Three cables placed as dictated in Table 1
  - Pull from beneath phalanges mimicking tendons (Fig. 4)
- Actuators
  - Produce a 15N force in each cable
  - Produce a maximal force of 8N normal to fingertips
  - Stroke length of 10mm, stroke speed of 20 mm/s
  - Real-time performance

Passive Extension
- Spring extensor mechanism returns actuated digits to resting position
- Mechanism consists of a single spring for each digit, each mounted on the base assembly
- Springs are chosen with an approximate constant of 0.5 N/mm to maintain tension in the Bowden cables
- Mechanical stops used to prevent hyperextension

Conclusion
We designed and implemented an orthotic assistive exoskeleton that can dynamically amplify residual hand strength for both pinching and grasping motions. Future evaluations of strength and dexterity include:

- Quantification of grasping strength via a percent utilization of EMG measurements.
- Quantification of precision control via deformation measurement on a ball of Playdoh™ during pinching motions.

References and Acknowledgements

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Table 1. Bowden cable arrangement pertaining to each linear actuator.

<table>
<thead>
<tr>
<th>Cable</th>
<th>Digit</th>
<th>Connection Link</th>
<th>Action</th>
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<tbody>
<tr>
<td>1</td>
<td>Index</td>
<td>Distal</td>
<td>Coupled Flexion of DIP and PIP</td>
</tr>
<tr>
<td>2</td>
<td>Third</td>
<td>Distal</td>
<td>Flexion of DIP, PIP, MCP</td>
</tr>
<tr>
<td>3</td>
<td>Thumb</td>
<td>Proximal</td>
<td>Flexion of CMC and IP</td>
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</tbody>
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Figure 1. Demonstration of precision pinch posture, used to pick up a pen (left) and power grasp, used to hold a mug (right).

Figure 3. Assembly of hand/forearm showcasing three usable digits: index, thumb, and the remaining finger group.

Figure 4. The poly-articular tendon-driven mechanism in the index digit.

Figure 2. Band design common to all exoskeletal digits.

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151