

Squishy Volumes: Evaluation of Silicone as Camera-less Pressure-Based Input for 3-Dimensional Interaction

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ABSTRACT

Low cost sensors and materials are increasingly of interest to designers for developing new ways to gather 3-Dimensional input. Silicone is a low cost material with capabilities of a variety of forms and sizes, thereby facilitating flexible construction. Given these properties, users can construct unique input solutions for a variety of applications. However, aside from other existing methods of measuring volume deformation, molded silicone (without added components inside the silicone and without added external cameras) for volumetric input has not been largely explored. In this paper we present an evaluation that investigated the parameters of silicone as volumetric input. The silicone volume has no added components inside making it easy to construct and use, however some external but small, flexible, and portable low-cost components are used for deformation measurement. We present the 3-dimensional input results as a function of the physical pressure on the silicone by the volume of silicone. Researchers can use these input metrics to design a silicone-based device with desired size and thickness to achieve the desired sensitivity and resolution of input for their application.

Index Terms: B.4.2 [Input/Output Devices]; ;— [I.3.1]: Hardware Architecture—Input Devices Three-dimensional displays; H.5.2 [User Interfaces]: Interaction styles—

1 INTRODUCTION AND MOTIVATION

There is growing interest in interactive multi-dimensional display technologies, such as VR/AR/MR, as such there is a need for more 3-dimensional or volumetric input. Soft input can be extremely useful for VR/AR/MR applications to provide interaction capabilities that more closely match those of the objects which a user interacts with, yet research is still needed in this area. Hard input has been explored extensively, but there is still a need for exploring more methods of soft input. There are a few of technologies that have developed a soft surface for interaction [1, 3, 6, 11, 12, 16], but require either additional equipment external to the input device or may not be as flexible [10, 3, 7]. However, the technique described in this paper has the potential to provide more flexibility in multiple sizes and form factors, passive haptic feedback, multiple degrees-of-freedom for interaction, and is made of low-cost materials. Many of these other techniques are restricted physically and handedness by the sensors and solutions used [1, 16]. Due to the selection of materials used for

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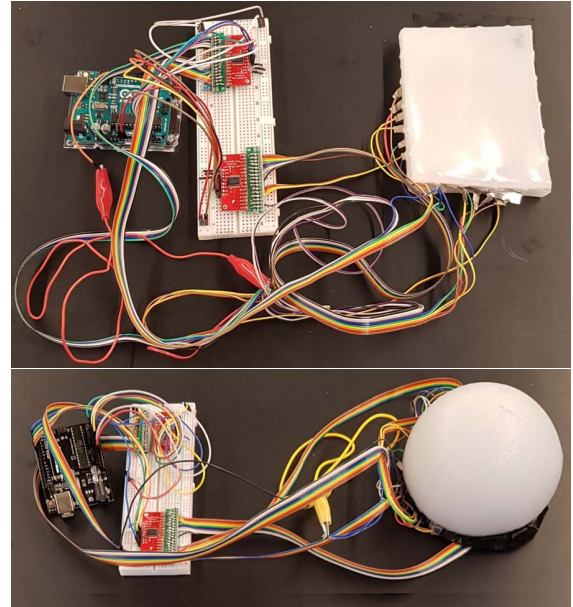


Figure 1: Two prototypes using Silicone for pressure-based input.

our solution, our device is more flexible to be cut and molded to a large number of sizes and form factors to tailor the input, such as smaller pieces on the ends of finger tips, a larger two-handed sphere, multiple smaller spheres for two-handed input, and on other props.

In this paper, we present the implementation details of our technology for replicability of the device. We investigated the change of material properties, such as size, resolution of underlying grid, and thickness of silicone surface to understand how different design decisions would affect the sensitivity and resolution of input. We fabricated several samples of the silicone pad with varied thickness and by systematically controlling the depth at which a force is applied at a specific point on the silicone pad (using a Haptic Master), we were able to investigate the following hypotheses:

H1: As thickness of Silicone decreases, precision of depth (y) decreases but precision of x-y increases.

H2: As thickness of Silicone increases, the larger the resolution of input depth is provided.

We present the results of a system evaluation to investigate, Squishy Volumes, of the change in size/area and thickness of material that will help other researchers and designers to know what properties will provide a desired sensitivity and resolution as they implement their own versions. We also present a variety of interaction techniques combined with different form factors that demonstrate how our SquishySphere device could be used.

2 RELATED WORK

Squishy Volumes provide a natural passive haptic feedback through the deformity of the material silicone used, unlike cloth, foam, or fabric used in [6, 9, 11]. By using silicone on its exterior, the sensor provides a tactile experience comparable to real-world object manipulation. As an example, tasks such as manipulating virtual models in a similar way to sculpting clay may be difficult. When an artist sculpts objects with the hands, the artist receives tactile feedback from the clay itself; the object moves directly in response to the palms and fingers. The harder the artist presses, the more the object yields. Likewise, soft touches and movements allow more subtle changes to be made. Our device provides this type of soft versus hard pressure variability in input. Our device supports multiple degrees of freedom unlike [12]. The technique presented in this paper does not use external cameras, unlike [2], therefore can be made to be wireless and portable. Our device is developed from low cost technology and does not use more expensive tracking to enhance the performance like [16], thereby making it affordable to use in combination with other objects, such as 3D printed prosthetic limbs. In the remainder of this section we describe the details of these other devices as well as their strengths and weaknesses compared to our proposed input design.

Prior research developed and investigated digital foam, a sensor that used conductive foam to create a modified spherical sensor that responds to pressure [11]. They began with a flat, two-dimensional sensor that has 100 pressure points in a 10×10 grid. The researchers were able to show that when the sensor was pressed at a certain point or points, a corresponding, computerized grid would deform where the pressure was occurring. The conductive foam works because as the foam is pushed down, its resistance is lowered. With this drop in resistance, there is an increase in voltage, which can be quantitatively measured and represented on the graph. These ideas were transformed into a spherical sensor with a plastic spherical core and foam protruding from the plastic in all directions. The number of pressure points was reduced to 21 because the points need to be far enough away from each other that they do not touch. The researchers were able to show on a computer simulation a sphere that would become indented when the foam was pressed in that area. The resolution of this device is limited to the number of pressure nodes included in the device itself.

A more in depth investigation was conducted on Digital Foam which revealed performance properties of the device [10]. Our device is similar in purpose and shape, however we are using different materials and integration that may be easier for someone to build in their home. The other difference is that this device was created for a desktop computer, whereas we have designed our device to be used in virtual or augmented reality for immersive 3D interaction. Thus, our device provides for different form factors, applications, and resolution of data input, but we can compare the performance results to the Digital Foam in changing the resistance and tracking pressure. Researchers [16] investigated the user interaction data with the deformable surface to understand the best location of placement of the components. During studying these surfaces, the researchers were using pressure sensing gloves in their fingertips and Optitrack [5] to track the position of the fingers. However, in our designed input device we track the pressure from users bare hand on the surface and don't need the Optitrack to track the position of the finger so, that the tracking system location does not bound the user.

Pyzoflex [9] is a device developed to gauge real-time pressure input using a piezoelectric foil but lacks the feature of physical deformability leading to lack of passive haptic feedback. However, our input device not only can read the value of pressure, but when a user physically deforms the silicone, force feedback is provided naturally from the material itself. SOFTii [6], a soft tangible input device, is developed to sense the pressure input. It uses fabric for providing haptic feedback while a user is interacting with the device.

Squishy Volumes are different from it as it uses silicone to design the exterior where the user interacts with the device. With the use of silicone in comparison, a fabric provides an increased passive haptic feedback during the interaction.

Previous researchers [15] used time domain reflectometry to detect touch on a flexible touch strips and surface which can be used for wearable computing. However, using this system enables the user's touch to be detected only in the lines of the touch strip designed. SmartSleeve [8] was presented a deformable sensor, that can be used for sensing surface and deformation gestures at real-time. In comparison with SmartSleeve, our device uses low-cost and easy to built sensor which makes it easy to access and built for usability. Stretchis [14] was designed using fabrication method which had highly stretchable user interfaces and could sense the touch by user's and would provide visual output too as a feedback. Skweezes [13] was developed to support squeezable shapes which had conductive padding along with electrodes. This was designed to detect gestural interaction by applying or squeezing pressure. However, this device is limited by number of gestural interaction i.e., up to 7 only. Project deForm [2] used malleable surface of interaction to detect 2.5D touch gestures. It used light scanning technique to detect the shape deformation. However, setting up this system might be cumbersome and there might be interference or obstruction of view of the camera. Textile++ [7] was designed and developed using the principle of the resistive touch sensing. This device can detect pressure input and only XY coordinate position of the touch. This is limited while a user wants to work with three dimensional input.

3 PROTOTYPE IMPLEMENTATION

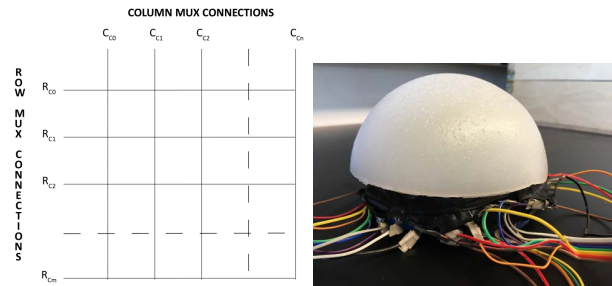


Figure 2: (Left) The pressure sensor is an $m \times n$ grid of conductive leads. The columns and rows of this grid are each adhered to a separate layer of velostat paper. A layer of flat or spherical (Right) silicone is placed on top of these layers.

A simple velostat-based pressure sensor has been developed and demonstrated in [4] providing 2-dimensional input, but does not transform that to 3D input nor attempt to investigate the input results with added deformable material. We developed our own set of prototypes for volumetric input (Figure 1). These prototypes can be built inexpensively. For the input control, we lined two layers of velostat paper with conductive tape to form a grid (Figure 2). These layers are sandwiched together under a layer of silicone. When a user presses the silicone, the pressure causes the two layers to meet, changing the circuit. An Arduino and two multiplexers measure the difference in resistance when two areas of the conductive Kapton tape meet to calculate the x-z position of a user press, while the molded Silicone controls with amount of depth or pressure of a user press. Kapton tape is useful to give the leads something to adhere to (while providing superior adhesion to silicone), while the silicone provides passive haptic feedback. This soft tape is more playable to deformable material than copper tape. During development of our prototype, we utilized a breadboard rather than printed circuit boards. In a future implementation, we can refine and condense the

implementation on customized boards.

A half spherical sensor, named SquishySphere device, was developed through a similar process, except the velostat paper was vacuum-formed around a 3D printed half sphere object. The 3D printed object was designed in CAD software and then 3D Printed. Designed to be hollow, it will allow for smaller boards and cables to be tucked inside to develop a full spherical sensor that can be wireless. The silicone mold was also formed using a 3D printed hollow sphere. We created two 3D printed molds to shape the silicone as a hollow half-sphere as well. To build a full spherical sensor, we built a copy of the hemispherical core, then put the two together. By connecting their leads, we were able to get a sensor core with seven row leads. Using two silicone panels, we reached 14 columns.

4 SYSTEM EVALUATION

We conducted an evaluation to test the capabilities and identify parameters of our input system. Specifically, we tested for the capabilities of input sensitivity/resolution and input speed/latency. For input resolution, we measured the change in input values based on a press at different (along x-z axes) locations on the 2D grid and at different depths (along y-axis). To ensure consistency across the different conditions, we used a HapticMaster precision pressing on different conditions of silicone thickness. We ran the speed test to find out how long it takes the sensor to take one reading, i.e. reading each sensor point and saving it in a two-dimensional array. The thickness test utilized different thicknesses of silicone to determine if having a thicker piece of silicone over the sensor would change any of the results. We tested four thicknesses: 1/8", 1/4", 3/8", and 1/2". We made a 5×5 flat sensor and put the different thicknesses of silicone on top of the sensor (Figure 1). To get a consistent amount of pressure each time we pressed on the sensor, we used a Moog Haptic Master. It is a robotic arm that can move up and down on a stand. We positioned the sensor directly under the Haptic Master's arm so that the spherical knob at the end of the arm would press directly into the middle intersection of the sensor.

For the experiment itself, we taped the sensor to the edge of the counter, placed one of the silicone layers (one selected from the set of thickness conditions) on top of the sensor, and had the Haptic Master arm above the counter. Using programmable C++ code, we programmatically moved the arm so that it was barely touching the silicone layer. With the Arduino code, we recorded five matrices that each were an average of 50 readings. Each matrix had a value for each point on the 5×5 sensor. The range for these values could vary between 0 and 1023. We also recorded the initial coordinate position of the Haptic Master. Then, we lowered the Haptic Master arm onto the silicone layer and pushed down until the Haptic Master stand began to lift off the ground. We then knew that it was at its limits and would not continue to press into the silicone any more. The same readings were recorded with the five matrices each with an average of 50 readings and the final coordinate position of the Haptic Master. This process was repeated three additional times. Thus, we now had minimum and maximum readings for each of the four thicknesses of silicone.

5 RESULTS

The sensor effectively takes a reading at every point of its grid, meaning that $m \times n$ iterations occur. In Figures 3 to 6, we present a reported heatmap of the pressure change (from dark-least amount of pressure to light-most amount of pressure as it is displaced across the silicone material from the four conditions of silicone thickness. As shown, the most precise of pressure displacement is in the 3/8" thick silicone. As the silicone becomes thinner, the pressure is more broadly displaced horizontally. Furthermore, as the silicone becomes thicker, the precision of pressure is lost through the added vertical area and not sufficient amount of pressure reaches the bottom of the volume (supporting H1).

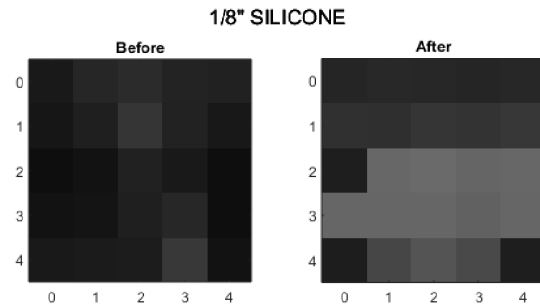


Figure 3: 8-bit grayscale pressure heat map on 1/8 inch thick Silicone.

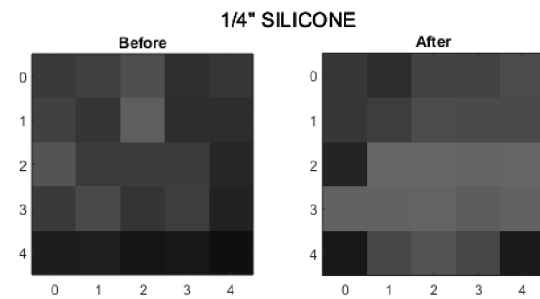


Figure 4: 8-bit grayscale pressure heat map on 1/4 inch thick Silicone.

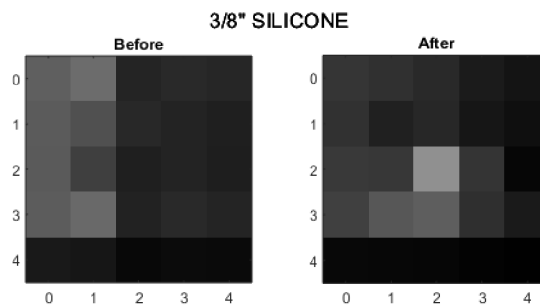


Figure 5: 8-bit grayscale pressure heat map on 3/8 inch thick Silicone.

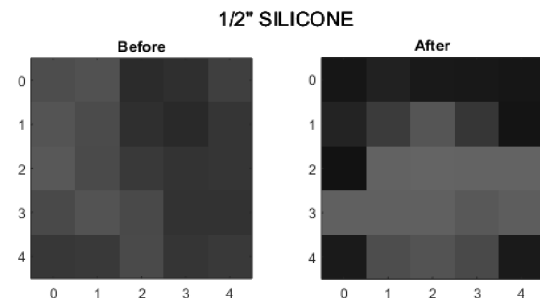


Figure 6: 8-bit grayscale pressure heat map on 1/2 inch thick Silicone.

In Figures 7 to 11 these results present the change in reported pressure value for each unit of the row/column of the input grid

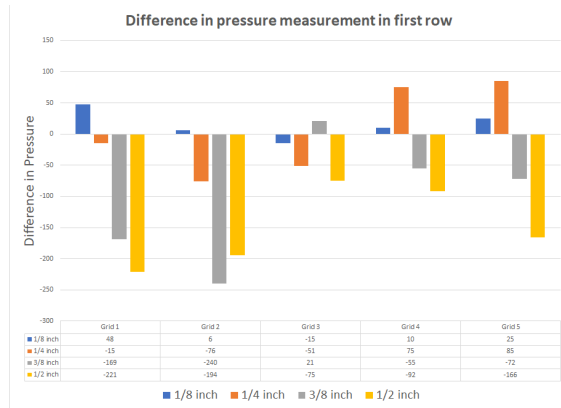


Figure 7: First Row: Pressure across Silicone thickness conditions.

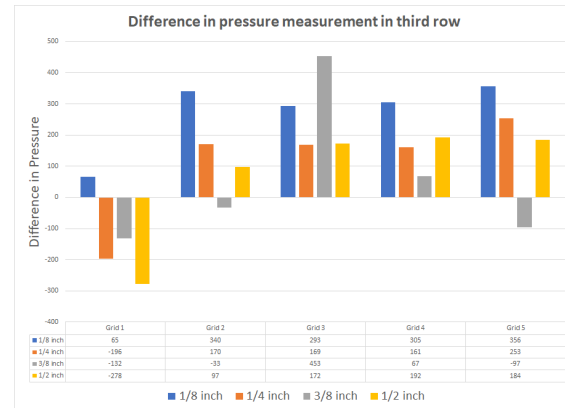


Figure 9: Third Row: Pressure across Silicone thickness conditions.

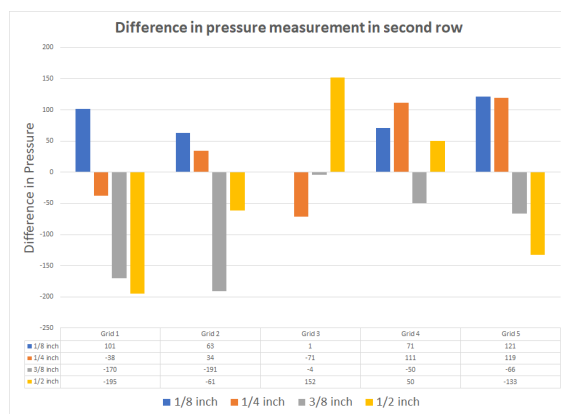


Figure 8: Second Row: Pressure across Silicone thickness conditions.

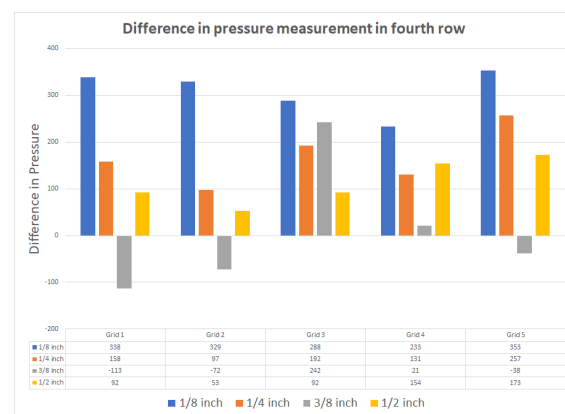


Figure 10: Fourth Row: Pressure across Silicone thickness conditions.

from calibration to when the Haptic Master arm deforms the surface. Each bar represents that position for each of the silicone thickness conditions. First, notice that the pressure values are reported positive change in areas where the Haptic Master deforms the silicone as in Figures 9, 10, and inner of 11 as compared with the negative change in Figures 7, 8, and outer of 11. This represents the displacement of the material released.

We hypothesized that the thicker the silicone, the more sensitive the input values would provide the specific location of pressure and provide a higher precision of the value of the amount of pressure since there is more variability. We see this most predominately in these Figures 7 to 11 (supporting H1). The specific location of the pressure is more easily identified in the thicker silicone samples. Additionally, the values changes of pressure input are more distinct in the thicker silicone samples. In the future, with these values we hope to layer this positioning to measure directional input as well.

6 RESEARCH PLAN

The Squishy Device Project, utilizing Silicone as a camera-less pressure-based input, has the potential to be used in an array of mediums (including VR/AR/MR, as in Figure 12, application areas, and professions. An example idea of use for the device was to create a more realistic and intuitive, clay, modeling simulation. The idea was to use the pressure sensing technology and apply it to a mesh in order to create an interactive 3D shape that would be easier to manipulate due to the actual object interaction. The Squishy device has the potential to do this and more. The following sections describe

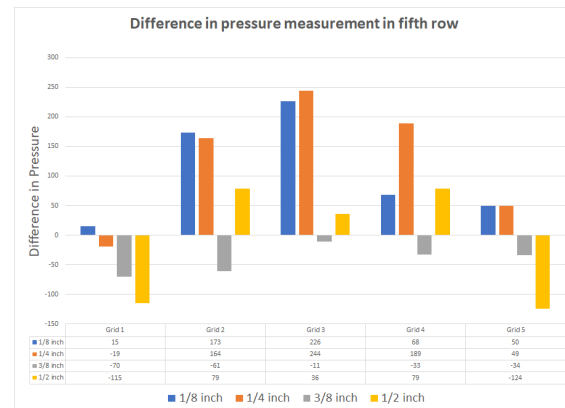


Figure 11: Fifth Row: Pressure across Silicone thickness conditions.

potential interaction modalities and application areas we intent to explore in our future work.

6.1 Interaction Modalities

There are a variety of ways that this device can be used. One interaction modality is to push, squeeze, and squash the silicone material to deform virtual meshes in the 3D and immersive environments. This is the more direct interaction and use of this device. However,



Figure 12: A user interacting with Squishy Device and viewing the manipulation of the virtual object in Microsoft Hololens.

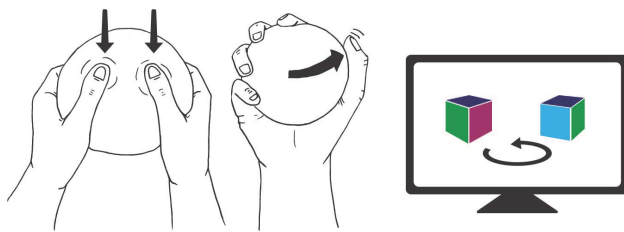


Figure 13: Pressing can not only deform virtual objects (left), but can be used for object manipulation like translate, rotate (right), and scale.

there are other ways this can be incorporated into the interaction technique. The user can twist the material for rotation, squeeze the material for scale, and drag the material for translation. This will allow the device to be used for 3D object manipulation. Simple double squeeze can act as a selection. These interaction modalities described can be used for two-handed or one-handed interaction on one volume as in Figure 1. However, additionally the volumes can be split into two devices with one in each hand to divide up the control. Therefore, two-handed interaction can be more rich or the devices can be smashed together to create other interaction modalities. Furthermore, this device can also be used with single hand (see fig.13) to interact while deforming meshes in a virtual environment. Each fingers can be used to apply pressure at different points of the device while interacting and working with meshes or 3D objects to deform the shapes in an immersive environment.



Figure 14: Design concept for using SquishySphere device for division of labor/input across two hands.

6.2 Application Areas

One idea that was formulated was to integrate a smaller version of the device onto the fingertips of prosthetic hands (Figures 14 and

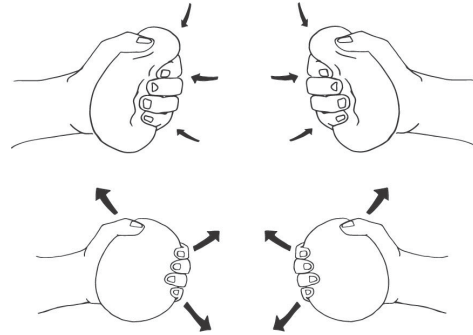


Figure 15: Two hands press and squeeze two individual Squishy-Sphere devices.

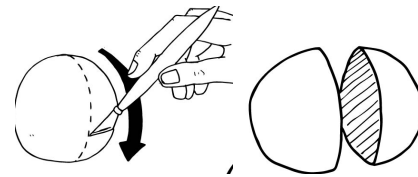


Figure 16: Cutting sculpting tool used on SquishDevice (left) and resulting virtual object change (right).

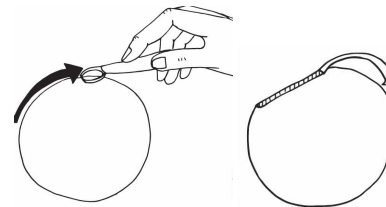


Figure 17: Scraping sculpting tool used on SquishDevice (left) and resulting virtual object change (right).

18) with the purpose of controlling grip strength. The silicone would be on each of the finger tips with a smaller pressure sensor grid underneath and it would be able to detect that amount of pressure given in relation to the object and adjust the grip accordingly (Figure 1). This would mean that the user would be able to control grip-strength based on what objects they are interacting with. The amount of pressure applied to a glass cup is not the same amount of pressure that would need to be applied to pick up a softer, less delicate, object. This would allow more natural motions for users and prevent over-exertion with objects that would have the potential to damage or break. Given the low-cost materials, these could be added to 3D printed prosthetic hands, especially used for low-income areas.

A more artistic outlook for this device is to expand on the clay manipulation. This would not only be the usage and interaction of hands on the device, but also the interaction with tools. This idea would use the same pressure sensing concept and create a simulation where the user will be able to manipulate clay with hands and tools. Certain tools have certain shapes (Figure 15) and the apply different areas of pressure to an object. These tools can be applied directly to the silicone shape without additional sensors added to the tools. We can measure the displacement of the pressure for each force and direction. This would be utilized in the program and it would detect what tool is being used by shape and pressure applied.

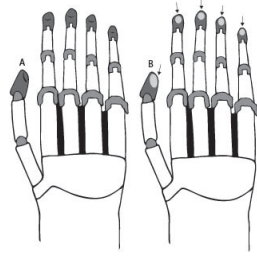


Figure 18: Design concept for placement of silicone on prosthetic hand. "A" is an depiction of the hand and "B" is where the silicone and pressure sensor grids will be placed.

7 SUMMARY AND CONCLUSION

In summary, we presented a novel soft, deformable input device called SquishySphere device. We presented two types of devices: cubic and spherical that allow for soft deformation input for 2D and 3D. We also presented an evaluation of the input for different sizes and silicone thickness using a precise form of deformation through the use of a HapticMaster arm. The purpose of this experiment was to test the resolution of the input given varying thicknesses of the materials and physical pressure on the device. We present the results of this evaluation to provide a roadmap for how this technology could be used for a variety of applications. In conclusion, as the silicone becomes thinner, the pressure is more broadly displaced horizontally. Furthermore, as the silicone becomes thicker, the precision of pressure is lost through the added vertical area and not sufficient amount of pressure reaches the bottom of the volume. Sensitivity (or resolution of the values) also follow this format. We show that the thicker the silicone, the more sensitive (or higher resolution of) the input values, however contrary to the precision of location, this holds true even as the silicone becomes too thick. In this paper, we also presented several interaction modalities and application areas for development. Initial user feedback of these interaction modalities have revealed promise for VR/AR interaction. This paper would allow other researchers to build and test their own Squishy devices or Squishy Volumes for a variety of sizes and form factors, with the results on sensitivity of the input as a guide for design.

8 FUTURE WORK

In the future, we will conduct a user study using the interaction modalities of modeling in AR and for the prosthetic hand interaction in the real world. We would like to layer the silicone so that we can additionally measure force direction across the techniques. These applications would involve using Unity more to track the directional force with which one pushes on the silicone layer. With further development, we would like to build out the control unit smaller or communicate wirelessly so that the sphere is self-contained. This will enable a user to move and rotate the spherical input device freely throughout the virtual reality environment. These ideas lead to making virtual reality more collaborative as users could pass the squishy ball around within the virtual reality environment.

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