Programmable Materials (Skintillates) - Final Report

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Technical Report No. UCB/EECS-2016-120
http://www.eecs.berkeley.edu/Pubs/TechRpts/2016/EECS-2016-120.html

June 8, 2016

Programmable Materials - Skintillates

Chapter 0: Introduction

Team - Written

Programmable Materials is a project that revolves around skintillates – an on-skin wearable that mimics a tattoo. It is a fashionable wearable with six layers from bottom to top (Figure 1.1): an adhesion layer to be placed on top of skin, an electronics layer embedding LEDs, a conductive layer made with medical electrode-grade silver, an ink-jet printed art layer designed in illustrator, and a regular temporary tattoo substrate on top. The electronic layer connects to a microprocessor, which handles the data collection and communication with personal mobile device or laptops.

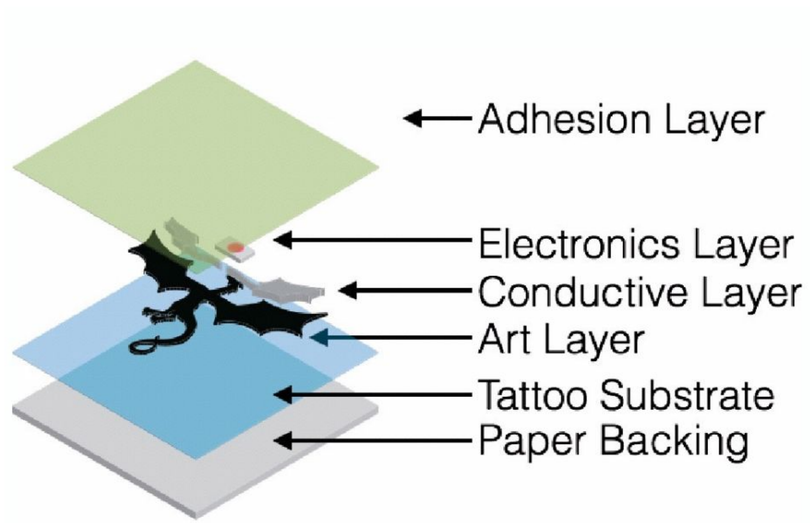
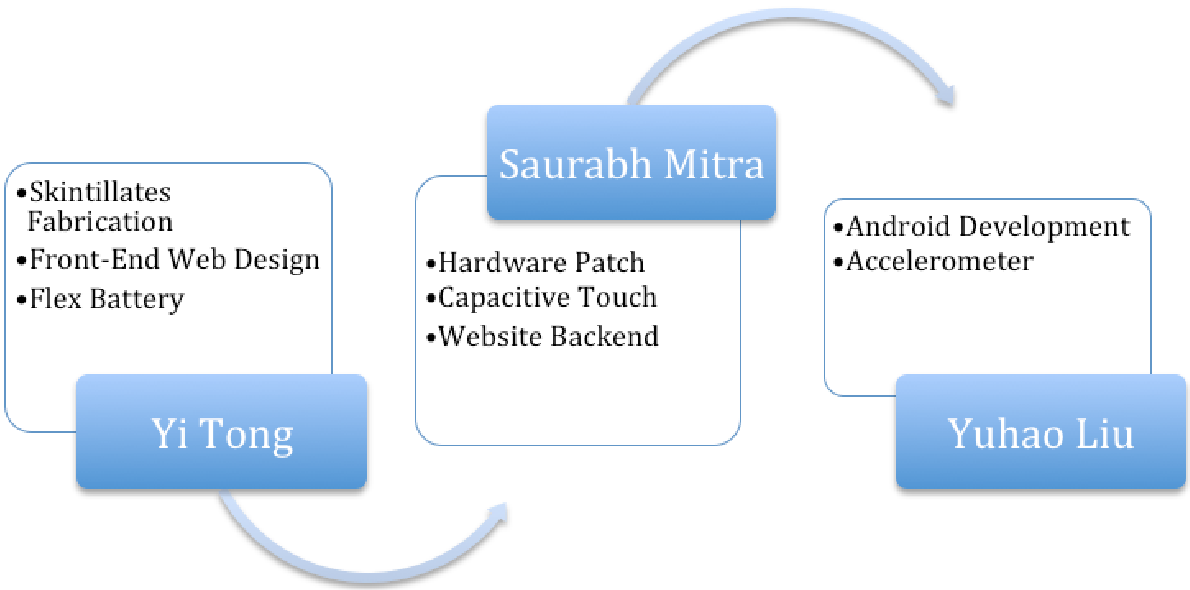


Figure 1.1 Components of Skintillates

The goal of our project is to develop software applications for skintillates and improve its usability. We started off analyzing the existing hardware problems that might affect user experience. The original skintillates had a lot of wires coming out off the tattoo, linking to a big microcontroller powered by regular batteries or a computer. Since Skintillates are wearables to be applied directly onto the skin, the exposed electronics will cause discomfort for the users who wear them. We addressed the concerns by improving portability, increasing compactness and extending battery longevity. We proposed solutions such as replacing the regular arduino microcontroller with a fingertip-size microprocessor, separating a hardware patch from the tattoo itself, introducing bluetooth connections and experimenting with rechargeable flexible batteries. Besides the hardware aspect, we brainstormed dozens of ideas for applicable software extensions of skintillates. The main ideas included using skintillates for augmented reality, personal health tracking, and music player. Then we moved on to learn the techniques of the fabrication process and built two initial prototypes using mbed microcontrollers. One used an embedded accelerometer to detect motion and light up LED light on skintillates based on body movement. The other prototype had one button on the tattoo which triggered music on a demo app on Android phones. The prototypes successfully gained attention from the audience during our exhibition. People are amazed by the power of skintillates and their form factor. At the same time, people expressed concerns with battery life and durability of hardware. After the expo, we decided to put more effort into providing feedback to users from the hardware, building a more robust hardware solution, and extending software features. We utilized sensors and developed mobile apps and web servers linked to skintillates for user interactions.

Division of Work



Chapter 1: Technical Contributions

Saurabh Mitra

Introduction

The history of computing hardware and semiconductor technology is unified by a single theme: computers must shrink and their power must grow as time progresses. Thus, the expensive mainframes and servers that filled rooms decades ago are now outperformed by the smartphone that fits in one's pocket. However, this advancement in semiconductor technology has had one relatively recent side effect: the ubiquity of embedded devices. According to Freescale Semiconductor, "Today there are about 150 embedded microprocessors around the home in various appliances, media players and other consumer electronic devices, plus there are another 40 or 50 in your car" [1]. Indeed, 64% of American adults in 2015 owned a smartphone of some kind, up from 35% in the spring of 2011 [2]. However, smartphones are no longer the cutting edge in device technology. Today, in 2016, given the current rise of the Internet of Things trend paralleled by the surge in the Maker Movement, we are at the cusp of a revolution in cheap, ubiquitous smart devices. Smart watches, smart cars, smart televisions, smart fridges, smart thermostats, and even smart toasters, are all now networked together and can be controlled by each other. Integrated circuits have also shrunk to the point that various biosensors can be embedded into wearable health trackers, like the FitBit.

Our capstone project's goal is to bring this Internet of Things Wearable Maker Revolution forward one more step by embedding programmable circuitry, sensors, and light-emitting diodes into temporary tattoos (Skintillates), and creating hardware and software that can enable the general public to utilize them. The original phase of this process was to conceptualize the final user experience and plan use cases. This allowed us to determine what kinds of technologies would be necessary and plan our design. We conducted academic and market research to further enhance our knowledge of the subject matter, and prototyped a few basic Skintillates using larger processors and batteries. Once we had a clear direction for our project and an idea of the technical challenges, we began testing and evaluating various aspects of a potential modular consumer edition. Our final prototype will feature various software capabilities that we have experimented with without sacrificing customizability or cost.

Literature Review: Current Solutions and Competitor Analysis

Before we could begin our project, we needed a sense of what had already been developed in academia in the fields of wearables and programmable materials. In addition to academic research, we needed to peruse market research relevant to the field of wearables and consumer electronics. Michelle Nguyen and Yi Tong's papers go over academic literature review, while this paper (along with Yuhao Liu's paper) examines market reports to determine which direction our project should proceed.

One of the primary categories of competitors in the field of wearables is smart watches. While it is difficult to ascertain the potential popularity of Skintillates, if we study the market and deduce the reasoning behind the popularity of smart watches, we may be able to find analogues for our project, and therefore, derive an estimate of the potential popularity of our final Skintillates. For example, Senior Consumer Analyst Tamara Sender states, "37% of people interested in buying a smartwatch expect them to become an everyday item in the near future,"[3] and "22% of watch owners see their watch as a fashion accessory," [3]. According to her study, not only does a hefty group of wearable consumers foresee a rise in the smartwatch industry, they also value the watches as a fashion statement. Because normal tattoos are often forms of fashionable individual expression, Skintillates are likely to to pique these consumers' interest. In addition to the fashionable aspects of watches, a lot of the functionality of smartwatches can be implemented in programmable tattoos, and these features are valuable to consumers. For example, "26% of consumers who are interested in making their homes better connected would be interested in using a smartwatch to control or monitor smart devices such as smart TV, smart kitchen appliance, or smart door locking systems in their home," [3]. All of these features can be implemented in Skintillates in a way that enables a user to trigger any of these action by touching various areas on the tattoo. If programmable tattoos serve both the functional and fashionable purposes of smartwatches, but are even more customizable for users individual fashion preferences and functional requirements, there is likely to be a strong market for Skintillates.

In addition to smartwatches, consumers in recent years have increased the popularity of fitness-tracking wearables, like the FitBit and Nike Fuelband. According to research analyst Rebecca McGrath, “fitness technology has been at the forefront of wearable technology, and as the technology develops, improves, and becomes more integrated into overall wearable technology advancements, interest in, and the impact of such devices is likely to increase,” [5]. To summarize, although the field of fitness wearables is highly competitive, the development of technology will lead to an increase in the proliferation of these devices. This means that the wearables industry, where the competitive forces are strong, might easily be upset by a new entrant that targets the same market with a different approach using the same technology that has already matured. Furthermore, reports claim, the concept of a “Second Skin” is a growing trend, and “sales and usage of wearable devices are expected to grow exponentially in the coming years,” [4]. Also, “31% of exercisers have not used, but are interested in trying, a wearable fitness device, while 28% are interested in smart fitness clothing that tracks their movement and exertion,” [4]. This demonstrates that the fitness market is interested in wearables that can track fitness, and this functionality can be implemented into programmable tattoos. The report also asserts, “the launch of the Apple Watch paves the way for further exploration into wearables, such as smart jewelry and wireless patches that can be worn directly on the skin,” [4]. This suggests that the market is ripe for skin-attached wearables.

Approach: Hardware Challenges

We began our prototype and implementation phase by experimenting with tools we had available. We wanted to determine what was technically feasible given the constraints of our hardware and software capabilities, and this paper will discuss the hardware creation process and challenges specifically. In addition to the hardware challenges, we also had to work on improving the design of the skintillates themselves to be more durable, and enable capacitive touch sensors with the limited number of gpio pins available. Please refer to Yi tong's paper for a description of the fabrication process and capacitive touch sensing. Once the Skintillates were made, we needed to design android apps that allow users to interface with them. Please refer to Yuhao (Vera) Liu's paper for details about Android apps.

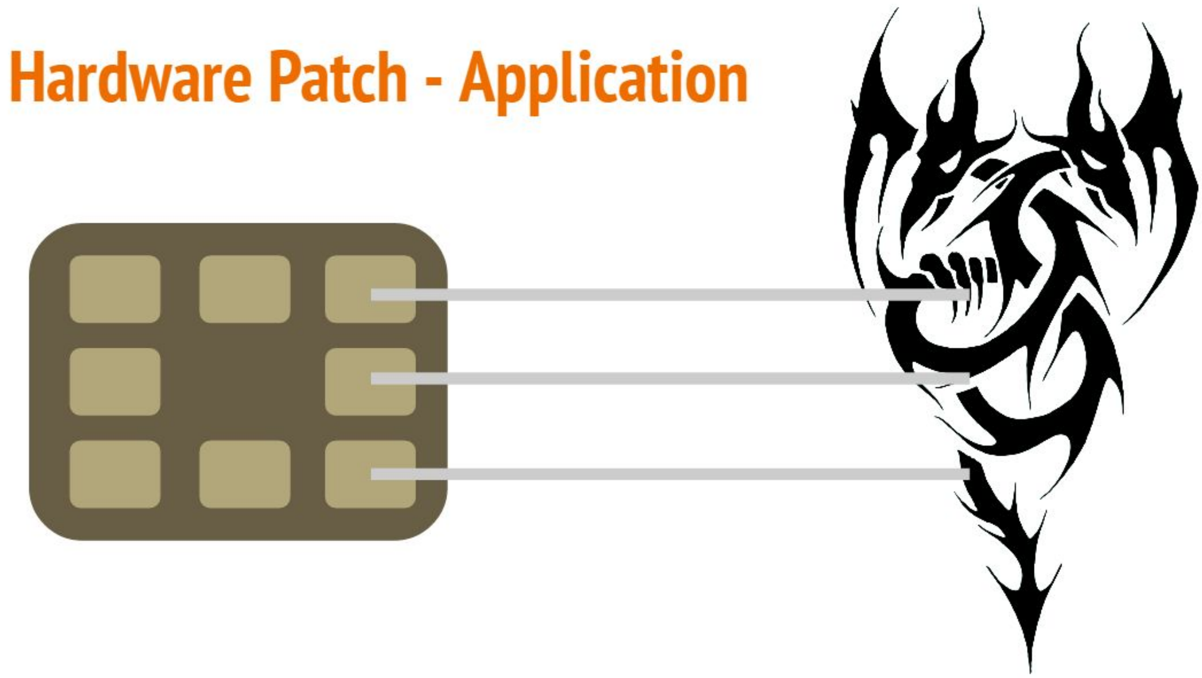
Skintillates are based off of temporary tattoos with a bit of customization and some fancy hardware. Standard custom temporary tattoos are not very challenging to create. Retailers of hobbyist arts & crafts supplies sell special packs with two components: glossy paper that can be printed on with any inkjet printer, and sticky tattoo substrate. First, a user must design a tattoo with any content creation software (or onto a physical medium and scan it), and print it onto the provided paper. Next, the user must apply the tattoo substrate to the printed design, and then apply the substrated printed tattoo to skin to create a regular temporary tattoo. The main action that converts these tattoos into "electronic" or "programmable" tattoos is the application of electrode grade medical silver screen printing ink between the tattoo substrate and the printed art layer. This can be done by first using a vinyl cutter to cut stencils, and then using the stencils to screen print a thin layer of silver onto the printed art layer. After that, we proceed as normal and add the silver-imbibed art layer to the substrate layer. Finally, we can apply the tattoo and take several measurements. For instance, if the tattoo is applied to a joint (like a wrist), flexing the joint will either relax or stretch the silver ink, changing the spacing between the conductive silver particles. This alters the conductivity of the silver layer of the skintillate, and thus, we can measure how much the joint is bent by measuring voltage drops. This can be used to track gestures or posture. Furthermore, measuring voltage changes in general can be used to measure hydration levels. Excess skin moisture will decrease resistivity, and we can use this to estimate levels of perspiration. Lastly, we can detect a user's touch on an area of the skintillate by calculating the change in capacitance of a certain patch. When a user touches the patch, the capacitance increases because the finger acts as a natural biological capacitor. However, there were many limitations. At the start of our project, Skintillates were wired: sensor data was transported to an arduino microcontroller through general purpose digital and analog input/output pins, and the circuitry and processor were powered from USB power or coin-cell batteries. There was also no user interface, and therefore, no way to interact with a Skintillate without a serial data console. Given the state of the project, before we could continue, we first needed to determine what was possible given our hardware constraints. In order to embed circuitry and batteries into a tattoo, they must be a fraction of a millimeter in thickness, or the tattoo substrate will not attach to skin properly and break. We later deemed these infeasible for a prototype, and developed alternative methods of powering these tattoos and communicating with other smart devices.

One of our primary challenges was coupling existing battery technology with our power and form factor requirements. The tattoos consist of various elements: silver ink to act as conductive lining, conductive pads (made of ultrathin copper) to act as connectors between silver ink traces and the microcontroller, a bluetooth module, and a microcontroller. While some microcontrollers can draw as little as 30 microamps [7], which is equivalent to about 0.1 milliwatts at 3.3 volts, microcontrollers that integrate bluetooth lowenergy modules can draw significantly more power. Bluetooth Low Energy alone has been proven to draw at least 0.2 mW of power [8]. For prototyping, we are using an RFduino, which has a peak draw of 18 milliamps, but can idle at 2.6 microamps [11]. In addition to the power drawn by integrated circuits, much of the sensing will come from measuring the conductivity of specific traces of silver ink, which is done by polling with voltages and measuring the response. Ideally, these tattoos should provide sufficient current to drive all the circuit components at a minimum of 3.3 volts and hold enough charge to do so over the course of a few days. More importantly, however, these batteries must be under a millimeter thick, flexible, rechargeable, and resilient. In the past, such requirements would have instantly rendered a project infeasible. Fortunately, according to Dr. Xiaoxi He, in recent years, "the change in target markets is inevitably driving change in the technology landscape too"[6]. This has led to a proliferation to small-form-factor batteries in the commercial market, and now there are rechargeable batteries that are "as thin as 500 microns, and bendable!” [9] for a relatively fair price. Most of the options offered by PowerStream claim to hold tens of milliamp-hours of charge, which should be sufficient for our testing purposes. However, further experimentation is necessary to fully validate these claims, and that is the final phase of our project.

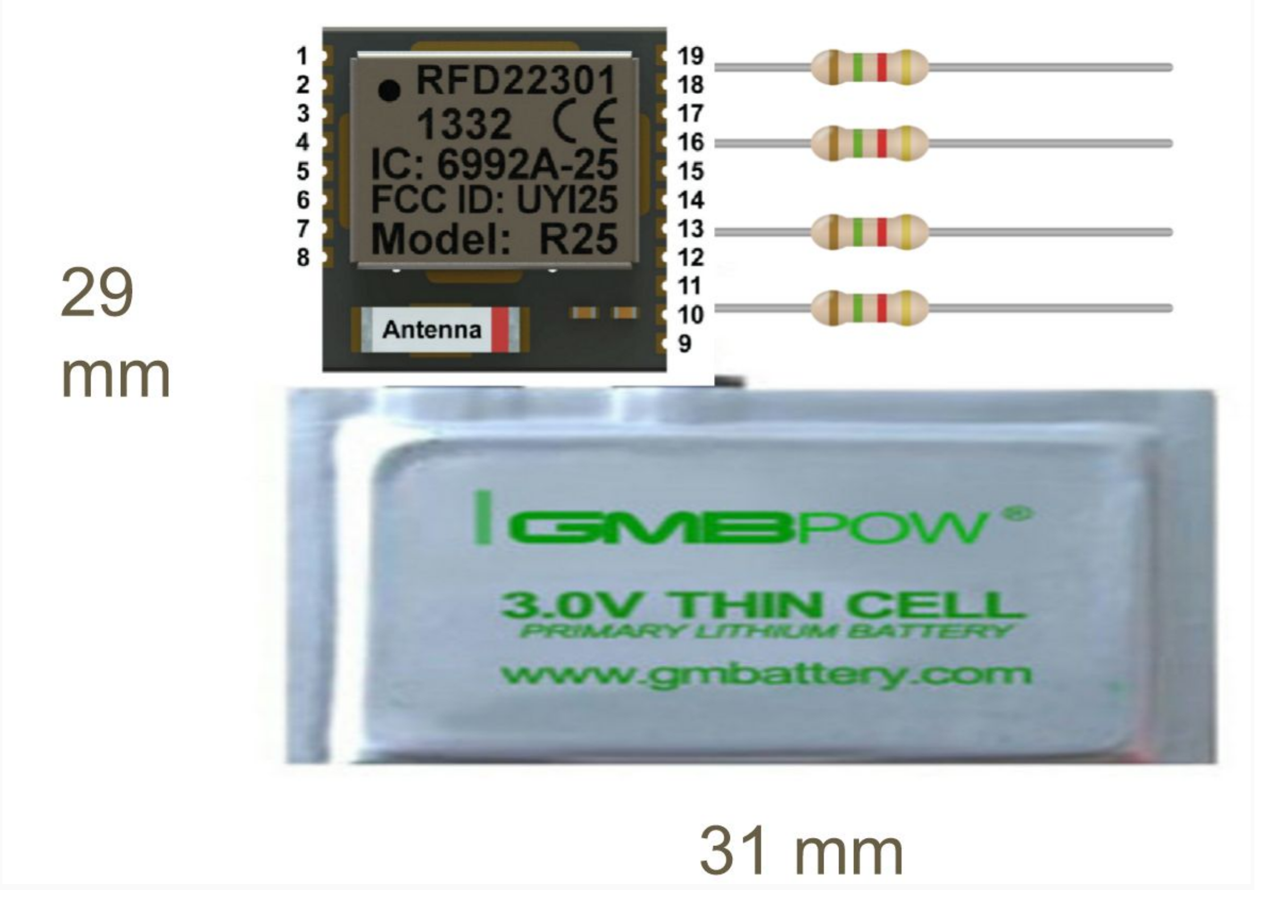
Design: Commercializable Hardware

Since our final goal is to bring skintillates to general consumers, we needed to overcome the technical challenges that prevent users without specialized tools and skills from building them. Regular custom temporary tattoos are quite easy to fabricate. However, Skintillates are not. Consumers typically do not own vinyl cutters or screen printing screens, and they are not typically proficient with Adobe Illustrator. Consumers also cannot be expected to solder wires to GPIO pins or program C. Given the state of affairs of Skintillates, before we could continue, we needed to determine what features an average may desire in a Skintillate. The “brain” and “battery” of a Skintillate are reusable but expensive. The ink and silver are relatively cheap but non-reusable. While consumers should not need to buy multiple “brains” or “batteries”, they should be able to buy packs of silver-laced artistic tattoos, and they should easily be able to construct the skintillate from the two separate parts. I will discuss these challenges in this paper.

One of our primary challenges is that microcontrollers and breakout boards are user-unfriendly. Ideally, a Skintillate should be configurable to the point where users can determine exactly which GPIO pins are necessary for their application. Users will then connect the appropriate areas of their tattoos with whatever microcontroller they see fit. However, this ideal case is inviable in market. Instead, our arduino needs to be preprogrammed and modular enough to apply to a variety of tattoos. We designed a microcontroller housing that neatly conceals the microcontroller and has 8 isolated conductive pads on the bottom. These conductive pads will be connected internally to GPIO pins on the microcontroller inside. For instance, if we want to control 3 capacitive touch buttons and 2 LEDs, this means our hardware patch needs 7 connectors to the GPIO pins - one send pin and 3 receive pins for capacitive touch, and 2 pins for the LEDs, and one pin for the LED Ground. A final pin is necessary to be able to charge the battery, and the included charger will be designed to fit our patch and only activate the charge connector and the ground connector. This hardware patch and charger can be sold separately (for $50 to $100), and will not need to be replaced. All of our pre-made tattoo designs will be built to exactly fit our 8 isolated conductive pad model. Users will load the appropriate software for the particular tattoo. For example, if the user uses a 6-button “media controller” skintillate, he or she may select a smartphone app tattoo, and the microcontroller will automatically know to read the 6 pads that are connected to the 6 buttons and send the appropriate bluetooth commands to the media device. Please refer to the figure below to see a diagram of our hardware patch connected with a skintillate.



Ideally, this housing will also contain the battery, which brings us to our next challenge: physical and technical constraints of the modular model. The first constraint is size. The smallest Bluetooth Low-Energy microcontroller currently on the market is the RFduino, which measures 15 mm square and 3.5 mm thick [12]. This means that our housing must be at least 3.5 mm thick. We also need a battery that fits this constraint and stores as much charge as possible. Ideally, this battery should provide sufficient current to drive all the circuit components at a minimum of 3.3 volts and hold enough charge to do this for 48 hours. More importantly, however, this battery must be under 3.5 mm thick, rechargeable, and resilient. Most of the options offered by PowerStream claim to hold tens of milliamp-hours of charge, which should be sufficient for our testing purposes. For example, there is a 14 mm x 29 mm [9] battery that holds 90 mAh, and this can be assembled with the RFduino into a 31 x 30 mm patch (See figure below). Once users have this patch, they can attach any Skintillate to it. Later on, we tested our estimation of the battery life of the small flexible batteries, and found that they indeed powered the rfduino for at least several hours without losing voltage. We have not yet tested if the battery will last days, and this is one of our future plans.



Conclusion

Skintillates are high-tech programmable tattoos intended to bring wearables to the next step by combining programmable circuitry with temporary tattoos. Our project has achieved a working Skintillate that is reasonably user friendly. In the future, to progress the Skintillate further, we need to develop more software applications, like experimenting with emotion and health tracking beyond basic movement. We also need to test battery life more strenuously, such as by forcing constant power activation or attaching the accelerometer to a constantly-moving source.

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Chapter 2: Engineering Leadership

Team-Written

Introduction

Skintillates are on-skin wearable electronic devices that mimic temporary tattoos. Although skintillates were originally prototyped in the Hybrid Ecologies Lab at UC Berkeley, our project extends their potential by developing software applications and improving the consumer usability of hardware components. Our goal is to move “Skintillates” from a standalone interactive device project to a consumer product that belongs to the internet of things. The concepts covered in Engineering Leadership all apply heavily to any aspect of the conversion of an academic project to a marketable product. In this paper, we will first analyze the industry we are entering in order to plan our technology strategy and marketing accordingly.

Industry Analysis

In traditional Industry Analysis, six criteria are used for defining a company: customer, geography, status, product, form, and industry. In our case, form, status, and geography are not applicable since we do not have a startup company. We did some initial market analysis last semester based on research papers and market reports gathered from IBIS and Mintel. Back then we still has a broad project scope and were exploring the whole wearable electronics industry. This semester, our project is more defined, and we realized that skintillates have some unique features that are not comparable to traditional wearables like smartwatches and Fitbit.

Our product consists of a smart electronic tattoo that communicates with a mobile app. We define our industry to be an intersection of smart wearables and tattoos. A skintillate is an electronic tattoo in terms of hardware, but our application will extend it to the "Internet of Things" field by connecting it to a smartphone app. Therefore, this industry definition fits much better to our project. The cases we studied in the industry analysis module help us accurately define our product and find our niche in the crowded market. Instead of becoming another player in the consumer wearables, we linked our project with the fashion industry and the wearable industry while being under the umbrella industry "Internet of Things".

Our entire team is based in Berkeley, California. Proximity to Silicon Valley also gives us the advantage of being exposed to different projects in incubation programs and having early access to the latest research breakthrough. Since the wearables market evolves quickly and is becoming fairly crowded, it is important for us to differentiate Skintillates from other wearable devices. The first step in distinguishing our project from existing competitors is to be well aware of events and progress in the field and know about new features of wearables at once. Our customers will be discussed in the next section in combination with tech strategy.

Tech Strategy

Although we are not aiming to launch our product to market by the end of our capstone project, it is still helpful to make decisions about the market segment and go-to market plan (Friedman 2012). From the Virgin Mobile case (Srinivasa 2003), we learned that one of the most important aspects of tech strategy is choosing the correct market segment. Virgin Mobile was attacking a stable industry with a difficult barrier to entry: the cellular telephone market (Srinivasa 2003). With the amount of infrastructure it takes to set up a cellphone network combined with the acquisition of customers who are likely under a contract with another company, an early-stage cell phone provider has little likelihood of success. However, Virgin Mobile realized that there was an untapped market segment that could potentially benefit from cellphones, but were not targeted by existing giants like AT&T: young people. Because young people are likely to earn less and be less willing to follow long-term contracts, Virgin Mobile changed their business model to accommodate these types of customers, while adding features to excite the specific target demographic (Srinivasa 2003).

Similarly, the most important part of launching a Skintillate venture is appropriately targeting the right audience. Since Skintillates are still in research phase and the market is still emerging, our target audience would most likely be tech savvy young professionals who are willing to try new gadgets and have a sense for fashion. From the market research we did on wearable market, we realized that even though almost 80% of general population are familiar with one type of wearable devices and their concepts, only 21% of them would actually become a consumer (PWC 2014). And the people who have became wearables consumers are mostly well-educated people with stable financial income. Among them, almost half of them are between age of 18 and 34 (PWC 2014). Therefore we decided to target the similar group of audience, but appeal them with our key differences: “wireless” and “aesthetic” (Ramasamy 2014). The popular products in the market right now are mostly focused on functionality, rather than the decoration purpose. However the younger population would care more about their appearances. Even though wearables might have new features they want, they would still care about how wearables change their look. We are hoping to market Skintillates as customizable wearables where the users can decide the design of what the tattoo is going to look like, while the core functionalities remains.

Marketing

Skintillates was initially a research project. The original prototype connects to laptops or smartphones with wires and uses standard Arduino microcontrollers and coin-cell or regular batteries attached. In the marketing module of our leadership boot-camp, we learned to create a buyer persona and propose differentiation for our product in the market. Our persona for skintillates is someone who is young, fashionable, tech-savvy, passionate about new gadgets, and always excited to try new things. This persona is likely to have at least a smartphone, if not a smart-watch or another wearable, and has the typical technical skill of a millennial - enough to operate new technology, but not necessarily enough to operate low-level hardware or program smartphone apps. To attract customers within this persona category, we have to improve the usability of skintillates.

First of all, our customer will not spend effort or time on programming, compiling, and porting code onto a microcontroller, despite the customizability benefits. To accommodate this, we developed applications for different user scenarios, including Android apps and a web server. These applications also help us extend the breadth of our user base for marketing purposes. Our second concern is with usability of skintillates. Since it can be marketed as a fashionable wearable, portability is the top concern. We replaced the wire connections with bluetooth low energy to send signals from microprocessor to mobile phone. Therefore users can take skintillates everywhere and it will not interfere with their normal activities. We bundled the battery, microprocessor, and sensors together into a hardware patch. The hardware details are safely hidden from the customers. Another usability concern is with the discomfort of batteries or microprocessors attached to skin. The hardware patch mitigates this problem as well. We replaced original Arduino board with RFduino, a mini-microprocessor that is as small as a fingertip. We embedded flexible batteries that are more suitable to place on arms than normal batteries.

For product differentiation, our main marketing point is that skintillates are fashionable and relatively cheap compared to other wearables such as Fitbit and smart watches. The introduction of a sealed hardware patch was a great point to reduce cost. Since the hardware patch is separable from skintillates themselves, the customers can reuse the hardware patch for different designs of skintillates. The substrate layer is a fragile temporary tattoo. The hardware patch can save the customers from throwing away processors and batteries after the skintillate breaks down, or going through the effort of reconnecting everything when they replace the tattoo layers. The flex batteries we use to power the hardware patch is rechargeable, saving lifetime cost of skintillates.

The customer positioning and marketing strategy we learned in the leadership module helped us a lot in defining the direction and goal of our final product. We aim at making our product user friendly with a clear and precise targeted persona definition.

Conclusion

Skintillates are thin, on-skin, and aesthetically pleasing wearable devices. These unique characteristics open up an opportunity for them to become a platform for “Internet of Things”. By enables wireless connection and expanding the capacitive touch capabilities, we are building the infrastructure for Skintillates to be customized to different interactive devices. The first generation of panel control and crowdsourcing applications we are building are great stepping stones for “Skintillates” to become a fully-fledged platform to democratize wearable technology.

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