Hand Development Kit: Soft Robotic Fingers as Prosthetic Augmentation of the Hand

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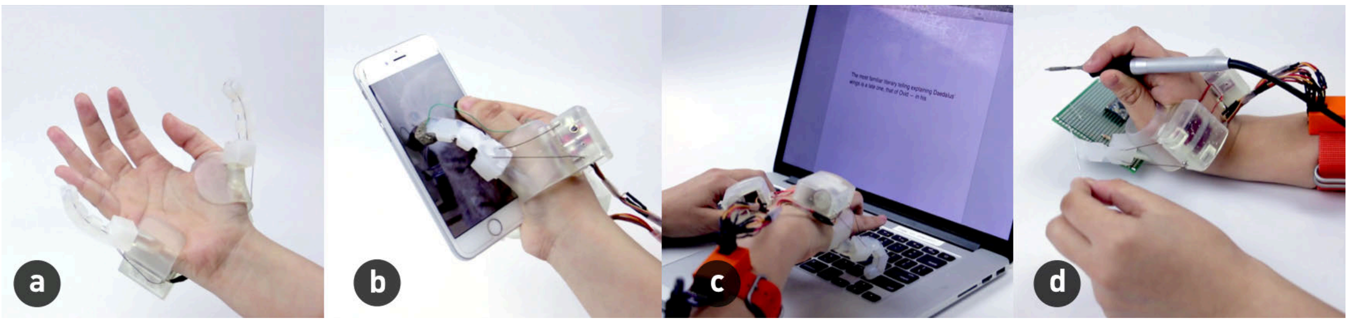

Figure 1: a) The configuration of our system. b) performing multi-touch gesture with the soft robotic finger. c) the soft robotic finger supports keyboard typing. d) the fingers can hold and adjust the position of an object in tri-manual tasks.

ABSTRACT
Recent developments in wearable robots and human augmentation open up new possibilities of designing computational interfaces integrated to the body. Particularly, supernumerary robot is a recently established field of research that investigates a radical idea of adding robotic limbs to users. Such augmentations, however, pose a limit in how much we can add to the body due to weight or interference with other body parts. To address that, we explore the use of soft robots as supernumerary robotic fingers. We present a pair of soft robotic fingers driven by cables and servomotors, and applications using the robotic fingers in various contexts.

Author Keywords
Synergistic Interaction; Human Augmentation; Wearable Robotics

ACM Classification Keywords
H.5.2 User Interfaces: Input devices and strategies (e.g., mouse, touchscreen)

INTRODUCTION
The field of robotics has investigated wearable robots for increasing human capabilities, assisting users with disability or augmenting physical abilities of users with normal physiology. Parallel-limb exoskeletons and prostheses are well known examples, that are designed to enhance existing human limbs or to substitute lost ones with replacements of equivalent functionality [3]. But two other forms of wearable robots pose a more interesting potential for human augmentation, that are series-limb exoskeletons and Supernumerary Robots (SR) [1, 2, 4, 7]. Particularly, SRs do not need to strictly follow human biomechanics since they are designed to add extra actors to the body.

Various forms of SR fingers have been presented along with various control strategies [7, 8], where they mostly focus on making robots behave similarly to human ones. Recent studies presented a wider variety of interaction scenarios [5] and customizable design [6] of SR fingers. However, most of the prior works remain utilizing rigid mechanical structures and actuators, that pose limitation in how much or what kind of mechanisms we can add to the body.

To address that, we propose supernumerary soft robotic fingers. Soft robots have several benefits over rigid mechanical systems – they are lightweight and compliant, and a single robotic part can undergo higher-dimensional actuation. By using a standard molding-casting process, we aim to demonstrate how we can standardize the fabrication of SR fingers. We also present applications using our system such as supporting touch interaction on smartphones, keyboard typing, and object manipulation.

IMPLEMENTATION
Our device is composed primarily of parts easily accessible or made using standard fabrication processes. In addition to that, the tendon-based system we used allows all other

UIST '17 Adjunct, October 22–25, 2017, Quebec City, QC, Canada

ACM ISBN 978-1-4503-5419-6/17/10.
https://doi.org/10.1145/3131785.3131805

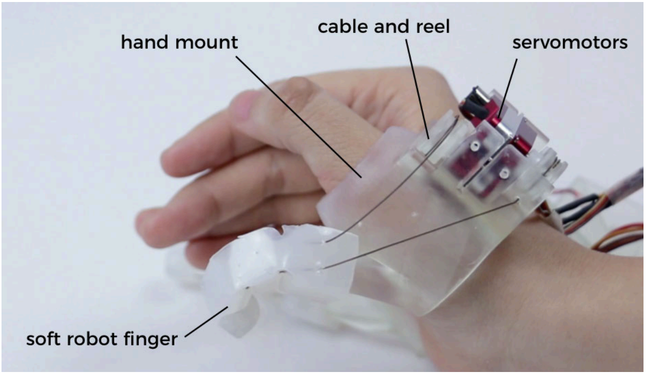

Figure 2: Configuration of our system. The servomotors are mounted on the back of the hand attachment module, pulling the strings for robotic control.

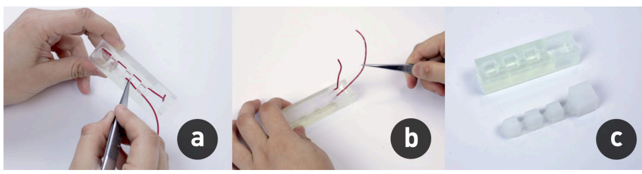

Figure 3: Fabrication process of the robotic fingers. a) channels are created by threading wires into the mold. b) after curing, the wires are pulled out to leave the channel open. c) final casted finger piece.

electronic parts to be contained separately from the soft robotic actuator, making the entire system modular (figure 2). Once a finger with different size or motion is needed, one can simply fabricate a new soft robotic finger with the desired properties and replace the ones no longer needed.

Soft Robotic Finger

A soft finger is casted using a 3D printed mold with DragonSkin 3A material. Our design includes teeth on one side, guiding the constriction pattern of the finger when driven by tendon wires. Two channels for tendon wires are created while casting the soft robotic finger (Figure 3 a, b). Tendon wires through the channels are reeled onto servomotors, that drive two-dimensional motions of the finger (figure 4)

The current prototype is composed of a uniformly distributed teeth structure and two tendon wires, where potentially alternative designs can be used for more articulated motions.

Hand Attachment Module

The robotic fingers are mounted on the hand through an attachment module worn around users' fingers. The module has a horn onto which a robotic finger can press-fit, in addition to a servomotor mount on the back. The horn angle and placement can be easily customized, therefore, a user can choose modules based on what s/he needs. In this demo, we present two designs of attachment modules – one on the thumb side and one on the fifth digit side (figure 1 a).

DEMO APPLICATIONS

Our demo applications are designed for users with varying degrees of physical fitness. The applications can help users

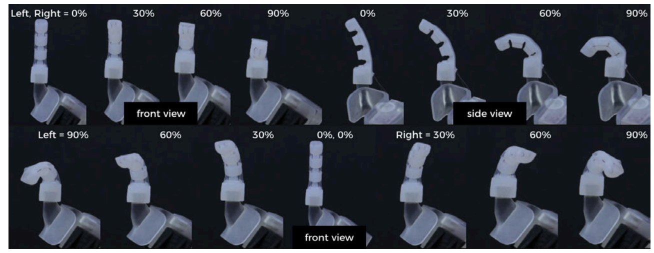

Figure 4: Front and side view of the tendon driven control. The use of two tendon wires allows for expressive control of the robot in 2D control space.

with motor disability to achieve normal capability, as well as users with normal physiology to utilize the additional fingers for more complex actions.

Touch and Keyboard Interactions

The extra thumb can assist in touch interactions on a smartphone (figure 1b). The soft robotic thumb can perform touch gestures on the screen, including scroll and navigating forward/backward. In addition to that, the robotic and a user's thumbs can collaboratively perform multi-touch interactions such as zooming.

For the implementation, we mounted a piece of conductive fabric on the fingertip to enable capacitive touch. Touch gestures are preprogrammed in our software, that are executed through a simple function call. Future systems can utilize electromyography sensors to acquire residual muscle signals from a thumb amputation site, where the gestures are triggered through pattern matching.

The robot can also help executing key combinations on a keyboard. Pressing keys such as shift, control, or alt, can be automated by the robotic finger, increasing efficiency and auto-correcting users' mistakes (figure 1 c).

Object Manipulation

The additional fingers can also hold and manipulate target objects while a user is operating on those. A good example would be soldering, in which we often need clamps to fix soldering targets. Using our robot, a circuit board can be held within the hand, as well as its orientation adjusted to afford an optimal setup for soldering (figure 1d).

CONCLUSION

In this paper, we proposed supernumerary soft robotic fingers. They are lightweight, compliant, and offer higher-dimensional actuation compared to rigid mechanisms such as servomotor joints. The soft robotic can be fabricated easily through a standard molding-casting process, where alternative design of the channel and teeth structure can be incorporated if a more complex behavior is necessary. We also presented applications for touch gestures on smartphones, keyboard typing, and object manipulation.

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