NailDisplay: Bringing an Always-Available Visual Display To Fingertips

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ABSTRACT
This work presents a novel and always-available nail mounted display known as *NailDisplay*. The proposed display augments the use of a finger by allowing for always-available visual feedback owing to its fast accessibility and binding user controls with the display, *i.e.* what you control is what you see (through the display). Potential benefits of *NailDisplay* are demonstrated in three applications: from displaying to combining it with user controls. In the first application, *NailDisplay* can reveal what is occluded under a finger touch, making it a solution to operate small UI elements. In the second application, *NailDisplay* is complementary to an imaginary interface, helping users to learn an imaginary interface (*e.g.*, on the users' arms) and allowing them to reassure the interface when their memory of it becomes unclear. In the third application, *NailDisplay* is integrated with rich finger interactions, such as swiping in the air. We also report users' feedbacks gathered from an explorative user study.

Author Keywords
Always-available display; Nail-mounted device; Transparent finger

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interfaces: Interaction Styles

INTRODUCTION
A finger nail can easily control the visual display of a mobile device, owing to its flat and smooth surface, as well as visibility while users' hands are involved in manual tasks. While nail beauty is a major aesthetic in the fashion industry[1], display technologies increasingly emphasize flexibility and durability in product use[2]. We believe these two fashion and display technology trends will soon converge.

[1]http://aboutnails.info/
[2]http://www.oled-info.com/flexible-oled

CHI 2013, April 27–May 2, 2013, Paris, France.

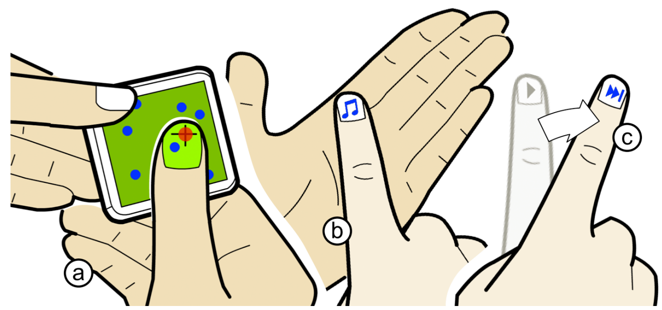

Figure 1. Three scenarios of operating with *NailDisplay*. **(a)** *NailDisplay* **allows users to select small targets precisely with their fingertips becoming transparent. (b)** *NailDisplay* **helps users learn imaginary interface and reassure a function (e.g., play music) when their memory of the interface becomes unclear. (c) Users can switch to the next music selection by swiping their fingers rightward with** *NailDisplay*.

Early works on finger mounted devices developed schemes to augment fingers with a haptic display. In such approaches, vibrators are attached to fingernails in order to generate tactile feedback on the touch screens [1, 2]. FingerSight [5] extended this idea by mounting additional cameras on fingertips, allowing for individual fingertips to view objects and transmit signals back through tactile feedback. SenseableRays [15] added a photo sensor, which transfers projected patterns to tactile feedback. SmartTouch [11] envisioned a new layer of skin made of a thin circuit capable of generating tactile output on fingertips through electrical stimulation. FingerFlux [18] augmented a fingertip with a more expressive, attractive and repelling force by mounting a passive magnet on the fingertip.

Previous research also demonstrated how to sense finger-based interactions, including finger pointing [13], tapping [14], bending [20, 16], and clicking [9]. This work adopts a different approach to finger mounted devices in order to turn fingernails into visual displays. Instead of a replacement, *NailDisplay* is considered here to be complementary to tactile output and other input methods applied to fingertips.

This work presents an always-available nail mounted visual display, known as *NailDisplay*, which binds user controls with the display. Figure 1 illustrates three possible scenarios for *NailDisplay*. In the first scenario, *See-Through Touch* reveals what is occluded under a finger touch, allowing for precise pointing and operations with small UI elements. In the second scenario, *Touching the Imaginary* allows users to

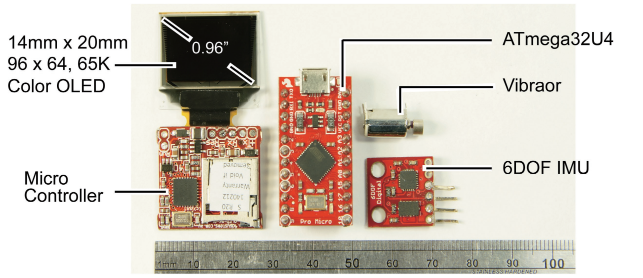

Figure 2. ***NailDisplay*** **prototype, which consists of a 0.96” OLED display module, ATmega32U4 microprocessor, and sensors such as a 6DOF IMU and a vibrator, depending on the experimental applications**

learn and reassure the imaginary interface when the memory of the interface becomes unclear. In the third scenario, *Free Finger Interaction* transforms finger movements (*e.g.*, swipe) into visual output, allowing for free finger interactions.

In contrast to other always-available visual displays (*e.g.*, projections on a body [8] and wrist watches [9]), *NailDisplay* creates a symbiotic input and output on the fingertip, subsequently minimizing visual separation between the input and output and ultimately allowing for a direct input display scheme with no location constraints. Moreover, in contrast to solutions to fat finger problems using special visualization approaches (*e.g.*, Shift [17]) or back-of-device interaction [3], *NailDisplay* transforms fingertips into a transparent display, allowing users to see through their fingertips for precise selection without modifying the original interface.

PROTOTYPING

To fit the curve of a nail and to superimpose contents, the flexible t-SWNT film [19] is an advanced technology. However, no functional module as small as a normal nail is commercially available. Therefore, this work adopts the 4D Systems 0.96” OLED module, which is rigid and slightly larger than the adult thumbnail yet is still reasonable for the proposed prototype. According to Figure 2, the display module has a 20mm x 14mm screen, allowing for a resolution of 96 x 64 with 65K colors for each pixel. An Arduino board with an ATmega32U4 microprocessor is used to bridge the display module with other electronics (*e.g.*, accelerometer or vibrator) for I/O, depending on the applications. To compensate for this slightly larger and opaque screen, an image of natural nail appears on the screen and the display content appears only in the nail area to simulate a smaller nail display (Figure 3). An adjustable finger ring allows for easy wearing, and the portion around the fingertip is left open for native haptics.

POTENTIAL APPLICATIONS

This section introduces potential applications of *NailDisplay* when used with user controls.

See-Through Touch

Fat fingers make direct touch inoperable with small UI elements accurately [3]. *NailDisplay* allows for a transparent fingertip, making it a feasible means of mitigating this problem. According to Figure 4a, users operate with a virtual keyboard, allowing them to instantly view the key pressed on the fingernail. In this case, *NailDisplay* reveals what is occluded

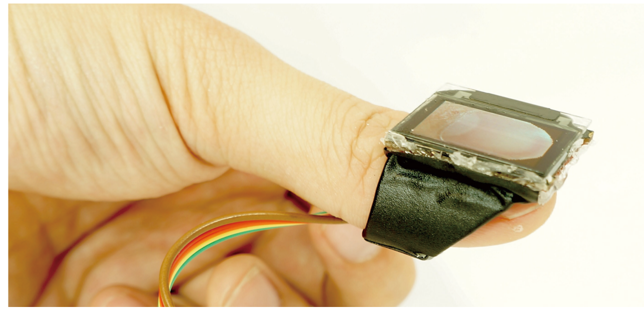

Figure 3. Resulting screen on the fingernail, which is 5mm-thick. The prototype is combined with an adjustable finger ring, allowing for easy use. The portion around the fingertip is left open for native haptics.

under the fingertips and helps users to confirm each touch action. *NailDisplay* also allows users to point to an extremely small target. Figure 4b demonstrates this notion. The cross hair shown around the fingernail tip [10] displays a precision pointer. Users complete a selection by taking off the finger. In contrast to Shift [17], which creates a callout of the occluded content, *NailDisplay* shifts the content to the fingernail.

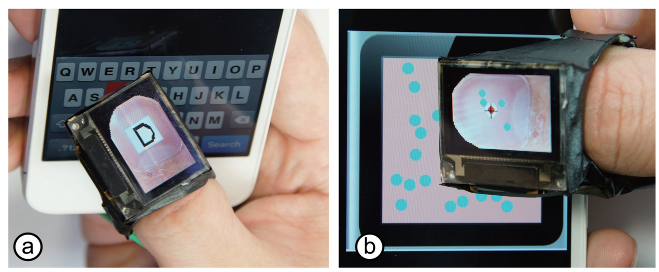

Figure 4. (a) Use of ***NailDisplay*** **to type on a virtual keyboard by revealing the key of press. (b) The occluded content shifts to** ***NailDisplay*****, allowing users to point to a small target. Notably, in this application, a watch size screen is simulated on a large touch screen.**

Touching the Imaginary

NailDisplay tightly binds a finger touch with the display, allowing visual outputs for devices without screens. According to Figure 5, users browse through musical selections stored in a screen less media player. To achieve this, a pressure strip sensor is attached along the center of the music player, along with a long capacitive button beneath. When users touch the pressure sensor, *NailDisplay* displays the current mode (*e.g.*, album, artist or song lists). Users switch to another mode by swiping their fingertip against the device edge (Figure 5a), and navigate through artists by moving their finger along the pressure sensor (Figure 5b). When a musical artist of interest is found, users play that particular musical selection by again sliding their fingertip against the edge of the musical device.

NailDisplay, once worn, is always available, allowing for maximum mobility. *NailDisplay* is thus considered here as an auxiliary output to an imaginary interface, which relies on the spatial memory of users [6]. In addition to helping users to learn an imaginary interface, *NailDisplay* allows them to reassure the interface when their memory of it is unclear. For instance, this work demonstrates the feasibility of using *NailDisplay* as a visual output for an arm input interface [12]. In Figure 6a, the wrist watch as enhanced by an ultrasound rangefinder can detect the location of the users’ touch on their

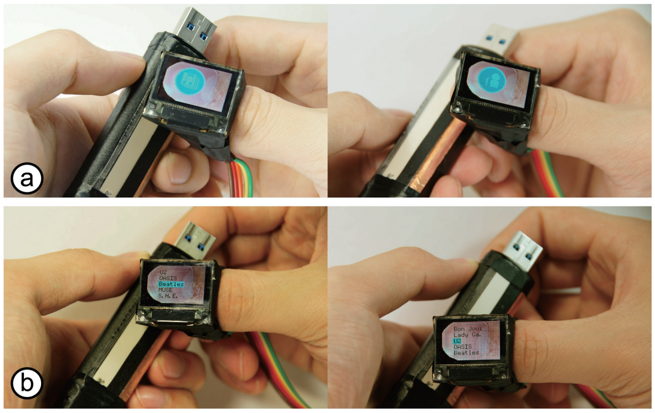

Figure 5. Use of a screen less music player. (a) Users switch from the album to the artist mode by swiping the finger against the device edge, and (b) navigates through artists by moving the finger along the device.

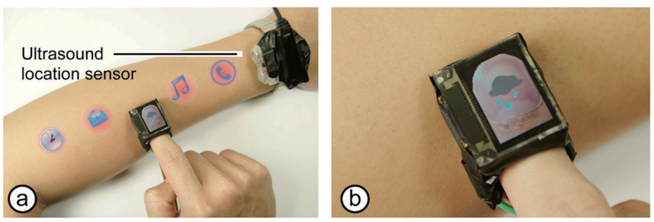

Figure 6. Positioning of invisible virtual buttons in line along the arm. (a) Users acquires the latest weather conditions by tapping on where the icon is located on their arm. (b) Close up view of *NailDisplay*.

arm. The invisible virtual buttons are positioned in line along the arm. According to Figure 6b, users check the date and weather for that day by touching certain locations of the arm.

Free Finger Interaction

A finger allows for rich input modalities, enabling subtle and fast access to input. In this example, *NailDisplay* is used as a visual output binding to free finger input. Several possible free finger interactions can be applied, such as bending, swiping, poking, or circling the finger. Here, swiping is selected to demonstrate the feasibility of the proposed prototype. We enhance *NailDisplay* with an accelerometer in this application. An HMM based gesture recognizer detects swipe gestures. According to Figure 7, when an incoming call arrives, users receive the notification by peripheral awareness [4], and check the caller's name on *NailDisplay*. A two step action is performed to answer or ignore a call. Users first swipe rightward or leftward to answer or ignore a call. Users then swipe downward to confirm the action on *NailDisplay*.

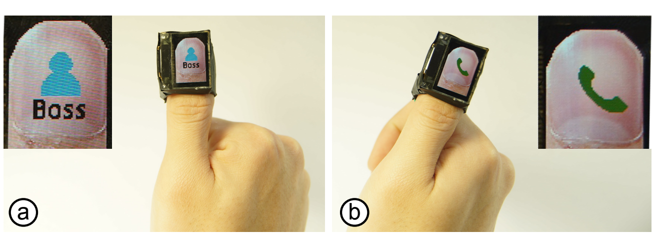

Figure 7. Demonstration of Free Finger Interaction. (a) The user checks the caller's name with *NailDisplay*, and (b) answers the call by swiping the finger rightward.

EXPLORATIVE STUDY

An explorative user study is conducted to understand how effective users found *NailDisplay* to be while performing tasks in given scenarios.

Seven participants (4 females) were recruited from the university. Except for the male participants, all female participants but one had experience with nail beauty. The study lasted for one hour, including one free exploration session and three scenario sessions. Following a 5-minute introduction, participants can freely explore the *NailDisplay* prototype and describe their initial impressions. The free exploration session lasted 10 minutes. During the scenario sessions, participants were instructed to perform interactive tasks, which include *See-Through Touch*, *Touching the Imaginary*, and *Free Finger Interaction*. Participants were encouraged to share their thought through think-aloud protocol. Each scenario session began with a 5-minute demonstration and training, followed by several tasks to perform, lasting approximately 15 minutes. All activities were videotaped.

Visibility and Orientation

Four participants reported a visibility problem, largely owing to the occasionally severe skewness of their fingernails when performing the tasks. This problem occurred in the transparent touch function, when the participants had to bend their finger inward in order to complete some pointing tasks. Also, in the imaginary touch function, when users slid fingertips on devices without screens, visibility of the *NailDisplay* changed constantly when the finger was in motion. This skewness became the worst with single handed operations. Similarly, pointing and sliding tasks also induce orientation problems. A rotation invariant design of visualization is preferable to tackle the orientation problem. For instance, rotation free circle size rather than a linear bar is used to represent volume scale. To handle this limited yet dynamic visibility on *NailDisplay* due to skewness, visualization can be designed in different abstraction levels, and then adapt to an appropriate level, depending on the available visibility.

See-Through Touch: Precise Pointing

All participants found *NailDisplay* to be useful in the selection task. Three participants described they need some practices to become accustomed to a vertical separation between *NailDisplay* and the touchscreen. Other participants did not find this separation to be problematic. Of particular interest in investigating *NailDisplay* is to determine to what extent vertical separation and inclination between *NailDisplay* surface and touch surface (*e.g.*, surface of fingertip) might affect the resulting touch interaction. Some participants stated that they did not see through their fingertips but, rather, an elevated yet isolated display on the fingernail. This is an actual situation since *NailDisplay* does not support eye tracking. With a truly transparent fingertip, users reported that they would like to roll their fingernail to fine adjust the pointer. Such a feature should be developed in *NailDisplay* in the future. Notably, users' finger orientation was not recognized on the touch screen. Therefore, the proposed prototype assumed a preset orientation when participants performed pointing tasks. Nevertheless, the participants did not find it difficult to read text and icons with ill orientation alignment.

Touching the Imaginary and Free Finger Interaction

During the *Touching the Imaginary* session, participants preferred to browse icons rather than text. However, none reported problems in reading because they could easily achieve a higher clarity by retrieving *NailDisplay* closer to the eyesight. During the *Free Finger Interaction* session, all participants enjoyed the scenario of operating a music player by swiping a finger in the air. However, some users reported that they would still enjoy this feature without a display on the fingernail. Two participants reported experiencing fatigue during the session. Those users suggested a touch function in the palm (same as in the imaginary phone [7]) or pinch on the index finger to obtain physical support.

Desired Features of NailDisplay

Participants found *NailDisplay* to be good at displaying private information, because they could easily conceal *NailDisplay* from others' eyesight. For instance, positioning *NailDisplay* on the thumb could be easily covered by other four digits. Users also mentioned to play sound with *NailDisplay*. This is owing to that when *NailDisplay* is completely hidden (*e.g.*, hand in pocket), sound notification could inform users to check information on the fingernails. One user mentioned that would enjoy using *NailDisplay* as a translator while reading books. Three participants liked the notion of having multiple functions on different fingers. For example, multiple *NailDisplay* in a row on four fingers allows users to read a meaningful sentence. Additionally, with a microphone on the pinky finger and a speaker on a thumb, users can directly talk to the caller via finger devices after answering the phone using *NailDisplay*. Finally, the participants did not appreciate the aesthetic function, mainly owing to the slightly oversized current prototype. Miniaturizing *NailDisplay* to the size of acrylic nail tips would likely make the participants to enjoy this feature.

CONCLUSION

This works presents an always-available nail mounted display known as *NailDisplay*, which tightly binds user controls with the display on fingertips. Efforts are already underway in our laboratory to deploy *NailDisplay* plus an eye tracking device which allows for a truly transparent fingertip. Of particular interest is how this transparency can further help point out objects precisely on extremely small screens, such as a ring display. As for visualization, efforts are also underway to investigate the visibility problem while using *NailDisplay* bimanually and single handedly. Future research should also determine which visualizations are more effective for this limited yet dynamic visibility condition. In a different track, we also are interested in understanding what benefits and interactions could be provided by multiple *NailDisplay* devices.

ACKNOWLEDGEMENT

We gratefully acknowledge the helpful comments of the Associate Chairs and the anonymous reviewers. This paper was partially supported by National Science Council of Taiwan under NSC100-2622-E-002-016-CC2.

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