Tech Note: Digital Foam

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ABSTRACT

This paper presents a new input device called Digital Foam designed to support natural sculpting operations similar to those used when sculpting clay. We have constructed two prototypes to test the concept of using a conductive foam input device to create 3D geometries and perform sculpting operations. The novel contributions of this paper include the realization that conductive foam sensors are accurate enough to allow fine grained control of position sensing and can be used to build foam based input devices. We have designed a novel foam sensor array by combining both conductive and non-conductive foam to allow interference free sensor readings to be recorded. We also constructed two novel input devices, one flat input device with one hundred sensors, and a second spherical design with twenty one sensors, both allowing user interactions by touching or squeezing the foam surface. We present the design idea, foam sensor theory, two prototype designs, and the initial application ideas used to explore the possible uses of Digital Foam.

Keywords: Digital Foam, Input Device, Interface Design, Augmented Reality, Spherical User Interface, Prototype Interface

Index Terms: D.2.2 [Software Engineering]: Design Tools and Techniques—User interfaces; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Prototyping I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques

1 INTRODUCTION

Surface modeling and geometry capture are used in a range of fields including Augmented Reality (AR), Virtual Reality (VR), computer graphics, medical imaging, visualization systems, and artistic fields [16, 2, 13]. To support these systems, a variety of different input devices and techniques have been developed to assist the modeling process. Clay and similar materials have been used for sculpting real models for many years. This familiarity with sculpting has lead us to investigate how a similar input device can be constructed for a computer. We identified some of the natural modeling techniques used when sculpting, such as multi-handed and multi-finger input. To support similar clay-like modeling techniques we conceptualized a user interface made of conductive foam since it naturally supports sculpting operations.

We have invented Digital Foam, a new technology allowing us to capture the shape and size of a piece of foam. This paper presents the implementation of two new hardware interfaces constructed using Digital Foam that we believe encompasses the above criteria and will allow users to sculpt and capture high detail geometry for 3D modeling. Two applications for navigation and sculpting employing Digital Foam input are described to demonstrate its functionality.

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2 RELATED WORK

There are a number of different techniques that have been used to capture physical geometries. A common technique is to measure the physical object and manually enter dimensions. More recently, commercially available laser scanners [17] allow the capture of complex geometries with a high polygon count. These scanners are not designed for real time manipulation tasks and we found deformations and corrections are usually needed to correct the captured model. The Façade system [2] uses a number of photographs taken from different angles; these are processed manually to create a reconstruction of the geometry. The Tinmith system uses pinch gloves and fiducial markers to track a user's thumbs allowing a range of CAD-like interaction techniques including construction at a distance, AR working planes, infinite carving planes, orthogonal laser carving, and surface of revolution as described in [16] using AR. VR systems such as Virtual Clay [12] provide an interactive freeform modeling environment. McDonnell et al. also developed an interactive sculpting framework that encompasses modeling techniques based on the subdivision of solid geometries. It supports clay like manipulations, and more, allowing intuitive sculpting to be performed with physics based responses and haptic feedback using a Phantom device [11].

A large number of input devices allow the creation, manipulation, and navigation of 3D geometries. The "two - 4 - six" input device [10] is designed to support 3D manipulations with six degrees of freedom. It was designed for interactive presentations of virtual objects using multiple sensors as inputs. Orientation is tracked using gyroscopes and a rocker leaver, and an elastic touchpad is used to control rotation, translation, and manipulation operations. The Cubic Mouse [5] is a cube-shaped input device with three rods that protrude through the faces of a cube. By pulling and pushing on the rods, motion is specified on the corresponding X, Y and Z axis. This input device also has 6 degrees of freedom (DOF) tracking to allow registration with a virtual environment.

Malleable surfaces such as [13, 18, 9] are similar in design to Digital Foam. These devices use a camera mounted underneath a silicon membrane. The silicone membrane has colored dots printed on its surface that are observed by the camera. Deformations can then be calculated in software allowing a reconstruction of the silicon's surface shape. A limitation of these malleable surfaces is that to construct a malleable spherical prop where all surfaces can be squashed is not simple and perhaps not possible. A support structure is required to hold the stretched silicon in place preventing depression in some locations. Compared to using foam where all surfaces can be depressed.

There are only a limited number of reported uses of conductive foam as an input device [15, 4]. An example of a foam based sensor used in a garment is described by Dunne et al. [4]. Polypyrrole [1] coated foam is embedded into a garment near the shoulders. The sensors are then used to detect movement events. The authors reported: "Results indicate that while the sensor performs well when detecting simple movement events (switch-like interface), there are challenges to overcome in coordinating the responses of multiple sensors in more fine-grained interaction tasks" [4]. During our experimentation with a conductive foam input device, we found it possible to take accurate readings (of resistance changes) from conductive foam unlike when used in a garment. Using our unique construction technique the resolution and response of the foam sensors is high enough to support a 3D input device.

3 Digital Foam Implementation

The initial goal of this research is the real-time capture of the shape of a piece of foam. To achieve this, we use the variable resistive properties of conductive foam as described in [1]. By measuring the voltage difference of the conductive foam when it is compressed, we are able to take accurate measurements that are mapped directly to the physical size of the foam. From these measurements we obtain the physical topology of the foam and use this to create a matching geometry. Given these properties, we have developed two prototype input devices that allow real-time capture of their physical shape. The first design uses a flat piece of foam (shown in Figure 2(e)) allowing users to press on the top surface of the foam. In the second iteration, a spherical prop was created (shown in Figure 3(c)) that allows the user to press on the surface from many different angles.

3.1 Sensor Theory

Figure 1 depicts the operation of a single foam sensor. As the foam is depressed, the resistance of the foam reduces. The initial resistance of a 24mm thick piece of foam is 20k Ohms and when depressed to 2mm the resistance changes to 1.5k Ohms. We then used a voltage dividing circuit and an analog-to-digital converter (ADC) to calculate the current size of the foam sensor. The ADC is connected to an MSP430 microcontroller allowing us to take readings from the foam sensors, process them and, send the information to a computer.

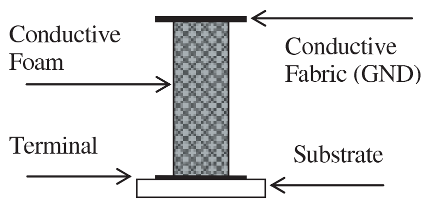

Figure 1: Single conductive foam sensor. A resistive measurement is taken between the conductive fabric and the terminal.

3.2 Flat Digital Foam

We chose to build the first Digital Foam prototype using one hundred (10 x 10) foam sensors producing a 90mm x 90mm working area and a working depth of 20mm. This was chosen so as the construction was not too complex while at the same time providing sufficient resolution to allow multiple fingers to press the foam surface without overlapping. One hundred terminals were etched onto a printed circuit board (PCB) as shown in Figure 2(a). Before we built the first prototype we envisaged that a single piece of conductive foam would be placed directly on top of the terminals. However, we found in practice that the readings of closely located sensors were inaccurate. The reason for this is we desired a resistance measurement between the terminal and the conductive fabric directly above that terminal. However, when a single un-insulated conductive foam piece is used, corresponding depressed foam sensors provide a shorter path of resistance and an incorrect reading is measured. To overcome this limitation, we constructed a custom piece of foam that combines ordinary non-conductive polyurethane with conductive polyurethane (Figure 2(b)). Providing an insulating layer between each discrete sensor removes interference of closely located sensors.

We used a sheet of conductive fabric laid over the top of the sensor array to complete the circuit. The final input device is show in

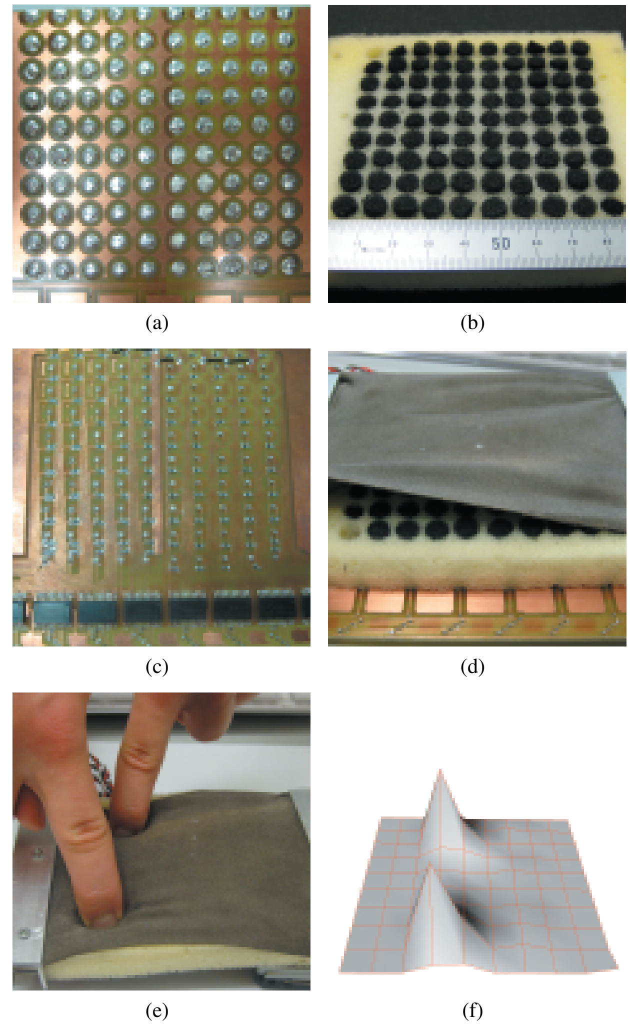

Figure 2: (a) Terminal array etched onto PCB. (b) Conductive foam sensors embedded in non-conductive polyurethane foam. (c) Analog-to-digital converter chip array and back side of terminals. (d) Complete 10x10 sensor array. (e) User pressing two separate locations on Digital Foam. (f) Inverted geometry with two finger presses in Digital Foam.

Figure 2(e) where a user is depressing two separate locations with their index fingers. The corresponding geometry shown in Figure 2(f) is inverted to avoid occlusion's in the figure and to verify two finger presses are visible. We have also found the working area large enough to have two users operate the input device with both hands and it was still possible to avoid overlapping on the resulting geometry. Because the flat Digital Foam senses each point separately, there are no shadowing effects as with standard touch screens and the DiamondTouch [3]. Although we have not made multiple copies of this sensor, it would be very simple to have multiple copies side by side. This combination of multiple flat Digital Foam boards can be scaled up to areas large enough to cover entire tables with sensors.

3.3 Spherical Digital Foam

3D geometry creation often starts with a base shape on which carving and other operations are performed to generate a sculpted solid. We constructed a spherical prop, with a diameter of 110mm, made of Digital Foam so that all surfaces of the sphere can be used for interactions that map to corresponding locations on the geometry.

The construction of a spherical prop with a Digital Foam outer sensor array is more difficult compared to the flat Digital Foam. The design has an inner skeletal plastic sphere (Figure 3(a)) used as a support structure for the outer foam layer. The sphere contains a MSP430F1232 microcontroller, ADC, Intersense Inertia Cube 2 [8], Lithium Polymer battery and Bluetooth wireless electronics. The outer surface of the plastic sphere has evenly spaced terminals each of which is used as discrete input for foam sensors. Similar to the flat Digital Foam we used non-conductive foam to provide both a support structure and electrical isolation so that corresponding sensors do not give false readings. With the limited area of the inner plastic skeleton, we reduced the number of sensors to twenty one to reduce the electronics size and save room on the initial prototype.

The foam sensors attached to the sphere are depicted in Figure 3(b) and the final input prop with conductive fabric outer is shown in Figure 3(c). The conductive fabric is connected to a ground signal and as such acts similar to a Faraday cage blocking wireless signals. To allow a wireless connection is was necessary to put regular spaced holes in the conductive fabric allowing the 2.4 GHz Bluetooth signal to be transmitted for both the foam and orientation sensors. An example of the spherical prop is shown in Figure 3(e) where a user is grasping the left side of the prop and the resulting deformed geometry is show in Figure 3(f).

4 Design Specifications

Each of the foam sensors is attached to a 10-bit ADC. The length of the foam sensor determines the resolution achieved. Given a 20mm thick piece of foam, a 10-bit ADC provides 1024 levels that change depending on how far the foam is depressed. The initial 20mm thick foam size was chosen for ease of construction although we are currently experimenting with more precise electronics to help maintain the maximum resolution while increasing the operating length.

All communications to the Digital Foam are performed over a Promi ESD class 2 Bluetooth connection. Each Digital Foam input device has its configuration stored on the hardware. When a connection is made, the configuration describing the device's shape, sensor locations, and a tessellation order is provided. Sensor readings are transmitted at 30Hz with a latency of less than 8ms with one hundred sensors. As the number of foam sensors increases additional ADC's channels are required increasing the read time.

5 Limitations

The haptic response of Digital Foam depends on the foam type used. The density of the foam determines how malleable the surface is and in turn how far it can be depressed. Unlike the Phantom [11], the response of Digital Foam is not controlled by the computer and does not support dynamic material emulation. Another consideration is the foam springs back unlike clay, so the shape is not retained. Some form of actuator is required to maintain the deformed shape and to add more functionality. Finally the scaling of the sphere is a problem, there is a limit to the size that would be practical to construct and use.

6 Initial Technique and Application Design

To explore the uses of Digital Foam, we have begun the design of interaction techniques that may be used for sculpting and geometry capture. The goal is to design a CAD like application that can be operated without the need for other input devices. Therefore, we are currently exploring a combination of navigation and manipulation techniques. All the following techniques described are currently in an initial prototype stage and no final implementation has been completed. We have also suggested where Digital Foam may be used as a direct replacement for existing systems, thus removing the need for an input device such as a mouse.

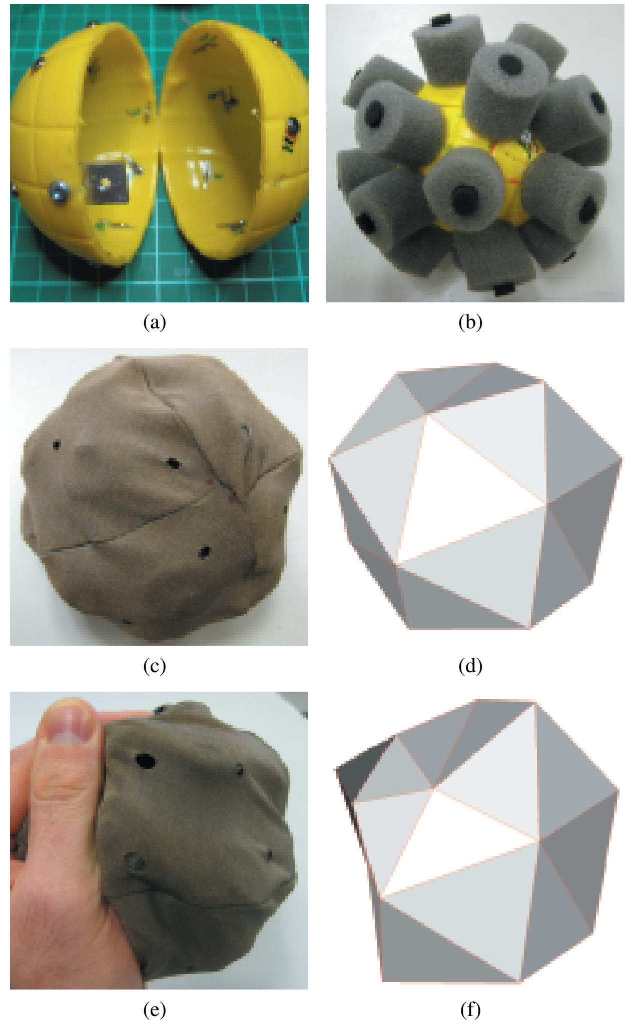

Figure 3: (a) Plastic inner skeleton with sensor terminals. (b) Foam sensors attached to spherical prop. (c) Spherical prop with conductive fabric outer in place. (d) Geometry representation of sphere prop. (e) User squeezing part of the prop. (f) Geometry captured while user is squeezing the prop.

7 Navigation

Orientation tracking allows us to perform simple menu navigations. By rotating the spherical prop up-side down the geometry is no longer updated by the foam sensors and a menu is displayed. The user can navigate through the menu options (rendered on the X axis) by rotating around the heading for the first menu level. By rotating around the pitch a user can navigate through sub menus (rendered on the Y axis), a simple but effective technique.

The normal operation of the orientation sensor is mapped directly to the geometry. This is intended to support the sculpting process by allowing an intuitive means for navigation around the geometry.

The spherical Digital Foam offers another unique navigation technique that manipulates the camera's view. Simply by pressing the sphere's surface the camera is shifted to the location of the finger press. This allows for a very quick intuitive way of viewing the geometry from any direction. The pressure reading from the finger press may be used to act as a zoom function. As the user presses harder the camera zooms in closer and returns as the pressure is released. A user viewing a 3D scene on a 2D traditional screen requires not only the manipulation of a virtual 3D object but the camera's viewing position. The orientation of the object may be controlled via the orientation of the digital foam sphere. A clutching mechanism, such as that proposed by Hinkley et al. [7], allows the object's position to be adjusted only when required. If the user wishes to change the camera view angle to the back of the object, the rear of the sphere is depressed and the camera viewing position is moved to reflect that position and the pressure to reflect how close the camera is to the object.

Another interesting technique for model exploration we have designed is similar to that presented by Hinkley et al. where physical props are used to represent a skull model and cutting plane as described in [6]. Using Digital Foam we replace the cutting plane with the user's fingers so that where the user squeezes the surface, the corresponding model becomes cut away. The shape of the cut away area is determined by the user's fingers, according to the location and how hard the Digital Foam is pressed. This could be further configured to have a range of different predefined shapes that are used to provide a cut-away shape in the model such as cubes, spheres, planes etc.

8 Sculpting

One of the main goals of Digital Foam is to support natural sculpting operations similar to those used when sculpting clay. When performing geometry capture, current AR systems [16] allow a transparent overlay to be placed on top of the real world view. This allows sculpting operations to be guided by the world view and is similar to using tracing paper and a pencil to copy an image.

The first technique proposed is to use the raw data of the input prop for modeling. The user may turn the raw sculpting operation on and off easily while creating geometries. To do this the orientation of the prop can be used. Once again the use of a clutch is essential for ease of use and understandability. In a way that is similar to the menu navigation, the user can rotate the prop to exit raw sculpting, release their fingers and return to the raw sculpting. This allows for cumulative model manipulations to be performed. Scale is also easily controlled by directly mapping a scale value to a combined average of all the sensor readings. This allows users to squeeze the spherical prop with their hands and the geometry size is reduced accordingly.

Given the existing work performed in geometry modeling and capture we would also like to consider using Digital Foam with existing systems. Mizuno et. al's [14] virtual sculpting is an example where we would like to replace the mouse with Digital Foam. This will allow carving operations to be performed with one's fingers. Their system uses a range of predefined chisel shapes that could be replaced with a user's fingers that determine the chisels shape while carving.

9 Future Work

Currently we are in the process of constructing a higher resolution version of the spherical prop. This is required to better support the sculpting process and allow users to generate more complex 3D models. It is also our intention to evaluate the performance of Digital Foam with a user study that measures the usability in terms of accuracy and speed. We would also like to compare existing geometry capture techniques such as those used in the Tinmith system with Digital Foam.

10 Conclusion

We presented Digital Foam, a new 3D user input device. The design of the input device has been chosen to allow for the sculpting and creation of 3D geometry based on real world objects with the intention of supporting three dimensional sculpting applications. We described the conductive foam sensors design including the novel approach of using a combined conductive and non-conductive foam array to reduce interference. The construction of two input devices that use foam arrays have also been described. Finally, we proposed some possible applications that will explore practical uses for Digital Foam.

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