

Designing Zooming Interactions for Small Displays with a Proximity Sensor

by

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Abstract

Small, high resolution touchscreens open new possibilities for wearable and embedded applications, but are a mismatch for interactions requiring appreciable movement on the screen surface. For example, multi-touch or large-scroll zooming actions suffer from occlusion and difficulties in accessing or resolving large zoom ranges or selecting small targets.

Meanwhile, emerging technologies have the potential to combine many capabilities, e.g., touch- and proximity-sensitivity, flexibility and transparency. A current challenge is to develop interaction techniques that can exploit the capabilities of these new materials to solve interaction challenges presented by trends such as miniaturization and wearability such as tiny screens that only one finger of one hand can fit on.

To this end, *Zed-zooming* exploits the capabilities of emerging near-proximity sensors to address these problems, by mapping finger height above a control surface to image size. The *EZ-Zoom* technique adds the pseudohaptic illusion of an elastic finger-screen connection, by exploiting non-linear scaling functions to provide a usage metaphor.

In a two-part user study, we compared *EZ-Zoom* to touchscreen standard *pinch-to-zoom* on smartphone and smartwatch screens, and found (a) a significant improvement in task time and preference for the smallest screen (equivalent task time for the smartphone); and (b) that the illusion improved users' reported sense of control, provided cues about the interaction's spatial extent and dynamics, and made the interaction more natural. From our experience with the study, we conclude requirements for the development of proximity sensors in order to afford such interactions.

Our work goes on to reflect on how *zed-zooming* can be incorporated into seamless interaction tasks. We aim to identify some characteristics of a zooming interaction that would need to be considered when designing a complete one, and explore how these characteristics play into a complete and usable zooming interaction.

Lay Summary

As displays get smaller, zooming emerges as an important interaction. The mismatch between current zooming techniques and the size of the displays calls for new zooming interactions. Emerging technologies have the potential to sense fingers above and around the display.

Zed-zooming is an interaction technique that uses the space above the display to manipulate the zoom. Users touch the point they want to zoom into, and lift their finger to activate the zoom. The *EZ-Zoom* technique makes the image scaling slow down when the finger reaches a certain height. This synthesizes the feeling of a rubber band connecting the finger to the display; as the finger gets higher, image scaling slows down.

We found users were more efficient with *EZ-Zoom* on smartwatches and preferred it over *pinch-to-zoom*. We also found the rubber band illusion gave a sense of control and made the interaction more natural.

Preface

The experiments described in this thesis were conducted with the approval of the UBC Behavioural Research Ethics Board (certificate number H15-02611).

Prof. Karon MacLean helped frame, write, and edit parts of this manuscript, and provided supervisory assistance for this research.

Haihua Zhang, an undergraduate student in Psychology mainly contributed during the Winter 1 term of 2016. She contributed to the psychology aspect of the study as well as the brainstorming phase. She also helped with some of the figures in the Evaluation (Chapter 6) section in Winter 2 term of 2017.

Kevin Chow, an undergraduate student in Computer Science joined in Winter 2 term of 2017. He contributed to parts of the implementation, specifically the experiment suite code. He also assisted in carrying out the study. He is currently the main contributor for the ongoing work for the Summer 2017 terms (Chapter 7).

SPIN lab members also contributed with feedback and early edits for parts of this manuscript. Paul Bucci, specifically, contributed to early editing. Lab-mates were also valuable resources for brainstorming and feedback throughout the project.

Prof. John Madden and Mirza Saquib were in an ongoing collaboration with us throughout the project. They helped us with our understanding of the Gelly sensor and its capabilities. They assisted with making us early prototypes of the sensor. Saquib taught us how to fabricate them step-by-step. They both gave us input on the current and future capabilities of the sensor. Their input in brainstorming were essential in assessing the technical feasibility of our ideas.

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Dedication

To my parents, who gave me the thirst to learn and the encouragement to question everything.

Chapter 1

Introduction

Information devices with smaller screens, such as those on smartwatches and fitness trackers, are making their way into users' everyday lives with ever-widening possibilities for application. These devices require users to zoom a lot to see the small content and therefore increase the need for usable zooming interactions. However, their small interaction surfaces are a mismatch with many current interaction techniques – most notably the standard *pinch-to-zoom*, which enables users to zoom and pan to the center of two contact points [16].

Pinch-to-zoom on displays narrower than a few fingers' width is complicated by difficulty in precise selecting and pinching, visual occlusion of display content by the fingers [4, 15, 33], and the frequent clutching (repeating a single zoom gesture with an intervening lift to reset it) that is required to zoom further than one zoom action allows [4]. The intrusiveness of clutching is exacerbated when users must do it frequently, *e.g.*, when switching frequently between content close-up and overviews [4]. Meanwhile, multitouch gestures on hand-sized displays, such as smartphones, are tricky in one-handed use [15].

We offer a new approach that involves zoom control in the space above the control surface. To *zed-zoom*, near-proximity technology senses user movements in the zed-dimension above the screen's surface. The user initiates zooming by touching the center of a region of interest, then controls zoom amount by moving the finger up and down *above* and orthogonal to the display surface (Figure 5.1). This method has several advantages over *pinch-to-zoom*. It is easier to select small zoom targets, finger occlusion is avoided, and large zooms are achievable with a single continuous gesture. Single-finger zooming facilitates one-handed interaction.

It is important to consider that the loss of surface contact in mid-air interactions can compromise efficiency, accuracy, and in some cases, intuitiveness. Haptic sensation allows users to avoid relying only on proprioceptive feedback by providing tactile guidance. With haptic feedback, users can perform actions more efficiently and accurately [27] as opposed to performing actions without any tactile guidance. For example, in the case of *pinch-to-zoom*, the user receives feedback as their fingers are “pinching” relative to one other along a surface.

1.1 Approach

1.1.1 Pseudohaptic Illusion as a Solution to the Loss of Haptic Sensation

To rectify the lack of haptic sensation, we investigated the helpfulness of a *pseudohaptic illusion of a physical connection* between finger and screen. We reasoned that it could restore this proprioceptive zoom-extent cue, indicate information such as an outer spatial limit to proxemic sensing range, and provide a metaphor to underlie the direct manipulation concept.

We examined various relationships between finger height and graphical image scale (*scaling functions* – Figure 5.2a) for their ability to trigger an illusion of an elastic connection, as an artifact of coordinated physical-graphic movement. The most successful of these is a piecewise-linearized logarithmic function (Figure 5.2a).

In the implementation here, the image grows larger as the finger “pulls” it upwards. Beyond a sensed threshold, the connection might “pop” loose, the image resetting to its initial size; alternatively, it could “lock” at maximal zoom. The illusory “force” occurs as an artifact of coordinated finger-image movement: the perception appears to be of the *change* in force, and thus this perception does not manifest at standstill.

1.1.2 Prototyping

We grounded our design ideas for *zed-zooming* using sensors from the current research in the materials engineering (electroactive polymers) lab at UBC [32].

These materials raise the near-term possibility of simultaneously sensing touch localization, proximity, shear, and pressure with a transparent and flexible surface (Chapter 3). Specifically, the “Gelly” sensor is currently at an early-stage research, and only offers touch localization and near-proximity together in one sensor. These capabilities together might offer a space in which to design better interaction solutions to small-screen zooming. While not yet at a state allowing direct use in interactive prototypes, their existence gives us guidance into what kind of sensing (parameters, resolution, accuracy and bandwidth) may be most feasible to deploy in a 1-5 year time frame, and hence make smarter choices about proactive interaction development.

We therefore simulated the capabilities of such sensors using a proxy technology: the Leap Motion Controller. We utilized the hand tracking device as a way to input finger distance away from a smartwatch and smartphone. This way, users were able to manipulate the scale of the content on the screen seamlessly as though a proximity sensor was embedded in the devices.

This thesis describes an exploration into the design space that such technology will afford, making use of creative prototyping techniques to simulate its capabilities in specific contexts.

1.1.3 Evaluation

To understand our interaction technique’s viability, and its effectiveness in addressing the loss of haptic sensation in mid-air zooming, we investigated the illusion triggering and the usability of the interaction technique. We ran a two-part study. The first part aimed to investigate any pseudohaptic illusions that participants may feel, how the strength of the illusion is affected by audio and visual cues, and whether the illusion was helpful for users in terms of getting cues on the extent of the interaction space. The second part of the study measured the utility of *zed-zooming* techniques compared to *pinch-to-zoom* and users’ preferences.

1.2 Contributions

From our technique design and evaluation, we contribute:

- A near-proximity interaction that facilitates zooming on small touch displays; and with phone-sized screens, performs comparably to *pinch-to-zoom*.
- Insight into how auditory feedback and image content determine the extent to which users perceive a pseudohaptic illusion of elasticity with *EZ-Zoom*.
- Design recommendations based on a usability study comparing *EZ-Zoom* variants to the current standard touch-display technique, *pinch-to-zoom*
- Recommendations for the developmental direction of the Gelly sensor.

1.3 Overview

Previous work relevant to this research is summarized in Chapter 2. Chapter 3 gives detail to the capability and limitations for one instance of the emerging class of low-cost, embeddable proximity sensors, to ground our explorations. Chapter 4 outlines the process we followed to prototype for a future technology. Chapter 5 explains the design of the interaction. Chapter 6 presents a two-part study and its results. Chapter 7 discusses the results of the study and ongoing research building upon them. Finally, chapter 8 summarizes our findings and outlines directions for future work.

Chapter 2

Related Work

2.1 Near-Proximity Sensing Technology

Some consumer devices already support proxemic interactions in finger-range-scale proximity, such as the Samsung Galaxy S4 (1.5cm range; [31]) and Fogale Sensation (3.5cm; [10]). Other sensors in development, such as the "Gelly" sensor, offer touch and proximity capabilities (e.g., with electroactive polymers) and are transparent, stretchable, and bendable [32] with a current proximity range of 2cm. More details on this sensor can be found in Chapter 3.

2.2 Challenges and Approaches in Surface Zooming

Surface pinch gestures date to Wellner's Digital Desk, produced at Xerox in 1991 [36]; multitouch zooming functionality evolved over the next 15 years. *Pinch-to-zoom* as we know it was commercially deployed in 2007 with the Apple iPhone and is possibly the most successful and ubiquitous interaction gesture for touchscreen devices, the principal zoom method for most commercial phones and tablets.

However, *pinch-to-zoom* has problems on new screens that approach the scale of a few finger widths, a point at which multiple touches do not fit or have room to slide. Beyond the obvious issue of content *occlusion*, a leading complication comes when significant rescaling is needed: each movement must be small, leading to *clutching* (multiple pinches). *Transitions* present another challenge, particularly when frequent; e.g., when users are trying to identify something on an interface they may zoom in and out multiple times, switching between details and high-level context [4, 17, 19, 28]. This workflow requires an easier way to switch between zoom and *pan* (translation) modes, and a smoother transition between the detail and overview scales.

Additionally, *pinch-to-zoom* may be difficult for one-handed use. Zeleznik et al. [37] claim the importance of one-handed gestures with the "sandwich problem" in which people feel that one-handed interactions are more natural as they may use their other hand for something else, such as holding a sandwich.

Pinch-to-Zoom-Plus avoids the need to clutch, by translating the *rate* of pinch-

ing and spreading to zoom extent, following an automatic pan to zoom-center. Small but quick movements can accomplish larger zooms, and thereby reduce the need for clutching [4]. However, this method still requires two-fingers on-screen, with occlusion on watch-scale screens.

Other techniques expand the interaction area outside a small display’s surface, permitting larger gestures and avoiding occlusion. SkinTrack senses a finger with watch-embedded infrared sensors; users zoom with sliding movements on their arm, a technique that can work when the device is situated on the skin [38]. SideSight lets users *pinch-to-zoom* on the surface around a smartphone using infrared sensors embedded long each side of the device [7], and is more suitable for a device resting on a larger surface than for handhelds.

These techniques offer interesting alternatives. They share the loss of a direct engagement with the screen; as with a mouse, there is a level of indirection between the user’s hand and the screen [11], with a potential for loss of usability or control. Further, sliding on elastic, compliant surfaces such as the skin may be less controllable or predictable than on glass.

EZ-Zoom takes a different approach. The in-air finger minimizes occlusion, and accesses a control range above the surface that is independent of screen size (although dependent on sensor range). It can further reduce clutching with a scaling function optimized to zoom tasks typically performed on the device. Zed-zooming offers multiple implementation paths to transitions, although these are not addressed in this thesis.

2.3 Non-Surface Solutions

Various studies pertaining to non-surface gesture solutions on small displays exist. Harrison et al. (2009) claim that conventional input mechanisms such as buttons and touch screens cannot be scaled to smaller displays [14]. They explain that this limits the benefits users get out of their devices. They aim to solve this problem with non-surface gestures. In order to do this, they utilize a magnetometer on the back of the device and mount a small magnet on a finger. The approach, however, requires that users manage an additional small object on their finger, and therefore results in a bulky prototype.

Kratz et al. (2009) equipped mobile devices with distance sensing capabilities [18]. They used infrared sensors to sense coarse movement based hand gestures and static position based sensors. Sweeping hand movements and hand rotations were used to indicate scrolling and selection on a mobile device. They concluded that Around-Device Interaction has the potential to solve occlusion problems on small-screen devices. We therefore build upon this concept, but aim for more

fine-grained gestures that new proximity sensors can provide.

Zooming interactions with non-surface solutions have also been a topic of various studies. By embedding a depth sensor on a wearable device, Sridhar et al. (2017) developed a prototype to sense on and around the skin finger input [34]. The device had the ability to sense mid-air and multitouch input of fingers on the back of the hand while wearing the wearable device. The prototype was used for various applications; a music controller, virtual reality/augmented reality input, a map on a watch, image exploration on a large display, and controlling a game. The researchers were able to demonstrate the capabilities of a device that receives input away from the device's screen. However, the setup with a depth camera does not allow for a feasible prototype in the near-future. This demonstrates the need for a close-range proximity sensor to interact with small devices.

The Apple Watch's Digital Crown is a side knob that controls zoom level [3]. This type of solution avoids *pinch-to-zoom*'s issues on small displays, but the need to move from screen to zoom-control for different interactions can impede fluidity.

Marquardt et al. (2011) highlight the rich interaction space "above the surface" [23]. We use this space to mitigate occlusion; however, above-surface interaction may have weakened proprioceptive cues. Nancel et al. (2011) attributed the slowness of mid-air circular movements versus linear movements to the lack of guidance [27]. Air+Touch (2014) describes two in-air zooming techniques that would similarly suffer from lack of guidance based on [27]'s findings: a) lifting the thumb high above the control surface toggles zoom / pan modes before a tap, followed by scrolling to pan or zoom in/out – like a virtual slider; b) pan by touch, and zoom with in-air cycling [8].

Transture (2015) was motivated by insufficient small-screen space for *pinch-to-zoom* gestures [12]. To trigger zooming, the user circles in-air and continues circling to zoom; movement outside the initial circle registers as panning. The authors found that "participants wanted to disable panning function in the zooming zone". This might imply that zoom and pan were difficult to handle simultaneously; in-air gestures with limited proprioceptive feedback could be a factor. Zed-zooming is modal, and will rely ultimately on a smooth zoom/pan transition.

Harrison et al. (2008) magnified content by how close the user leaned towards the screen using a camera and found that this direct manipulation was natural and intuitive [13]. We also take a direct manipulation approach, using local finger movements.

Past studies on non-surface solutions make it evident that in-air techniques can provide solutions to the real-estate problem that comes with small-screened devices. However, a usable and feasible zooming interaction that reduces occlusion is yet to be designed.

2.4 Importance of Haptic Feedback

Mine et al. (1997) highlighted the importance of haptic feedback for users. Humans rely on haptic feedback and physical constraints to execute precise interactions and to prevent fatigue [24].

Nancel et al. (2011) reiterated the importance of haptic feedback for users [27]. They compared freehand and device-based techniques in the context of mid-air zooming and panning interactions on large wall-sized displays. They compared a gesture with a 1D-path movement on a physical device, a gesture with a 2D-path movement on a physical device, and a gesture that had freehand movement without any physical device guidance. They concluded that freehand techniques, which do not provide haptic feedback for users, exacerbated fatigue and decreased accuracy. Gestures in freehand interactions were less efficient than input gestures that had added guidance.

Due to the lack of guidance of haptic feedback, non-surface interactions can cause fatigue and inefficiency.

2.5 Pseudohaptic Illusions

To address the loss of direct haptic sensation inherent in in-air interaction, we introduced *illusory* haptic feedback.

Pseudohaptic illusions simulate haptic input by integrating multimodal feedback [29]. The result may differ from that of real haptic sensory input – e.g., fainter, and/or apparent only during motion; yet may still fundamentally alter the sense of an interaction [22]. Moreover, adding physically realistic behaviours to graphics can improve controls usability and precision [1]. When it also provides a metaphor, it can make the interaction more intuitive [1]. As an example, humans’ relatively poor position acuity can lead to greater reliance on visual input when visual and proprioceptive cues conflict. Exploiting this produced the sense of “bumps and holes” on a screen by accelerating or decelerating a mouse cursor [20].

Mandryk et al. aimed to reduce a cursor’s inadvertently crossing screens in multi-monitor displays when a user is trying to access a widget on the boundary [22]. If a user is moving their mouse quickly towards the target widget, the cursor will slow down while over the widget, making the interaction feel sticky and preventing an unwanted leap to the next screen.

Lee et al. present an interaction where a circular cursor can “squeeze” as though it is made of rubber when it hits display borders and is pushed further by the user [21]. Physical simulation improves precision and realism, and contributes

to a more engaging and learnable experience.

These examples were generated in the context physical contact with a touch-screen or mouse. In this thesis, we sought to trigger a pseudohaptic elasticity illusion *without* contact, by manipulating the amount of zoom per distance the finger travels in the zed-axis with supporting auditory feedback.

Chapter 3

Possibilities of the Gelly Sensor as an Interface Device

We utilize the "Gelly" sensor (Figure 3.1) as an archetype of an emerging class of sensing while designing interactions. This was useful in grounding our explorations and making them technically feasible. We situated our constraints in a product we would expect to see emerge out of efforts like those in John Madden's lab in the next 5 years.

It is a mutual capacitance based touch/proximity sensor with hydrogel as flexible electrodes, and PDMS (polydimethylsiloxane) as the substrate and dielectric to enable stretchability of the device. It is currently being developed by Prof. John Madden and his team in the Electrical Engineering Department of UBC[32].

The fabrication of Gelly requires the use of hydrophilic hydrogel material for the electrodes of the sensor. Layers with grooves are made by creating a metal mould and then pouring a the PDMS polymer and co-polymer with a catalyst then leaving it to cure in 80°C for an hour. This layer with grooves is then bonded to a uniform dielectric layer to form channels. A mixture of salt, water, and acrylamide monomer, initiator and accelerator is made, and injected into the channels formed. A sigma-delta ADC type CDC (capacitance digital converter) is used to convert the capacitance to a digital output using a 32kHz signal.

In this chapter, we will state the current capabilities of Gelly, discuss its limitations and trade-offs to consider while designing products with Gelly.

3.1 Current Capabilities of Gelly

Gelly can accurately detect the position of a finger up to 5 mm above the surface of the sensor. It can detect the presence of a finger above the surface up to 20mm. Its frequency of polling for proximity and touch is currently roughly 700 ms, but this can be increased in the near future with the use of a better CDC. Its touch sensing resolution is 5mm.

Although some functionalities are not yet implemented, Gelly has the theoretical potential to simultaneously sense pressure, shear, and stretch sensing ca-

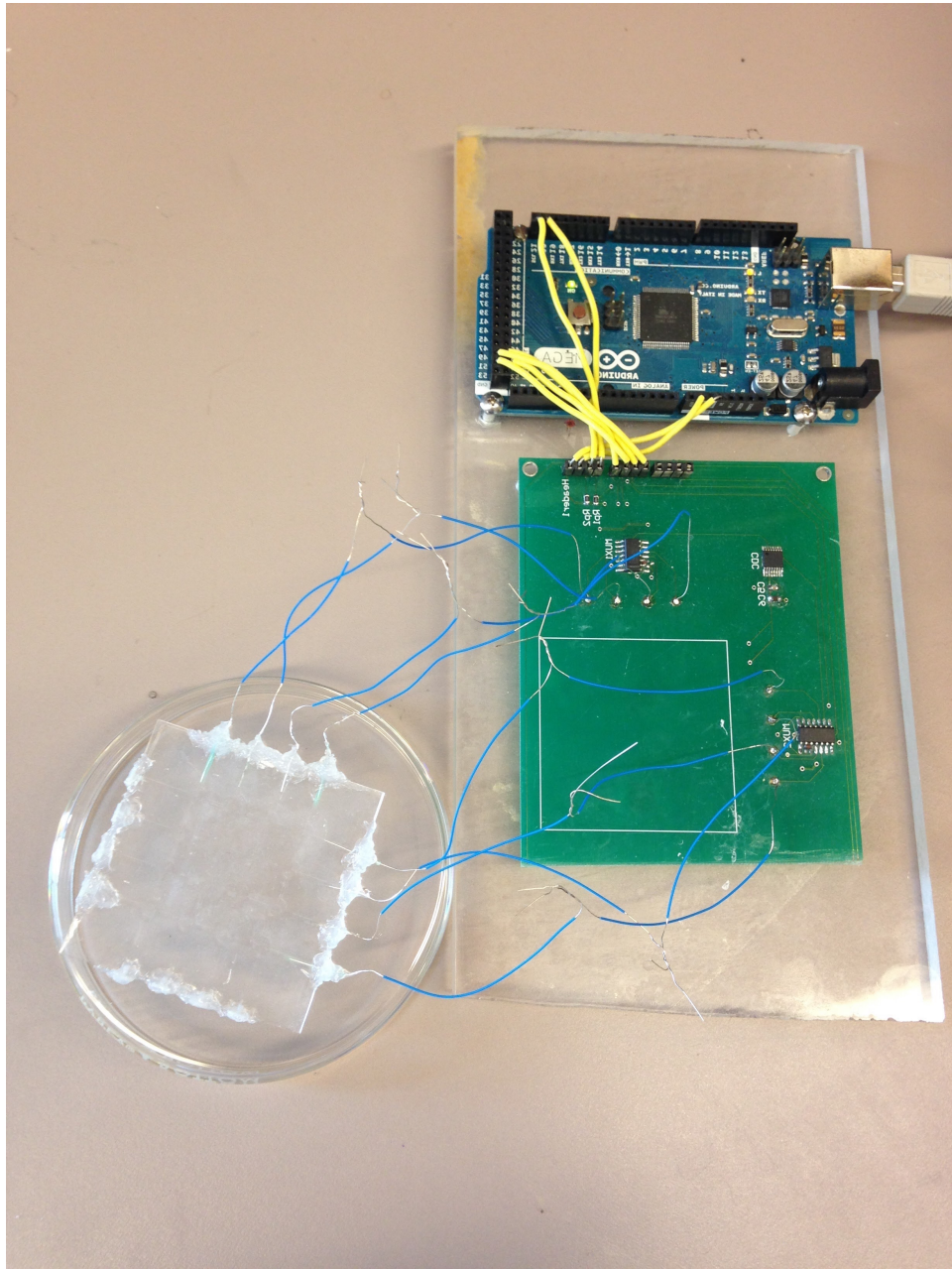


Figure 3.1: The Gelly sensor

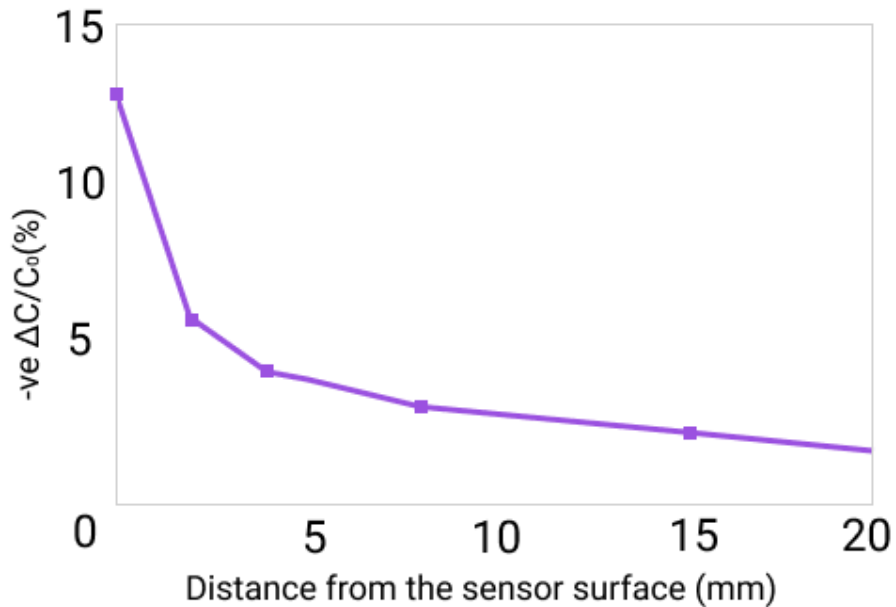


Figure 3.2: Change in capacitance due to a hovering finger at various distances from the top of the sensor. The change in capacitance upon approach of the finger is negative[32].

pabilities in the near future. These features may need be able to exist in one sensor at the same time. There are currently certain tradeoffs to the availability of these features.

Gelly's current features are the following;

- Flexibility; It can be bent without breaking.
- Stretchability; It can be stretched up to 300% its original size.
- Transparency; Rather than wires, the electrodes are filled with hydrogel, which is transparent. This results in a transmittance of 90% which is approximately the same as clear glass.
- Cheapness; The material costs roughly \$1 per meter square.
- Scalability; The sensor can make up to hundreds of meters square and it is still expected to work.
- Thinness; It can theoretically be made approximately 100 microns which is as thick as a sheet of paper.

- Multitouch; It can sense gestures requiring multiple fingers and a single touch with localization. This gesture could require any number of fingers. As long as the fingers are 5mm apart, the sensor will be able to sense different touch points.
- Proximity sensing; It can sense a finger up to 20mm.

3.2 Possibilities of the Gelly Sensor

When Gelly's proximity range is increased, the sensor can be used to increase the interaction space of small displays. The space can be increased to above, around, or behind devices. Bend sensing capability of the sensor will add possibilities of wearables for active wear and various sports gear. Gelly is particularly suited for flexible devices and therefore have a lot of potential to provide value for wearable devices. Its main limitation will likely be the trade-off between its proximity range and horizontal resolution.

3.3 Limitations of the Gelly Technological Approach

There are certain compromises that may be inherent to Gelly's technological approach while extending the current capabilities and adding new capabilities.

Gelly proximity sensing requires users to interact with it using skin or conductive materials. As Gelly is a capacitance-based sensor, users must use their finger directly on or above the sensor or make use of conductive materials. This is a limitation of most capacitance-based sensors.

Increasing the vertical range of proximity sensing results in a decrease in horizontal resolution. To increase vertical range, the electrodes in the sensor need to be larger. This results in fewer electrodes on the sensor array and therefore a decrease in spatial resolution. All sensors with hydrogel electrodes have this limitation. This trade-off between vertical range and horizontal resolution is critical when designing products with proximity capabilities using Gelly.

Finally, the addition of shear sensing capabilities would make the sensor less transparent. This may be solved with more engineering in the future, but it is a current limitation of the technological approach.

3.4 Limitations of the Current Gelly Prototype

The Gelly prototypes available at the time of this research suffered from a number of limitations which made it non-representative of the technology's true potential.

These are limitations of the current prototype but are planned to be improved in the near future.

The surface of the sensor feels highly frictioned. This is a disadvantage of the current sensor because it will be used to overlay the device's screen and will make the touch feel unpleasant to the user. If a layer was added to the outer layer, it might affect the flexibility and the stretchability of the material. Different techniques still need to be explored to find a solution to this problem.

The sensor's polling frequency is currently not high enough for most human activities as it is about 1.4 Hz. This would need to be increased to a minimum of 50 Hz to be humanly usable. Although Gelly's developers have noted that this is possible to fix, we have not yet tested and validated an improved prototype.

Lastly, the encapsulation of the hydrogel inside the sensor is not yet perfected. Gelly currently uses parylene, a biocompatible coating, for the hermetic seal. However, parylene can crack when it is thick, and if it is too thin, it will not be an effective encapsulant. This means that the sensor rapidly loses accuracy. The developers are looking to replace parylene by UV curable sealants that are flexible and stretchable, in order to position Gelly to be usable in the future.

We therefore used a proxy technology to simulate future the capabilities of Gelly. The Leap Motion Controller offered a cheap and accurate solution as explained in Chapter 4. In several years, Gelly and many other sensors will be appropriate for wearable device integration. Meanwhile, interaction technique functionality can be prototyped with existing technology.

Chapter 4

Case Study of Prototyping for New Technologies

As Gelly is at an early development stage, we used rapid prototyping techniques to simulate it using proxy technologies. This chapter thus demonstrates our case study of prototyping for new technologies that are not available for user studies.

This chapter gives detail on the process we took to prototype the interaction techniques we designed to take advantage of capabilities like proximity and pressure sensing. We first verified the present functionality of the technology by collaborating with its development team (section 4.1). This involved making the sensor and testing its capabilities with various programs.

We then used low-fidelity sketching to rapidly prototype our interaction ideas (section 4.2.1). This is another level of simulation of the capabilities of technology that cannot be used for studies. The prototypes are not interactive; they are used to animate ideas. The purpose of using rapid prototyping was to quickly get an idea of the value of concepts we were generating without doing a lot of engineering and development.

Once the interactions were more robust, we used a proxy technology to generate a high-fidelity prototype (section 4.2.2). We used similar rapid prototyping techniques for the design of the pseudohaptic illusion (section 4.3).

4.1 Functionality Verification

To get started with Gelly, we learned about the capabilities of the current sensor from Prof. John Madden and his team. In order to verify the basic functionality of Gelly, we used a Processing program that outputted capacitance values. We then wrote two programs to help us understand the current usability state of Gelly.

First we wrote a Matlab program that logged capacitance values for a given duration of time. It then visualized these capacitance values using a heatmap on a 4-by-4 grid as seen in Figure 4.1. The program was useful to visualize changes in capacitance for a saved lapse in time. Given a file of capacitance values, it gave an animation of what the heat map looked like. The heat map encoded touch points

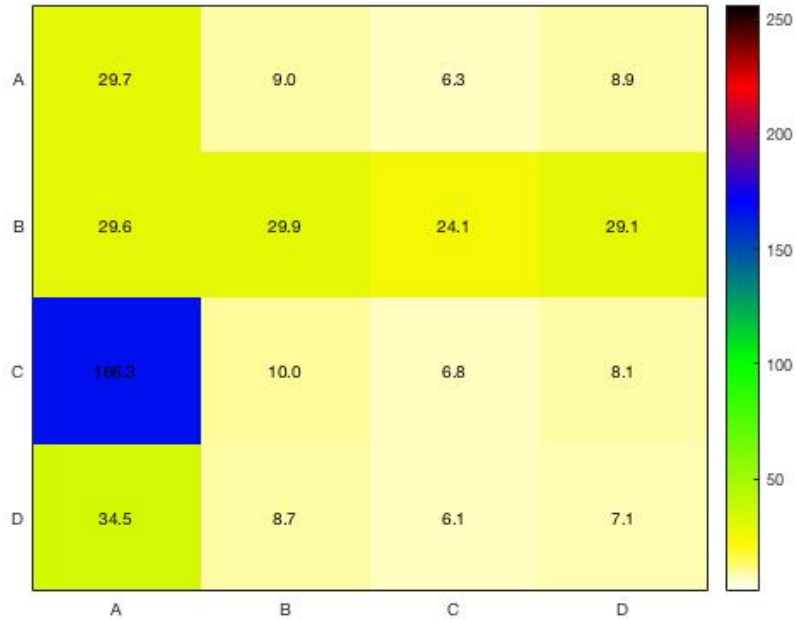


Figure 4.1: The final heatmap generated by the Matlab program to visualize touch and proximity capacitance data. On the right, there is the legend that shows distance of the finger away from the sensor.

with a dark blue hue and encoded proximity with saturation. The more saturated the red hue was, the closer the finger was to the sensor.

As shown in Figure 4.2, we tried several colors to find the best possible visualization that would encode proximity and touch visibly. We then finalized the heatmap generated by the Matlab program as shown in Figure 4.1. On the right of the heatmap, there is a legend that shows the distance of the finger away from the sensor.

The second program was written in Java. This program was initially written by Dr. Madden’s team. We changed the given program to provide more information about the delta change in capacitance, and to encode the proximity of a finger from the sensor with saturation. We also added controls to reset baseline values to account for sudden jumps in capacitance values.

This program provided a real-time visualization of capacitance values. It mapped the 4x4 grid in the Gelly prototype directly onto a visualization that had two

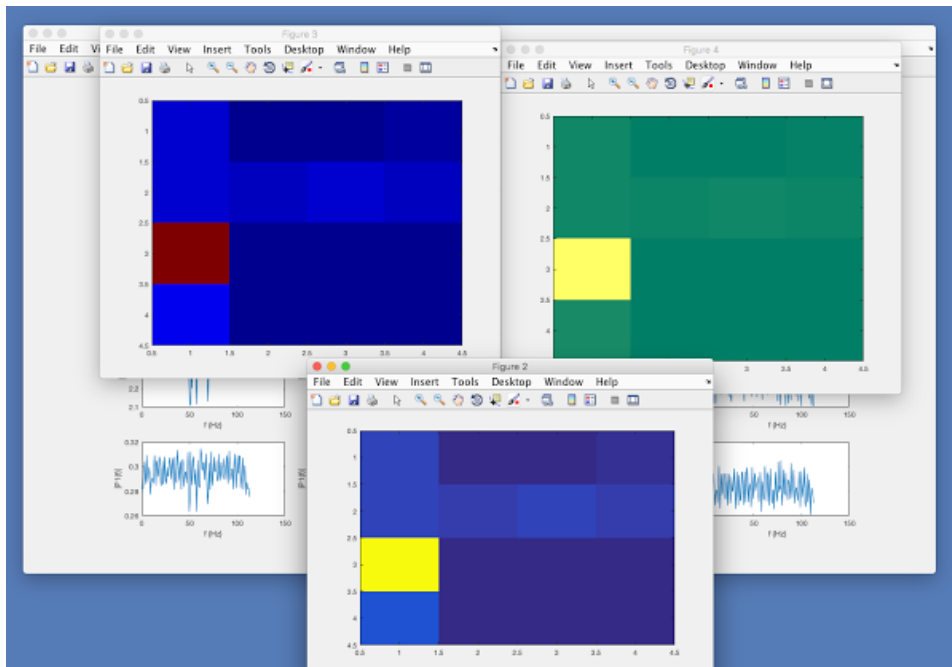


Figure 4.2: Heatmaps with three different color schemes generated by the Matlab program from the same capacitance dataset.

modes; a line plot as seen in Figure 4.3 and a real-time heat map as shown in Figure 4.4.

The line plot was useful to obtain raw capacitance data. As a finger approached a cell in the Gelly grid, the capacitance of that cell dropped until it hit its local minimum (approximately %15) on touch. The visualization provided a 4x4 grid of line plots that represent each cell on the sensor.

The heatmap was useful in getting a 3D understanding of touch and proximity of fingers. As a hand approaches the a cell in the 4x4 grid, the white cell on the visualization that represents the cell starts turning more saturated red. When it becomes a bright red color this indicates touch. Saturation is used to encode how close a finger is to the sensor. The 4x4 array grid is annotated in real-time with raw capacitance values and the delta change in capacitance values from a moving average. A negative value indicates a capacitance drop which signifies the approach of a hand. The raw data was specifically useful to identify problems such as sudden jumps in capacitance.

When we built sample prototypes of Gelly, the Java program gave us a sufficient understanding of how Gelly worked, and its current capabilities. It became

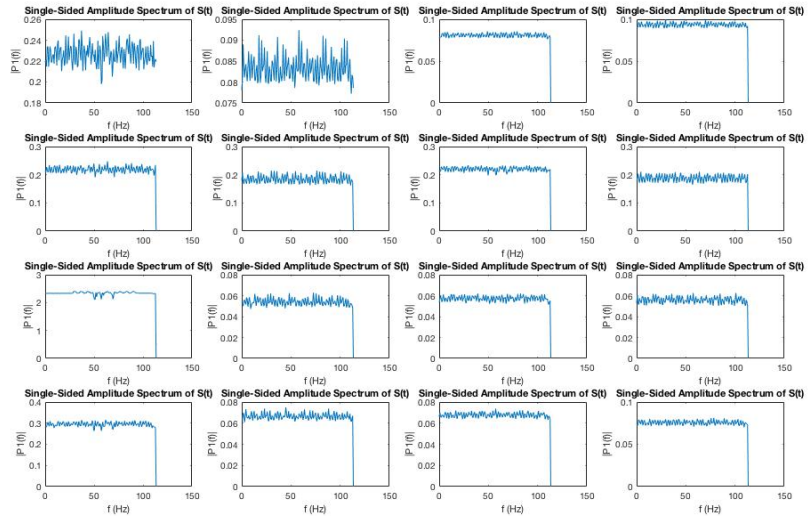


Figure 4.3: 4x4 grid of capacitance values received by the Java program.

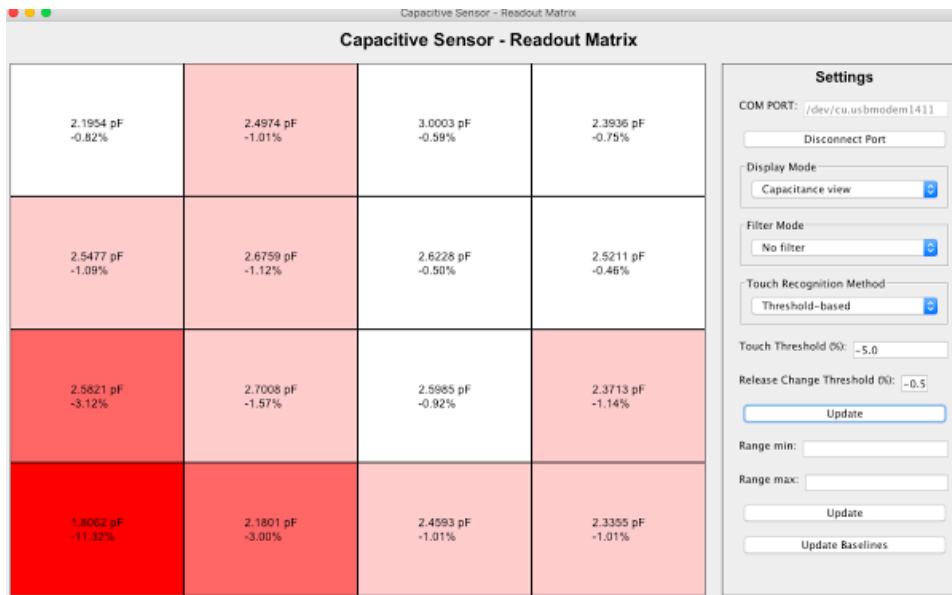


Figure 4.4: 4x4 grid of capacitance values received by the Java program.

clear that with the current state of the sensor, we would need to use proxy technologies to simulate the future potential of the sensor.

4.2 Prototyping for a Future Technology

It is important to prototype for developing technologies throughout the development process to determine what the technology will be able to afford. This way, not only do we have ideas of what problems they can solve, but we are also able to direct the development of the technology. We thus searched for ways to simulate this technology in a way that would help us take advantage of its potential capabilities and design for this kind of future technology.

To do this, we first found out about its potential capabilities. We worked with the domain experts; Prof. John Madden and Saquib Mirza. We inquired about the current state of Gelly, and its future possible capabilities. We found out about Gelly's current proximity range, which was about 0.5-2 cm high. We also understood that the higher the sensing range in the z-dimension the less resolution Gelly has in the x and y-dimension. We decided to focus on the proximity and touch capabilities of Gelly, and used these properties to choose our prototyping methods.

4.2.1 Low-fidelity Prototyping

Low-fidelity prototyping is an early stage prototyping method that is used to produce quick alternative approaches to the design [30]. As standard prototyping methods for proximity-based interactions are yet to be developed, we followed a low-fidelity prototyping methodology and began our interaction design with paper and whiteboard sketches. With these tools, we were able to generate as many sketches as possible without spending excess time on any one of them.

The next step was to bring these interactions to life. We made animated concept videos to achieve this. The designs were made using SketchApp and then by utilizing the power of Principle, they were animated to be medium fidelity prototypes as seen in Figure 4.5. These tools are not created for proximity prototyping. They use a circular translucent circle to represent a cursor and the cursor becomes more opaque to represent a touch interaction like tapping or swiping. We encoded the height of the finger above from the surface of the device to be the size of the cursor.

Lastly, we performed informal evaluations for each iteration. These concepts encompassed several near-proximity interactive functions.

The first interaction was a navigation method where users could hover on a folder to see the apps that the folder contains (Figure 4.6). They could then click

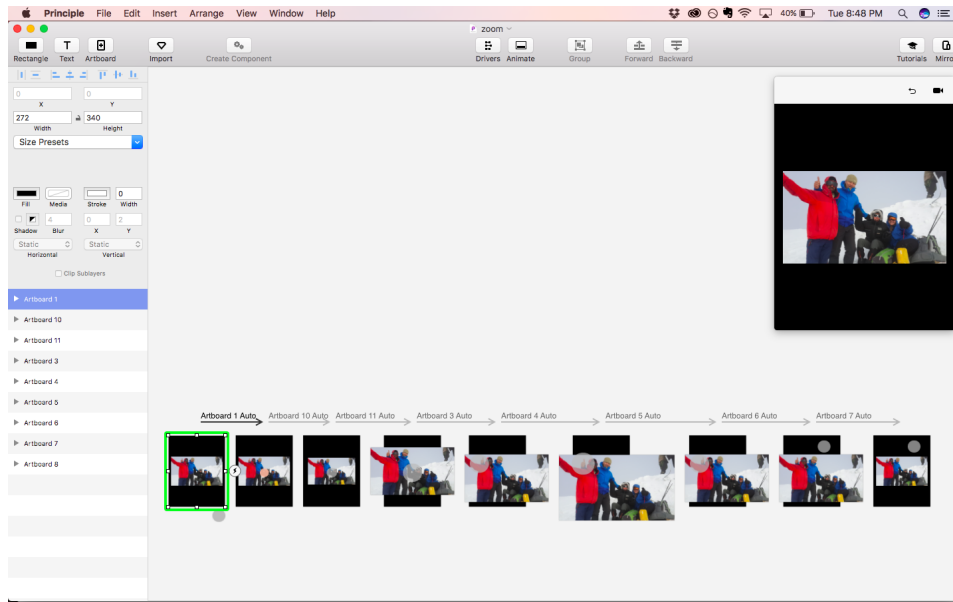


Figure 4.5: Zoom interaction prototyping using Principle.

on the folder to access the app of their choice with one click and without the need to navigate in and out of folders in search of an app.

Another application to this interaction is showing the latest notifications of an app on hover. The user can then click on a specific notification to directly access it (Figure 4.7).

The second interaction (Figure 4.8) was a reading app for very small displays. In this interaction, the user can make text glide right or left depending on the side they hover over. Their speed is determined by the distance of their finger from the screen. Once the user is happy with the speed, they can move their finger horizontally and remove it. The text will continue gliding in the specified direction and speed.

The final interaction was a method of zooming on small displays by using proximity in order to minimize occlusion of content, and allow for quick context to detail switching (Figure 4.9). This is the interaction on which this thesis focuses.

The animations for these interactions were also used in the process for preparing the Provisional Patent Application (application number: 62/481104).

Zooming emerged as a worthwhile focus as there was a need for a better zooming interaction on small displays and the interaction space was not enough to perform the current zooming techniques efficiently. We therefore went on to high fidelity prototyping for the zooming interaction.

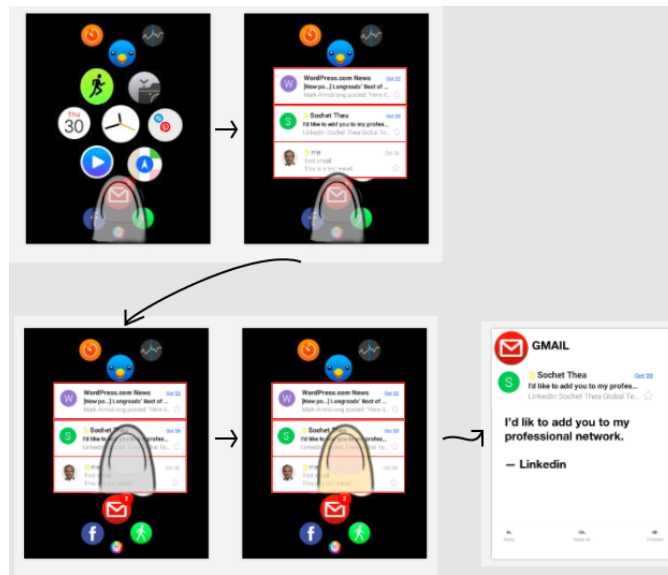


Figure 4.6: HoverPeek interaction animation simplified to 5 steps. Touch is indicated with a pink thumb. the grey thumbs indicate hover.

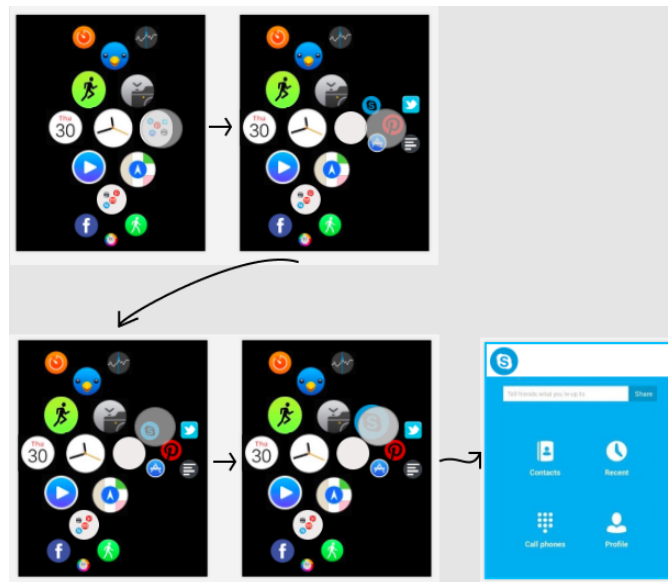


Figure 4.7: FolderPeek interaction animation simplified to 5 steps. The translucent cursor indicates a hover and the white opaque cursor indicates a touch.



Figure 4.8: QuickRead interaction animation simplified to 3 steps. The size of the cursor indicates the height of the finger above the screen. The larger the cursor, the further the finger from the screen.



Figure 4.9: Zooming interaction animation simplified to 5 steps. All the cursors in this step indicate proximity. The size of the cursor indicates the height of the finger above the screen. As the cursor gets larger, the finger gets further from the screen, and the image is scaled to be larger.

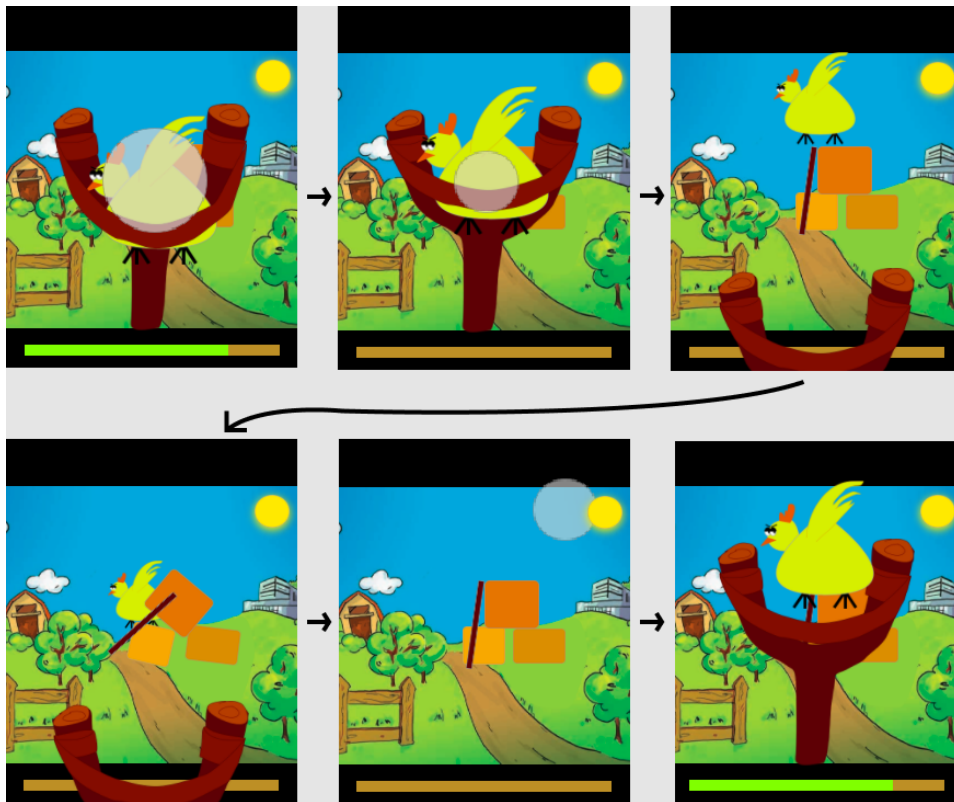


Figure 4.10: Angry Chicks game animation simplified to 6 steps. The size of the cursor indicates the height of the finger above the screen. The larger the cursor, the further the finger from the screen.

In order to simulate the idea of the pseudohaptic illusion, we also created a game animation, Angry Chicks (Figure 4.10). In the game, there is an elastic slingshot that can be "pulled upwards" using proximity to throw a chick towards blocks, similarly to the game "Angry Birds".

4.2.2 High-fidelity Prototyping

User studies and performance evaluation demands an interactive prototype with a robust and accurate mid-air sensing capability. Therefore we go beyond the low-fidelity by building a "proxy technology". This prototype is high-fidelity, is interactive, and is significantly more realistic than the previous prototyping that we had produced.

High fidelity prototyping was especially important to run user studies in order to iterate on and improve our interaction. To accomplish this, we used a Leap Motion Controller to simulate proximity sensing with its hand-tracking capabilities. The Leap Motion Controller is a cheap technology with no hardware overhead and has a high level of accuracy that can sense up to 0.1mm. We used the Leap with the Orion hand-tracking API (v3.2.0) [25]. The hardware is based on a pair of infrared cameras and three infrared LEDs (60 frames/second sampling). The LEDs illuminate the scene ($\lambda = 850nm$), which is tracked by the cameras to form an inverted-cone-shaped interaction space (150° wide and 120° deep); maximum tracking range is 800 millimetres [9]. Leap’s Javascript API has built-in web sockets, for front-end prototyping with web technologies.

We also used a smartphone and an Asus smartwatch to simulate the proximity-sensing small device. The touch capability of the display in conjunction with the Leap Motion Controller’s hand tracking was powerful enough to simulate the built-in proximity and touch sensitive displays.

We tried various methods of using the Leap Motion Controller to best simulate the proximity-sensing technology. The real proximity-sensing technology would be integrated on a phone or smartwatch and would sense fingers above it. This means that we needed to place the Leap in such a way that it would most accurately sense the hand above the phone. One way to do this is to place the Leap next to the phone on the table, looking upwards. However, this does not work well because the hand using the phone would be left out of the triangular sensing field above the Leap.

We then used the Leap in virtual reality (VR) mode. The Leap is optimized for VR when it is placed looking “down” at the hands as though the device is mounted in front of a user’s eyes. To simulate this environment, we placed the Leap on a ring stand. We then found the optimal angle and hand placement for the setup. Figure 4.11 shows the optimal setup for the Leap Motion Controller to simulate a device with build-in proximity-sensing capability.

Using this high-fidelity prototype, we evaluate *zed-zoom* techniques as described in Chapter 6. Both study components were performed on the Samsung Galaxy S7 smartphone with a 14cm x 7cm display. Part 2 of the study also included the Asus ZenWatch 2 smartwatch with a 4.1cm x 4.9cm display. Android devices gave access to a smartwatch browser [2].

The Leap was mounted on a ring stand to track users’ hands and fingers (Figure 4.11), and tracked the in-air interaction space directly above the device screen. Finger height above the display was sent to sockets using Leap.JS, to control image scale. To minimize latency, we avoided CSS transitions.

Standard *pinch-to-zoom* functionality was written using HammerJS on the smartwatch to allow for in-study measurement of zoom levels. Code latency was



Figure 4.11: Prototype setup with the Leap Motion Controller on a ring stand and the devices.

about 2ms.

4.3 Rapid Prototyping for the Pseudohaptic Illusion

For the pseudohaptic illusory effect of the interaction, it was also important to use rapid prototyping techniques to help understand both what we were ‘feeling’ and how to exploit the intended haptic percepts. We sketched possible pseudohaptic illusions using stretchy materials such as balloons and springs, following the simple rapid haptic prototyping methods developed by Moussette [26] (2011).

We employed a rapid prototyping approach to try different interactions and simulate how illusions would feel with minimal engineering effort. We only implemented as much as was necessary but were able to receive informal feedback from our labmates and iterate on our designs. It was a low-cost method to improve our illusion and interaction ideas without having to implement all of them.

Chapter 5

Interaction Design

Smaller screens afford less space on the device’s display for zooming interactions. By using proximity sensors, we can add the space above the display to increase the interaction space. In this chapter, describe our considerations and process for *zed-zoom* design, and three *zed-zoom* variants we have implemented. The first differs from the others by its scaling function (linear vs. linearized-log). We used various scaling functions to try out possible pseudohaptic illusions. We eventually termed the two variants of *zed-zoom* Linear and Elastic Zed-Zoom (*LZ-Zoom* and *EZ-Zoom*) respectively¹. The third technique is *EZ-Zoom* with auditory feedback.

While near-proximity sensing technology is under development, early prototypes are not yet sufficiently stable for interaction design development and testing. Our development approach therefore relied on simulating anticipated experiences first with sketching methods, then alternative, less mobile but otherwise appropriate existing technology. This gave our work the additional role of generating technical application specifications for further near-proximity sensor development.

This chapter will first explain the design of *zed-zoom*, *LZ-Zoom*, and *EZ-Zoom*. We will then talk about the design choices for the auditory feedback used to aid the pseudohaptic illusion. Finally, we present the details of the proxy technology used to simulate the experience of the future technology.

5.1 Basic Zed-Zoom Component

We chose a 16cm range of motion for our prototype following confirmation that the height and resolution sensitivity specifications that we derived in this range are technically feasible with mobile-friendly near-proximity technology. We tried various heights and decided on the 16cm range to allow for users to reach the limit with one hand motion. Another concern that was taken into consideration while deciding on the maximum range was that users have sufficient space in the *zed*-axis to move their finger, as movement is important in interactions that are enhanced with motion artifacts. A large reach for some hands, 16cm allowed us

¹We refer to the log-scaled zoom method as “elastic” for consistency.

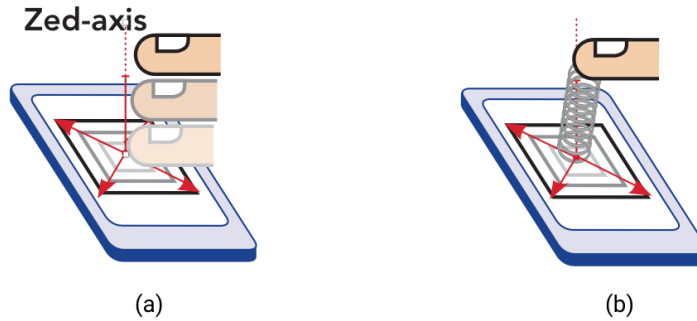


Figure 5.1: (a) *Zed-Zooming*: The user touches the graphical zoom target to select it, then moves finger up and down above the screen surface to zoom it. (b) *EZ-Zoom*: A pseudohaptic illusion of an elastic connection between finger and screen supplies an interaction metaphor.

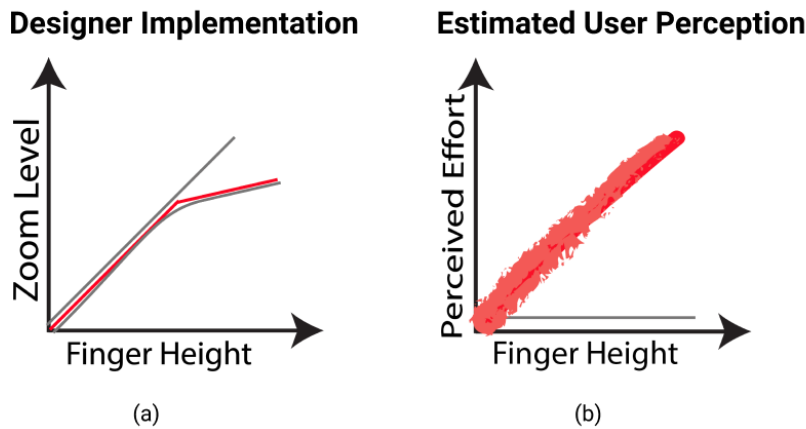


Figure 5.2: (a) A designer-defined *scaling function* relates zed-axis finger height to zoom level; its choice may impact controllability. The two grey lines represent two possible scaling functions: logarithmic and linear. We use the function that is represented by the red line; a linearized-logarithmic function. We choose this because the knee in the function amplifies the effect of the slow zooming. (b) Image scaling linked to finger lifting can trigger the *illusory perception of increasing force*, most strongly with the function highlighted in (a). The red scatterplot represents the user's perception because the perception is approximate. It is hard to measure the user's perception because it is a movement artifact. The plot is our conception of the user's perception and is not measured empirical data.

to observe how users grounded their gestures (*e.g.*, wrist or elbow braced near surface); however, this ultimately was not a focus of our study.

In our implementation, zed-zoom mode is triggered with a tap on the intended zoom target, and can be turned off at any time with a second touch anywhere on the screen.

5.2 LZ-Zoom and EZ-Zoom

We began simply, with finger height proportional to zoom scale (Linear Zed-Zoom, or *LZ-Zoom*). Content scales linearly with finger height up to the 16cm threshold, when content resets to its original position. In pilots, this did not tend to produce an elasticity illusion (Figure 5.2, grey lines).

We searched the scaling function space for relationships that would trigger an illusion, such as accelerating and decelerated scale speed with finger height. We found that decelerating scaling rate (*e.g.*, a logarithmic scale increase with finger height) makes users feel that the image is harder to pull as the finger is lifted higher (and vice versa as the finger descends), and describe this with terms that suggest elasticity or springiness. We believe this is because the finger must travel further per unit of scale change, thus evoking a sense of effort that increases with finger height (Figure 5.2b). Furthermore, we realized that the feeling of the image being harder to “pull up” could give users a subtle warning about the extent of the interaction space.

This elastic effect was felt most strongly when the log shape was accentuated with a sharper “knee”, achieved with piecewise linearization (Figure 5.2), red line. We termed zed-zoom with this linearized log scaling function *EZ-Zoom*.

Specifically, as the finger rises above the surface, screen content is magnified until the finger reaches the lower threshold setting (for the evaluation reported here, 11cm above the display). As the finger continues to rise, content scales more slowly (0.3 times the previous speed), making users perceive the image as harder to pull up. At 16cm, the image resets to its original size, representing the “snap” of an elastic connection.

5.3 Auditory Feedback

The auditory feedback we used had two parts: a continuous proportional stretching sound during finger movement, and a pop sound at breakthrough. We chose the auditory feedback to be mimetic of a real elastic object, to reinforce the elasticity metaphor. We used an audio track that had sampled a balloon stretching

almost to the point of bursting. The track started with rubber stretching sounds and got louder as it continued.

For the first 11cm of the interaction, we used the first part of the audio clip (lower frequency and volume); above 11cm, a louder, more frequent audio clip to represent the balloon stretching to its limit. Clips were 2s, played continuously during finger movement, and stopped when the user stopped.

For the pop, at the breakthrough point we played a single instance of the sampled sound of a snapping elastic rubber band, to reinforce the perception that the image snaps back to its original size along with the graphics.

Chapter 6

Evaluation

We conducted a two-part within-subjects study in a single session to identify any pseudohaptic illusions, observe what affects their strength, and evaluate the utility of *zed-zoom*. In **Part A (RQ1 and RQ2)**, we compare self-reported strength of pseudohaptic effects (as elicited by *EZ-Zoom*) on a phone screen based on (a) the presence or absence of auditory feedback as described above, and (b) variations in image content. We also qualitatively inspect how the pseudohaptic effect contributed to the experience and control of zooming. We assumed the illusion strength would not vary between phone- and watch-sized screens (rather, that the relative utility of *zed-zoom* would), and thus did not investigate screen size in this part. In **Part B (RQ3)** we compare user performance and reactions to our designs on a smartphone and a smartwatch.

Call for participation was done by email and printed flyers. 12 participants (five female) received \$15 for a 1-hour session. They were all right-handed with 2+ years of smartphone experience, spanned 11 countries and had experience including architecture, engineering, and creative writing. All 12 participants finished both parts of the study described in this chapter.

This chapter presents the study details which involve the participants and experimental procedure for both Part A and Part B of the study. After each method is explained for one part of the study, we present its results. The apparatus was set up as described in Chapter 4.

6.1 Research Questions and Objectives

We conducted an evaluation of *zed-zooming* techniques. Our inquiries are based on the following research questions regarding multimodal influence on the pseudohaptic illusion of elasticity, the utility of the illusion, and the usability of *zed-zooming* techniques compared to *pinch-to-zoom*.

6.1.1 Research Question 1

Is there a pseudohaptic illusion that a majority of the users feel? If so, how is user perception of the strength of the pseudohaptic illusion of elasticity impacted by auditory

feedback and image content?

Auditory event feedback (e.g., “popping” through a boundary) can modify haptic perception of *actual* compliance [35], so we wondered if it could have a similar effect on an illusory percept, thus facilitating the elastic illusion. We also noticed that different graphic content – e.g., round versus square shapes, or photos versus icons – sometimes seemed to “feel” different during zooming, suggesting that some image types could be more facilitatory than others. We tested the image of a round soccer ball and a rectangular photo of a group of people.

6.1.2 Research Question 2

Proximity sensors have a limited range of detection above the screen of a device. Can a pseudohaptic illusion help inform users of this limit?

With the flattening scaling function that best triggers the pseudohaptic illusion (Figure 5.2a), image scaling slows for vertical movement at the top of the interaction space. We posited that this could signal the limit’s approach, for greater control.

6.1.3 Research Question 3

Does zed-zoom, with or without a pseudohaptic illusion, assist in image rescaling on different screensizes compared to pinch-to-zoom? What do users prefer?

With *pinch-to-zoom*, the state-of-the-art zooming technique on small displays, users often must clutch to reach an intended zoom level. Since the range of a *zed-zoom* gesture can be substantially larger than a watch screen or even most smartphones’ width, we expect that the need for clutching will be reduced or eliminated, improving task speed and fluidity.

Other in-air zooming techniques have been proposed before. While they reduce occlusion and clutching, they suffer from the problems that arise with the loss of haptic sensations in mid-air interaction techniques.

To investigate our research questions, we conducted a two-part within-subjects study in a single session where all participants performed both parts. The first part of the study addressed the first and second research questions on the pseudohaptic illusion. The second part of the study addressed the third research question on the usability and user experience of *zed-zooming*.

6.2 Part A: Illusion

We first investigated the strength of the pseudohaptic illusion, and impact of audio cues (multisensory reinforcement) and the zoomed image’s shape and con-

tent. We took a mixed-methodology approach where qualitative interview study is embedded into a quantitative methodology for insight into hypotheses that, with *EZ-Zoom*:

H1: At least some illusion will be perceived with at least moderate strength for a majority of participants, on average through all conditions (audio and graphic manipulations).

H2: Illusions felt will be stronger for the 3-dimensionally (3D) suggestive ball image than for the 2D photo.

H3: Illusions will be strengthened by auditory feedback.

6.2.1 Part A Experimental Procedure

We conducted a 2×2 $\{audio, no\ audio\} \times \{ball, photo\}$ within-subject qualitative evaluation with presentation order randomized, employing *EZ-Zoom* alone – *i.e.*, the scaling function was linearized-log for all 4 conditions. *Ball* and *Photo* images are shown in Figure 6.1; and *audio* as described above.

For each condition, participants were first asked to zoom in and out for 40 seconds, for zed-zooming familiarization. We then conducted a short semi-structured interview after each condition, inviting participants to suggest and describe any real-world metaphors that seemed to fit that zoom experience for them, while continuing to access the prototype. Participants rated the intensity of feeling for each of their supplied metaphors on a scale of 0 (no effect) to 10 (very strong/believable effect). Last, they demonstrated and explained how they determined the spatial extent of the interaction space. Point height was sampled and logged.

6.2.2 Part A Results: Analysis of the Pseudohaptic Illusion

Altogether results tend to support:

- **H1: positive.**

11/12 (92%) participants felt at least some illusion with at least moderate strength, averaged over all conditions (Figure 6.2). One illusion dominated: *Elastic* manifested for 10/12 (83%) participants, felt by those participants at strength of 7/10 on average (moderate; Figure 6.4).

- **H2: very marginal.**

The image content’s impact appeared to be minor, although possibly nonzero. We varied (in confound) shape, dimensionality and content type; more work is needed to establish if patterns do exist.

<i>Elastic</i> (74%)	rubber, rubber band, hair tie, hair band, stretchy string, balloon, yoyo, chewing gum, spring, stretchy, bouncy, slimy, elastic, harder to move at the top then drop, stiffness, tension, tightness, spring, force, gravity
<i>Connected</i> (30%)	yo-yo, rubber bandy string, stretchy string, connected, string, not separated, connected with bar/pole
<i>Sticky</i> (11%)	chewing gum, glue, sticky

Table 6.1: Study Part A – Phrases used by participants to describe each percept, if that percept was felt. (%) indicates items counted in that category, out of all 31 unique terms supplied. Phrases could apply to multiple categories.

- **H3: positive.**

Audio presence seemed to influence the illusion. Participant descriptions attribute this more to the “pop” sound effect than the “stretching” effect.

To evaluate the presence, intensity, and benefits of the pseudohaptic illusion, we qualitatively analyzed participants’ self-supplied rich physical descriptions, and rankings of their strength by condition $\{audio, no\ audio\} \times \{ball, photo\}$.

Categories:

We found three thematic categories: *Elastic*, *Connected* and *Sticky*, shown along with representative participant-supplied terms in Table 6.1. We developed these by considering physical properties, metaphors, semantically related words, and the sentence context. We started by identifying key phrases in participant quotations through affinity diagramming [5], then organized these into categories by thematic analysis [6]. A single phrase could appear in multiple categories: e.g., “stretchy string” appears under both *Elastic* and *Connected*. Categories were cross-checked by lab members.

Condition Ratings:

Next, we assigned participant’s ratings for their self-supplied terms to these categories to produce an aggregate set of ratings for each condition and each category. For example, if a participant mentioned “stretchy string” and rated the intensity of their experience of a “stretchy string” as 8/10, the 8/10 rating would be aggregated in both *Connected* and *Elastic* categories for that condition (Figure 6.1).

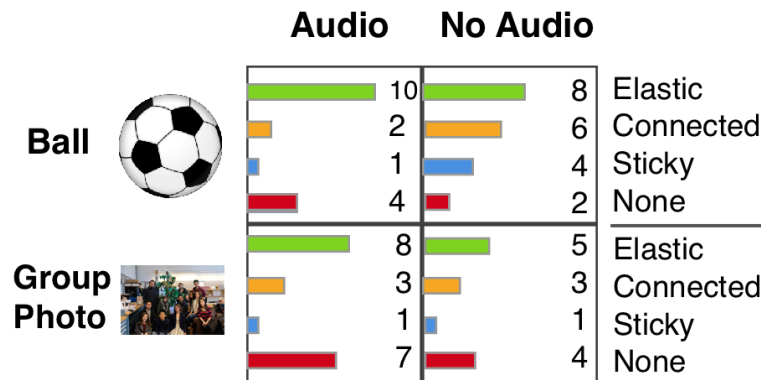


Figure 6.1: Study Part A – Number of participants (N=12) who self-reported a word in a given illusion category, by condition. The categories are derived by emerging patterns.

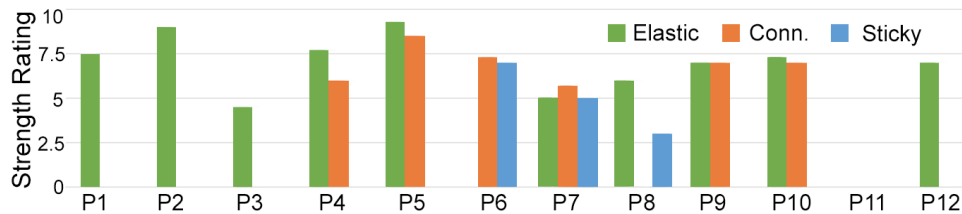


Figure 6.2: Study Part A – Average strength of illusion for each category throughout all conditions per participant.

When participants did not mention a term evoking a given category (*e.g.*, *Elastic*) at all, we set their rating for that category to zero, inferring that that form of the illusion did not occur for them. These individuals might have used other terms, implying that they were capable of feeling *some* illusion; or, they might have reported no illusion at all.

As seen in Figure 6.1, *Elastic* was the dominant percept, in all conditions. Specifically, *Elastic* was (a) felt by the majority of participants (7.8/12, averaged over all conditions); (b) the most prevalent illusion in every condition (*i.e.*, perceived by more participants than others) and (c) relatively insensitive to the multisensory conditions (auditory feedback, graphic geometry and content) that participants were exposed to.

Based on this, we narrowed our analysis to the *Elastic* illusion.

Figure 6.3 counts participants whose ratings fit into each of three bins: *high* (gave ratings of 7-10, indicating they felt a strong to completely believable elastic-

ity illusion); *moderate* (3-6, a moderately believable illusion); *low to no effect* (0-2, no illusion or a very slight illusion). Figure 6.4 shows condition-wise averages for all ratings assigned to the *Elastic* category.

6.2.3 Use of Multisensory Feedback and Pseudohaptic Illusion

Boundary Estimation:

When asked to estimate the reset boundary with *EZ-Zoom*, all 12 participants could correctly specify and describe where the image scaled more slowly – “*At some point, I don’t want to go away any further.*” (P12).

Some statements specifically indicate reliance on graphical and auditory feedback elements to navigate the interaction space. “*I don’t want it to burst so I’m moving more slowly.*” (P4), “*The image gets bigger, and you can tell it might be close to exploding. Sound is getting louder.*” (P3). “*When the sound gets louder there’s more tension in the rubber band because it’s about to fall*” (P12).

Some of these clearly had crystallized into a physical percept. When asked how they estimated the spatial extent of the interaction space, 9 participants referred to the illusion: “*[Spring] gets tighter. It moves less as you move further away*” (P10), “*As you get further up it’s more effortful*” (P8). Two other participants said they knew where the boundaries were out of “*intuition*” (P1, P9); they could not say exactly why.

Auditory Feedback:

Most participants found the constant auditory feedback annoying especially after continuous use. Even so, 9 participants demonstrated that they found value in the audio; e.g., “*helpful for getting info about the change in status about whether string is attached*” (P9).

The annoyance may have been tied to their perception of the pseudohaptic illusion, making them feel more work was needed to pull the image up: “*The stretching sound was not too bad but made me feel like I had to put in more effort*” (P9).

Audio as Training Wheels:

Two participants suggested persistent value: “*[with audio] the illusion is stronger. But you may not want to listen to balloon popping for a long time. One cool thing is that once I listen to it once I felt the illusion stronger. Make a tutorial with the sound and then get rid of it and it would not be as annoying*” (P8; similar words from P10).

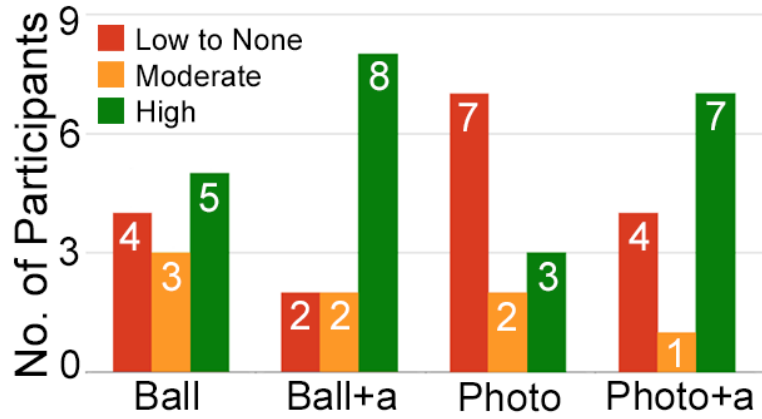


Figure 6.3: Study Part A – Incidence and strength of pseudohaptic elasticity perception (N=12). Number of participants who perceived elasticity, by condition. Binned into three strength levels based on ratings for the strength with which self-supplied descriptions were felt.

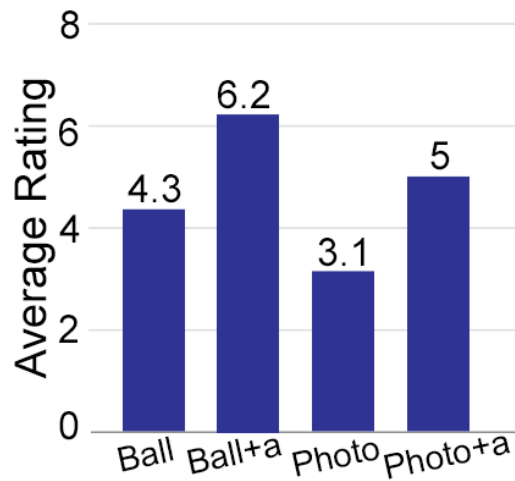


Figure 6.4: Strength ratings for self-described *Elastic* illusion, averaged by condition. [0-10]; overall average (4.7). (N=12)

6.3 Part B: Usability and User Experience

To investigate the utility of zed-zoom, a $4 \times 2 \times 2$ factorial within-subject design had factors of:

<i>zoom condition</i>	<i>PTZ, LZ-Zoom, EZ-Zoom, EZ+audio</i>
<i>screensize</i>	<i>smartwatch, smartphone</i>
<i>zoom extent</i> (to hit target)	<i>long, short</i>

We hypothesized that participants would:

- H4:** Compared to *pinch-to-zoom*, perform zed-zoom conditions **(a)** faster (smartwatch); **(b)** on par (smartphone).
- H5:** Perform **(a)** zed-zoom conditions with no difference in time for long and short zooms; **(b)** *pinch-to-zoom* long zooms more slowly than short zooms.
- H6:** Find more control in *EZ-Zoom* than *LZ-Zoom*; auditory feedback annoying after long exposure; and thus prefer *EZ-Zoom* on **(a)** smartwatch; **(b)** smartphone.
- H7:** Compared to *pinch-to-zoom*, find zed-zoom conditions **(a)** *more* useful (smartwatch); **(b)** *as* useful (smartphone).

6.3.1 Part B Experimental Procedure

Design:

Trials were blocked on *zoom condition* and *screensize*, with block order randomized. Within each *zoom condition* \times *screensize* block, participants performed five randomized repetitions of each *zoom extent*, for a total of $4 \times 2 \times 2 \times 5 = 80$ trials per participant. Participants began with two familiarization trials, using a surface and a zed-zoom technique respectively (*pinch-to-zoom* and *EZ-Zoom*).

Task:

For each trial, we asked participants to zoom into a solid-colored target square (centred on the screen) until it fit a translucent red frame. The trial began when the participant touched the screen (for *pinch-to-zoom*, when the user started the

pinch gesture). When the target was in the frame, the frame turned yellow to indicate that they should remain at that zoom level. When the target was kept at that zoom level for 0.5s, the frame turned green, signaling trial completion.

Metrics and Qualitative Data:

We measured task completion time for each trial. After completing all trials for a particular device, participants were asked to (a) verbally compare and rank the zed-zoom conditions versus *pinch-to-zoom* for that device for usefulness; (b) rank the three zed-zoom techniques by preference; and (c) give opinions on suitable use cases for this zooming approach in a short unstructured interview.

6.3.2 Part B Results

Task Completion Time

We ran a $4 \times 2 \times 2$ (*zoom condition* \times *zoom extent* \times *screensize*) repeated measures ANOVA on task completion time (DV, in seconds). Because sphericity was violated for the interactions of *screensize* \times *zoom condition*, *zoom condition* \times *zoom extent*, and *screensize* \times *zoom condition* \times *zoom extent*, we report p-values with Greenhouse-Geisser correction. We report statistically significant results ($p < 0.05$).

H4a,b: accepted. Figure 6.5 illustrates a significant interaction between *screensize* and *zoom condition* ($F_{3,33}=35.25$, $p < .001$). *Pinch-to-zoom* was significantly slower than zed-zoom techniques on the smaller screen (by 56%).

H5a,b: accepted. Figure 6.6 illustrates a significant interaction between *zoom extent* and *zoom condition* ($F_{3,33}=4.33$, $p < .05$). When participants needed to scale a large amount, it took significantly more time to apply *pinch-to-zoom* than when they needed to scale a small amount. Interestingly, for zed-zoom techniques, zooming a long versus short distance was similarly fast on average throughout the two *screensizes*.

User Preferences

We asked participants to rank the three zed-zoom conditions in order of preference for both of the devices (Figure 6.7).

H6b: accepted. For the smartphone, *EZ-Zoom* was ranked as most preferred by 10/12 participants, *LZ-Zoom* by 4, and *EZ-Zoom+ audio* by 1. *EZ-Zoom* was ranked last by no participants, *LZ-Zoom* by 3, and *EZ-Zoom+audio* by 6 (Figure 6.7).

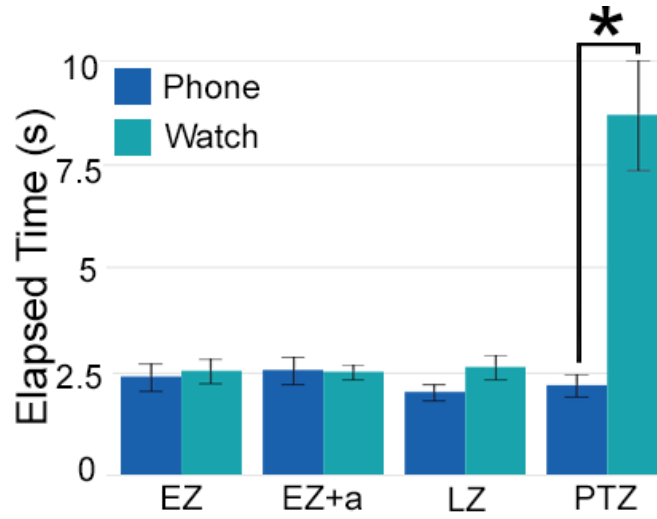


Figure 6.5: Study Part B – Average completion times by *screen size (zoom extent pooled)*, 120 observations/bar. 95% confidence intervals, *sig. at $p=0.05$.

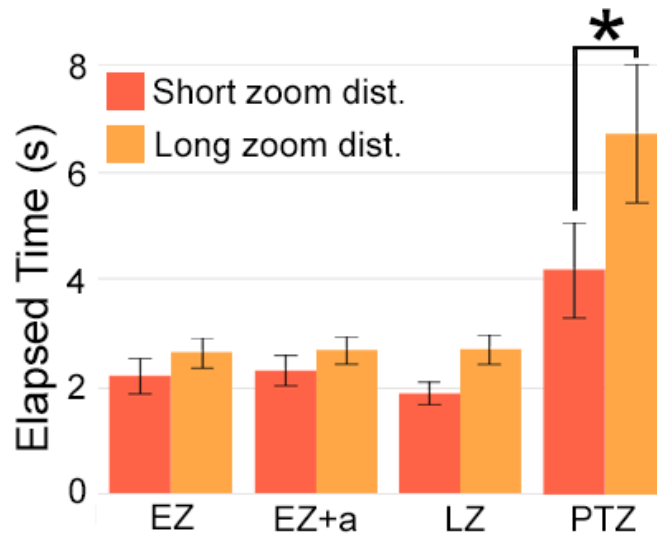


Figure 6.6: Study Part B – Average completion times by *zoom extent (screen size pooled)*, 120 observations/bar. 95% confidence intervals, *sig. at $p=0.05$.

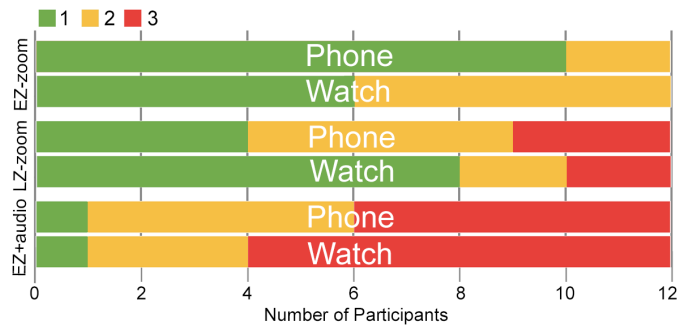


Figure 6.7: Number of times participants ranked each *zoom condition* as the most (green), 2nd (yellow), and least (red) for the smartwatch and smartphone *screensize* factors.

LZ-Zoom users found it was difficult to control the zoom at the top of the interaction space: “[*LZ-Zoom*] seemed too fast” (P1). Participants found *EZ-zoom with audio* unpleasant.

For the smartwatch, participants preferred *LZ-Zoom* and *EZ-Zoom* (Figure 6.7). For their top ranking, 6 participants chose *EZ-Zoom*, 8 *LZ-Zoom*, and 1 *EZ-Zoom+audio*. *EZ-Zoom* was ranked lowest by no participants, *LZ-Zoom* by 2, and *EZ-Zoom+audio* by 8. Therefore we cannot say *EZ-Zoom* was preferred over *LZ-Zoom* on the smartwatch, although taking least-liked values into consideration, it is close.

We asked participants to (a) rank pinch-to-zoom versus zed-zoom generally, and (b) discuss their relative potential utility in an unstructured post-interview.

H7a (smartwatch): accepted. 11/12 participants ranked zed-zooming as more useful than *pinch-to-zoom* on a smartwatch. “[*Zed-zoom*] doesn’t obscure the image and you can do it in one fluid motion rather than multiple small ones” (P8). “Please put [*proximity*] on the smartwatch, even though it would be a small augmentation on smartphone, on the smartwatch it makes the difference of buying and not buying one” (P9).

H7b (smartphone): accepted. We anticipated that zed-zoom would at least be seen as equivalent to the familiar *pinch-to-zoom*. In fact, the perceived utility of zooming techniques was split for the smartphone, with 6 participants choosing *pinch-to-zoom*, 2 choosing zed-zoom, and 4 calling them equal – *i.e.*, half found zed-zoom at least at-par. Reasons for *pinch-to-zoom* preference included being *more familiar with pinch-to-zoom*, and finding it more accurate and stable. However, 9 participants added that there were certain contexts where they would prefer proximity, *e.g.*, due to occlusion or where large zooms were required. “I’d rather do pinch for specifically zooming to a point...[proximity would be] better when you’re

swiping through pictures and you want to see something fast.” (P2). It is reasonable to guess that with practice, zed-zoom would become a viable equivalent to the current standard.

Chapter 7

Discussion

We inspect the production and use of a pseudohaptic illusion for zooming, then discuss benefits of *zed-zoom* relative to *pinch-to-zoom* and compare its variants. We then present the ongoing research on designing the full zooming interaction that is following the study.

7.1 Pseudohaptic Elasticity Illusion and its Value

11/12 participants felt a pseudohaptic illusion with at least moderate strength. Out of the self-reported metaphors the illusions that emerged were elasticity, stickiness, and connectedness. The dominant illusion among these was elasticity.

Among *zed-zoom* conditions, participants preferred *EZ-Zoom* on the smartphone, in interviews citing the control it afforded; but rated the *zed-zoom* methods equivalently on the smaller smartwatch screen. Their scaling functions may have been hard to distinguish on the miniature graphic display. One participant preferred *LZ-Zoom* because it was “*less effort to pull up*” and therefore felt faster (P9). This mention references the pseudohaptic illusion, but raises the possibility of illusory workload.

Participants reported finding more control with *EZ-Zoom* than with *LZ-Zoom* at the interaction space boundary. However, *LZ-Zoom* and *EZ-Zoom* yielded comparable completion times. Subjective impression of control *was* improved, based on participant comments and ratings, but further study is required to verify the practical utility of the higher precision, and ‘weigh’ its value relative to illusory effort.

Audio was found to be intrusive but useful, and may work in small doses. Despite its low popularity, the audio feedback we used gave users a tacit sense of the interaction space, and enhanced sense of control at its boundary. The feedback can be refined to be more subtle and/or infrequent.

If the contributions of auditory feedback to the illusion persist after it is disabled, intermittent audio could support the illusion while managing annoyance. Persistence may be possible because the audio triggers a metaphoric cognitive framework for the interaction. In a real-world social setting, audio may also be

intrusive. Audio may be equipped into a tutorial and then removed to have sufficient effects on the user's mental model.

7.2 Zed-Zooming Usability

Our study demonstrated clear utility for zed-zooming, in both performance and user preference. Unsurprisingly, both factors dramatically favored zed-zooming for the smartwatch display, where *pinch-to-zoom* has obvious difficulties.

Other options exist for small-screen zooming (for example, the Apple Watch's 'Digital Crown' knob). However, such secondary-control solutions are arguably less fluid than zed-zoom, and inconsistent with zoom conventions on larger displays.

Tablet users often employ a stylus for certain kinds of input and applications. Styli do not support the multitouch *pinch-to-zoom*, highlighting another zoom technique inconsistency. Zed-zooming should work with a stylus, with potential for consistency across a wide range of screen size and use modes.

As expected, participants required significantly more time to zoom larger distances with *pinch-to-zoom* for both screen sizes. Even on the smartphone display, users had to perform multiple pinches to achieve large distances, compared to lifting their finger higher in a single continuous zed-zoom gesture. Therefore, large zooms are achievable with a single gesture.

In contrast to *pinch-to-zoom*, users can *zed-zoom* with one finger. For applications and contexts where single-touch zooming is important, such as single-handed thumb- or one-finger or stylus interactions, zed-zooming is a solution. This solves the "sandwich problem" mentioned in Chapter 2, where users may want to hold another object with their free hand.

7.2.1 Limitations in Prototyping and Study

We simulated a technology that is too early in development to be tested with users, with a Leap Motion Controller. While generally very effective, the Leap had occasional glitches, causing the image to jump. Zed-zoom technique usability ratings likely suffered slightly as a result.

The *zed-zoom* variants we evaluated are not yet equipped with 'pan' and 'image freeze' functionality, both of which are necessary for effective zooming. Some participants cited this omission as a reason for preferring *pinch-to-zoom*. Users also lacked the ability to lock the zooming scale at a certain point. With the current state of *zed-zoom*, users need to keep their finger at a certain height to keep the zooming stable. The ability to transition between panning and zooming, and locking the zoom scale needs to be incorporated in the full zooming interaction.

Zed-zoom will likely do better with a developed and robust proximity sensor. Both prototyping limits are conservative with respect to *zed-zoom*. More reliable sensing and fleshed-out function will likely improve its position relative to other techniques.

When examining the form of illusion that participants found when EZ-Zooming under different conditions, we found participants often repeated the first metaphor they constructed in later conditions. Followup is needed to clarify if this was a true individual tendency, or a carryover bias.

7.3 Ongoing Research: Designing the Full Zooming Interaction

As the zooming technique used in the study was not a full interaction, the next natural step was to identify some characteristics of a zooming interaction that would need to be considered when designing one, and then to explore how they play into a complete and usable zooming interaction. This is an ongoing research project.

We found that most pan and zoom systems need the following three characteristics: (1) a method to transition from zooming to panning; (2) the reversibility of zooming (users should be able to adjust their zoom levels when needed); and (3) a method to zoom into and out of large scale levels (whether or not users need to clutch to reach large scale levels).

7.3.1 Possible Interactions

We designed three interaction techniques to test the aforementioned characteristics. We considered different methods to transition between panning and zooming such as coupling in-air panning and zooming, or decoupling the two action to pan on screen. We also considered having clear delimiters to transitioning such as by locking the zoom level with a gesture vs. transitioning to panning without a gesture. We also considered various ways to do multi-scale zooming and adjustment of the zoom scales. We designed three interaction techniques to demonstrate the various characteristics. Figure 7.1 compares the different interactions according to the three characteristics. The following subsections explain the three interaction techniques.

	Ease of Transition to Pan	Reversibility	Zooming to extreme scale levels
Balloon	Direct transition	Non-reversible	Requires clutching, easier than Push/Pull
Push/Pull	Locking mechanism required	Reversible	Requires clutching, gesture needed to re-clutch
Levels	Direct transition	Non-reversible	No clutching; rate-control with two speeds

Figure 7.1: Approach method vs. Characteristics of Good Zooming Techniques

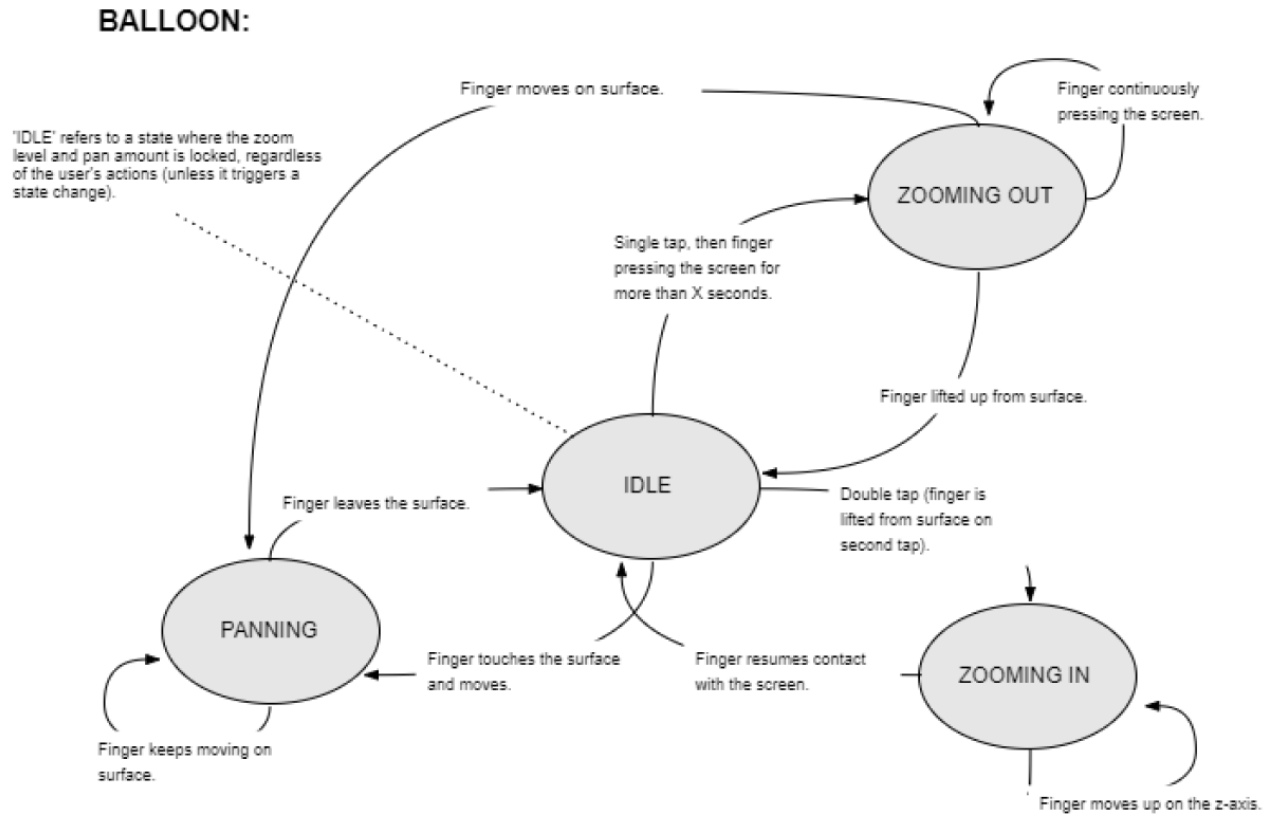


Figure 7.2: Approach 1: The Balloon Metaphor State Transition Diagram

PUSH-PULL:

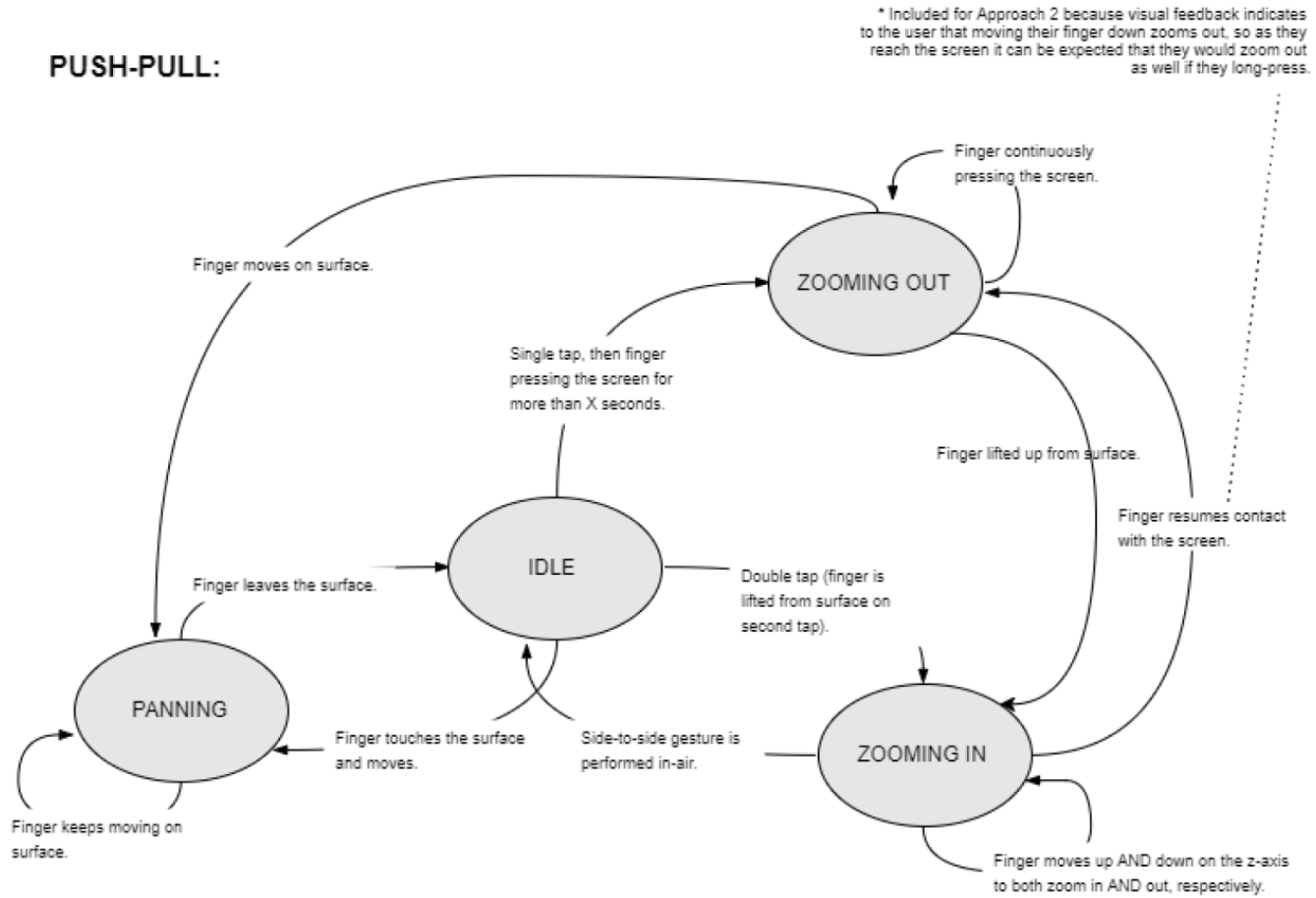


Figure 7.3: Approach 2: Push-Pull State Transition Diagram Diagram

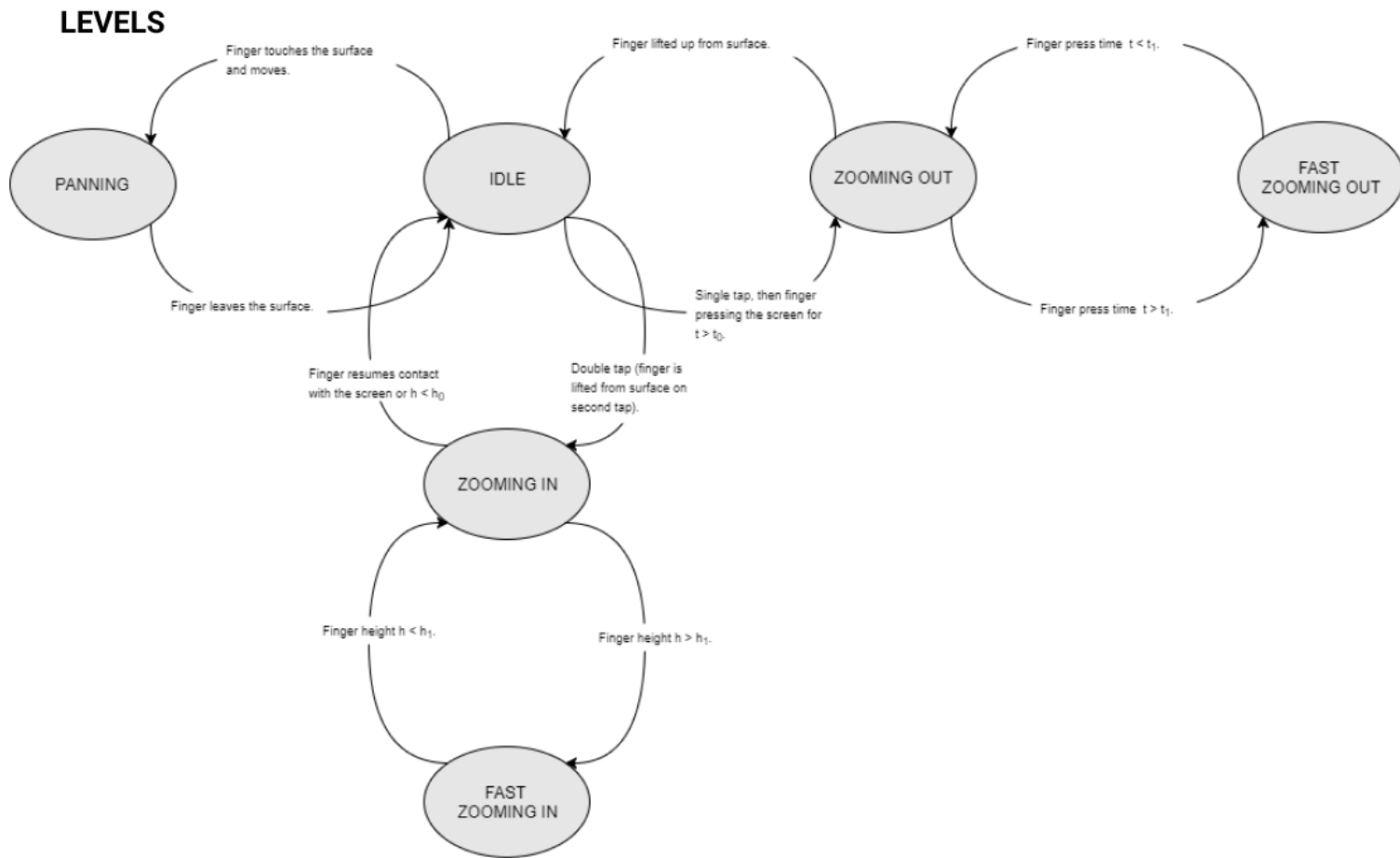


Figure 7.4: Approach 3: Levels State Transition Diagram

Approach 1: The Balloon Metaphor

This approach starts with a double tap on the center of zooming, and zooms in by lifting the finger up in the zed dimension. As the finger is lifted from the screen, the maximum position of the finger controls the scale of the content. This means that lowering the finger does not decrease the scale. The user starts a zoom out action by double pressing on the screen and keeping contact for as long as they want to zoom out. The zooming out action increases speed as the user keeps contact with the surface.

Zooming to a large scale can be achieved by double tapping and lifting the finger, then repeating this gesture multiple times. This makes it easy to quickly clutch and reach a high scaling value. However, the zooming action is never reversible in the other direction. Panning is done on the screen since lowering the finger during zooming does not change the zoom scale.

This approach requires clutching to zoom to large scaling levels and is not a reversible method of zooming. However, it has a direct and easy transition from zooming to panning. Figure 7.4 shows the state transition diagram of approach 1.

Approach 2: Push-Pull

This approach starts with a double tap on the center of zooming, and zooms in by lifting the finger up in the zed dimension. As the finger is lifted from the screen, the position of the finger is directly proportional to the scale of the content.

The user starts a zoom out action by double pressing on the screen and keeping contact for as long as they want to zoom out. The zooming out action increases speed as the user keeps contact with the surface. During in-air zooming, the user can zoom out by lowering it and perform a long press on the screen to continue zooming out. In this interaction, the zooming action is reversible in the other direction.

To lock the scale, the user needs to perform a horizontal swipe right gesture any time, including in air. Zooming to a large scale can be achieved by double tapping and lifting the finger, then locking the scale, and repeating this gesture multiple times. Panning is done on screen after locking the zoom scale.

This approach requires clutching to zoom to large scaling levels and requires a locking mechanism to transition from zooming to panning. However, it is a fully reversible zooming interaction. Figure ?? shows the state transition diagram of approach 2.

Approach 3: Levels

This approach starts with a double tap on the center of zooming, and zooms in by lifting the finger up in the zed dimension. However, this time the zed-dimension controls the rate of speed of zooming in. Until a certain height the rate is kept constant, after that height, the rate is increased to a higher constant speed.

The user starts a zoom out action by double pressing on the screen and keeping contact for as long as they want to zoom out. The zooming out action increases speed as the user keeps contact with the surface.

This approach is non-reversible and does not require any clutching. It provides a direct and easy transition from zooming to panning. Figure ?? shows the state transition diagram of approach 3.

7.3.2 Upcoming Study Description

There are many ways to support the three characteristics (transitioning from zoom to pan, reversibility, zooming to large scale levels) for a one-finger, in-air, zooming interaction for ultra-small displays. We expect that the ways to support these characteristics will vary depending on the use case.

Throughout the study described in Chapter 6, we discussed with participants what applications they would find zooming to be useful for on the smartwatch. We thus identified three potential zooming use contexts that participants found to be useful on an ultra-small display device such as a smartwatch; a map application, a remote-camera application where the user can look at the photo they took remotely, and an email-reading application.

For these use cases, we are interested in how the aforementioned three characteristics play into a complete and usable zooming interaction. What are the trade-offs that designers need to make while designing such a usable interaction? Which variation within the characteristics are most and least suited for a particular use context? Are there certain characteristics that are more valued for a particular use case?

We therefore plan to run a 3x3 within-subjects study with 5 participants where each participant will be asked to try the three approaches to zooming. For each approach, the characteristics above are present in different ways.

Participants will be asked to try each use context with each of the three interaction technique approaches described above in a randomized order blocked by the use context. Participants will first be asked to explore each case and think aloud. They will then be asked to follow tasks that will be designed to be common tasks on a smartwatch. After each case, they will be asked follow up interview questions about different characteristics. The questions will be targeted on the

participant's view of the importance and competence of each of the characteristic for that condition.

We will be asking what users think of the combination, and discuss how they would improve, or combine various features to make the interaction most usable for each application. We will then apply qualitative analysis to identify patterns among participants. The details of the study are work in progress.

Chapter 8

Conclusions and Future Work

In this chapter, we summarize the findings from our study, and give examples of possible future applications. We then discuss future work and outline the potential points of improvement for Gelly.

8.1 Findings: Zed-Zoom Promises a Broad Spectrum of Use

We designed and evaluated *zed-zooming*, a novel family of techniques based on emerging near-proximity sensing. We found that *zed-zooming* enables fluid, efficient zooming on displays of varying size. On displays so small that multitouch interactions are impeded, like smartwatches, *zed-zooming* far exceeds the abilities of the touchscreen standard *pinch-to-zoom*.

EZ-Zoom facilitates a pseudohaptic illusion of elasticity, which we theorize enhances proprioceptive position cues in the absence of actual contact. Participants' comments confirmed the illusion's presence, that it conveys information about the in-air interaction space above the control surface, and suggest that it enhanced their sense of control.

A damped region near the control range boundary may assist with fine control, but also might add to a perception of effort. We found that realistic auditory feedback on spatial height and breakthrough-point strengthened the illusion, and this facilitation may persist after the audio is disabled.

8.2 Applications

Once integrated into a full suite of zoom functions including pan, image-freeze and appropriate transitions, *zed-zooming* has obvious application for a broad range of media – browsing maps, reading text, and perusing photo collections. Users with impaired vision will benefit from quick zooming even on larger devices. *Zed-zoom* on larger devices will be useful for stylus interaction, and quick image editing, same-hand zooming, and quick zooming during social media or

games. In situations where users need quick one-finger zooming and to see the content clearly, *zed-zooming* may become essential.

8.3 Next Steps in Developing *Zed-zoom* Interactions

Many extensions of *zed-zooming* are possible and promising.

8.3.1 Full-Zoom Function

Both panning and the transition between panning and zooming are crucial to the real-world usage of our zooming technique. The interaction technique also needs to support multi-scale zooming, locking the scale at a particular level, and starting the interaction by first zooming out. Obvious transition mechanisms include dwell and quick secondary gestures. While not implemented in the *zed-zoom* versions evaluated here, we are already exploring a number of approaches. We have ongoing work on the different characteristics to consider while designing this interaction.

8.3.2 Combining Other Capabilities on the Sensor

We found that *zed-zooming* at an image-context level (e.g., zooming into a face) reduced the need for clutching.

Having multi-functional abilities in the sensor such as pressure sensing and shear sensing along with touch and proximity would undeniably give the sensor even more power. For example, what happens when the user wants to *start* by zooming out to a smaller size? A pressure sensitive surface could provide a quasi-inverse of the finger-lift control, and continue to build the proprioceptive illusion of springiness.

With the addition of shear sensing, users could make small panning adjustments using the shear capabilities of the surface, rather than larger movements that are less ergonomic.

8.3.3 Stylus Input

Zed-zooming is a single-touch input, suggesting stylus input and an interaction technique that is consistent across a broad range of screen sizes. However, writing and stroking with a stylus is ergonomically different from surface interactions with the finger; *zed-zooming* could be as well.

8.4 The Future of In-Air Sensing with Gelly

Our work demonstrates the potential value of a transparent touch and proximity sensor. There is an opportunity for Gelly and other such sensors to increase the interaction space of small displays with otherwise limited screen real-estate.

More work needs to be done on the Gelly sensor before it can be usable on real devices. Our project has been useful in guiding the development of this new technology in a humanly usable way.

Our explorations revealed high potential value in sensing the interaction space above the surface to a height of approximately 3-5 cm, with 1 mm resolution. The Gelly sensor currently can detect a finger up to 20 mm away from the screen with 5mm horizontal resolution. A priority should be to overcome current trade-offs between vertical range and horizontal resolution to attain more accuracy in this high-value space.

The sensing range of proximity sensors is currently too limited for most real-world applications. However, as technology matures they will become more and more useful. In addition to detecting proximity above screens, these sensors could become ubiquitous on wearables, to compensate for the lack of a traditional touch screen. In the future, as flexible displays become more common, flexible sensors such as Gelly will make their way into wearables and into our daily lives.

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Appendix A

Prior Art Analysis Provided to Qualcomm

The prior art analysis provided to Qualcomm reviews relevant academic literature and patents. It also compares Gelly with existing products.

**The Gelly Project:
Proximity-Driven Human Interaction Concepts**

Review of Prior Art

Version 1.0
October 25, 2016

Haihua Zhang
Dilan Ustek
Prof. Karon Maclean
Prof. John Madden

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I. Review of Relevant Academic Literature

Search Parameters

Keywords: hover, touch interface, small device, gesture recognition, interaction, proximity sensing

Primary venues searched:

- CHI: Conference on Human Factors in Computing Systems. The ACM (Association for Computing Machinery) CHI is the premier international conference on Human-Computer Interaction. It is held by ACM-SIGCHI (Special Interest Group on Computer-Human Interaction).
 - [2] CHI 2015
 - [3] CHI 2016
 - [5] CHI 2008
 - [6] CHI 2011
 - [7] CHI 1992
 - [8] CHI 2010
- UIST: The ACM Symposium on User Interface Software and Technology (UIST), a premier forum for innovations in human-computer interfaces, covers areas including graphical & web user interfaces, tangible & ubiquitous computing, virtual & augmented reality, multimedia, new input & output devices, and CSCW (Computer-Supported Cooperative Work).
 - [1] UIST 2014
 - [9] UIST 2016

Reference Descriptions

1. *“Air+touch: interweaving touch & in-air gestures”*, Chen, Harrison et al. *UIST'14 (CMU)*

Technology: a smartphone + a depth camera to simulate future, more advanced hover-capable devices.

This paper explored interactions that interweave touch events with in-air gestures. They classified these gestures into three types: Before touch, between touch and after touch.

Relevant gestures:

- Tap & Circle in the air for continuous zooming, applied in map application. Raising the finger up before touching down switches between pan/zoom modes. They choose circle-to-zoom as a way to solve the clutching problem, but research has shown that linear gesturing is a more natural mapping for zooming, and it could be difficult for users to draw a circle in the air.
- Proximity determined scroll rate: flick to scroll, then finger height maps the speed of scrolling. Similarly, in our Quickreader interaction design, we map the distance from the screen to the speed of scrolling through text. This shows to us that it is a viable technique to map distance from the screen to variable values.

2. *“Transture: Continuing a touch gesture on a small screen into the air”*, Han, Ahn et al. *CHI'15 (KAIST)*

Technology: A concept of interaction on small devices. There are no implementations yet.

This paper proposed the concept of increasing the input space of small screen devices by continuing the gesture in the air. Users can start a “Transture” by touch, then hover, and finally end with a touch.

The paper explored interaction techniques in mid-air for small screens, but compared to sticky zooming, their interactions are not efficient as they take multiple steps to achieve one task. The interactions need to be done in a small space and require precision, which is hard on a small display. Eg: They divide a circular space to three parts: one for panning, one for zooming, and one is the dead zone. So users have to go to be careful of which zone they are in to successfully conduct different interactions.

- Panning: Users start with the usual panning gesture. Panning continues after leaving the touched state and continues to move in the same direction.
- Zooming: Users draw a circle in the air to register a zoom, the center of the drawn circle will be the center of a circular region, which will be divided into three circular regions: dead, zooming and panning. Users then move their finger to the zooming zone and gesture a circle in order to zoom continuously. The direction of the circular gesture determines whether a zoom in or out is registered, and the distance from the center determines the zooming speed. The user can move to the panning zone to pan and adjust zooming center.
- Marking menu: Users draw a V in the air to start the menu. When the menu pops up, users can then drag to 4 sides out of the watch to scroll through options continuously. Drawing a V here is in the step of gesture registration because such a shape occurs rarely while performing panning gestures and thus can serve as a start point of the interaction.

3. “Pre-Touch Sensing for Mobile Interaction”, Hinkley, Heo et al. CHI'16 (Microsoft Research)

Technology: Mobile phone with a self-capacitance touchscreen that can sense multiple fingers above a mobile device, as well as grip around the screen’s edges.

The study explored possible interaction techniques on a self-capacitance touchscreen, and put emphasis on the anticipatory role of hovering.

They made a table demonstrating the design space of pre-touch to show that their contribution mainly lay in Background interaction and hover interaction. Background interaction here means to characterize the context of activity taking place ‘behind’ the foreground—such as sensing the user’s fingers approach the screen and fading in a context-appropriate interface to suit.

This gave us the idea to sort our contributions in a similar way but using the existing and popular interaction design on the smart phone and smart watch, and compared them to our design on Gelly. Most of the interactions are not suitable for applying to a smartwatch, as it often requires multi-touch and the detection of grip.

They classified interactions into three categories:

- Anticipatory reactions - Video controls that can fade in/out as the finger approaches/leaves, while sensing the grip to change the place of the controls. The Calm web browser presents users a clean web page; the hyperlinks and play controls only show up when fingers approach the display.
- Retroactive interpretations - Dispatch the tap to either large or small targets by inspecting the finger approach trajectory. The same technique can be used to discriminate flick vs. select. But their user study showed this design didn’t work well.

- Hybrid touch+hover gestures - Users can select a file by tapping and menus will show up at the position where the other finger hovers. A soccer game where users can strike the ball by touching and move over the ball using proximity.

4. *“The Continuous Interaction Space: Interaction Techniques Unifying Touch and Gesture on and above a Digital Surface”*, Marquardt, Jota et al. IFIP'11 (U of Calgary)

Technology: an interactive horizontal touch-sensitive SmartBoard surface(tabletop), and a Vicon motion tracking system. This tracking system is composed of 8 high-speed infrared (IR) cameras. The continuous interaction space is the unification of touch and hover interaction modalities. The author claims the space above the screen is a continuum and aims at exploring the space between hover and touch.

They proposed a video navigating method: lifting the finger to improve scale precision. As the hand goes higher, the slider will be rescaled to a larger size and the user can gain more precise control of the sliding bar.

We were designing a proximity controlled video player before, as there is currently not a video player on most smartwatches. However, this study explores interactions on large displays while ours is a small display, and it could be hard to achieve precision.

5. *“Lean and Zoom: Proximity-Aware User Interface and Content Magnification”*, Harrison, Dey. CHI'08 (CMU)

Technology: a computer with a built-in camera to calculate a user's lean proximity.

This paper used a Lean and Zoom system to detect users' proximity to a computer display and magnified the content on the screen proportionally to the proximity.

In the user study, they found that users described this technique as natural and intuitive, and could improve their performance and comfort. This finding supports out claim that sticky zoom will a more natural mapping and thus easier to use than pinch-to-zoom.

6. *“Mid-air pan-and-zoom on wall-sized displays”*, Nancel, Wagner et al. CHI'11 (LRI - Univ Paris-Sud & CNRS)

Technology: The display wall consists of 32 high-resolution 30" LCDs laid out in an 8x4 matrix, 5.5 meters wide and 1.8 meters high. A VICON motion capture system to track passive IR retroreflective marker.

In [8] the author claims that use of circular gestures to pan and zoom avoids clutching, thus users would feel that the interactions are more smooth and uninterrupted. However, in this paper, they found that linear gestures had higher efficiency than circular gestures because of the lack of surface in guiding a circular gesture.

7. *“The perceptual structure of multidimensional input device selection”*, Jacob, Sibert, CHI'92 (Naval Research Lab)

Technology: Computer and three-dimensional tracker.

Jacob and Sibert claim that panning and zooming are integrally related: the user does not think of them as separate operations, but rather as a single, integral task like “focus on that area over there”. This supported sticky zoom as it allows users to pan and zoom at the same time using one finger, while in pinch-to-zoom or crown-zoom(as used in Apple Watch), users have to first zoom and then pan around, which does not feel smooth but rather feels clunky.

8. “Clutch-free panning and integrated pan-zoom control on touch-sensitive surfaces: the cyclostar approach”, Malacria, Lecolinet et al. CHI'10 (Telecom Paris Tech)

Technology: a SmartBoard(on the wall), a vertical, front-projection 121x90.5cm interactive whiteboard with a display resolution of 1024x768px.

The study design is cited by [6], the mid-air pan-and-zoom on wall-sized displays study, but the result of the comparison between circular and linear gestures is different from [6]. The reason is explained in [6]. We learned from their user study and designed similar tasks: zoom in a circle enough to make it turn green until the user finds the right target. Their task required the users to zoom out of a circle to see the color change.

9. “AuraSense: Enabling Expressive Around-Smartwatch Interactions with Electric Field Sensing”, Zhou, Zhang et al. UIST'16 (CMU)

Technology: a smartwatch augmented with electric field (EF) sensing (a Microchip MGC3130 electric field sensing chip)

This paper used electric field sensing on a smartwatch to achieve the combination of skin track, hovering gesture and single hand gestures. They quantified the basic feasibility and accuracy of the six example interaction modalities and showed that it allowed high-fidelity sensing. But they did not explore the usage of proximity, instead, the main focus is on periphery control or above-screen gestures.

10. “3D-Press: Haptic Illusion of Compliance when Pressing on a Rigid Surface”, Kildal. ICMI-MLMI'10 (Nokia Research Center)

Technology : a graphics tablet and a stylus with a vibrotactile actuator.

The paper explored methods to create a compliant illusion on a rigid surface by using vibration and friction. Although it did not use any visual or audio cues similar to ours, they still managed to create the illusion successfully. We plan to adopt the way they conducted the user study partially, in terms of the control of different variables to create the illusion. In their study, they vary settings in four design parameters to create 16 different settings and tested them one by one. The result showed that most settings are able to provide a robust illusion of compliance. We also decided to test multiple conditions by varying the animation and sound, to prove that Sticky Zoom can create the stickiness feeling under different settings (eg: when you are outside and can not play the sound).

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II. Review of Relevant Patents

Search Parameters

Disclaimer: We do not have experience in doing patent search and did not understand everything fully. The following is only meant to help the patent experts.

Search keywords: hover + interaction + proximity + sensor/sensing + gesture

Search tool: Google Patent Search

A. References of Highest Current Relevance

1. *Hover-based interaction with rendered content (Microsoft) WO 2016025356 A1*

<https://patents.google.com/patent/WO2016025356A1/en>

1. A method comprising rendering content on a display, detecting an object in front of, but not in contact with, a front surface of the display, determining, at least partly in response to detecting the object, a location on the front surface of the display that is spaced a shortest distance from the object relative to distances from the object to other locations on the front surface of the display; determining a portion of the content that is rendered at the location or within a threshold distance from the location; and displaying, in a region of the display, a magnified window of the portion of the content.

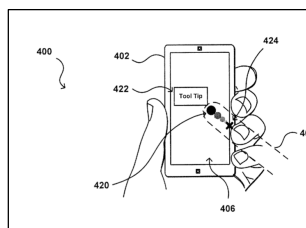
The claim contains an interaction like zooming, in which the user needs to lift up an object in order to zoom out and get closer to the screen in order to zoom in, which is the reversed direction of sticky zoom (8). They also claimed hover panning(10, and the method of zooming when a finger is not detected anymore(11).

2. *Non-occluded display for hover interactions (Amazon) US 20140282269 A1*

<https://patents.google.com/patent/US20140282269A1/en>

Abstract: When users hover, the displayed information can be an enlarged version of the element to help the user disambiguate selection of multiple elements.

However, they did not mention it in the claim, and in the description, their design is showing a larger hover box of the occluded key when the user is typing on a keyboard.



3. *Input interaction on a touch sensor combining touch and hover actions (Cirque) WO 2014152560 A1*

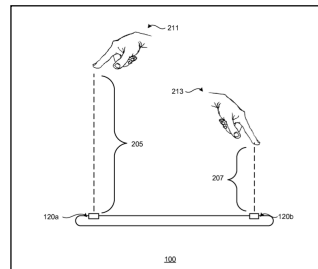
<https://patents.google.com/patent/WO2014152560A1/en>

Abstract: A system and method for defining a gesture to be any combination of touch and hover actions, the touch and hover actions being combined in any order and any number of discrete touch and hover actions that define a single gesture or a series of gestures. They are claiming the method of combining gestures of touch and hover.

4. Proximity sensor-based interactions (MS) US 20150253858 A1

<https://patents.google.com/patent/US20150253858A1/en>

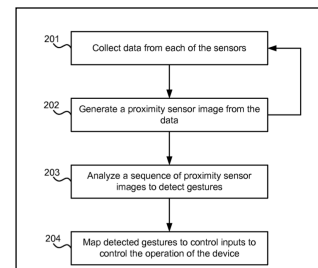
This patent claims receiving values from 1-3 proximity sensors and to perform operations based on the values. They also claim a sensor comprising a capacitive display. Claim game, map, security and authentication applications, claim velocity detection. Claimed computing devices: laptop, smartphone, tablet, portable media player, or video game device. Smartwatches are not mentioned.



5. User input using proximity sensing (MS) US 9063577 B2

<https://patents.google.com/patent/US9063577B2/en>

This patent does not include any specific gestures or interaction methods but claims the process of sensing and the composition of the device itself. The devices comprise of multiple sensors to detect user input in the interaction area that extends outwardly from a surface of a casing of the device, at least in a plane of a display portion or on the sides of the device. The gestures are detected by creating sensing images and mapping to certain operations to control the program.



6. Hover gestures for touch-enabled devices (MS) WO 2014143556 A1

<https://patents.google.com/patent/WO2014143556A1/en>

This patent claims a method of detecting hover gestures, including the finger(s)' positions, proximate, and movement. Hover gestures include: finger tickle, circle gesture and holding a finger in a fixed position for a predetermined period of time. The claim includes associating the finger position with an icon displayed on the touch screen, displaying additional information associated with the icon. --- Magnify, HoverPeek, FolderPeek all need to hover for a while and associate the icon with finger position. Their design is on the mobile phone and use hovering to see the recent/missed call of a calling app and see the calendar items for a current day.

7. One-handed gestures for navigating ui using touch-screen hover events (Motorola) US 20140362119 A1

<https://patents.google.com/patent/US20140362119A1/en>

This patent claims a zoom function by proximity: detecting presence of user digit in proximity to the screen, entering a hover-zoom model, distance between digit and the screen determines a zoom factor for the display, location of the user digit is used to determine a direction to pan on the display, including panning on the display/viewport by an amount of the digit's movement. It is almost the same as Sticky Zoom, but they start the zoom not by touching but persistent hovering for a determined period of time.



8. Multiple hover point gestures (MS) WO 2015100146 A1

<https://patents.google.com/patent/WO2015100146A1/en>

In the instruction they mention: The gather gesture may be used to reduce screen brightness, to limit a social circle with which a user interacts, to make an object smaller, to zoom in on a picture, to gather an object to be lifted, to crush a virtual grape, to control device volume, or for other reasons.

Claim: detecting a plurality of up to 10 hover points, without using a camera or a touch sensor, and produce independent categorization of data and tracking data.

Claim the multiple hover point gesture is a gathering, spreading, cranking, rolling, ratcheting, poof, and sling shot gesture.

B. References of Potential Future Relevance

We found several references that are of lower relevance to our current project but will probably be useful in the future.

9. *Method and apparatus for hover-based spatial searches on mobile maps (Nokia) WO 2013124534 A1*

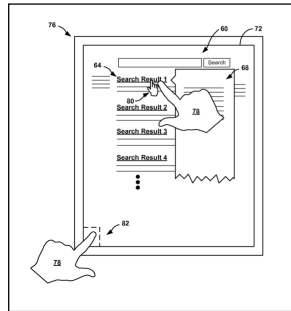
<https://patents.google.com/patent/WO2013124534A1/en>

This one is about maps, not related to our design, but if we implement map apps in the future this should be useful.

10. *Hover-over gesturing on mobile devices (Google) US 8255836 B1*

<https://patents.google.com/patent/US8255836B1/en>

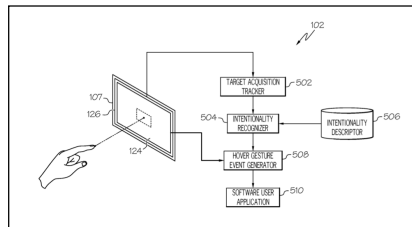
This patent claims two-handed touch+hover gestures on a mobile device. It does not cover Gelly since we are only using one handed gestures at the moment.



11. *System and method for interacting with a touch screen interface utilizing a hover gesture controller (Honeywell) US 20140240242 A1*

<https://patents.google.com/patent/US20140240242A1/en>

System and method to recognize the interaction intentionally in order to reduce the inadvertent interaction. We will probably use it for the future development of Gelly.



III. Comparisons of Gelly with Existing Products

1. Comparison between Samsung Air View and Gelly

	App	Video	Photo	Dial	Text
Airview	<p>Hover over a day inside a month-view calendar to preview events on a day.</p> <p>Hover over an album inside the photo gallery to preview several photos.</p> <p>Hover over a message to preview the whole message.</p>	<p>Hover over a video file to preview the content of a video.</p> <p>Slide-hover over the control bar to preview a given point of the video.</p>	N/A	Speed dial preview: hover over a key on the keypad and shows which contact it is assigned to.	Hover over a part of the text in a web page to magnify.
Gelly	<p>Magnify: Hovering over apps makes it bigger and easier to touch(necessary for the small screen.)</p> <p>Hoverpeek: hover over any app icon to preview notifications, and click to open directly to certain content.</p> <p>Folderpeek: Hover over a folder and preview the apps contained in the folder, click to directly open the app.</p>	N/A	Sticky Zoom: touch the photo to start, lift up the finger to zoom in, get closer to zoom out, go further from screen to zoom in.	N/A	QuickRead: hover on the left or right side to scroll a sentence from left to right, while hover height determines the scrolling speed.

Summarization: In short, the Samsung features are based on previewing and magnification, but for a smartphone, they are nice-to-have features rather than things that are absolutely necessary. Some hover functions are so slow and unnecessary that users would rather choose to click. Previewing is a common trend between the Air View and our interactions, but the above table shows why we claim that it is different and useful. Our interaction techniques focus more on replacing clicking with hovering to make it more efficient in controlling apps and folders and improve the performance of tasks that are difficult to perform on small displays, such as clicking on a small icon, zooming, and reading.

Appendix B

Study Proposal

This appendix contains the study proposal used in the experiment discussed in [Chapter 6](#).

Zoom Study

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Researchers

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Document prepared by: Dilan Ustek, Haihua Zhang (w/ input from MacLean)

Purpose

In this user study, we want to compare the StickyZoom interaction techniques with the regular pinch-to-zoom zooming technique on a smartwatch to compare effectiveness and preference. We also want to find out how the visual cues for zooming and audio influences the feeling of connectedness/elasticity of the finger to the image.

Contributions

Our contributions will be:

1. An exploration of the design space of proximity zooming interactions and the design of the StickyZoom interaction technique with variations of how it could be implemented: a proximity-based zooming technique designed to facilitate zooming on direct-touch displays which are (a) small compared to the user's finger reach; (b) work with just one finger; and (c) minimize occlusion..
2. Usability evaluation (performance and qualitative feedback) of multiple StickyZoom implementations, as compared with the current standard touch-display zoom technique (pinch to zoom).
3. Insight into the conditions under which a pseudo-haptic illusion can be induced for the StickyZoom in-air (non contact) interaction, and data on its impact on performance when it is in effect.

Research Questions

RQ1: What are the usability and user experience of the StickyZoom interaction techniques, relative to the standard pinch-to-zoom technique?

Which technique, out of the regular zooming technique and all conditions of sticky zooming techniques

- have the highest **performance** in a zooming task? (timing)
- have any apparent **learnability** issues? (observation)
- are **preferred** by user s? (ranking)
- are considered **easy to use**? (ranking)
- are considered **pleasant**? (ranking)

RQ2: How do audio cues and changes in the C/D ratio for zooming influence the **pseudo-haptic illusion of elasticity(connectedness)** of the finger to the image on a screen? (subjective rating)

Expected Outcomes

We expect to learn:

With respect to “sticky” pseudohaptic illusion:

- A. If there is still a feeling of elasticity without the image of a spherical ball
- B. If there is a feeling of elasticity with or without audio for a rubber band snapping, when there is an image of a person, not a spherical ball.

With respect to StickyZoom (and variations) performance relative to standard:

- C. On average, which technique was the most efficient in terms of how long it takes to perform 1 task.
- D. Which technique was the most pleasant for users.
- E. Whether there were any learnability issues to be concerned about.
- F. Which technique users had a preference towards.
- G. Which technique was considered easy to use by users.
- H. How users define the experiences of all the techniques.

Related Work

Pinch-to-zoom on Small Screens

On nearly all smart devices with a touch screen, the most popular way of zooming is pinch-to-zoom. However, as some researchers [PTZ, 1] have pointed out, “precision-pointing and occlusion problems” are two of the obvious problems of pinch-to-zoom. When it comes to the zooming on smart watches, precision becomes less important because usually zooming situation like checking photos doesn’t require high degree of precision. But the occlusion problem become even more serious on small screen devices, and Stickyzoom is mainly aimed at fixing this problem.

Usually when people do zooming on screens, they tend to zoom in and out for many times, switching between the details and high-level context. [PTZ,2,3,4] This interaction requires users to repeat the same gestures continuously, which can be tiring and time-consuming, especially when the screen size is small, there is high rate of false positive operation. Thus, another important goal of Stickyzoom is to allow users to zoom in and out efficiently, without the constraint of the screen size.

In [PZT], the results of their experiment showed that zoom acceleration reduced effort, that is, the number of pans and clutches, but not reducing the task time. The reduction of task time only showed in the longitudinal study later, after the users gradually get used to the new technique. However, we believe Stickyzoom can help reduce the task time during the experiment as well. In order to solve the occlusion problem, researchers has been exploring the space around smart watches. [SkinTrack 14] put up with new interactions allowing users to “zoom in and out by scrolling on the hand”. The technology in [SideSight 13] allows users to move fingers on the surface around the screen, to enlarge the space for doing pinch-to-zoom. However, they both did

not solve the problem of clutching, which means users still need to exert repetitive zooming gestures in order to zoom in or out to the ideal ratio.

In-air Technologies and Interactions

In 2011, the [Continuous Interaction Space11] pointed out there are “rich interaction space between “on the surface” and “above the surface”, and named this interaction space as continuous interaction space. They believed in this area, three-state interactions could be designed to avoid occlusion and improve precision, such as lifting fingers to adjust scale precision when controlling a video timeline.

Since then, there have been many hover technologies, interaction techniques and concepts developed, like the [Air+Touch 6] and [PreTouch7]. [6] used depth camera back plane chassis with a smart phone to achieve in-air gestures. They proposed a gesture vocabulary called “Air+Touch”, dividing interaction gestures into three phases: Before/Between/After touch. Based on this concept, they designed a series of interactions including non-clutching scrolling and zooming. The [Pre-Touch Sensing 7] paper mainly contributed to the background sensing interactions. Their self-capacitance touchscreen was able to sense the hovering and gripping above and around the mobile phone, and support the “graceful degradation to a one-handed version of the technique”.

[Transture 8] focused more on hover interactions on small touchscreens, and designed in-air interaction techniques such as panning, zooming and activating menu on a smartwatch with the depth camera, in order to to delimit the constraint of the screen size. They also admit that pinch-to-zoom is hard to operate on small screens due to the insufficient space for multi-finger gesture.

Circular vs. Linear Zooming

Among all these hover interactions designed, there are two existing zooming techniques: Transture zooming starts with drawing a circle on the screen, and divides the interaction space into three circular regions: panning, zooming, and dead. In the zooming region, the distance between the zooming center(also the circle’s center) determines the zooming ratio, the direction of a circling gesture determines zooming directions. If users move their finger to the panning region, they can pan while zoom[8]. This interactions solved the problem of the limited interaction space for zooming, but according to the result of the experiment, “participants wanted to disable panning function in the zooming zone”, which implies that panning and zooming are not connected well in this design, possibly because the technique is complicated, and hard for users to handle two modes at the same time.

[Air+Touch 6] proposed a zooming techniques based on the After Touch concept: Users start the zooming by touching the screen, then lift high up and draw circles in air to do continuous zooming. Zooming directions are determined by cycling directions. Users can quit zoom mode by tapping the screen again or doing non-cyclical motion for a short period.

In contrast to the linear gesture of Stickyzoom, both of the interaction techniques above are based on the circular movement of fingers. Nevertheless, research has demonstrated the possible weakness of circular gestures. In [Mid-air pan and zoom 10], researchers found that when participants were doing zooming tasks, linear gestures are generally faster compared with circular ones, especially on 2D surface and 3D free hand conditions. They concluded that “the lack of a surface to guide the gestures significantly degrades the technique’s usability.

What's more, [Lean and Zoom 12] has proved "the notion of learning forward for visual enlargement is natural", and we believe that lifting up the finger to see the objects more clearly is similarly natural and intuitive, thus makes Stickyzoom have higher learnability and memorability, compared with the above circular gestures.

Illusion and User Experience

Despite solving the problem of occlusion and clutching, we also want to create a more pleasant experience of zooming by trying to create an illusion during the zooming process. In [3D Press 15], the author used kinaesthetic cues and cutaneous cues to create a perceptual illusion that involves "pressing on a rigid surface and perceiving that the surface is compliant". According to previous research, perceptual illusions are defined as "systematically-originated errors in the perception of figures or scenes, which are observed in almost all people". [3D Press, Haptic Perceptual Illusions 16]. In their results, 80.3% of the descriptions showed that the user perceived the illusion of compliance, and proved the multimodal illusion was robust under various conditions.

In our design, we want participants to feel a certain extent of connectedness between their finger and the pictures in the screen through the synchronization between the visual cues on the screen and the kinaesthetic cues of their fingers.

Data sketch

- Transcripts of the think-aloud process of the initial familiarization process and during the tasks: note the specific words implying illusion and feeling. (Qualitative+Subjective)
- Ranks of elasticity for the ball image, photo, and with/without audio. (Quantitative + Subjective)
- Ranking results for all interaction techniques (Quantitative + Subjective)
- Time spent on task through sticky and regular zooming techniques (Quantitative+Objective)
- Interview: opinions of the user experience, rankings of preference, ease of use, and pleasantness, questions and places need to be improved. (Qualitative+Subjective)

Protocol

[10 min intro- including signing]

Initial explanation:

In this experiment, we're studying ways that you can use proximity (your height above the surface) to zoom the screen contents in and out. In front of you is a smartwatch and a smartphone; we've created a prototype setup that allows us to measure your finger's height above their screens, to mimic some new technology that we think will be coming to mobile devices before long.

We are asking you to focus on the experience of the interaction technique rather than the polished quality of this early prototype - which I must warn you, does not always work perfectly. In fact, you may experience some glitches, and I'll ask you to do your best to ignore these. If at any time you're not sure whether what you see is a glitch or an intended behavior, please ask.

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- Leap doesn't work great, try not to move your hands around too much while interacting. If at any point you see a hand image on the screen it means you need to remove your hand and bring it back, show it [LIKE THIS] in front of it, then point your index finger to interact.
- We ask that you do not put your fingers too close to the leap as it will not see your hands if they are too close, so moving upwards on the device only will prevent this problem.

1. Illusion

15 min

(Smartphone: Samsung galaxy S7)

	Audio	No Audio
Ball	Ball with audio	Ball without audio
Photo	Photo with audio	Photo without audio

Conditions will be fully randomized for each participant. Each participant will encounter and rate each condition one at a time, number of repetitions being once.

Users will be given smartphones with an image of a ball, a group photo, or some text and will be asked to zoom in by touching the image, and then pulling their finger up as their wrist continues to be set on the same platform as the phone. They will be asked to point one finger as to focus their attention to the illusion and feeling rather than the gestures (learned from the pilot 0 that we have done). For both of the image conditions, there will be two conditions: with and without audio feedback (that is, the sound of an elastic balloon stretching to a max point, and then going back to the initial size when it hits the top limit) as the image is pulled up and as it snaps back after a certain threshold.

After about 20 seconds of exploration, participant will be asked:

- Can you describe what you feel as you move your finger up and down above the image? Is there anything it reminds you of?
- If first one: *"When you scroll with a mouse and the cursor moves either slower or faster relative to your hand movement, it can make the mouse feel "heavier" or "lighter" - or when you use a scrollbar to scroll up and down and if it is slower to react when you hit the top and bottom, it feels magnetic or sticky. he have you ever felt that or can you imagine what that would be like? This is what we call a "pseudo-haptic illusion" - when you think you feel something even you don't really. It's the kind of thing we'd like to know if you experience any effects here."*
- *On a scale of 0-10, 0 being no effect, 10 being a very strong effect, how strong was this effect? (ON PAPER)*

...

- Are there places in the space where your movement seems easier or harder, or does it

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always feel about the same? [if yes]: Where in the space is it more difficult/easy to move through?

- If they say it “breaks/falls/drops” etc, show me, roughly, at what point [height above the surface] it is going to break/fall? If they didn’t say anything reset.

- ...
- If user is changing speeds around the slow region, ask: *Why did you slow down/increase your speed/stop at that point?*
- ...
- If there was auditory feedback: *“What does the auditory feedback remind you of?”*

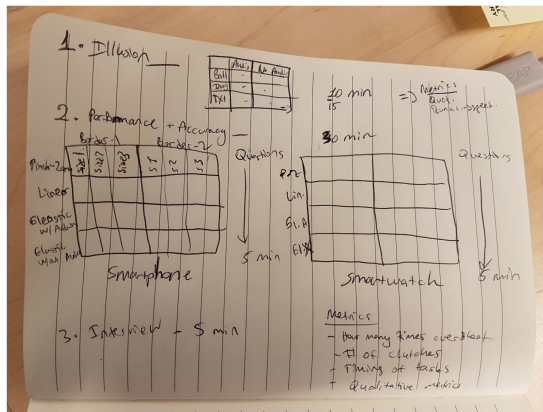
After they are done with all 4, they will be shown all of them again and given the opportunity to revise as they would like:

Metrics:

- Rating from 0-4 for each condition.
- User’s description of what they feel as they move their fingers up and down, and if it reminds them of anything, unconstrained think aloud, capturing all the words.
- User’s reactions captured from the unconstrained think aloud.
- Whether or not user can identify the slow region (before the break of the elastic rubber band)
- **Leap measurements of speed of hand in different regions**
- Measurement of distance where the user predicts the image to be at the limit range

2. Interaction Usability: Objective Performance and Qualitative Feedback

(30 mins)



Performance

Metrics: All tasks will be automatically timed from the start of the image-touch. The number of clutches, overshoots, and *dropping* of the image while zooming in the elastic condition will be recorded.

Task: A square will appear on the screen as well as a larger square frame. Your task is to zoom into the small square such

that it fits into the frame's borders. As long as it is somewhere in the range of the red border, it will turn yellow. You need to keep it in the yellow range until it turns green which is when it will restart to the beginning (frame turns red again). If you pass the border, you can always go back down.

The task will be repeated for two other blocks of different sizes such that in total there will be a small, medium, and a large block (to have different zooming amount). There will be 5 trials per size which means 15 trials, in a randomized way.

3 sizes * 5 = 15 trials for a given square of a certain "border". Then, they will be asked to repeat these 15 trials for a different border such that there is a larger range of accepted "success".

This will be repeated for 4 conditions:

- Pinch-to-zoom [*baseline*]
- Linear proximity zooming without Audio (no illusion expected condition)
- Elastic proximity zooming with Audio: the sound of an elastic balloon stretching to a max point, and then going back to the initial size when it hits the top limit
- Elastic proximity zooming without Audio

This whole thing will be repeated for smartwatch again.

Estimated time: 2-3 minutes per condition which means about 12 minutes for device. X2 devices = ~24 minutes. + 10 minutes for questions which equals to about ~30 minutes.

Interview

(10 mins)

-> Goal: To compare user experience of zooming techniques

Users will be asked verbally and will be allowed to retry the above 4 conditions.

- Rank all 4 zooms in order of ease of use. Why?
- Rank all 4 zooms in order of pleasantness. Why?
- Rank all 4 zooms in order of preference. Why?

- In which case do you think are they useful for? You don't have to give an answer to each condition.
- What do you think of auditory feedback? Did you find it helpful / annoying? How would you change the auditory feedback if you could?
- Any questions?

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Study Design Description

Participants

Number: 10

Description: Adults aged 18-50 who have had min 2 years of smartphone usage experience.

Incentive: \$15/hr

Rationale: Participants should have familiarity with the smartphone and how to interact with a touch screen device.

Independent Variables

Condition (all 4 stated above - including pinch-to-zoom)

Dependent Variables

Time it takes to accomplish each task.

All rankings, ratings, and descriptions stated by participant as described above.

Session Time Budget

1 hour per participant.

Apparatus

Analysis

*RQ1: How do visual and audio modalities influence the virtual **illusion of connectedness** on a screen? (subjective rating)*

2x2 factorial ANOVA with a Bonferonni correction

RQ2: How is the usability of the StickyZoom interaction techniques?

*- Which technique, out of the regular zooming technique and all 4 conditions of sticky zooming techniques have the highest **performance** in a zooming task? (timing)*

The tasks will be timed and then normalized according to how many circles that task required in order to reach the end. Then they will be averaged within the conditions and each condition will be compared between users to find any outliers and statistical significance.

*- Do any of the techniques, out of all 5, have any apparent **learnability** issues? (observation)*

8

Familiarization and other observations' notes will be analyzed for anything that sticks out as a problem during the initial learning phase.

- *Which interaction techniques do users have a **preference** towards? (ranking)*

ranking analysis

- *Which interaction techniques do users consider **easy to use**? (ranking)*

ranking analysis

- *Which techniques do users consider **pleasant**? (ranking)*

ranking analysis

- *How do users define the **experience** of all 5 techniques? (interview)*

Analyze notes for any patterns

RQ3: How is the prototype's performance relative to what is needed to zoom?

- *Is it interfering with the experiment?*

Analyze notes during observations.

- *Is the prototype's performance adequate to support fluid proximity based zooming?*

Analyze notes during observations.

Overview and Rationale for Study Approach

1. We decided to get rid of panning for the first part of the experience, that is, the participant will only be allowed to zoom in and out without panning when they are performing the task. The first reason is that we want to test the fluidity and efficiency of StickyZoom when users quickly zoom in and out, thus panning is not a crucial part of the process. Secondly, adding panning to the process might influence the illusion of connectedness, which is an important factor we want to test in the user study. Thus the panning in both StickyZoom and regular zoom will be excluded in this study.
2. In paper [6] the researcher calculated the overshoot frequency of each technique, but we will not be counting the overshoot. First, it is because precise control is not a focus of StickyZoom: Usually on the smartwatch and smartphone, users don't need very precise zooming, especially when zooming a picture--what StickyZoom is designed for. Also, from the study's perspective, if participants are asked to try their best to be precise, they might be too cautious on the zooming process to experience the enjoyable feeling of stickiness we want to test.
3. There will be a familiarization process at the beginning of the study, for the users to play with different techniques freely and get used to them. We added this part because most participants possibly don't have experience with using a smart watches, the unfamiliar feeling might cause them to fail the first several tasks. Thus adding the practice period can both help them feel smooth when perform the tasks and reduce the training effect.

Also, this can help us examine the learnability of both types of zoom: if participants feel they can conduct zooming smoothly after playing with it for several minutes, it shows the interactions are learnable. Most importantly, we are comparing different conditions of StickyZoom, and the practice part will allow them to calibrate to different conditions, giving them a comprehensive understanding of each condition.

4. In each task, we will randomly assign numbers of trials it will take to reach the correct circle that will be the end to their task. The numbers assigned for each condition will be the same, but the orders will be randomized. This is to control the number of times participants zoom in and out are the same in every condition, so that we can better compare the consumed time and test efficiency.
5. As we noticed that it is hard to create a “stickiness” illusion, we changed the point of the experiment from looking at how to create the stickiness illusion, to looking at if people are feeling any physical sensation, if that is due to the zooming effects, and whether that is accentuating the zooming experience.
6. Users are not asked to rate the level of stickiness, as this would be a leading question. They are therefore asked to describe the experience and then rate the level of the given feeling.

Target Publications

UIST 2017

Ethics

Ethics Form Number
Video Recording?
Declarations
Amendments Required

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Appendix C

Participant Checklist

This sheet was used to keep track of things to do before and after each participant during the study.

Participant Checklist

TODO before each participant:

- Connect computer to UBCVisitor, click on random webpage and click accept.
- Computer volume set to (full -7)
- Turn off phone's autolock.
- Run: node leapnode.js
- Connect watch to UBCVisitor, click on random webpage, and click accept.
- Turn off bluetooth on phone, put it on airplane mode.
- Connect phone to UBCVisitor, click on random webpage, and click accept.
- Connect leap and test setup using visualizer.
- Set up speakers and test audio level. (max vol - 6)
- Open procedure:
<https://docs.google.com/document/d/1ATczB5LJWWZ9I8lnzhIEwmTP8Kgg4MdRWD7ulhaTPaQ/edit#>
- Print out Participant Answer Sheet:
https://docs.google.com/document/d/1itlXoTUvSVe4_LTQpVtbvARYzNXg-ruS9VjiuWgklFA/edit
- Prepare Coding Sheet
- Prepare Consent Form.
- Prepare \$15.
- Prepare payment confirmation signature form.
- Prepare NDA to be signed.
- Set up voice recorder.

TODO after each participant:

- Turn off recorder and check.
- Upload recording on the drive.
- Check PID is on all forms.
- Put Coding sheets on drive
- NEVER delete any data.
- Put all data under their folder with their PID. Put unnecessary data in another folder under their folder.
- Upload data to Drive and then to SPIN server.
- Check all forms.

Appendix D

Study Script and Coding Sheet

This sheet is the detailed study script and coding sheet that was used for each participant throughout the study.

Participant Number: _____

Zoom Study Steps and Coding Sheet

Introduction to Study

Hello! Our names are... We are in Prof. Karon MacLean's SPIN lab

Signing the consent form

Signing the NDA.

You are allowed to leave the experiment at any point you'd like.

Let us know if you need a break. The study has two main sections and we will give a short break in between anyway.

In this experiment, we're studying ways that you can use proximity (your height above the surface) to zoom the screen contents in and out. In front of you is a smartwatch and a smartphone; we've created a prototype setup that allows us to measure your finger's height above their screens, to mimic some new technology that we think will be coming to mobile devices before long.

To set up, I would like to know if you are right or left handed?

- Set participant up next to the leap according to which hand is their dominant hand.
- Check visualizer.
- Ask if comfortable.
- Arrange wrist on a surface.
- Start voice recorder.

We are asking you to focus on the experience of the interaction technique rather than the polished quality of this early prototype - which I must warn you, does not always work perfectly. In fact, you may experience some glitches, and I'll ask you to do your best to ignore these. If at any time you're not sure whether what you see is a glitch or an intended behavior, please ask.

- *Leap doesn't work great. try not to move your hands around too much while interacting. If at any point you see a hand image on the screen it means you need to remove your hand and bring it back, show it [LIKE THIS] in front of it, then point your index finger to interact.*
- *We ask that you do not put your fingers too close to the leap as it will not see your hands if they are too close, so moving upwards on the device only will prevent this problem.*
- *If you see an image of a hand, it means that the leap has not recognized your*

hand. You can take your hand behind the leap, and put it back into the frame so as to calibrate it.

Part1 - Illusion

Introduction

CHECK THAT PARTICIPANT ID IS NOT GENERATED.

In the first part of the study, we will test your reactions to 4 conditions of zooming only on a smartphone. You will see and hear things relevant to the interaction. You should pretend that the speakers are from the device you are working on.

EXPLAIN HOW TO ZOOM ! starts with a touch and might end with a touch.

*We will allow you to explore each condition for about 20 seconds. You are encouraged to think out loud; no constraints while you explore them.
After each condition, you will be asked what kind of object each of the interactions remind you of interacting with, and how strong that effect is.*

Conditions are randomized on the settings page. Play the conditions and ask:

Condition 1: _____

1. Can you describe what you feel as you move your finger up and down above the image?

2. Is there anything it reminds you of?

3. *"When you scroll with a mouse and the cursor moves either slower or faster relative to your hand movement, it can make the mouse feel "heavier" or "lighter" - or when you use a scrollbar to scroll up and down and if it is slower to react when you hit the top and bottom, it feels magnetic or sticky. he have you ever felt that or can you imagine what that would be like? This is what we call a "pseudo-haptic illusion" - when you think you feel something even you don't*

really. It's the kind of thing we'd like to know if you experience any effects here."

4. On the sheet next to you, could you rate the strength of the illusion you're reminded of?
5. Are there places in the space where your movement seems easier or harder (due to visual and auditory cues -- might need to ask about speed or control--), or does it always feel about the same? [if yes]: Where in the space is it more difficult/easy to move through?
6. Was there anything in the movement of the images or the audio feedback that warned you that the image might drop soon, BEFORE it happened?
7. Can you show me, very roughly, a point [height above the surface] in the range where it might break/fall/drop? Just zoom into the image until you get there and tell me "NOW" while keeping your finger there and I will tell the program to note that.

Condition 2: _____

1. *Can you describe what you feel as you move your finger up and down above the image?*
2. *Is there anything it reminds you of?*
3. *Any illusion effects that remind you of something?*

4. On the sheet next to you, could you rate the strength of the illusion you're reminded of?

5. *Are there places in the space where your movement seems easier or harder (due to visual and auditory cues -- might need to ask about speed or control--), or does it always feel about the same? [if yes]: Where in the space is it more difficult/easy to move through?*

6. Was there anything in the movement of the images or the audio feedback that warned you that the image might drop soon, BEFORE it happened?

7. *Can you show me, very roughly, a point [height above the surface] in the range where it might break/fall/drop? Just zoom into the image until you get there and tell me "NOW" while keeping your finger there and I will tell the program to note that.*

Condition 3: _____

1. Can you describe what you feel as you move your finger up and down above the image?

2. Is there anything it reminds you of?

3. *Any illusion effects that remind you of something?*

4. On the sheet next to you, could you rate the strength of the illusion you're reminded of?

5. Are there places in the space where your movement seems easier or harder (due to visual and auditory cues -- might need to ask about speed or control--), or does it always feel about the same? [if yes]: Where in the space is it more difficult/easy to move through?

6. Was there anything in the movement of the images or the audio feedback that warned you that the image might drop soon, BEFORE it happened?

7. Can you show me, very roughly, a point [height above the surface] in the range where it might break/fall/drop? Just zoom into the image until you get there and tell me "NOW" while keeping your finger there and I will tell the program to note that.

Condition 4: _____

1. Can you describe what you feel as you move your finger up and down above the image?

2. Is there anything it reminds you of?

3. *Any illusion effects that remind you of something?*

4. On the sheet next to you, could you rate the strength of the illusion you're reminded of?

5. Are there places in the space where your movement seems easier or harder (due to visual and auditory cues -- might need to ask about speed or control--), or does it always feel about the same? [if yes]: Where in the space is it more difficult/easy to move through?

6. Was there anything in the movement of the images or the audio feedback that warned you that the image might drop soon, BEFORE it happened?

7. Can you show me, very roughly, a point [height above the surface] in the range where it might break/fall/drop? Just zoom into the image until you get there and tell me "NOW" while keeping your finger there and I will tell the program to note that.

--- REVISION--

Allow users to revise the above ratings.

Part2: Usability and User Experience

Introduction

- CHECK THAT PARTICIPANT ID IS GENERATED.

In the second, and final, part of the experiment we will ask you to perform a task on both of the devices (smartwatch, and smartphone). We are looking for performance here so we ask that once you start a task, you finish it as quickly as you would, in a natural manner (no need to rush). The timing starts once you click to start the zooming so you do not have to finish all trials, and can stop between the trials.

Your task: A square will appear on the screen as well as a larger square frame. Your task is to zoom into the small square such that it fits into the frame's borders. As long as it is somewhere in the range of the red border, it will turn yellow. You need to keep it in the yellow range until it turns green which is when it will restart to the beginning (frame turns red again). If you pass the border, you can always go back down.

There will be regular pinch-to-zoom, and proximity zooming versions of this task. You are allowed to pinch outside of the box, because it is so small.

One thing to note is that the watch goes back when trying to ptz sometimes and so try to make sure your fingers are staying on the image and you can just scroll it back..

Let's do one example with the watch.

Show both a prox zooming, and a pinch-to-zoom example.

- [Delete trials] TRIALS ARE DELETED

You will be prompted to do this trial a couple of times for 4 different conditions of zooming. After you've done all 4, you will be asked for your preferences.

Ok, we will now start the experiment [start experiment]

(Check as it is completed)

<i>Completion</i>	Pinch-to-Zoom	Linear	Elastic w. Audio	Elastic W/out Audio
Phone				
Watch				

[DONE] -> CHECK ALL DATA LOGS ARE COMPLETE

Interview After PHONE:

For these questions, we would like you to pretend like there are no glitches and imagine the proximity technology has reached a point where it works really well.

1. **USEFULNESS:** Between the pinch-to-zoom and your favorite proximity zooming technique, which of the two do you find more useful? WHY?
2. **USABILITY:** One the sheet next to you, could you rank: among the 3 proximity zooming techniques, which one you'd be happier to use in the long term for this device? WHY?
3. In which cases do you think they might be useful for? It can be proximity vs pinch-to-zoom or more detailed proximity comparisons if you have any in mind; you don't have to give an answer to each condition. Maps vs text? Moment in day/life, certain context?

Interview After WATCH:

For these questions, we would like you to pretend like there are no glitches and imagine the proximity technology has reached a point where it works really well.

1. **USEFULNESS:** For the watch, between the pinch-to-zoom and your favorite proximity

zooming technique, which of the two do you find more useful? WHY?

2. USABILITY: One the sheet next to you, could you rank: among the 3 proximity zooming techniques, which one you'd be happier to use in the long term for this device? WHY? What do you think of them? (Can try them again)
3. In which cases do you think they might be useful for? It can be proximity vs pinch-to-zoom or more detailed proximity comparisons if you have any in mind; you don't have to give an answer to each condition. Maps vs text? Moment in day/life, certain context?
4. (If they haven't said anything about elasticity) Ask about elasticity....

Auditory:

1. Overall, what do you think of auditory feedback? Did you find it helpful / annoying? How would you change the auditory feedback if you could?

Exit

- Any questions or comments for us?
- Thank you!
- Signing payment form
- Payment

Appendix E

Call For Participation

The appendix is the call for participation we used in our study.

THE UNIVERSITY OF BRITISH COLUMBIA



Department of Computer Science
201-2366 Main Mall
Vancouver, B.C. Canada V6T 1Z4
tel: (604) 822-3061
fax: (604) 822-4231

Developing and Evaluating Touch Sensors

Principal Investigator: Karon MacLean, Professor, Dept. of Computer Science, [REDACTED]

Co-Investigators: Dilan Ustek, MSc Student, Dept. of Computer Science, [REDACTED]
Alicia Woodside, Undergraduate Student, Dept. of Computer Science, [REDACTED]

Version 1.0 / 13 June, 2016

The Sensory, Perception, and Interaction (SPIN) Research Group in the UBC Dept. of Computer Science is looking for participants for a study evaluating the performance of a variety of touch sensors. You will be compensated \$15 for your participation in a single 1-hour session.

We will ask you to touch and perform various gestures on sensors constructed from materials that are safe for human touch. We may also ask you to place the sensor on your body such as your wrist and perform the same gestures. Your touch interactions may be recorded over your shoulder.

Please email me to sign-up for the study.
You may also contact me if you have any questions.

Dilan Ustek
MSc Student, UBC Computer Science
[REDACTED]

Version 1.0 / June 13, 2016 / Page 1 of 1

Appendix F

Consent Form

This appendix is the consent form we used in our study.



STUDY CONSENT FORM

Department of Computer Science
2366 Main Mall
Vancouver, B.C. Canada V6T 1Z4
tel: (604) 822-3061
fax: (604) 822-4231

Project Title: Developing and Evaluating Touch Sensors

Principal Investigator: Karon MacLean, Professor, Dept. of Computer Science, [REDACTED]

Co-Investigator: Dilan Ustek, MSc Student, Dept. of Computer Science, [REDACTED]
Kevin Chow, Undergraduate Student, Dept. of Computer Science, [REDACTED]

The purpose of this study is to assess the performance of the different touch-responsive sensors in order to provide direction to their development, and understand their limitations. Touch and pressure sensitive sensors are constructed from standard household materials such as fabric, plastic, silicone, and/or other raw materials that are safe for human touch.

You may be asked to touch and perform various gestures on the sensors. You may also be asked to wear the sensor on your body and perform the same gestures and/or perform daily activities while interacting with the sensor. This study is part of a graduate student research project.

You may refuse or skip any task or question without affecting your reimbursement.

SPONSOR: This study is funded by Qualcomm Canada Inc (36%) and NSERC, a Canadian federal granting agency (64%) through a collaborative research grant. A patent currently in process could lead to commercialization. There is a potential for UBC investigators who are also inventors to financially gain from this research, should a patent be viable and purchased by the sponsor. Your own participation in this study will not lead to any personal financial gain, outside of the remuneration for your time (below). You are entitled to request any details concerning this potential benefit to the researchers from the principal investigator.

NON DISCLOSURE: Because of the patent in process, we will ask you to read and sign a non-disclosure agreement (NDA) as a condition of participation in the study. This simply means promising to not discuss the technology you see during the study for a set period of time. You are under no obligation to do this; if you choose not to, we will be happy to invite your participation in a different study at a later time. The NDA process is overseen by UBC's University Industry Liaison Office (UILO) (contact on NDA form).

COMPENSATION: We are very grateful for your participation. You will receive monetary compensation of \$15 for this session.

TIME COMMITMENT: 1 × 1 hour session

RISKS & BENEFITS: This experiment contains no more risk than everyday computer use or commercially available actuated toys. There are no direct benefits to participants beyond compensation.

STUDY RESULTS: We plan to publish the analyzed, anonymized results of this study in peer-reviewed articles where we hope they will positively impact the development of this class of technology in both academia and industry.

CONFIDENTIALITY: *You will not be identified by name in any study reports. Any identifiable data gathered from this experiment will be stored in a secure Computer Science account accessible only to the experimenters. Video excerpts will be edited to remove identifying information (including but not limited to obscuring face and/or voice) and will not be used in publication unless permission is explicitly given below.*

VIDEO RELEASE: *You may be asked for video to be recorded during this session. You are free to say no without affecting your reimbursement.*

I agree to have VIDEO recorded: Yes No

I agree to have ANONYMIZED VIDEO EXCERPTS presented in publications: Yes No

You understand that the experimenter will ANSWER ANY QUESTIONS you have about the instructions or the procedures of this study. After participating, the experimenter will answer any other questions you have about this study. Your participation in this study is entirely voluntary and **you may refuse to participate or withdraw from the study at any time without jeopardy**. Your signature below indicates that you have received a copy of this consent form for your own records, and consent to participate in this study. Any questions about the study can be directed to Dilan Ustek, ustekd@cs.ubc.ca.

If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the UBC Office of Research Ethics at 604-822-8598 or if long distance e-mail RSIL@ors.ubc.ca or call toll free 1-877-822-8598.

You hereby CONSENT to participate and acknowledge RECEIPT of a copy of the consent form:

PRINTED NAME _____ DATE _____

SIGNATURE _____

Appendix G

Non-Disclosure Agreement

This is the Non-Disclosure Agreement form signed by all participants in the beginning of the study.

NON-DISCLOSURE AGREEMENT

BETWEEN:

THE UNIVERSITY OF BRITISH COLUMBIA, a corporation continued under the *University Act of British Columbia* with offices at 103-6190 Agronomy Road, Vancouver, British Columbia, V6T 1Z3, Attention: The Director, University-Industry Liaison Office, Telephone: (604) 822-8580, Facsimile: (604) 822-8589

("UBC")

AND:

_____, an individual residing

at _____,

Telephone: _____

(the "Recipient")

WHEREAS:

UBC may disclose, deliver or transmit to the Recipient certain confidential or proprietary information to enable UBC and the Recipient to discuss future research collaboration.

THE PARTIES AGREE AS FOLLOWS:

1.0 CONFIDENTIAL INFORMATION.

1.1 UBC will provide Recipient with information concerning user interaction methods which are part of a user study in which the Recipient has agreed to participate ("**Confidential Information**") and include, without limitation, know-how, show-how, concepts, prototypes, models, manuals, papers, discoveries, inventions, research or technical data and other proprietary information. Confidential Information may also include information furnished during discussions or oral presentations. However, Recipient is under no obligation to maintain the confidentiality of Confidential Information which Recipient can show:

- (a) is or subsequently becomes generally available to the public through no act or fault of Recipient;
- (b) was in the possession of Recipient prior to its disclosure by UBC to the Recipient;
- (c) was lawfully acquired by Recipient from a third party who was not under an obligation of confidentiality to UBC;
- (d) was independently developed by employees, agents or consultants of the Recipient who had no knowledge of or access to UBC's Confidential Information as evidenced by the Recipient's records; or

- (e) is required by an order of a legal process to disclose, provided that Recipient gives UBC prompt and reasonable notification of such requirement prior to disclosure.

2.0 OWNERSHIP.

2.1 The Confidential Information is and will at all times remain the exclusive property of UBC and nothing in this Agreement grants the Recipient any right, title or interest in or to the Confidential Information.

3.0 DISCLAIMER OF WARRANTY.

3.1 Recipient acknowledges and agrees that the Confidential Information is experimental in nature and that any use of the Confidential Information by Recipient will be at the sole risk and liability of Recipient. UBC MAKES NO REPRESENTATION OR WARRANTY, WHETHER EXPRESSED OR IMPLIED, WITH RESPECT TO THE CONFIDENTIAL INFORMATION, INCLUDING ANY REPRESENTATION OR WARRANTY AS TO ITS ACCURACY, COMPLETENESS, MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT ON THIRD PARTY PROPRIETARY RIGHTS. ALSO, UBC WILL NOT BE LIABLE FOR ANY INDIRECT, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGE OR LOSS ARISING FROM ANY USE OF THE CONFIDENTIAL INFORMATION BY RECIPIENT EVEN IF UBC HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGE OR LOSS.

4.0 USE & PERIOD OF CONFIDENTIALITY.

4.1 Recipient will not use the Information for any purpose other than to participate in the user study. Recipient will not de-compile or reverse engineer the Confidential Information or use the Confidential Information to develop, or cause to develop, all or part of any process or product whether for internal use or for commercial purposes.

4.2 Recipient will use the Confidential Information for the purpose set out in Article 4.1 for a period commencing on the date of this Agreement and ending 3 years thereafter unless terminated earlier by one party upon giving the other party at least 5 business days written notice. At the end of such period and at the request of Provider, Recipient will return or destroy all copies of the Confidential Information, except that Recipient may provide a sealed copy of the Confidential Information to its legal counsel for archival purpose.

4.3 Recipient will use the same care and discretion to avoid disclosure of the Confidential Information as Recipient uses with its own similar information that the Recipient does not wish to disclose for a period of 5 years from the date of this Agreement irrespective of the expiration or earlier termination of the period of use described in Article 4.2.

5.0 ASSIGNMENT.

6.1 The Recipient will not assign all or part of this Agreement without the prior written consent of UBC.

6.0 GOVERNING LAW.

7.1 This Agreement will be governed by and construed under the laws of British Columbia and the applicable laws of Canada without reference to its conflict of law rules. Any action or proceeding brought to enforce the terms of this Agreement will be brought in a court in Vancouver, British Columbia, and the parties hereby consent and submit to the exclusive jurisdiction of such court.

8.0 GENERAL.

8.1 No provision of this Agreement will be deemed waived or any breach excused, unless such waiver or consent excusing the breach is in writing and signed by the Provider. A waiver of a provision of this Agreement will not be construed to be a waiver of a subsequent breach of the same provision.

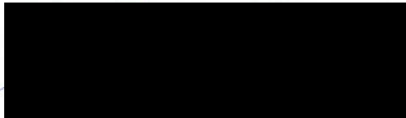
8.2 This Agreement contains the entire agreement and understanding of the parties with respect to its subject matter and supersedes all prior proposals, negotiations, agreements, understandings, representations and warranties of any form or nature, whether oral or written, and whether express or implied, which may have been entered into between the parties relating to its subject matter.

8.3 This Agreement may be signed in counterparts either through original copies or by facsimile or electronically each of which will be deemed an original and all of which will constitute the same instrument.

8.4 In this Agreement, unless the contrary intention appears, "days" means calendar days.

SIGNED BY THE PARTIES AS AN AGREEMENT and effective as of the date of the last signature.

THE UNIVERSITY OF BRITISH COLUMBIA
by its duly authorized officer:



Date: *March 1, 2017*

Signed, sealed and delivered by

Name:
Title:
Date:

Appendix H

Participant Rating Sheet

This appendix is the rating sheet used by participants in our study.

Participant ID: _____

On a scale of 0 to 10, with 0 being **no effect**, and 10 being a **strong effect**, how strong was each condition?

Condition 1:

0	1	2	3	4	5	6	7	8	9	10
no effect					moderate effect					strong effect

Condition 2:

0	1	2	3	4	5	6	7	8	9	10
no effect					moderate effect					strong effect

Condition 3:

0	1	2	3	4	5	6	7	8	9	10
no effect					moderate effect					strong effect

Condition 4:

0	1	2	3	4	5	6	7	8	9	10
no effect					moderate effect					strong effect

Please rate the following by labeling each cell from 1 to 4 where 1 is the **most** and 4 is the **least**.

I'd be happy to use for the long term:

PHONE

Pinch-to-Zoom	
Proximity Zoom 1	
Proximity Zoom 2	
Proximity Zoom 3	

WATCH

Pinch-to-Zoom	
Proximity Zoom 1	
Proximity Zoom 2	
Proximity Zoom 3	

Appendix I

Thematic Analysis Coding Sheet

This is the coding sheet used to analyze qualitative data from the study discussed in Chapter 6.

Participant #	Elasticity	Connectedness	Sticky			Elastic	Conn.	Sticky
1	0/a	0/a	0/a	0	P1	7.5	0	0
2	0/a	0/a	0/a	0	P2	9	0	0
3	0/a	0/a	0/a	0	P3	4.5	0	0
4	0/a	0/a	0/a	0	P4	7.7	6	0
5	0/a	0/a	0/a	0	P5	9.3	8.5	0
6	0/a	0/a	0/a	0	P6	0	7.3	7
7	0/a	0/a	0/a	0	P7	5	5.7	5
8	0/a	0/a	0/a	0	P8	6	0	3
9	0/a	0/a	0/a	0	P9	7	7	0
10	0/a	0/a	0/a	0	P10	7.3	7	0
11	0/a	0/a	0/a	0	P11	0	0	0
12	0/a	0/a	0/a	0	P12	7	0	0
Average		4.333333	3.666667	0.9566667			70.3	
Ball w/ Audio								
1	0/a	0/a	0/a	0				
2	0/a	0/a	0/a	0				
3	0/a	0/a	0/a	0				
4	0/a	0/a	0/a	0				
5	0/a	0/a	0/a	0				
6	0/a	0/a	0/a	0				
7	0/a	0/a	0/a	0				
8	0/a	0/a	0/a	0				
9	0/a	0/a	0/a	0				
10	0/a	0/a	0/a	0				
11	0/a	0/a	0/a	0				
12	0/a	0/a	0/a	0				
Image								
1	0/a	0/a	0/a	0				
2	0/a	0/a	0/a	0				
3	0/a	0/a	0/a	0				
4	0/a	0/a	0/a	0				
5	0/a	0/a	0/a	0				
6	0/a	0/a	0/a	0				
7	0/a	0/a	0/a	0				
8	0/a	0/a	0/a	0				
9	0/a	0/a	0/a	0				
10	0/a	0/a	0/a	0				
11	0/a	0/a	0/a	0				
12	0/a	0/a	0/a	0				
Image w/ Audio								
1	0/a	0/a	0/a	0				
2	0/a	0/a	0/a	0				
3	0/a	0/a	0/a	0				
4	0/a	0/a	0/a	0				
5	0/a	0/a	0/a	0				
6	0/a	0/a	0/a	0				
7	0/a	0/a	0/a	0				
8	0/a	0/a	0/a	0				
9	0/a	0/a	0/a	0				
10	0/a	0/a	0/a	0				
11	0/a	0/a	0/a	0				
12	0/a	0/a	0/a	0				
		1.083333	1.833333	0.6666667				
		60	1.75	0.4566667				
	10 elastic	6 conn.	3 sticky					
	8 yo-yo, rubber bandy string, stretchy string, connected, string, not separated, bar, pole							
	20 hair band, Silly, Elastic, rubber, rubber band, hair tie, stretchy string, balloon, chewing gum, spring, stretchy, bouncy, harder to move at the top than drop, stiffness, tension, lightness, yo-yo, spring, force, gravity							
	3 Chewing gum, glue, sticky							
	8 connected, string, not separated, bar, pole							
	20 hair band, Silly, Elastic, rubber, rubber band, hair tie, stretchy string, balloon, chewing gum, spring, stretchy, bouncy, harder to move at the top than drop, stiffness, tension, lightness, yo-yo, spring, force, gravity							
	3 glue, sticky							
	One problem in getting the overall average (4.7) of elasticity through all conditions is that it is mixed with a lot of 0s when there were other conditions than elasticity as well, and since all 4 conditions are mixed (image no audio is weak), then there's a small number.							

