An Anatomically Accurate Biomimetic Robotic Hand with Textile Connective Tissues

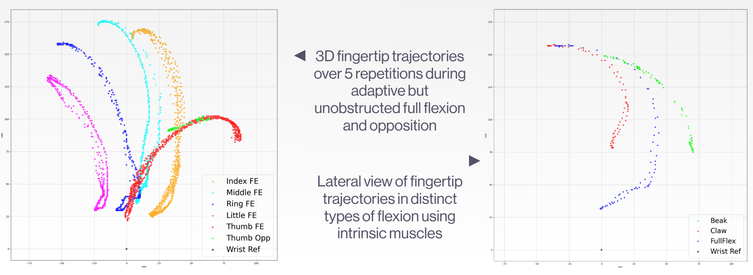
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Even the most advanced robotics are still mostly unnatural in feel and function - prosthetic embodiment is inadequate, abandonment rates are high. How can modern design and production technologies help?

Artificial hands are developed and employed widely for solving challenges in present-day robotics, with an increasing number of such systems being integrated into our daily lives. For humanoid or human-centric applications in medical or industrial sectors demanding increased naturality, biomimetics offers a promising approach [1][2]. However, replicating biological structures and functions to the detail commonly results in excessive complexity in both design and production, preventing widespread adoption [3][4][5]. This work presents a biomimetic hand developed with the use of modern procedural design methods and additive and textile production technologies, evaluated with a modular actuator frame through grasp and gesture demonstrations and finger trajectory analysis. The results aim to exemplify how leveraging these advancements may enable the creation of naturally compliant robotic devices with intricate functionality, while simultaneously satisfying the industrial requirements for robustness, cost-effectiveness and production scalability, therefore bringing the universal applicability of such systems within reach.

Result: an easy to produce, highly biomimetic hand



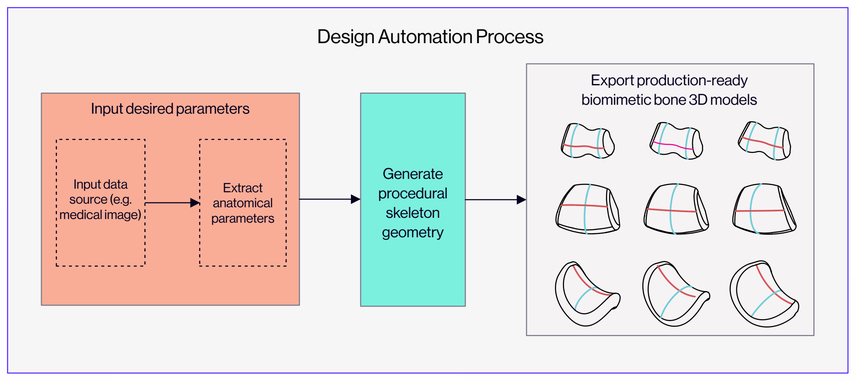
The life-sized prototype is actuated by a modular forearm frame, which can be configured to either a compact or an extended version for prosthetic or industrial applications respectively, with varying detail in finger and wrist control. High-power N50 and coreless DC micromotors are used with worm gearboxes (7 for the simple, 16 for the complex version) to achieve ~15N grip strength with up to 0.5s full closing speed, and holding torque limited only by tendon strength and mechanical integrity. The complete wireless system weighs 1.2-1.45kg (actuators and batteries included), depending on the forearm version used.

For validation, finger trajectory analysis was performed via a single 120 FPS camera and a marker-tracking Matlab implementation resulting in curves highly similar to cadaveric measurements [10]. Demonstrations of the Grasp Taxonomy [11] were also examined, finding the compact hand capable of performing 28 out of 33 grasps, while the extended system enabled the performance of all 33, alongside advanced movements such as claw and beak finger requiring independent intrinsic muscle activity.

The developed hand serves to highlight how recent advances in procedural design methods and flexible manufacturing technologies can enable the production of highly biomimetic systems that are naturally soft and durable at once, combining geometrical complexity with simple, cost-efficient production, and through this, promote the viability of their integration into artificial limbs and similarly sophisticated systems in rehabilitation and robotics in general.

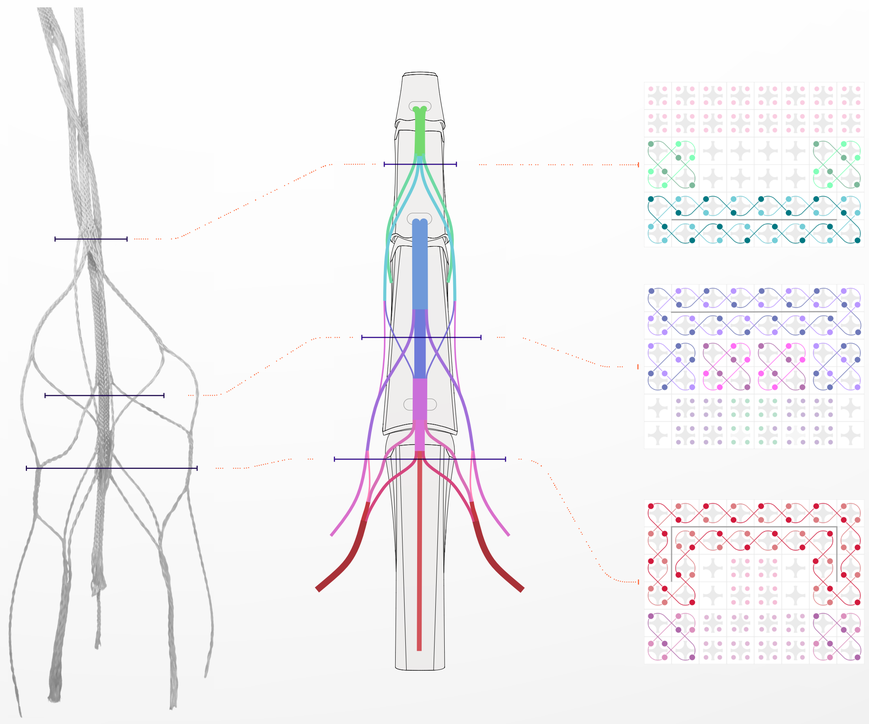
Materials and Methods: Scaling and Automating Biomimetic Tissues

Procedural Skeleton



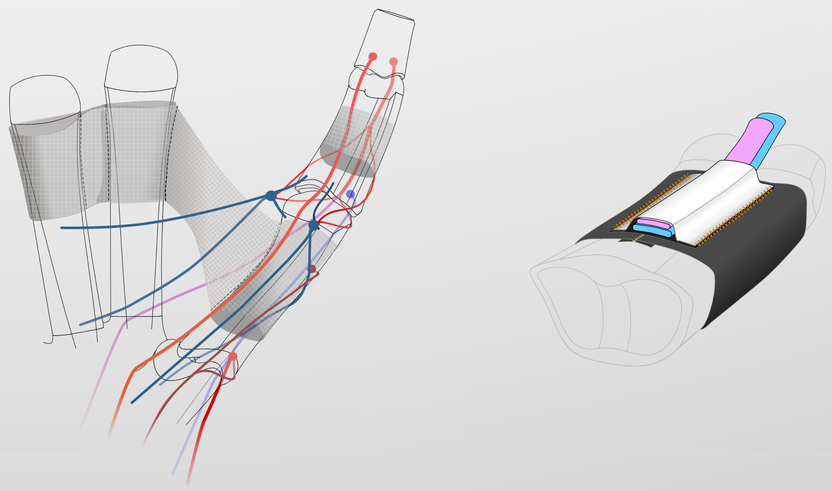
- Automated modeling of anatomically correct surfaces & exporting production ready components, built in CAD software (PTC Creo Parametric 11)
- Procedural generation of articulating joints from just a few key parameters (e.g. joint size, bone length, desired RoM and DoF)
- Capable of generating biomechanically accurate ginglymoid, condyloid and saddle joints (for now) with natural obliqueness, RoM and DoF distortions [6]
- Parameters can be extracted from medical images (e.g. X-ray) for deep personalization, supported by semi-automatic software

3D Braided Tendons

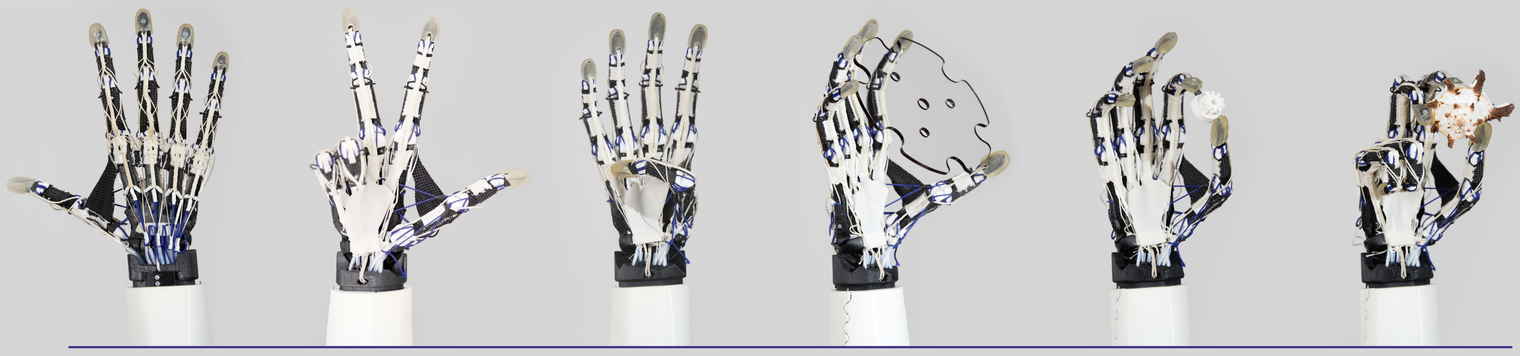


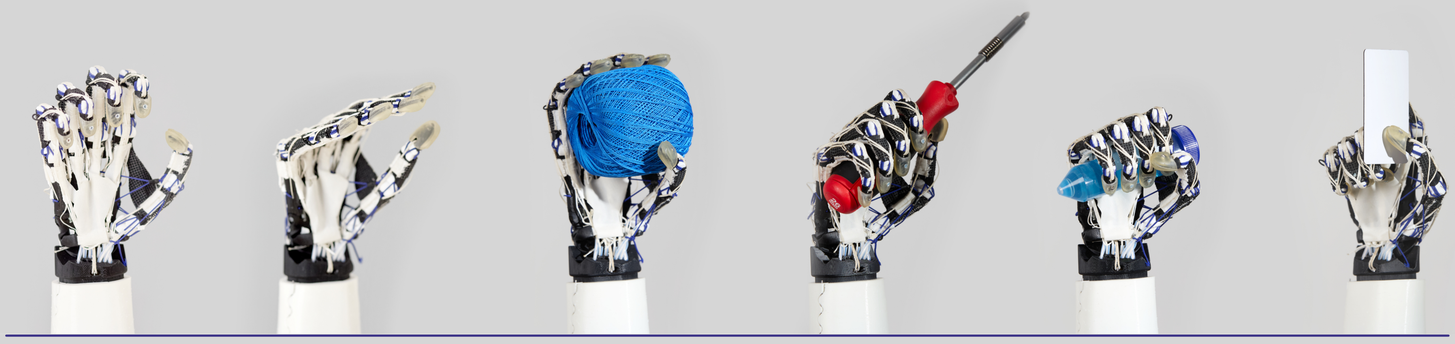
- Producing elaborate anatomical networks as soft and strong, homogeneous multi-branching braided structures to avoid forming weak points at intersections
- Proprietary, custom 3D braiding [7] machinery and visual scripting software for highly automated manufacturing and freedom of design
- Highly tensile PES fibers interlaced in mimicry of collagenous tissue microstructures - tensile strength similar to human tendons (breaking load at ~170kg for cross-section of ~8mm^2) [8]
- Simplifying the assembly of complex mechanisms - only requires connecting to the actuator and fixation at tendon insertion points

Textile Reinforcements



- Intrinsic muscles [9] can be actuated independently towards fine motoric control, or enhance compliance in underactuated configurations when passivated by elastics (shown in blue)
- Tendon pulleys and palmar ligaments formed out of bilayered, low-friction nylon fabric sheaths reinforced by UHMWPE fibers
- Fat and muscle pads realized as lightweight, 3D printed lattice structures of spatially varying density
- Soft, removable skin based on a simple, two-layer sewing pattern designed to allow natural flexibility and wrinkling around joints





References & Acknowledgement

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