Capstone Project Report - Programmable Materials

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Technical Contributions

Yuhao Liu

1. Introduction

1.1 Project Overview

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.

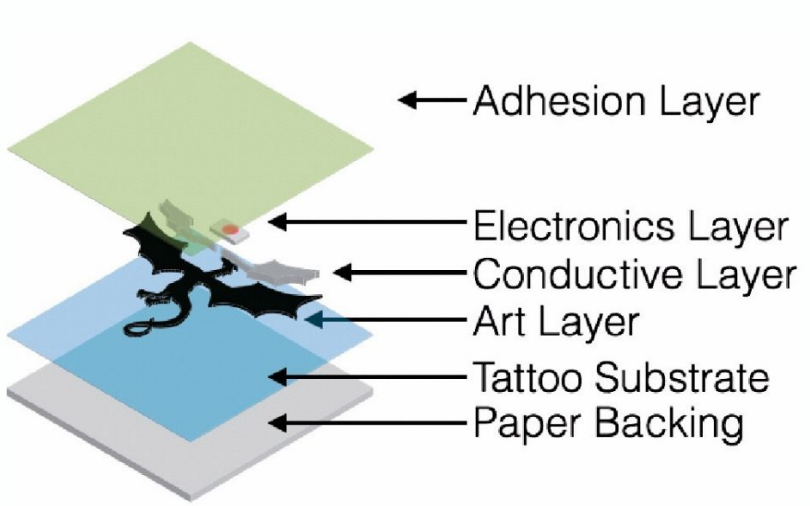

Figure 1.1.1 Components of Skintillates

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 has a lot of wires coming out off the tattoo, linking to a big microcontroller powered by regular batteries or computer. Since it's a wearable to be applied

directly onto the skin, the exposed electronics will cause discomfort for the users who wear it. We addressed the concerns by improving portability, increasing compactness and extending battery longevities. We proposed solutions such as replacing the regular arduino controller with a fingertip-size microprocessor, separating hardware patch from the tattoo, 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 processors. One used 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 can trigger music on a demo app on Android phone. The prototypes successfully gained attentions from the audience during our exhibition. People are amazed by the power of skintillates and its form factor. At the same, people expressed concerns with battery life and durability of hardware. After the expo we decided to put more efforts into providing feedback to users from the hardware and extending software features. We utilized sensors embedded in RFduino processor and developed mobile apps and website linked to skintillates for user interactions.

1.2 Task Breakdown

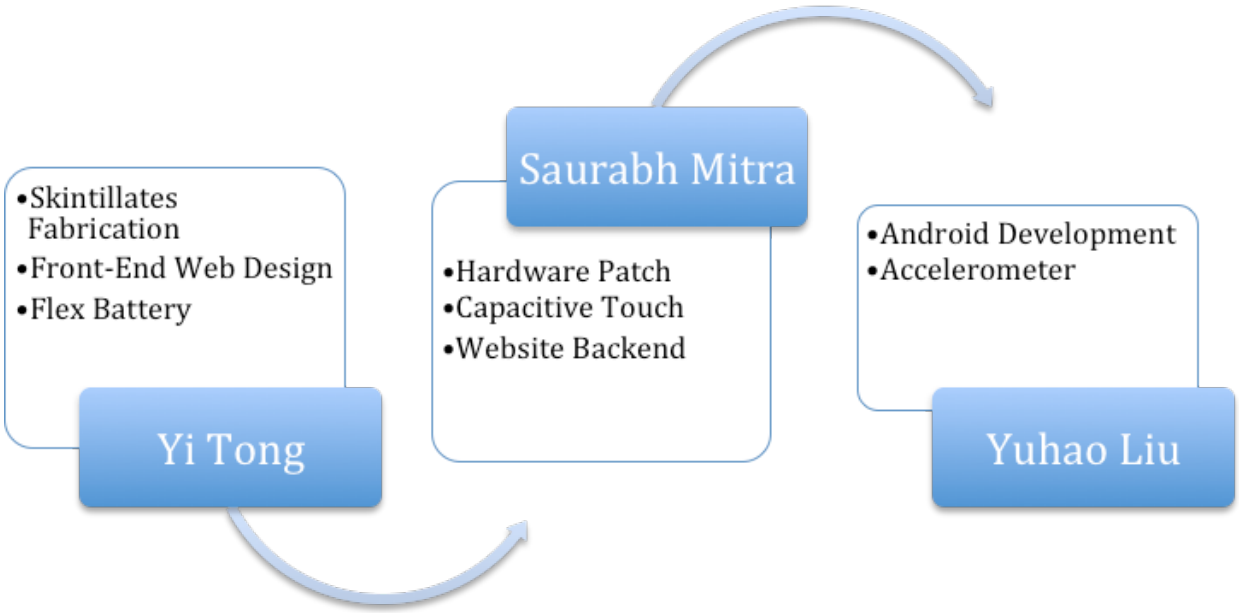

Figure 1.2.1 Task Breakdown of Our Project

This paper is going to elaborate on my technical contribution including user studies, mobile app design and development. These contributions, combined with work of Saurabh Mitra on modularity and compactness of skintillates hardware and contribution of Yi Tong towards fabrication process, prototyping and web design, enhance the user experience of skintillates itself. The final deliverable of our project is a user-friendly e-textile with hardware compatible with various mobile applications for different user scenarios.

2. Problem Statements

This section will layout preliminary task analysis and address user needs of our product.

2.1 Entertainment Aspect

We want to implement interactions on skin for situations where phones are not readily accessible. For instance, when the user is jogging or on the go, it's not convenient for them to pull out their cellphones. Skintillates will allow the user to perform tasks like starting a soundtrack with one simple tap on the arm. With Skintillates, people have a new way of interacting with electronic devices.

2.2 Social Aspect

At large events like music festival, night club or concerts, people usually do not have their hands free but still would like to engage with the crowd. Smartphone usage is prevalent in such social gatherings (Pew Research Center 2015). People sometimes send snapchat or twitter to share that they are having a good time, or wave their hands along with the music to engage with DJ or singer. Skintillates can be of great use in such scenarios.

Apart from social gatherings, wearable technologies could also be play an important role in sports games. Sports fans usually put up masks or themed colors on their faces and arms to show their support for their teams before they go to a game. Replacing those one-time body decoration with reusable Skintillates is much more economical-friendly. Skintillates could be reused for different games, unlike foam hands, color sticks, and noises makers which are thrown away right after each games. Another advantage is that wearable technologies are software heavy and can be used across different genres of games and teams. Normal physical devices do not have the compatibility . For example, soccer horns are not generally used for basketball games.

2.3 Fashion Aspect

Technology used to have no roles to play in the traditional fashion market. The application of digital technology in fashion has been limited to low-fidelity prototypes like LED-lit up dresses. These so-called digital fashion could not get the desired appreciation from high fashion designers or social acceptance from daily life wearers. Wearable technology perfectly fits this gap as it brings software closer to decoration (Singh, 2014). The new era of wearable technology has come with the movement of devices from users' hands to their bodies. According to (Sender 2014), wearable technologies need to integrated aesthetic elements in order to appeal to fashion market. Since the fashion industry emphasizes appearance over usability, skintillates design need to address design flexibility and creativity, following design-prototype-evaluation process in the development phases. Users could customize their skintillates by having their own design for the tattoo substrate layer.

3. Design Approach

This section is going to walk through our design process and our design choices reasoning given the evidence from the market research.

3.1 Initial Design

Originally we planned to build one mobile software with different functionalities under three tabs: health, social and entertainment. For the social part, the application serves as a hub for transferring messages through communication with skintillates. As for the health function, the

application will display graphs with user's health data for analysis and visualization purposes. For entertainment part, it serves as a music player, connecting with buttons on skintillates.

After trying some popular social/health Android apps and mobile interfaces like Facebook, Yelp, Fitbit and Youtube, we decided that tab-based (Gube 2009) main interface would be appropriate for our app. The tab-based interface makes our code manageable by splitting modules and separating data structures. It also gives user freedom and flexibility as the user can switch between the two interfaces.

Under the health tab, we planned to have plot with heart rate and exercise intensity as Y axis and timestamp as X axis. User can click on "Share My Health Data" under the health data tab and the interface jumps to user's facebook or twitter account. □Because of restricted power on microprocessors, analysis and visualization of health data will be performed on the mobile platform. Under the social tab (represented as a death mark from Harry Potter series), we created a List View of teammates with a plus button to add more teammates. Each cell of teammate will show a 'Delete' button if swiped to left, the teammate will be deleted once the user clicks on its 'Delete' button. Under the List View there is a 'Summon' button, this is for scenarios when the user wants to call for a meeting on phone instead of pressing the button on skintillates. Under the entertainment tab (represented as a music logo), we designed an iTunes-like interface with album cover and list of songs.

3.2 Health App

In the new trend of wearable devices, healthcare technologies have diverged from mainstream technologies. Traditional wearable devices such as smartwatches and Google glass are more

focused on software and interaction with physical devices, while health care wearables like Fitbit and Xiaomi wristband are purely focused on health analysis and tracking. Fitbit Inc., Apple and Xiaomi are the most trendy brands with dominant market share of 58.2% (IDC 2015) in the health wearable market. The strong competition, high switching cost for migrating personal data and purchasing new gadgets and scaling effect in production stage set a high barrier for new entrants to the market. One of the differentiating features of skintillates is that it is designable and fashionable. But for health aspect there is no outstanding advantage over other existing products on the market. Given these factors we eventually abandoned the health application.

3.3 Crowdsourcing Website

For the social aspect of our application, we brought in the idea of website to replace the original message-sending app. To address the social needs, instant sharable contents are more efficient than peer to peer communications, especially for crowded and loud social gatherings. For our intended scenarios such as concerts, sports game and nightclubs, big screens are usually attract the most concentration from the crowd. A website is more useful in this case. A ethernet shield is required for arduino to send HTTP request to a url. But we do not want Ethernet shield to add redundancy to our hardware patch, so we choose to develop a phone app to establish connection with website. This application does not have interface on the phone, it runs a thread in the background for crowdsourcing and post the data to website. The website updates its front end interface based on data gathered from the phones. The webpage is displayed on screen and users will see real-time updated crowdsourcing data on it.

3.4 Final Applications

After several user testing and interviews, we decided to separate our extensions to multiple mobile applications to better demonstrate the breadth of skintillates utilities. We think this approach could help us attract broader users interested in different applications of this new wearable technology. Since we have different target users for our apps, it is more reasonable to separate out apps for different user bases. For instance, our remix app are intended for soundtrack-remix lovers such as DJs, electronic musicians or songwriters. Whereas our music player app will be used more often by people who enjoy listening to music during daily activities such as exercising. The website we built is more suitable for display on big screens at social gatherings. The variety of applications will be helpful in marketing and promotion facing different target audiences.

4. Development

4.1 Android Bluetooth Connection

To improve the portability of skintillates, I use Bluetooth Low Energy technology to establish connections between Android apps and microprocessors. Bluetooth Low Energy (BLE) is the best choice to save users from tangled, easily breakable wires connecting skintillates to the phone. With wireless connection users can take skintillates wherever they want.

In our android application, a background service runs continuously searching for devices. The device name is set to be “Skintillates” on RFduino. Once this device is found, the phone app establishes connection and busy waits for characteristics. The characteristic is like a signal tag

associated with messages sent from a particular device. Once the signal is read in on Android application, background music player service gets triggered. The signal gives the information on which button is pressed, so the phone could interpret which sountrack to play or pause.

Figure 4.1.1 Flow of communication

4.2 Remix App

I developed the remix app in Android Studio. This app is intended for people to play with different soundtracks and remix effects. It is connected to RFduino with planted capacitive touching code. Users could play with up to three soundtracks from the database. The three buttons on skintillates control play/pause of each soundtrack.

Because we want our phone app to serve as a facilitator for skintillates, The interface only had audio visualization corresponding to sound effects. We would like to keep the interactions on phone as minimal as possible to exclude ourselves from normal remix apps, addressing the features of skintillates. For our soundtrack database, we chose different genres of tracks including tracks for drum, bass and acoustic

songs. I used the open source library Android-Visualizer developed by Felix Palmer to display plots with visual effects corresponding to soundtracks (Felix 2014).

4.3 Music Player App

I implemented another music player app with the same background settings as the remix app. It accepts signals through BLE from RFduino. The middle button on skintillates corresponds to play/pause of the song while left and right buttons correspond to “switch to last song” and “switch to next song”. The interface layouts album cover and list of songs in a scrollable listview.

4.4 Accelerometer

We started with movement-related data gathered from accelerometer. The movements collected from accelerometer in microprocessor are velocity and acceleration rate along x, y and z- axis based in real world coordinates. The prototype we built for our first expo was sending out a binary signal indicating whether the user is moving or not. The LED light under the substrate layer lights up when sum of squares of acceleration difference is larger than zero. When the user is running, shaking arms or jumping upside down his skintillate will light up.

For our final product, we detect two kinds of activities on our accelerometer - MPU 6050 attached to RFduino: shaking and raising. For shaking, we use a threshold for the accumulated values of calibrated acceleration rate in x, y and z direction. Once their sum reaches the threshold, a shaking is detected and is interpreted as “dancing” mode. When calibrated acceleration rate in z reaches a threshold, a raising is detected and is interpreted as “raising hand”. These two signals get sent to phones connected with RFduino on BLE. The phone app

runs a service in the background constantly pulling data from BLE. Once a shake or raise is detected, it gets sent to the website url via a HTTP PUT request.

Apart from detecting dancing moves and how many people are throwing their hands in the air, these detections could be used as the base for automatic voting and team-cheering for more applications in the future.

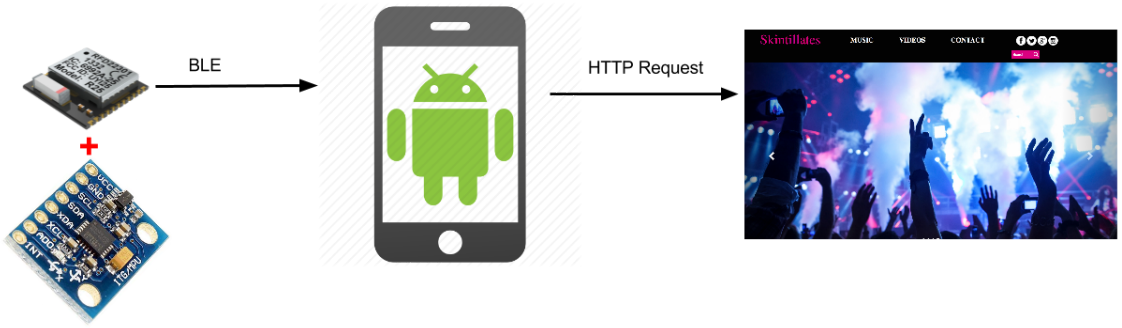

Figure 4.4.1 Connection Between RFduino, Phone and Website

5. Conclusion

Since our project lies within the concentration of Visual Computing and Computer Graphics, with our technical advisor specializing in Human Computer Interaction, we focused on designing smooth user flows and usability. Software development is important because it adds skintillates to the booming market of “Internet of Things”. It makes skintillates unique and differentiates it from normal electric tattoos. Our whole project is developing around skintillates and aims at making it more user friendly in both hardware and software sense. Our mobile app will be a strong point of commercializing skintillates. It adds the social aspect to skintillates featured with

more fun user interactions. We are also leveraging our programming capabilities as well as our gains from leadership courses.

Chapter 2

Engineering Leadership

1. 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.

2. 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.

3. 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.

4. 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.

5. 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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