AlterNail: Ambient, Batteryless, Stateful, Dynamic Displays at your Fingertips

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ABSTRACT
Beyond phones, watches, and activity tracking devices, a new ecosystem of functional and fashionable wearable technologies can easily, safely, and economically be designed, prototyped, and integrated directly on the body. In this paper, we present AlterNail, a fingernail form factor, ambient, low-power, stateful, wireless, dynamic display with onboard vibrational sensing. AlterNail integrates a batteryless design using inductive coupling with e-ink technology to enable both quick dynamic and long-term static fingernail based visual designs without the need for power. We also detail the use of simple vibrational signals to uniquely identify everyday objects as they are handled using AlterNails. The intentionally limited interactional functionality of AlterNails, coupled with the rich personal and dynamic expressive potential, combine to present a compelling range of opportunities for designers of new interactive wearable technologies. We detail a range of practical and playful applications using this technology.

Author Keywords
wearables; cosmetic computing; ambient devices; fingernails.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g. HCI).

INTRODUCTION
Over the past few years, wearable technologies from fitness trackers to networked smartwatches have seen massive growth, adoption, and platform diversification. Recent reports project that one-third of the US population will regularly use a wearable by 2019 [1]. By being *on the body*, wearables are well suited to a broad range of unique applications beyond those using other types of mobile devices. Wearables enable immediate access to body based sensing, provide personal and glanceable interfaces, and also play a role in personal fashion due to their public and semi-public visibility. As we move beyond the existing wearable platforms of fitness trackers and smartwatches, an entirely novel design ecosystem will emerge along with new interaction styles. Much of this evolution will come from research and development into new wearable form factors and bodily sites of interaction. There is already a deep history of such development as we move away from screen based designs towards clothing [23, 24], glasses [27], contact lenses [20], tattoos [15, 12, 31], implantables [26] and beyond [10]. One key distinction across this wearable ecosystem is that some of these designs are more easily and often removed than others. In this paper, we focus on a specific class of wearables that are worn for days or weeks at a time without removal — artificial fingernails. We call our *cosmetic computing* inspired design AlterNails (Figure 1).

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Figure 1. AlterNail being worn and closeup of an AlterNail design.

Cosmetic Computing
Cosmetic Computing is a vociferous expression of radical individuality and an opportunity for deviance from binary gender norms. It is a catalyst towards an open, playful, and creative expression of individuality through wearable technologies. It's a liberation call across gender, race, and body types. Leveraging the term "cosmetics", originally meaning "technique of dress", we envision how intentionally designed new-wearables, specifically those that integrate with fashionable materials and overlays applied directly atop the skin or body, can (and should) empower individuals towards novel explorations of body and self expression. Unlike many modern traditional cosmetics that are culturally laden with prescriptive social norms of required usage that are restrictive, sexually binary, and oppressive [34], we desire a new attitude and creative engagement with wearable technologies that can empower individuals with a more personal, playful, performative, and meaningful "technique of dress" — *Cosmetic Computing*.

Our research is related to the work of Vega et al. on Beauty Technology [30] that merges technology with beauty products. Cosmetic Computing differs in its pivot away from engaging directly with "beauty" as a theme. This emerging area utilizes already culturally accepted practices, such as makeup [30], temporary tattoos [15, 12, 31], and artificial fingernails [30] as sites for technology. It also provides an entry point for non-technical hobbyists to get involved with the design and creation of wearable devices [25, 18]. We expand this vocabulary of on-skin wearable devices with new capabilities such as a dynamic display with no internal power supply.

AlterNails

The fingernail provides a unique substrate for combining interactive electronics with cosmetic forms. As a rigid, static surface, fingernails afford easy attachment of planar electronics and avoid durability and wiring complications that often arise from flexible connections that attach to more dynamic and malleable substrates such as human skin or clothing. Fingernails are also highly visible and provide a readily glanceable display atop the fingertip. When we touch, handle, and interact with surfaces, objects, and people, our hands and fingers and hence our fingernails are intertwined within the interaction, making our fingernails a compelling site for designing new technologies. In fact, using the fingernail as a substrate, we are able to design new interactions previously unattainable due to size constraints and the location of current wearable devices. Finally, fingernail based technology takes advantage of the broad cultural acceptance of attaching and wearing artificial fingernails.

In this work, we present AlterNails, small interactive electronics that attach to fingernails with commonly available acrylic nail glue. A central focus of our design was to avoid developing yet another wearable device to care for, charge, and nurture. The result is a compelling example of how to develop personal wearable devices that embed interaction, information, and fashion while avoiding the need to replace or charge batteries. Each AlterNail has a small e-ink display that is always available and easily glanceable. This display is powered and updated when a user interacts with an AlterNail enabled smart object. Such objects are embedded with a wireless power transmitter and a vibratory motor. As objects are touched and handled, the AlterNail is powered wirelessly via inductive coupling. The AlterNail performs simple sensing and computation based on the application, updating the e-ink display as appropriate. We argue that the power and interaction limitations provide a constrained but rich new design space appropriate for a range of small, functional, fashionable new wearable devices and applications.

RELATED WORK

Companies and research groups have begun to explore the mass potential for finger and fingernail mounted technology [32]. This work includes subtle and readily available input devices [11, 6, 7, 16], passive technology such as NFC and RFID [5, 30, 29], and larger fingernail displays [28, 33]. There has also been research into fingernail interactions that are chemical, rather than electronic [13, 17]. While these projects have explored the potential for fingernail-worn technology, they all possess either a static display or wires for power and communication. Our work also builds on prior work in parasitic power; that is, devices that are powered externally. Researchers have harvested power from human movement [14], public landscapes [21], personal objects [22], and radio waves [19]. In addition to power harvesting, wireless power is becoming more universal as smart watches and other wearable devices become increasingly popular. Our work is novel in that AlterNails don't store wireless or parasitic power; rather, they operate opportunistically. AlterNails are low-power (typically 1 milliwatt) and generally only require 250 millisconds of power to power up, read and sample sensors, and send new outputs to the e-ink display. After this time period, power is no longer necessary.

MOTIVATION

Fingernails are at the heart of countless interactions. Designing technology at this crux allows us to explore a new realm of embodied interaction. Fingernails also allow us to design and prototype ever-present, yet subtle displays. While the fingernail presents unique opportunities for interaction, it comes with its own set of challenges. The most prominent consideration is physical size. Since the fingertips are the foundation of interaction, bulky devices situated here would impede not only potential applications, but everyday activities. The largest component in existing fingernail mounted devices is the battery. In addition to size constraints, including a battery poses other unique challenges for a fingernail mounted device, such as how and when to charge. Our view is that it is neither feasible nor desirable for a user to frequently remove and charge their fingernail devices.

Taking account of these constraints, we opted to design our fingernail worn device without a battery or other internal power supply. Our device uses resonant inductive coupling to power wirelessly. With this design comes new constraints. The wireless power receiver supplies up to 5V intermittently — well beyond the 1.8v operational levels required by our hardware. The AlterNail is only powered when in close proximity to a transmitter. This introduces a hardware constraint, as well as an interaction constraint. First, all components must operate at a low voltage and be able to function with intermittent power. It also means that AlterNail interactions are best focused around contact with objects — specifically specially designed AlterNail enabled smart objects that are capable of powering, communicating, and updating the AlterNail wirelessly.

With this new set of constraints, we chose to use e-ink displays. This type of display is ideal for our application for 5 main reasons: (1) e-ink displays can be manufactured at a small scale (6x6 mm), (2) e-ink displays operate at low voltage (5V), (3) they can be designed in a wide variety of custom configurations, (4) they are low-cost, and perhaps most importantly (5) e-ink is bistable, which means it doesn't need power to hold an image. We leverage this property of e-ink displays since they only need power for a few milliseconds to change state and do not require any power to maintain state [8, 9].

Given these constraints and considerations, we designed and fabricated several AlterNails. AlterNails are ambient, the display is always available, yet changes slowly and in a subtle way; batteryless, the device is powered wirelessly; stateful, the e-ink display (as well as the non-volatile microcontroller storage) maintains state even after power is removed; and

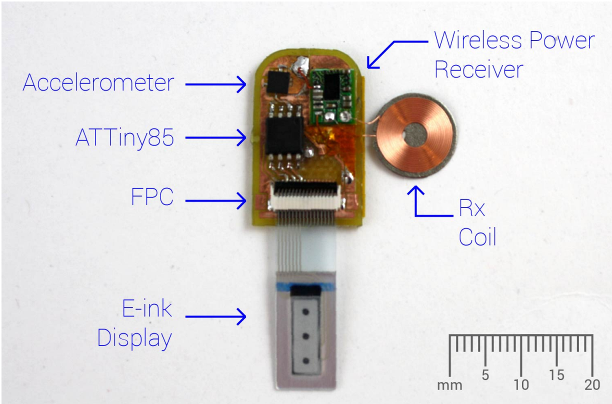

Figure 2. Custom designed AlterNail with accelerometer, ATTiny85, a wireless power receiver, inductive coil, and e-ink display.

dynamic, the display changes throughout the day based on interactions with various everyday AlterNail enabled objects.

ALTERNAIL DESIGN

The heart of our device is a custom-built printed circuit board (PCB). Our PCB contains an ATTiny85 microcontroller, an analog accelerometer, a wireless power receiver with attached coil, and an e-ink segmented display (Figure 2). When a user interacts with an AlterNail enabled smart object, power is transferred from the object to the AlterNail. These AlterNail enabled smart objects are each programmed with a unique vibration pattern. Upon start-up, the AlterNail uses the accelerometer to detect these vibration patterns and determine which object the user is interacting with. Identification information can also be sent wirelessly over the inductive coupling link such as NFC without using vibration. Once the object has been recognized, the e-ink display updates. This display is maintained even after the user has stopped interacting with the object. In our functional prototype we used a series of individually addressable dots that can be reconfigured by the AlterNail (Figure 2). This e-ink display has a refresh rate of 250 milliseconds. We are using the Wireless Power Reference Solution from IDT for both our transmitter and our receiver. At peak power, the entire system consumes about 1 milliwatt from the microcontroller at 300 μA and the e-ink at 1 μA when switching.

AlterNails are easy to apply and remove; they use commonly available acrylic nail glue to attach to the fingernail. Additionally, we have designed custom vinyl sticker overlays that conceal the electronics and allow for user personalization. AlterNails are low-cost at less than $4 USD bill of materials per AlterNail. This allows users to easily reapply, replace, or reprogram them every few weeks. AlterNails are approximately 16 mm by 26 mm and 4.6 mm thick. Thickness can be further minimized by utilizing a thinner PCB.

AlterNails require interaction with specially designed AlterNail enabled smart objects in order to function. These objects contain a wireless power transmitter, a microcontroller, and optionally a vibration motor. The enclosed components are small and can easily be added to a number of everyday objects and artifacts as we demonstrate in Figure 3.

APPLICATIONS

While our design includes several constraints, it also lends itself to a variety of interactions that fuse fashion and function. We highlight a selection of four interaction categories: (1) pick a design, (2) credits and usage, (3) object status, and (4) free form designs (Figure 3).

Pick a Design: AlterNails can be used for displaying designs as objects are touched. For this family of interactions, each AlterNail enabled smart object is associated with a particular e-ink configuration; when the user interacts with an object, its "visual" is displayed on the AlterNail. With regards to our current prototype, this means having objects that trigger specific dot configurations; however, we can imagine rich interactions with more intricate e-ink designs. Tapping a "Learn Korean" flier could display the phone number for later use. Daily activities, such as playing basketball or knitting, could showcase icons as a quasi-diary. Specific locations could reveal unique designs, reminiscent of Snapchat's geofilters, Pokémon Go, and other geocaching applications [4, 2]. For example, touching the turnstile at a baseball stadium could showcase the home team's logo.

Credits and Usage: AlterNails can also be used to track credits and usage. The simplest of these interactions is an activity counter. The AlterNail displays a new dot each time the user interacts with a specified object. This is useful for tracking water consumption, snacking, and other habits. The AlterNail can also measure length of interaction: adding a new dot for every x minutes spent interacting with an object. This is useful for measuring practice of an instrument, timing bike rides, and keeping track of other daily activities. Another variation of this interaction includes AlterNail enabled smart objects that add dots, as well as objects that take them away. An example is an AlterNail that tracks hand washing. Unsanitary surfaces such as trash bins and toilets add dots to the AlterNail, whereas hygienic fixtures such as sinks and showers remove all dots from the AlterNail.

Object Status: AlterNails can also be used for checking the status of objects. Touching a bus stop could display when the next bus is arriving. Grasping a flashlight could show battery levels. Tapping a conference table could reveal whether or not the table has been reserved. Gripping a handsaw could display the amount of wear on the blade. Touching a malfunctioning washing machine could reveal failure details.

Free Form Designs: We can design AlterNails that are NFC driven and powered by mobile devices. In this case, AlterNails could be used for notifications, such as an incoming text or an alarm. While similar to Ringly [3] and other wearables, AlterNails are unique in their physical location, as well as their ambient nature: rather than vibrating or lighting up with notifications, AlterNails change slowly and in subtle ways.

We can also imagine interactions in which smartphones provide additional information to AlterNails. Rather than gathering all information from objects, we can discern location, time, and other factors directly from the user's smartphone. Borrowing from one of our previous examples, simply being at a baseball stadium and interacting with a smartphone could

Figure 3. Left: Credits and Usage scenario demonstrated with an AlterNail enabled cookie jar. When the user opens the cookie jar, a new dot is added to their AlterNail display. Middle: Object Status scenario demonstrated with an AlterNail enabled chisel. As displayed by the AlterNail, this tool has been used three times today. Right: AlterNail updated through NFC from a smartphone. The user can discreetly check that they have one new email without unlocking and looking at their phone.

cause the team's logo to appear across the AlterNail, rather than requiring the user to be in contact with a particular AlterNail enabled turnstile. The smartphone would detect the user's location, determine the appropriate e-ink configuration, and power/communicate with the AlterNails via NFC.

We ran an informal user study to evaluate user reception to AlterNail. It is beyond the scope of this paper to describe the study design and outcomes in their entirety. We engaged 6 participants and allowed their reactions and responses to inform our discussion and future steps.

DISCUSSION AND LIMITATIONS

E-ink display: Our e-ink display consists of five addressable dots. This segmented display was chosen for its cost and availability in small quantity. Obviously, richer custom visual e-ink elements would yield more expressive overall designs. This constraint is commercial rather than technological. Tiny, intricate, and custom e-ink displays can be manufactured at low cost in large quantities. As *cosmetic computing* and wearable e-ink displays become more commonplace, we anticipate small, detailed, and custom e-ink displays to become more commercially available. This opens up a new range of potential interactions for AlterNails, as well as other *cosmetic computing* platforms.

One vs Many: While many of our interactions require just one AlterNail, we envision users wearing multiple AlterNails. Currently, AlterNails are individual and do not interact with each other; users have a separate AlterNail for each function. In future iterations, we envision networked AlterNails with complementary or paired designs and interactions. We also envision AlterNails networking with traditional wearables, smart textiles, and other *cosmetic computing* devices to form an ecosystem of functional and fashionable wearables.

Alternative sensors: We are using an accelerometer to detect vibration patterns and distinguish between objects; however, there are a number of different sensors and methods that we could use instead. Our main constraint is that the sensor must be small and low-power. Within these constraints are light modulation, tilt detection, RFID, and NFC to name a few. These further low-power sensing capabilities can create richer embodied interactions, such as simple expressive and discrete gestural triggers and cues.

Proximity to power: While AlterNails are powered in close proximity to a power transmitter, future iterations could leverage recent research into charging technology at a distance. They could also utilize existing research on wireless charging via TV signals and other RF [19]. Small bits of charge could be stored and used on demand as well (i.e. tapping the AlterNail to change its display).

Fabrication: Future iterations of AlterNails could also leverage new 3D printing capabilities, specifically the ability to print conductive material inline with physical designs.

Advantages over current wearables: In addition to their subtle and always-available displays, AlterNails provide several other advantages compared to traditional wearable devices. AlterNails can gather valuable information about what objects the user is interacting with, and how they are interacting with them. For example, a wrist worn device can detect if the user is near a Bluetooth enabled object. However, AlterNails can distinguish whether or not the user is actually touching the object, and with which fingers. AlterNails also differ from existing wearable devices in that they can be customized both in fashion and function. As mentioned previously, a wide range of e-ink displays can be designed and manufactured. These displays of information can be either straightforward or ambiguous. For example, a new text message could trigger a "new text" display, or simply add another flower to an existing design. This versatility can enable both personal and shared interactions. Rather than trad "one size fits all" found in many wearables, AlterNails and other *cosmetic computing* platforms have the unique ability to fit within one's sense of personal style.

CONCLUSION

In this paper, we presented AlterNails: ambient, batteryless, stateless, dynamic displays on the fingernails. AlterNails are powered wirelessly through objects and provide a framework for new interactions that go beyond current mobile devices. We hope that our work inspires other AlterNail applications as well as wearable technologies across our emerging cosmetic computing landscape.

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