Poster 3

Give:
- Design and rapid fabrication framework for customized soft exoskeletons
- Expert-free fabrication via vision-based closed-loop printing using FDM

Get:
- Clinical collaborators to inform design choices and meet patient needs

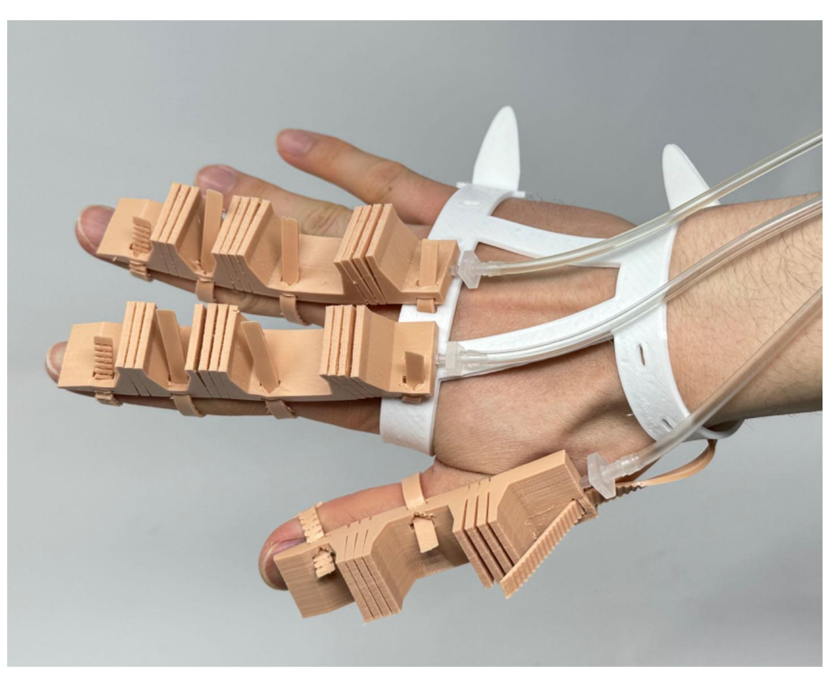
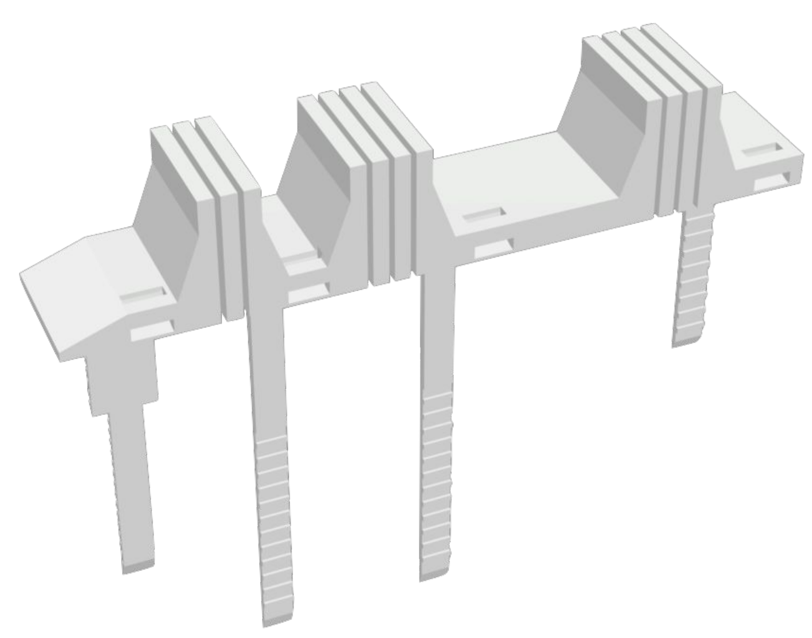
Fully FDM-Printed Soft Hand Exoskeleton

Lehong Wang,† Zilin Dai,† and Markus P. Nemitz

Department of Robotics Engineering, Worcester Polytechnic Institute, MA USA

Introduction

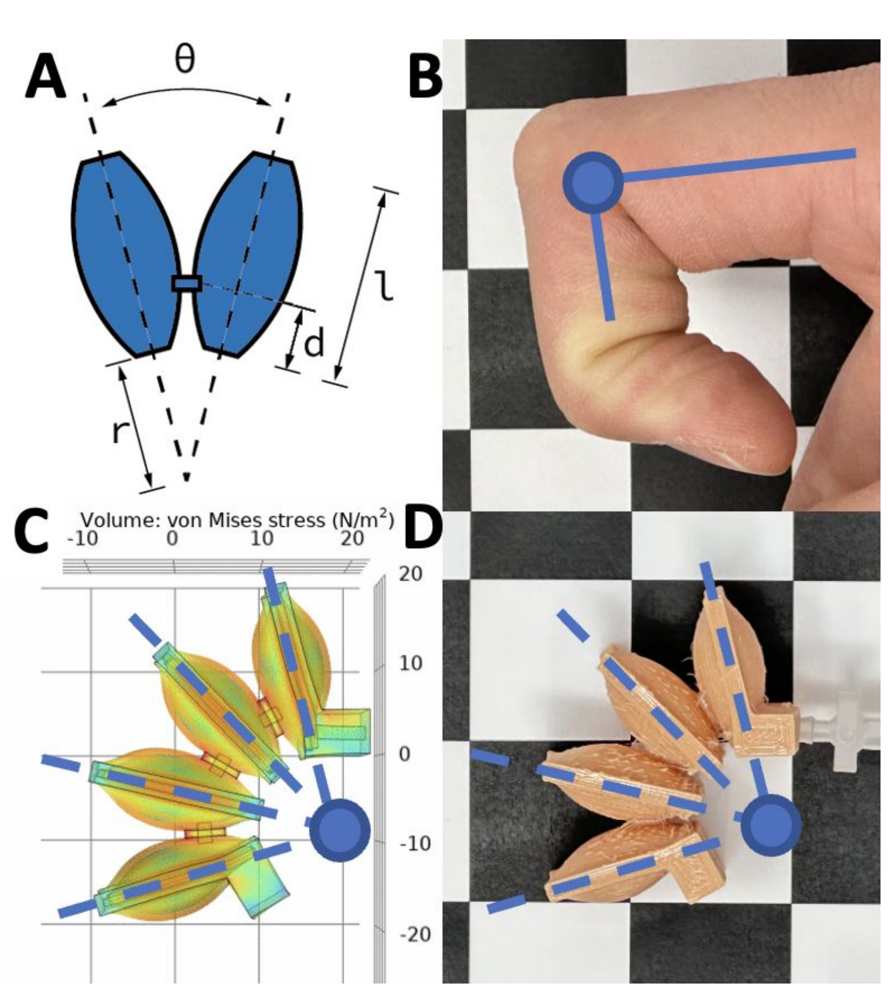
- Current exoskeletons heavily rely of injection molding.[1] Additive manufacturing enables effective customization of designs instead.
- 3D printed exoskeletons have typically been comprised of rigid materials; they do not conform to human ergonomics.

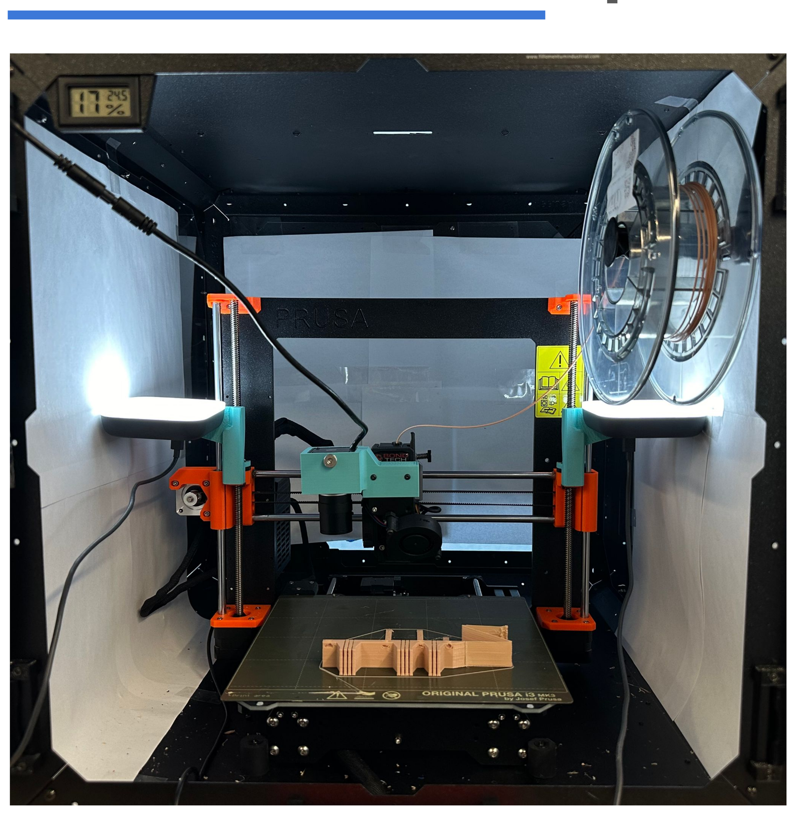
We introduce a design of an exoskeleton that is printable via standard FDM; the design is comprised of pneumatic actuators printed from FilaFlex 60A. It includes printed straps around the palm to connect the exoskeleton to the wrist. Actuators are placed above the MCP, PIP, and DIP to enable flexible extension and bending, while the blocks serve as the skeletal component for the exoskeleton.

Structure & Design

The motion of the actuated bellows is designed to match the motion of the bending fingers. The exoskeleton trajectory is analytically calculated by modeling the inflated membrane as circular curves and the connections as rigid tangent links. The actuator movement can be modeled as a circular motion around a virtual point, that coincides with the finger joint, allowing the bellows to guide the fingers organically.



Fabrication Setup



To make the actuators impermeable against leaks, we applied a vision-based, closed-loop FDM printing process.[2] Our FDM printer is equipped with a camera on the extruder head and diffused light sources on both sides. Our system inspects the printing quality of each layer, and if defects are detected, it initiates a fixing procedure called *ironing*. Ironing is the process of revisiting already deposited parts of a 3D print with a heated print nozzle only.

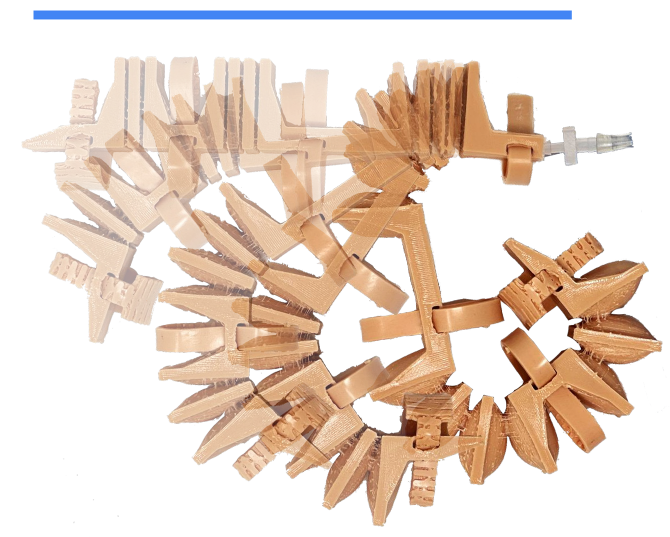
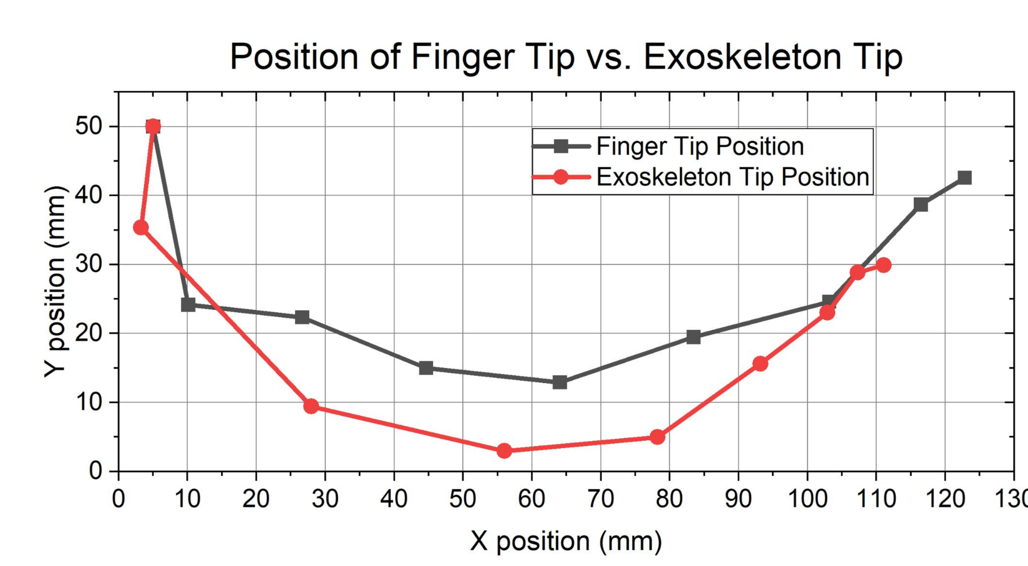
Main Contribution

- The design of fully FDM-printed soft hand exoskeletons for 3D printing with commercially available desktop 3D printers.
- Enhanced designs tailored to accommodate diverse finger sizes and trajectories for optimal comfort.
- Application of our vision-based, closed loop printing process to 3D print high-quality and impermeable soft devices.

Experiments

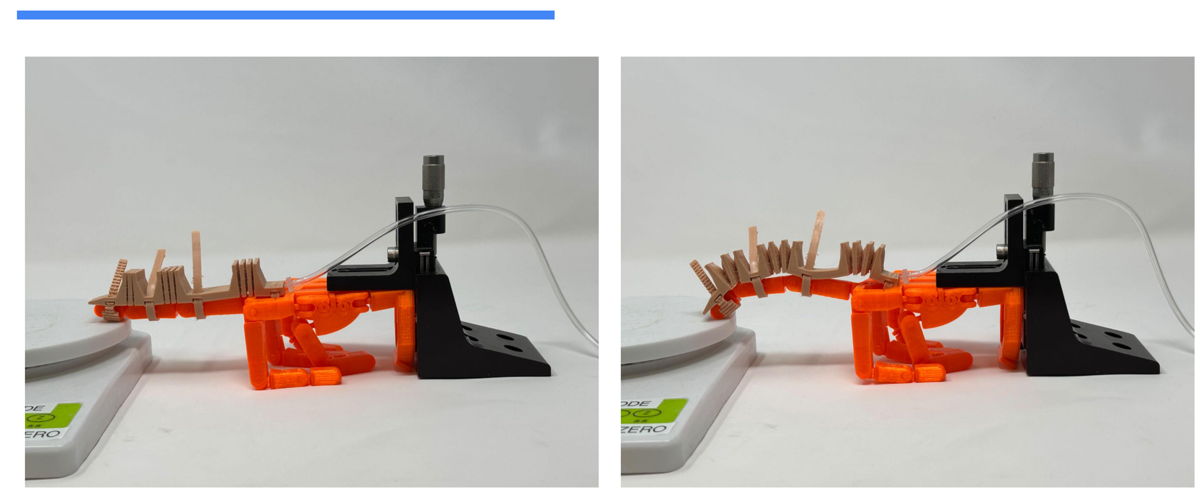
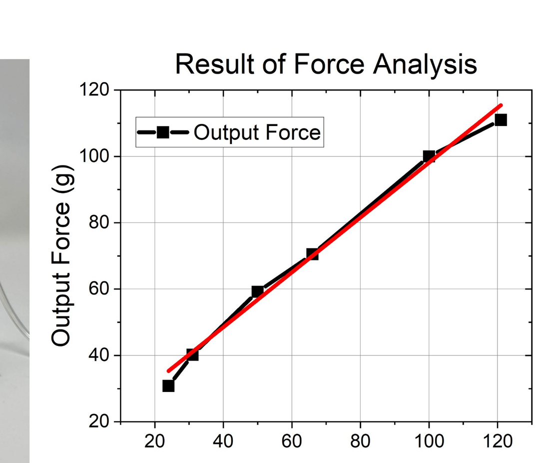
Experiments were conducted with objects requiring different grasp types. The human subject was able to hold objects weighing from approximately 20g to 400g without exerting any voluntary force via finger muscles.

Trajectory Analysis

The correspondence between the voluntary movement trajectory of the fingertip and the trajectory of the exoskeleton tip during inflation highlights the alignment with natural human finger movements.

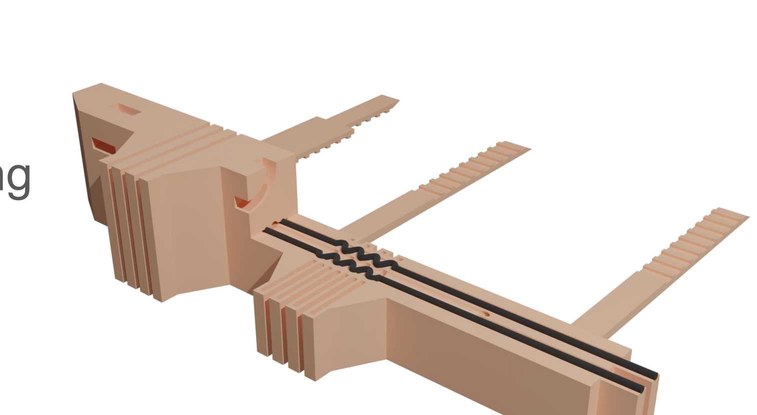
Force Analysis

The experimental setup illustrates the measurement of input air pressure versus the force exerted by the exoskeleton fingertip. To mitigate external influences, a hand skeleton is employed, ensuring fidelity to human hand structure. The observed correlation between pressure and force demonstrates a near-linear relationship.

Ongoing Work

Our current work focuses on multi-material printing to embed conductive TPU material as sensing elements for the state estimation of the exoskeleton. This approach could enable data collection for rehabilitation and feedback control.



Citations

[1] Wang, Jiangbei et al. "Design, Modeling, and Testing of a Soft Pneumatic Glove With Segmented PneuNets Bending Actuators." IEEE/ASME Transactions on Mechatronics 24 (2019): 990-1001.

[2] Y. Wu, Z. Dai, H. Liu, L. Wang, and M. P. Nemitz, "Vision-based FDM Printing For Fabricating Airtight Soft Actuators," 2024 IEEE International Conference on Soft Robotics (RoboSoft), San Diego, United States, 2024.

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