Exploring the Affordances of Bio-Electronic Nails

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Figure 1: Bio-e-nails are made from a modified form of Alganyl [6]– a biodegradable plastic; the nails embed a Near-Field Communication (NFC) chip that can be programmed for various applications such as navigation; and after use, the bio-e-nails can be composted or recycled for reuse.

ABSTRACT

We developed bioplastic nail extensions that integrate Near-Field Communication (NFC) chips to facilitate hands-free interaction with the phone. Using bioplastics as a scaffolding material for electronics, we aim to address existing sustainability challenges regarding disposal and recycling while also exploring the affordances of this material, such as customization and material exploration. We outline the low-tech fabrication process for our Bio-Electronic(-e) Nails, followed by a demonstration of how to wear and program them. Subsequently, we present three applications utilizing tag-based interactions: medical or emergency contact information, navigation setup, and automated text or Short Message Service (SMS) communication. We designed the fabrication process for designers at large while enabling expression through fashion by embracing the temporary nature of the bioplastic.

CCS CONCEPTS

• **Human-centered computing** → *Interactive systems and tools.*

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KEYWORDS

biobased materials, wearable technology, biodegradability, artificial nails, sustainability

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1 INTRODUCTION

Hands-free interactions have been explored to enhance interactions where the typical finger-based interactions such as tapping or swiping may be inaccessible due to situational impairment [42], distractions-induced risks [16], or while mobile [12, 30]. Prior research has shown that by embedding electronics, such as Radio Frequency Identification (RFID) chips, in artificial nails, interactions with mobile phones can become swift and seamless [23, 24, 37]. However, these past works have used off-the-shelf materials such as acrylic nails or stickers [17, 37] as substrates for the electronic components, thus creating a composite material that is hard to recycle or biodegrade, raising sustainability concerns. Building upon prior research, we explore the affordances of biodegradable materials that provide an ideal landscape for designing and fabricating temporary wearables, such as smart artificial nails, typically intended as *non-permanent* beauty enhancements.

We introduce bio-e-nails, artificial nails with embedded electronics, which we designed with a sustainable approach using biobased materials. We developed a fabrication process based on biodegradable plastics, such as Alganyl [4], which can be easily tuned for strength and flexibility, decomposes in soil, and dissolves in water. Our intentional choice of substrate material brought flexibility to the design process, as we had direct access to the raw ingredients and could expand the exploration space without relying on off-the-shelf products.

After making the bio-e-nails, we demonstrate their use in daily smartphone interactions. We designed our nails to be pre-programmed to trigger specific functions on the phone with a quick and discrete tap. Aligning with prior research, we focused on scenarios where obtaining assistance can be critical and usual gestures are unavailable. Thus, we programmed the bio-e-nails to perform three functions: (1) navigate to a predefined location while driving, (2) discreetly call for help when in danger, and (3) automatically text the current location to a friend. Last, we ran experiments that show the potential for a circular life cycle since the embedded electronics can be harvested easily upon decomposition of the biodegradable substrate.

The bio-e-nails presented in this work illustrate our commitment to fostering sustainability in beauty technology by exploring diverse biomaterial affordances beyond biodegradability. The affordances we consider in our approach include low-tech fabrication, customization, and flexibility in design. Our nail-based interactions showcase their potential, especially when traditional gestures may be impractical or unavailable during critical moments.

2 SUSTAINABILITY CHALLENGES IN WEARABLE AND BEAUTY TECHNOLOGY

As wearable technology has seamlessly become an integral part of our daily lives, HCI research continues to provide innovative solutions that intersect multiple disciplines [14, 15]. Significant effort has been made toward developing devices such as smartwatches [1, 32, 41], earbuds [18, 29], and armbands [27] that enable individuals to monitor their health, ensuring hands-free communication and streamlined notifications for safety. Beyond these efforts, wearable technology has expanded its applications to include fashion items worn daily, such as rings [3], shoes [2, 31], and jackets [8]. A more recent trend includes fashion items worn for aesthetic enhancements, such as artificial nails, eyelashes, hair, and makeup, collectively referred to as beauty technology [38].

Beauty technology encompasses the body of work that augments everyday cosmetics by adding features supported by electronics [36, 38]. Thus, besides the typical motivations for cosmetic use, such as beautification or altering appearances, beauty technology adds features by utilizing electronics. FX e-makeup [35], for example, is a prototype for special effects makeup embedded with electronics to sense and use facial muscle movements as inputs for performing commands (e.g., turning on a TV). iSkin [39] is an on-the-skin tattoo-like interface combining aesthetically appealing designs with electronics that utilize touch as input.

Similarly to fast fashion, beauty technology presents sustainability challenges influenced by factors such as material composition, production processes, and end-of-life disposal, with the added caveat of e-waste [13]. For instance, wearables for beauty technology integrate electronics or conductive coatings [38], posing difficulties for proper recycling due to the challenges of separating electronic components from off-the-shelf cosmetics [13].

Concerned with sustainability, recent Human-Computer Interaction (HCI) research shows a growing interest in biobased materials, such as mycelium skin [34], mycelium composites [22, 33, 40], bioplastics [4, 19, 43], biofoams [20, 21], bioclays [7, 9, 10, 28], and bacterial cellulose [5, 11, 25, 26]. This interest is driven by the ability of these materials to break down in a home-compostable environment, enabling the reuse or reharvest of electronic components at the end of the wearable or interactive artifact's life.

In this work, we adapted the Alganyl bioplastic recipe [4, 6] to make a material that has increased strength and less flexibility so that it emulates an artificial nail. We also propose a streamlined fabrication process to make bio-e-nails in which a Near-Field Communication (NFC) chip can be easily embedded. While biodegradability is still one key feature of bio-e-nails, our approach provides opportunities for recycling or repurposing the NFCs when the bio-e-nails reach the end of their life. Despite limitations like short lifespan and specific mechanical properties of some biobased materials, this paper explores their potential in beauty technology through bio-e-nails.

This novel application eliminates reliance on off-the-shelf products and showcases bioplastic's potential for biodegradation, customization, and low-tech fabrication. Bio-e-nails aims to unlock a unique design space in beauty technology by embracing bioplastics' suitability for temporary use cases such as artificial nails. Biodegradability enables the recycling of embedded NFC tags. Readily available ingredients and low-tech fabrication methods contribute to bio-e-nails' design versatility in terms of color, shape, and size.

3 FABRICATION

We developed a fabrication process that does not required expert knowledge and can be implemented using kitchen and craft equipment. As mentioned, we intended the bio-e-nails to maintain the original purpose of aesthetic expression, therefore our proposed fabrication includes options for customization in terms of size, color, shape, thickness and embellishments. To create the bio-e-nails, designers can perform the following steps.

Step 1. To make the bioplastic substrate for the bio-e-nails, start by mixing 250 ml of water, 8 g of Agar Agar, and 6 g of Vegetable Glycerin in a saucepan over medium heat, constantly stirring until the mixture becomes highly viscous. Remove from heat when the mixture reaches the boiling point after approximately 5 minutes. This recipe is an adaptation of the open-source Alganyl formulation [4, 6]. We adjusted the quantities to increase the stiffness to be more suitable for nails. Additionally, we tested 5, 6, and 9 drops of food coloring for pigmentation, with 9 drops resulting in the optimal color richness.

Step 2. Pour the hot mixture gently onto a flat surface, controlling a thin, steady, and centered stream. In 2 to 3 days, the mixture will cure in a circular material sheet of approximately 20 cm in diameter. After curing, the material will present a smoother side (the side in contact with the surface) and a slightly textured side (the side in contact with the air). Once cured, remove the bioplastic carefully with a spatula, and use scissors to cut it into rectangles slightly bigger than the plastic nail area, approximately 5 cm by 4 cm. If needed, repeat step 1 to create more layers.

Step 3. Hold together three of the previously cut layers on a flat surface. Place a cloth or towel on top, then press the three layers together with an iron. Place an NFC chip on the pressed layers, away from the edges. Line this up with a plastic nail to ensure correct placement. Finally, lay the fourth bioplastic layer on top of the others and iron again, covering it with a cloth first. We used the highest heat setting on the iron.

Step 4. To shape the bioplastic into a nail, place a plastic nail on the top and one on the bottom of the four swatches. Perform one final heat press with the iron to seal the edges securely. While heat pressing all four layers around the perimeter, ensure the closure and evenness of the material. Hold this swatch in place with clamps for another 24 hours to mold it to the nail shape.

Step 5. The binder clip configuration allows the bioplastic to conform to the curvature of the plastic nails. After 24 hours, cut out the shaped bio-e-nail. Finalize the shape by filing its edges with nail-grade buffers and an electric file until the desired shape is reached.

4 COMPARISON TO COMMERCIAL ARTIFICIAL NAILS

We compared our bio-e-nails to the commercial plastic nails (see Figure 2) in terms of flexibility, curvature, surface texture, dimensions, and weight. Both nails bend relatively similarly and have a similar curvature at the top. Due to our layering process during fabrication, the bottom of the bio-e-nail is flatter, however, it doesn't affect the adhesion to the natural nail.

Both nails are smooth on the tops, slightly rough on the edges, and smooth on the bottom. In terms of dimensions, our bio-e-nails have a thickness of 0.97 mm and a length of 27.02 mm. The commercial plastic nail is thinner, measured at 0.63 mm, and shorter at 24.94 mm.

One bio-e-nail weighs 0.364 g (excluding the NFC chip), while one plastic nail weighs 0.145g, measured before painting or adding additional enhancements. The significant increase in mass can be attributed to the multiple layers of material. The final bio-e-nail includes the weight of the NFC chip, which is 0.015 g, for a combined total weight of 0.379 g.

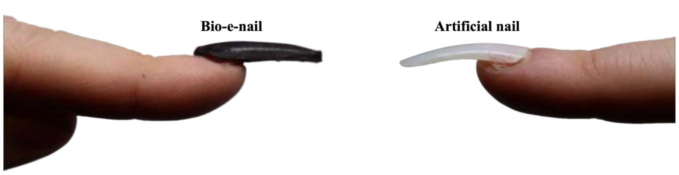

Figure 2: Comparison between our bio-e-nails and commercial artificial nails.

5 USING THE BIO-E-NAILS

As previously mentioned, our bio-e-nails are crafted from a sustainable bioplastic that decomposes easily in soil. However, this environmentally-friendly design comes with a trade-off: the bio-e-nails lack durability, as they are not water-resistant and may break when re-applied. Therefore, they are intended for temporary use, such as for a unique event. The following use cases highlight the advantages of integrating NFC chips into aesthetic nails, enabling seamless communication in various scenarios.

Texting current location to a friend: We demonstrate the applicability of the bio-e-nails by programming the pointer finger on the left hand to send the wearer's current location to a trusted friend. This means that even if the wearer is unable to type or use speech-to-text, a simple tap with the bio-e-nail will send their current location. We envision this application being used during a night out when the user may need to inform a sober friend or parent of their whereabouts. This action also allows for rapid safety measures in an emergency, as the sensor will promptly send the location, enabling the person under the influence to be escorted and cared for.

Navigation: We further programmed the bio-e-nails to navigate to a predefined location with a single tap. Recognizing the potential dangers of browsing or typing in a navigation app while driving, we demonstrate how the bio-e-nails can effortlessly guide the user to their home address with just a tap. This ensures safer and more convenient navigation, reducing the need to interact with the app while on the road.

Call Emergency Service: In the final demonstration (Figure 3), we programmed the bio-e-nails to call the local emergency number with a tap. We envision a scenario where access to a phone is restricted, or when high discretion is required. Instead of pulling out the phone, looking at it, and dialing a number, the bio-e-nail allows emergency or medical services to be called promptly, potentially saving your life.

6 REUSE AND END-OF-LIFE

Mechanical: Our proposed fabrication process, based on thermo-adhesion, enables easy separation of the bioplastic layers by using manual mechanical force. We successfully harvested and reprogrammed the NFC chips. The remainder of the bioplastic can be melted down, cured, and re-shaped into a new bio-e-nail.

Chemical: We leveraged the water-solubility of the bioplastic at low temperatures (less than 50C) to successfully recover and reprogram the NFC chips. When using small amounts of water (20 mL), the dissolved bioplastic solution can be brought to a boil and poured into a new bioplastic sheet.

Biological: Alternatively, our bio-e-nails can decompose in soil over time. Our experiments show a slow mass loss (10% over 10 days) in soil inoculated with bacteria and fungus and kept at 40C and over 80% humidity.

7 LIMITATIONS

Enabling ease of design and replicability, the NFC chip is limited to a small distance for communication. i.e., the nail-based interaction had to be located within 2.5 cm from the phone. Due to the sensitivity of NFC sensors and the dexterity required to bend the finger by

Figure 3: Example application: the user discreetly calls 911 (emergency number in the USA) when in danger.

Figure 4: We designed bio-e-nails to be circular: after they are programmed and used, they can be dissembled to harvest the NFC and compost the materials substrate. We experimented with the harvested NFC, and it worked as expected.

the sensor, we limited the interactions to the thumb, index (pointer) finger, and middle finger.

Additionally, the bio-e-nails are heavier and may need time for the wearer to adjust to their weight. Therefore, the wearer should also carefully consider the number of enhancements added to the nails. Moreover, we chose the material substrate to be biodegradable and thus temporal. We were able to wear the bio-e-nails for a week while performing the usual computer tasks, house chores, and mild dishwashing.

Furthermore, due to the size of the bio-e-nails we prototyped, they had to be removed before going to bed, as they would easily detach. Re-attaching them became part of the morning ritual, along with showering and brushing teeth.

8 DISCUSSION AND CONCLUSION

Driven by a strong desire to reduce the e-waste resulting from rapid prototyping, recent Human-Computer Interaction (HCI) research has been developing biodegradable biomaterials that can be made using kitchen equipment, crafting techniques, and store-bought ingredients. Instead of lab-based polymerization, focusing on low-tech fabrication opens up a space for material exploration and customization. For this work, we explored more than 30 recipes and made 60 nails until we achieved the first prototype. In other words, the key lesson we learned is that there is a particular affordance to having the opportunity to tune the material granularly: it allows for fine customization that comes with learning more about the material requirements of the desired artifact. With each new nail, we used touch, sight, and feel to get informed about the following steps: whether we needed more rigidity in the material, a smoother texture, a more vibrant color, or more dramatic length and curvature.

The usual motivation behind low-tech fabrication is routed in giving access to people at large to afford to make a material that, otherwise, would be too expensive or too complex for them. However, we discovered another dimension of creativity that is unlocked simply by having direct access to the formulation of the material. In our case, the tunability of agar-based bioplastics directly informed our research while designing, empowering us to achieve precisely the nails we wanted. Direct access to material formulation gives us a sense of creative freedom.

We noticed a tension between our sense of environmental responsibility and our desire to wear fashionable, new items. In a society where individualism is expressed through unique and personalized objects, undecorated humans can seem bland. We addressed this dilemma by choosing a material that is easily customizable yet temporary, allowing us to balance both sustainability and self-expression.

The resulting wearables decay due to our choice of a temporal biomaterial. Our bio-e-nails can easily be pulled apart, dissolve in warm water, and be consumed by non-human organisms if composted. Designing wearables that support decay could have a significant long-term impact on how people handle technology.

Through this work, we initially intended to develop a sustainable alternative to nail enhancements that can hold the same fashionable status and functionality. Through our research and design, the scope of this idea expanded past the aesthetics of fashion nails as we further engaged into the meaning of temporary wearables. Recognizing the sustainability challenges associated with wearable and beauty technology stemming from material composition, electronic waste, and end-of-life disposal, we designed the bio-e-nails to explore the affordances of bioplastics in beauty technology. We demonstrated their applicability in three real-life scenarios. Finally, we unpacked our thoughts and discussed sustainability and its implications in design through material choice and the implications on the user through the temporality of the resulting artifacts.

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