NailO: Fingernails as an Input Surface

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ABSTRACT
We present NailO, a nail-mounted gestural input surface. Using capacitive sensing on printed electrodes, the interface can distinguish on-nail finger swipe gestures with high accuracy (>92%). NailO works in real-time: we miniaturized the system to fit on the fingernail, while wirelessly transmitting the sensor data to a mobile phone or PC. NailO allows one-handed and always-available input, while being unobtrusive and discrete. Inspired by commercial nail stickers, the device blends into the user's body, is customizable, fashionable and even removable. We show example applications of using the device as a remote controller when hands are busy and using the system to increase the input space of mobile phones.

Author Keywords
Capacitive touch; printed electronics; beauty technology; gesture recognition; wearable electronics

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
In this Ubiquitous Computing era, we have witnessed increasing levels of technology embedded in our surroundings, blurring the boundary between physical and digital worlds. Moving beyond environments, the near-ubiquity and miniaturization of sensor devices enables technology close to our bodies, redrawing the line between technology and ourselves. In ways, people have started to view on-body devices as extensions of self [8]. Pushing this notion, Holtz et al. [7] implanted interfaces under the human skin, exploring interfaces that are *with the user at all times* and truly *always-available*. However, as medical purpose implants already raise social, ethical, and privacy concerns [4], the acceptability of implanting for pure interaction purposes are still left in question. Drawing inspiration from the multi-billion dollar cosmetic industry, we present a solution towards acceptable implant-like interfaces in the form of cosmetic extensions.

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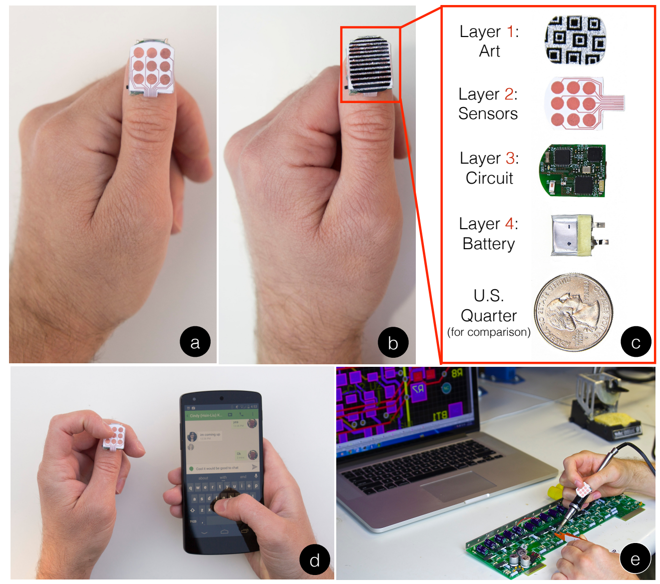

Figure 1. NailO prototype and applications: (a) Miniature and wireless prototype worn on the fingernail. (b) Sensor customization with additional nail art layer. (c) NailO is made of 4 layers. Each layer is shown individually, stacked on top of each other. (d) NailO used to increase input space of a mobile phone. (e) NailO used as remote controller for one-handed input, when the hands are busy.

Products such as nail art stickers and fake eyelashes are widely accepted as extensions to the body for decoration and self-expression. They seamlessly blend into our physical bodies when attached, and are easily removable. As people already wear these products for fashion purposes, we propose embedding technology into these products to extend their functionality and utility to interaction.

To afford usability in the form of cosmetic extensions, three main design themes must be realized: First, the interface should be small and unobtrusive. It should be designed with technology that can be miniaturized to the size of cosmetic products. When worn, it should be comfortable to an extent its existence could be forgotten. Second, the interface should afford natural interactions. The interactions should be simple, intuitive and require minimal cognitive mapping, building on natural body gestures. Third, the interface should be appealing and easy to wear. Like clothing and accessories, the interface can be easily customized. The mounting and removal process should also be simple and similar to existing cosmetic processes. As no device exists that satisfies the above criteria, our work is motivated to do so.

To the best of our knowledge, there is no device that leverages the fingernail as input interface. As a first step towards the vision of cosmetic-inspired wearables, we present NailO (Figure 1), a nail-like capacitive sensing interface to augment the fingernail into a robust yet fashionable input device.

The contributions of the paper are as following:

1. We present a novel input interface that leverages fingernails as input surface and develop a nail-mounted wireless and real-time capable prototype.
2. We perform user studies to assess performance and appeal.
3. We implemented scenarios to explore interactions.

RELATED WORK

Nail and finger mounted devices: Researchers have explored nail mounted outputs such as small displays [9]. For inputs, nail mounted cameras [5] were demonstrated. Furthermore, FingerPad project [3] presented Hall effect sensors to turn the fingertip into a touchpad. However, the project does not leverage the nail as an input surface, and requires bulky finger-mounted hardware. We are not aware of any project that leverages fingernails for input. All of the above-mentioned projects were wired for power and communications. In this project, we demonstrate a wireless and easy-mounting hardware solution. In contrast, rings as input were explored by a number of projects, such as magnetically tracking the rotation of the ring [2] and ring-mounted accelerometers [11].

Beauty Technology: Vega et. al. presented the vision of merging technology into beauty products as a new form of wearable computing [10]. Our work continues this vision and goes beyond the capabilities of decorative on-body electronics; NailO affords functional gesture input.

Capacitive Sensing with Printed Circuits: Conductive Inkjet Printing has created a low-cost and versatile solution for capacitive sensing [6]. Inspired by the paper-like form factor of printed circuits, we apply this technology to a sticker-like nail interface.

THEORY OF OPERATION

Capacitive touch sensing

NailO uses projected capacitance to sense finger touch gestures. In this method, the capacitance is measured on each electrode independently. During a touch event, a capacitor is formed between the finger and the sensing electrode. This capacitance is sensed indirectly by charging and discharging a resistor-capacitor (RC) circuit. With a known resistor, the charge time of an RC circuit is proportional to the capacitance. We choose capacitive sensing over resistive because a custom sensor can be fabricated with accessible technology.

Electrode Layer Design

We designed several conductive electrode patterns to fit the size of a fingernail and manufactured it using low-cost, roll-to-roll Conductive Inkjet Technology [1]. Drawing inspiration from the electrode designs for capacitive touch screens, we prototyped spatially separated electrodes in both single layer and two layers. For the single layer, each electrode represents a different touch coordinate pair and is connects individually to a controller (Figure 2, layer 2). When the electrodes are in two layers, they are arranged in a layer of rows and a layer of columns; the intersections of each row and column represent unique touch coordinate pairs. Because of difficulties of making two-layer in conductive inkjet technology we chose the single layer design. The two layer design is more appropriate for flex PCB technology.

PROTOTYPE

Hardware

Figure 2 presents the NailO system design. We constructed the hardware such that it fits on a fingernail. The hardware consists of four layers (top to bottom): (1) A decorative nail sticker layer for users to customize sensor appearance, (2) the matrix of sensing electrodes, (3) a printed circuit board (PCB), as shown in Figure 3 consisting of an ATmega328 (Atmel) microcontroller and MTCH6102 (Microchip) capacitive touch controller. The samples are transmitted to a laptop or a phone using Bluetooth Low Energy chip nRF8001 (Nordic). (4) a 10 mAh lithium-polymer battery powered the circuit.

With the mean power consumption of 4.86 mA, the device can wirelessly transmit data for at least 2 hours. This represents the worst case scenario, as no power optimization was performed. The battery life can be greatly increased by implementing a sleep scenario, e.g., waking up and transmitting when a touch event is detected.

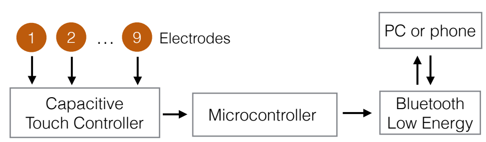

Figure 2. The system design.

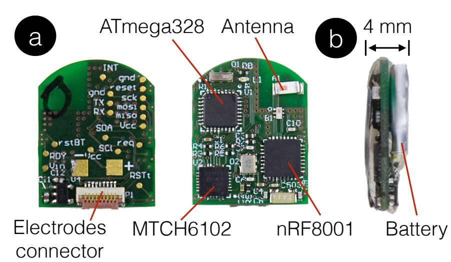

Figure 3. (a) PCB top, bottom. (b) side view of NailO's 4 layers.

Software

To embed the software on-chip for future iterations, we choose a thresholding algorithm over machine learning for a lightweight solution. However, from our pilot studies we found the baseline capacitive sensor values to differ between people, and therefore included an initial calibration phase to find the optimal parameters for each user. After calibration, the system feeds the optimal parameters to the gesture detection algorithm. The electrode matrix is presented as a Cartesian coordinate. For the 3 x 3 sensor grid, the sensor at the lower left corner is set as the coordinate origin. The software

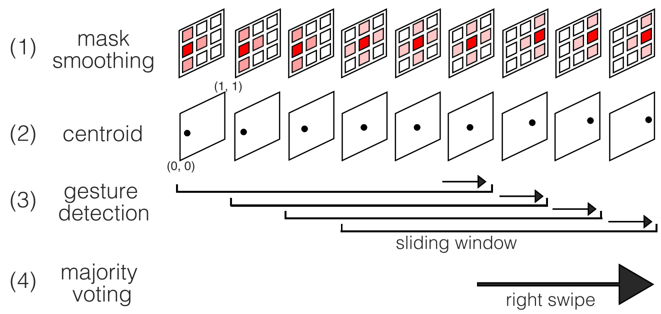

Figure 4. Software: Gesture detection algorithm.

reads in sensor data at around 30 frame/sec, feeding it into the algorithm. As shown in Figure 4, the gesture detection algorithm consists of four main steps, (1) spatial mask smoothing on the raw sensor values for each frame, (2) centroid calculation for each frame, (3) applying a sliding window to calculate centroid position change for gesture detection, (4) majority voting to output detected direction.

USER STUDY

Protocol

We recruited 10 participants (5 male, 5 female) from ages 21 and 28 (mean 25.5). 5 gestures were tested (Figure 5). Each study took about 40 minutes, and had two phases:

(1) *User study*: We mounted the electrode layer on the index finger of the user's dominant hand with cosmetic nail tape. Users were asked to perform swipe gestures with their middle finger using the 3x3 single layer electrodes. The participants had the option to choose a decorative nail sticker layer to apply on top of the electrodes. The 5 tested gestures include left/right swipe, top/down swipe, and long press (Figure 5). We choose this gesture set as they are commonly used input interactions which require low cognitive load.

For calibration, we collected 5 data sets for each gesture, sampling 40 data samples in a 2 sec interval for each data set. The data collection time took around 1 min. The calibration data was used to compute the optimal parameters.

For evaluation, on-screen instructions prompted participants to perform specific gestures. Each gesture was tested 12 times with a total of 60 gestures.

(2) *Post-study interview*: We elicited qualitative feedback towards the system: which gestures were favorable/unfavorable; preference for sensor appearance customization, and how the participant would use a nail-mounted sensor in everyday life. This feedback assisted us in the design of applications for NailO.

Results and Discussion

Accuracy: Accuracy is defined as the number of correctly detected gestures divided by the total number of gestures. The accuracy due to chance was 20%. The system achieved mean accuracy of 92.3% (SD: ±6.8%). Misdetection mostly occurred in the swipe down gesture. The nail curvature caused several right-hand participants to shift left towards the end of the swipe down gesture, resulting in lower accuracy.

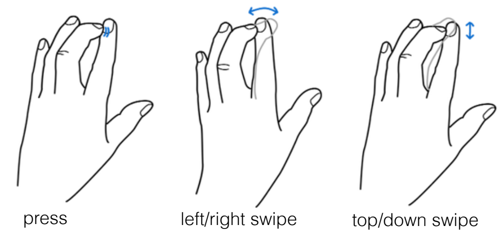

Figure 5. Gestures used in the user study

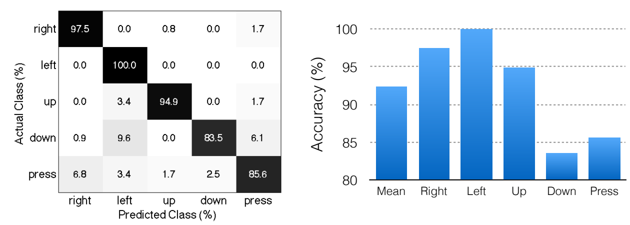

Figure 6. User study results. Left: confusion matrix for all participants. Right: overall mean accuracy and accuracies for individual gestures.

Alternative gestures: From the pre- and post-study interviews, the participants suggested alternative gestures, as depicted in Figure 7. We observed that participants with different hand structures preferred different fingers to perform gestures. Swiping with the middle finger was difficult for participants with middle and index fingers of similar length. Users found elongating the middle finger straining; these participants suggested thumb-based interactions. However, participants with longer middle fingers found the tested gesture natural and comfortable. For future iterations, we plan to manufacture the sensors for all ten fingers, allowing participants to select the nail sensor placement based on individual preference. Is it also necessary to print the electrode substrate in different sizes to fit different users.

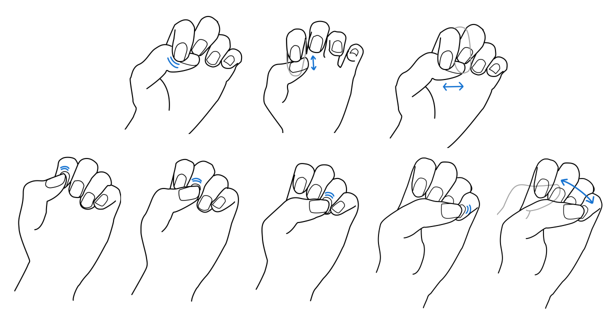

Figure 7. Alternative gestures (1) Thumb gestures (2) NailO on multiple fingers for continuous cross-finger gestures, and also discrete input.

Customizing the sensor: 8 out of 10 participants found it appealing to attach a nail sticker on top of the electrodes. Female participants were especially enthusiastic; they expressed they were more likely to use NailO on a regular basis if they could customize the designs. During the study, they carefully selected nail art designs which reflected their fashion style. Two of the male participants were also receptive to the nail decorations, but preferred simple, single-colored designs.

Other male participants either found the idea of decorating their nails unattractive, or preferred the cyborg look of the electrodes and chose to leave them exposed. One user also suggested a realistic nail design.

False Positives: For NailO to be worn in everyday life, it is important to avoid accidental recognition of gestures, i.e., false positives. We propose the use of an activation gesture, a 2-second press, before any other gestures can be performed. For activation to happen the mean of all electrodes has to remain above a predefined threshold for 2 seconds. With 5 participants (male: 3, female: 2) activation gesture was detected with 100% accuracy. Also, participants found the gesture intuitive and easy to perform. Futhermore, we found that the activation gesture was never detected accidentally when participants performed the swipe and press gestures.

APPLICATIONS

Building on participant feedback from the study, we show two use cases for NailO in Figure 1 and the accompanying video.

1. Remote control: *(1) Hands-full scenario*: As our fingers are dexterous, they have capability for simple interactions even when both hands are occupied. We developed an application for electrical engineers to navigate PCB designs on devices while both hands are occupied with soldering. Without having to break from the soldering process, they can zoom into the on-screen board layout with long press, and navigate by swiping in four directions.

(2) Private and subtle interaction: For scenarios where gesture or speech input are socially awkward or privacy intrusive; NailO affords gestures that are implicit and attract minimal attention. An example scenario is simple interactions with devices while in meetings. As it is considered impolite to openly interact with technology in these situations, NailO affords basic input to subtly control unexpected prompts from devices, such as rejecting a phone call.

2. Expanding the input space: Fingernails are an easily accessible location, so they have great potential to serve as an additional input surface for mobile and wearable devices. Such devices are typically small and thus are difficult to use for complex input. We present a mobile typing application where the user does not have to switch between different keyboards. When typing with the English keyboard, the user can employ nail swipe gestures to input punctuation or emoticons without having to alternate keyboards.

LIMITATIONS AND FUTURE WORK

Hardware: The envisioned form factor of NailO should be comparable to that of a commercialized nail art sticker. To achieve this, we are prototyping a flex PCB version of the circuit with an integrated electrode layer. The flex PCB will conform to the curved surface of the nail. The battery life is the limiting factor for the size and lifetime of the device; we plan to explore wireless powering options, to remove the battery and allow perpetual operation.

Input and Output: Beyond including the gestures in Figure 7, with flex PCB we can prototype robust 2 layer electrodes, turning the NailO into a X-Y coordinate touchpad. Along with the addition of an accelerometer, we can expand the input space to contact-less gestures. The system can also become an output device with the addition of LEDs or vibrators.

CONCLUSION

In this paper we present NailO, a novel nail-mounted input surface. The miniaturized hardware fits on a fingernail and wirelessly transmits data. We show that the system can detect gesture inputs in real-time with high accuracy (>92%). Also, we explored interaction scenarios using NailO as a remote control in ”hands-full” or privacy-sensitive use cases. NailO also broadens input space when coupled with mobile devices. Further, NailO’s customizable features fuses functional wearable electronics and cosmetics, which appealed to study participants. NailO is our first exploration; we plan to augment other cosmetic extensions to continue our study of cosmetic-inspired wearable technologies.

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