Toccando

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***Abstract*—Sophisticated touchscreens for modern day electronic devices have become ubiquitous in our increasingly high-tech lives. However, although the technology of touchscreens has dramatically improved over the past decade, tactile perception has been lost.**

Toccando aims to fill this lack of sensory output by providing tactile feedback in response to user input. Feedback is based on the ultrasonic vibration of piezoelectric speakers attached to a pane of glass. The basic concept uses a one-directional chain of events. First, the location of the user's finger determines whether the device is on or off. Second, this information is sent to a microcontroller that produces a corresponding waveform. The waveform is then amplified to a perceptible level. Finally, the waveform drives the speakers, causing the glass to vibrate and the user to experience a sensation on their fingertip.

Toccando will be a single finger input device aimed at enriching visual maps. It will consist of an Android map application and a hardware casing. The goal is to make smart devices more accessible when visual cues are unavailable or inconvenient. Its significance lies in the potential for improving accessibility and immersion, as well as providing additional support for the visually impaired.

I. INTRODUCTION

Touchscreens are an integral part of modern smart devices. These screens allow users to interact with their gadgets, quickly, easily and effectively. Bridging the gap between intent and functionality, touch is one of the most intuitive mechanisms for transmitting and receiving information. Touch is currently the leading method of operation for phones, tablets, and other smart devices. Nonetheless, aside from full-scale vibration, there is still a lack of physical feedback from contact with these devices. Therefore, due to the prevalence of gadgets that employ touch in their operation, the lack of precise tactile feedback in modern day devices limits the scope and significance of physical and virtual interactions.

Touch helps us understand our surrounding environment. Physical topographical maps are often used as educational tools, because of their ability to seamlessly relay information [15]. After all, education is only one potential application of tactile maps. In addition to improving accessibility for the visually impaired, tactile maps give users a tangible overview of a geographical area. We envision a future in which tactile maps allow drivers to access the contour of an upcoming turn, without ever taking their eyes off the road.

As it stands, there are three main physical methods of force production in surface haptic technology: moving overlays, ultrasonically vibrating surfaces, and electrostatic surfaces. Electrostatic surfaces use an electric field to attract skin to the surface, increasing the normal force and thus increasing friction [9]. Moving overlays make use of motors and a thin film on a static virtual display. The overlay in motion causes users to experience a shear force concentrated on their fingertips [1]. On the other hand, ultrasonic surfaces create a tactile impression on a bare finger, by vibrating the surface ultrasonically, reducing surface contact time with the fingertip. This reduction of time in contact with the surface leads to a noticeable decrease in surface friction [1]. The apparent change in surface texture is due to the duplex theory of tactile texture perception, in which vibrations are transduced by rapidly adapting mechanoreceptors in the skin, sending a vibrotactile signal to the brain. Therefore, stemming from the loss of friction, and by virtue of the duplex theory of tactile texture perception, the fingertip, interacts with a seemingly smoother glass surface [8]. All of the aforementioned methods aim to provide the end user with a similar experience: tactile feedback. Regardless of the technology used, several applications arise, including: Enabling map topology/topography distinctions and permitting sensory previews of environmental changes.

We have decided to employ the ultrasonic method of force production in our design, because of the precision it provides, the low cost of the hardware, and the simplicity of construction. The underlying principle behind using ultrasound lies in the *squeeze film effect*. The principle states that when material moves at ultrasonic frequencies close to resonance, the pockets of air between the material and other objects (in our case a finger) are increased, reducing the coefficient of friction. The result is a slipperiness akin to an air hockey table [12-13]. To create the squeeze film effect across a piece of glass and correlate the sensation with a visual image, we have designed Toccando to be a single finger input device. It works by varying the coefficient of friction at controlled intervals to simulate a flat surface. When friction is increased, the finger observes a sticky feeling, approximating the "edge" of an object [4].

The design has four main subsystems (as shown in Figure 1): the Digital Interface, the Digital/Analog subsystem, the Power subsystem, and Primary I/O subsystem. The Digital Interface refers to the Android phone. The Digital/Analog subsystem corresponds to our waveform generating mechanism. The Power subsystem consists of a power supply and an amplification circuit. The Primary I/O subsystem refers to the glass pane with attached piezoelectric speakers. Toccando will be a specialized case for the Samsung Galaxy

S4, with the glass placed over the screen of the phone and the remaining hardware tucked away in the surrounding space around the phone. Further discussion of each of these subsystems is contained in the following subsections respectively: B, C, D, and E.

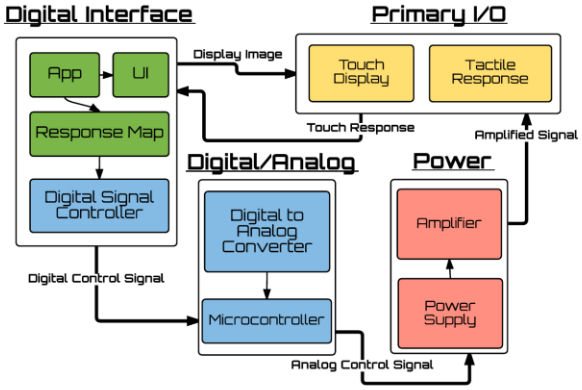

Figure 1. Block Diagram

Additionally, the design must meet specifications relating to mass, dimensions and power consumption.

Specifications	
Mass	<400 g
Height	<180 mm
Width	<90 mm
Depth	<25 mm
Battery Life	>10 hours
Response Time	<150ms

These specifications were designed to ensure compatibility with the Samsung Galaxy S4. Current phones and portable devices have variable masses between 125 g and 800 g (for tablets) [16]. For reference, we have included Figure 2, an illustration of current smartphones masses.

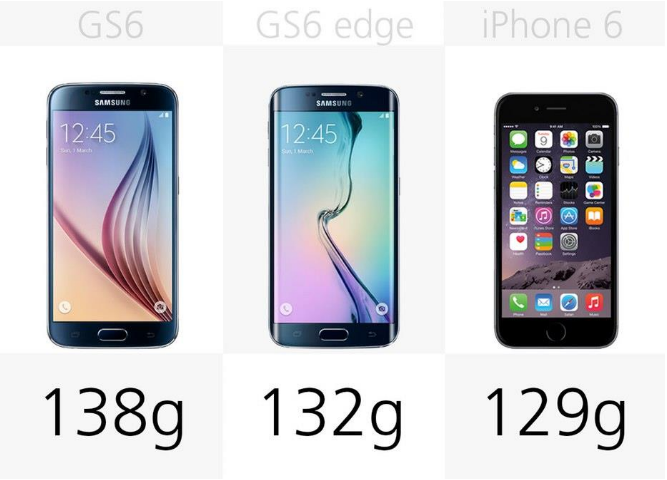

Figure 2. Mass Comparison

We've determined that the mass of Toccando should be 380 g. This value would make the entire portable device 500 g since the Samsung S4 weighs around 138g. The hardware components that we will use include an additional battery, the glass pane, as well as all the circuit board components. An additional battery will weigh approximately 23g and the glass weighs, 17g. The rest of the components should be no more than 366g. We have assigned a ~10% allowance to our mass specification and we estimate that the microcontroller and amplifier system will be well within this weight range.

We have taken similar considerations for the dimensions of the casing, based on the size of the Samsung Galaxy S4 [17].

A. Overview

The design of Toccando hinges upon a single chain of events that lead to a tactile output. As previously mentioned, the design consists of four main subsystems. The Digital Interface (Android phone) uses internal hardware to detect the user's finger. An important feature of our implementation is that our device will be single touch, not multi-touch. After the finger location is determined by the software, a signal is sent through USB to the microcontroller. The microcontroller generates an analog ultrasonic signal that is amplified by the Power subsystem. The resulting wave is sent to the Primary I/O subsystem, and is felt in the glass as a tactile response. A simplified overview is shown in Figure 3.

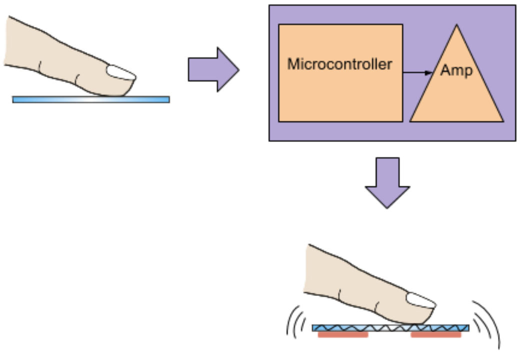

Figure 3. Simplified Overview

In the block diagram (Figure 1), the Primary I/O consists of the touch display and the tactile response. These blocks represent the glass pane with piezos attached, and the sensation output respectively. Several design choices were involved in constructing the touch display. We chose 1.1 mm soda lime glass in order to ensure a lightweight design and guarantee that the finger could still be detected by the phone. To handle the amplitude needed to create a sensation (above 50 V peak-to-peak), a standard piezo buzzer was selected at 35 mm. The size of the round piezos turned out to take up too much space on the glass. Our solution involved trimming the piezos to retain a length of 35mm, leaving a width of only 7 mm. These piezos were glued to a single edge of the glass as seen in Figure 6.

To date, we have used a transformer as our entire amplification system. However, in the final design we will need to use a much more sophisticated power amplification system. Thus, the Power system in our block diagram will be changed. We need a minimum of 1W to drive the piezos at a level sufficient for sensation. Experimentation in the lab resulted in a resonance frequency of 32 kHz for our pane of glass. The Digital/Analog block will generate a square wave at 32 kHz. We are using an ATmega32u4 breakout board. The choice of microcontroller addresses the ability to receive USB signal data. Creating the 32 kHz wave is a lesser task for the microcontroller in comparison to the overhead required to interpret USB packets coming from the Android phone. Bluetooth and wireless communication were possibilities that were also considered, however they were deemed too intensive, due to the overhead requirement for receiving messages. The system [needs to provide] a tactile response within 150 ms of a user’s touch response to avoid the unpleasant ‘sticky’ feeling associated with longer feedback delays [6]. We went with a cable connection to best address this speed requirement.

The Android device itself is the Digital Interface block. There are two subsections of the Digital Interface: the front end, which includes the App and UI; and the back end, which encompasses the response map, and the digital signal controller. The front end will provide visual cues. Whereas, the back end, will handle input location and boolean variable data.

To summarize, tactile feedback is expected from the design based on the assumption of accurate localization of user input; the interconnectivity of the different components (phone, microcontroller, piezoelectric speakers); and a discernible sensation on the glass surface.

An alternative design that was considered included the use of electrostatic surfaces but was deemed unreasonable due to continuously varying output requirements, and safety concerns related to the high voltages necessary for implementation [9].

B. Digital Interface

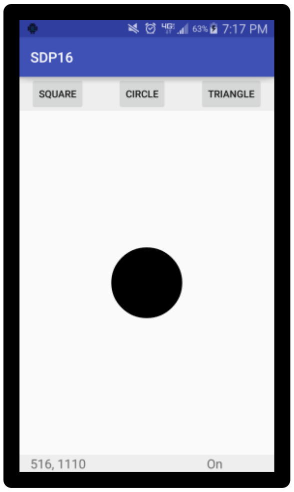

Figure 4. User Interface

NOTE: The “Increase Touch Sensitivity” option is toggled on because of the additional glass placed on the phone.

The Digital Interface block consists of an Android application and user interface, which sends an image to be displayed on the touch screen of the device. The application will consist of a response map, adapted to generate a control signal based on the location of a touch response. A prototype of the user interface is shown in Figure 4. The UI displays the coordinates of user input. Presently, it provides feedback using a precursory response map of simple geometry. Fundamentally, due to the use of Java on the Android platform, the Digital Interface block capitalizes on techniques learned from Data Structures and Algorithms in Java as well as design principles covered in Computer Organization and Hardware Design.

The application is written in Java for the Android platform and is backward compatible to Android version 3.0 (Honeycomb). The GUI displays simple shapes (square, triangle, and circle) that dynamically change the perimeter of the tactile response. Behind the scenes, the application uses a finger tracking API which taps into the phone’s internal hardware to retrieve the location of a finger on the screen. For debugging and demonstration purposes, the location is displayed on the bottom left hand corner as shown in Figure 4.

The map application is still under development. However, the same principles can be applied. A complex shape on the map will act in a similar way to the primitive shapes currently used in our application. For example, a road will be displayed in black and respond according to user input. A Boolean variable will be set to true or false depending on the finger’s placement on or off the road. In Figure 4, the “On” in the bottom right indicates that the finger is located inside the black region.

C. Digital/Analog

The Digital/Analog block will make use of the ATmega32u4 microcontroller. We chose this microcontroller because of its 12 Mbit/s data transfer rate, low power consumption, and its capacity for wave form generation [10].

The ATmega32u4, shown in Figure 3, will interpret the digital signal in order to convert it into the waveform necessary for tactile sensation. It will then send the newly converted signal, referred to here as the Analog Control Signal, to the Power block for amplification. The microcontroller will be programmed using techniques learned in the Computer Systems Lab, and Software Intensive Engineering.

Figure 5. ATmega32u4

In particular, the ATmega32u4 will make use of the USB Human Interface Device Class (USB HID) to receive signals from the Android operating system. The HID will designate the microcontroller as an accessory to the smartphone and will allow it to receive information. In order to transmit a valid signal, the smartphone must then act as the host device. Hosts must respond quickly enough so users don't notice a delay between an action and the expected response [11]. Due to compatibility issues, presently, there is still work that needs to be done, in interfacing the two devices.

D. Power

The Power block will power the device and ultimately be the input to the piezoelectric speakers. It should be lightweight and energy efficient and last longer than the battery of the smartphone. In building the amplifier, we will use techniques learned from the Circuit Analysis and Electronics courses offered at the University of Massachusetts in Amherst. The amplifier must be able to output a voltage sufficient for driving piezoelectric speakers.

E. Primary I/O

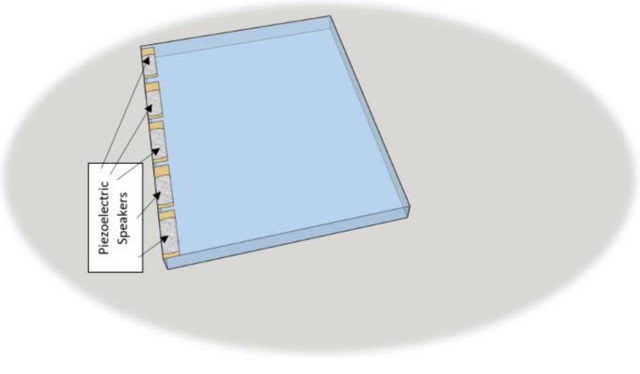

Figure 6. Glass Pane

The Primary I/O block is the beginning of user interaction, as well as the realization of the tactile response generated by the other blocks of the system. The glass pane of the Primary I/O block will allow the user to view all the graphical content displayed by the phone. In other words, this is where image content is displayed to the user, and also the medium through which sensation is conveyed. This sensation, referred to as the tactile response, will be achieved through the ultrasonic vibration of the piezoelectric speakers. The waves will propagate through the glass pane, and ultimately will be relayed to the end user. As such, the glass pane must be thin enough to permit an unimpeded touch response to be sent to the digital interface block. As previously stated, the Digital Interface block makes use of a response map to interpret touch responses in the generation of a digital control signal. The glass pane must then provide a binary tactile sensation within 150ms of user input to avoid the discomfort associated with substantial latency [6].

Under these circumstances the Primary I/O block makes use of amplitude modulation in the generation of textures. These textures are known as the block's tactile response. In addition to amplitude modulation, the Primary I/O block will rely on wave theory, in delivering an ultrasonic vibration at a resonant harmonic. Overall, the Primary I/O block will make use of techniques and ideas covered in Signals and Systems, as well as Electromagnetic Fields and Waves.

PROJECT MANAGEMENT

MDR Goals	
Binary Tactile System	Achieved – Not To Specs.
Microcontroller Compatibility	Under Development
Preliminary UI	Achieved
Detection of Input Location	Achieved

For the Midway Design Review, we have achieved the components necessary for a binary tactile system in which feedback is exhibited to the user through a low frequency vibration of the glass screen. We demonstrated that the Android device could indeed produce an app that recognizes finger location with respect to visual data. We were able to generate a USB signal from the PC and correctly display the message on a set of debugging LEDs connected to the microcontroller. Using a function generator, we created a low frequency signal that produced a tactile sensation on our glass pane with the attached piezos.

The Primary I/O block was built by the electrical engineering students, Casey Flanagan and Ygorsunny Jean. The user interface in the Digital Interface block was programmed by computer systems engineering student William Young. Integration of the two subsystems is being developed by computer systems engineering student Esther Wolf.

We are continuing our research on the ultrasonic vibration of glass and the fundamental frequency of piezoelectric speakers, to achieve the desired frictionless effect. Additionally, we have conducted power experiments using a Darlington pair circuit, and a transformer. However, since we are unsure of the desired output we cannot be sure of its power requirements. Since our goal is to power the system with 5V for 13 hours of time, we have estimated that we need a battery with a capacity of around 2600mAh, to compensate for the current and voltage. We know we need 1 watt of power so 200mA at 5V would give us the power needed to meet our specifications.

After the MDR demo, we have since continued to conduct experiments. A rodent repellent signal generator was connected to the piezos. The device gave us the ability to generate enough power at ultrasonic frequency. We were able to determine that the resonant frequency exists at approximately 32 kHz.

Progress needs to be made in integrating the multiple pieces and generating the appropriate sensation. Next steps include communicating to the microcontroller via the android phone instead of the PC, producing the appropriate signal from the microcontroller, building a power amplifier, and improving our Android app so that it displays maps.

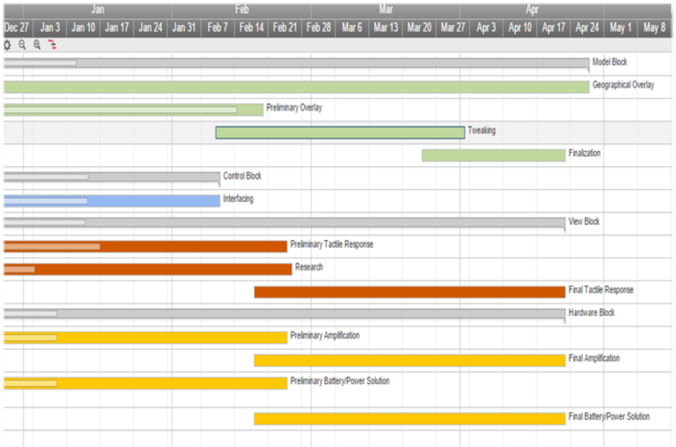

Fig. 5 Gantt Chart

II. CONCLUSION

Currently we are in the process of programming a response map application for the Digital Interface block. This will be done by computer systems engineer, William Young. He specializes in the Java programming language and has experience with programming graphical interfaces. Since we can already indicate the location of user input and provide visual feedback from a basic response map, we hope to scale functionality to a geographical overlay. This will provide us with an application for our design.

We also will be working to interface the Android device with the ATmega microcontroller. Regarding this, work done on the Digital/Analog block will be performed by computer systems engineer, Esther Wolf. Once the devices are properly interfaced, development on the mapping application will proceed in full.

Work on the Primary I/O block will be done by electrical engineer, Ygorsunny Jean. He will work to achieve ultrasonic vibration by determining the fundamental frequency of the system and will ensure that the user receives the expected tactile response.

Work on the Power block will be done by electrical engineer, Casey Flanagan. He will ensure that the device operates with efficiency with operating time greater than or equal to the paired smartphone or tablet.

Due to these factors, we are planning to work on the design of each block concurrently and hope to reach our milestones using sizable chunks of time. Nevertheless, we expect to encounter difficulties relating to proper tactile response and power consumption, as they are two of our most interdependent specifications.

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REFERENCES

[1] D. Meyer, M. Wiertlewski, M. Peshkin and J. Colgate, 'Dynamics of ultrasonic and electrostatic friction modulation for rendering texture on haptic surfaces', 2014 IEEE Haptics Symposium (HAPTICS), 2014.
[2] T. Watanabe and S. Fukui, 'A method for controlling tactile sensation of surface roughness using ultrasonic vibration', *Proceedings of 1995 IEEE International Conference on Robotics and Automation*, 1995.
[3] T. Maeno, K. Otokawa and M. Konyo, '4A-5 Tactile Display of Surface Texture by use of Amplitude Modulation of Ultrasonic Vibration', *2006 IEEE Ultrasonics Symposium*, 2006.
[4] M. Wiertlewski and J. Colgate, 'Power Optimization of Ultrasonic Friction-Modulation Tactile Interfaces', *IEEE Trans. Haptics*, vol. 8, no. 1, pp. 43-53, 2015.
[5] L. Winfield, J. Glassmire, J. Colgate and M. Peshkin, *Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (WHC'07)*, 2007.
[6] T. Kaaresoja, E. Hoggan and E. Anttila, "Playing with tactile feedback latency in touchscreen interaction: Two approaches," in Human-Computer Interaction–INTERACT 2011Anonymous Springer, 2011, pp. 554-571.
[7] A. W. Ng and A. H. Chan, "Finger response times to visual, auditory and tactile modality stimuli," in Proceedings of the International MultiConference of Engineers and Computer Scientists, 2012, pp. 1449-1454.
[8] S. Bensma¨ıa and M. Hollins. The vibrations of texture. Somatosensory & motor research, 20(1):33–43, 2003.
[9] A. Yamamoto, T. Ishii and T. Higuchi, "Electrostatic tactile display for presenting surface roughness sensation," in Industrial Technology, 2003 IEEE International Conference on, 2003, pp. 680-684 Vol.2.
[10] Atmel. (2015, July) "ATmega16U4/ATmega32U4" [Online]. Available: http://www.atmel.com/images/atmel-7766-8-bit-avr-atmega16u4-32u4_datasheet.pdf [Jan. 20 2016].
[11] J. Axelson, USB Complete: Everything You Need to Develop USB Peripherals, Third Edtion. Madison, WI 53704: Lakeview Research LLC, 1999.
[12] M. Biet, F. Giraud, and B. Lemaire-Semail. "Squeeze film effect for the design of an ultrasonic tactile plate".IEEE Transactions on Ul-trasonics, Ferroelectrics and Frequency Control, 54(12):2678–2688, 2007.
[13] T. Watanabe and S. Fukui. A method for controlling tactile sensation of surface roughness using ultrasonic vibration. InRobotics and Au-tomation, 1995. Proceedings, 1995 IEEE International Conferenceon, volume 1, pages 1134 –1139 vol.1, May 1995.
[14] Mullenbach, J., Shultz, C., Piper, A.M., Peshkin, M., and Colgate, J.E. Surface Haptic Interactions with a TPad Tablet. In *Proc of UIST 2013Ext. Abs*
[15] Education.usgs.gov, "27 Ideas for Teaching with USGS Topographic Maps", 2016 [Online]. Available:

http://education.usgs.gov/lessons/teachingtopomaps.html [Accessed 25-Jan. 25 2016].

[16] Tablet PC Comparison, "Tablet Comparison 2016 – Over 100 tablets compared side by side", 2016. [Online]. Available: http://tabletpccomparison.net/. [Accessed: 25-Jan-2016].

[17] Pdadb.net, "Samsung SGH-i337M Galaxy S 4 LTE (Samsung Altius) Detailed Specs | Technical Datasheet | PDAdb.net", 2016. [Online]. Available: http://pdadb.net/index.php?m=specs&id=4829&view=1&c=samsung_sgh_i337m_galaxy_s_4_lte_samsung_altius. [Accessed: 25-Jan-2016].