SOFTii: Soft Tangible Interface for Continuous Control of Virtual Objects with Pressure-based Input

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Abstract
We present SOFTii, a flexible input system for topography design and continuous control via external force. Our intent is to provide a tactile metaphor for pressure-based surface input. In this study, two prototypes of SOFTii have been fabricated: (a) The first prototype has one pressure surface for topography design with everyday tangible objects, (b) the second prototype, having two force input surfaces, performs as a deformable controller for video games and continuous shape modeling using a SVM algorithm. Both prototypes of SOFTii are constructed by layering Polymethylsiloxane (PDMS), ITO coated PET film, and conductive fabric and foam. The layer configuration allows the capturing of local pressure on the SOFTii surface via distributed electrodes. Here we further discuss the implementation of the device with possible usage scenarios.

Author Keywords
Input Devices, Soft Devices, ITO electrodes, SVM

ACM Classification Keywords
H.5.2. [User Interface (e.g. HCI)]: Graphical user interfaces (GUI); Haptic I/O; Input devices and strategies; Interaction styles; Prototyping.

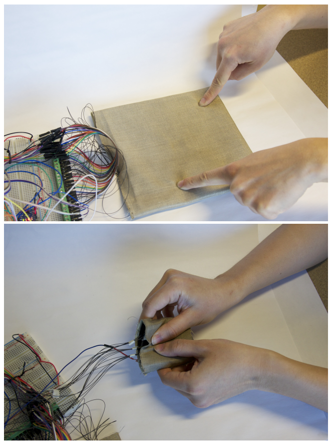

Figure 1: The two prototypes of SOFTII - a pressure sensing pad and a handheld bending device

Introduction and Related Work

In this paper, we attempted to integrate digital design with tangible tools by leveraging soft materials. SOFTii is a robust, flexible input system that provides a pressure-based tactile input metaphor for 3D modeling and game controlling. Our system benefits the advantages of Tangible User Interface (TUI) [3]. It supports quickly adjusting multiple parameters and seeing real-time feedback [9]. The first prototype of SOFTii captures the imprinted coarse shape profile by utilizing the deformable and conductive properties of electrodes distributed on soft materials. This pressure metaphor provides a quick method for topography design. The second prototype utilizes an SVM training model with a magnitude mapping method for the classification and recognition of local bending deformation. The direct pressure-based input and the passive haptic feedback provide a novel tactile experience in continuous shape modeling and game controlling.

Coarse Silhouette Sensing

Some researchers suggested that physical structures can enhance interacting experience between human and computer. One of the most popular techniques for shape sensing is employing a camera to capture the deformable physical shapes, reflecting the computing ideology "What you see is what you get". In particular, the Building Blocks [1] conventionally provides a direct mapping method between the physical shape and virtual geometry data. However, the primitive solid shapes limit the customization feature of the system. Metzget [7] proposes an approach for object detection using conductive foams. This method implies an array of capacitive sensors to detect the object via digital outputs. However, the system is ineffective in measuring the imprinting pressure caused by the physical objects. Our first prototype of SOFTii is inspired by this interpretation for sensing coarse shape silhouette, where the surface itself is a soft deformation-sensitive sensor. A grid of electrodes is utilized to estimate the imprinted pressure on the foam surface.

Soft Tangible Interface

Many unique human-computer interfaces have been proposed with tangible interacting experience. In particular, Pinstripe [4] is a system of textile capacitive touch sensors on clothes. The grid design supports pinching or rolling as input data. However, the touch-based mechanism in Pinstripe is ineffective in comprehending information from force input. Alternatively, PyzoFlex [11] is a pressure sensing device using piezoelectric foil. The array configuration allows surface pressure tracking. Similarly, sandwiching the ITO electrodes in between PDMS was also implemented by Nguyen [8], but was not completely explored. However, using solid materials prevents the system from generating passive haptic feedback and deformability for tangible interaction experience [6].

Shape changing interface

Recently, the shape changing interface has been developing rapidly for their dynamic properties [10]. This opens a different tendency for interactive scheme design, where users can consider physical deformation as a new type of input data. Coelho [2, p. 171] introduces an ideology of utilizing deformable objects for "recording the user's action and applying it in some other place or context". In particular, the inflatable mouse has a similar physical design to a regular computer mouse, but adds new interactive techniques from the ability of detecting the change in its volume [5]. This design inherits some limitations from the *"point & click"* paradigm.

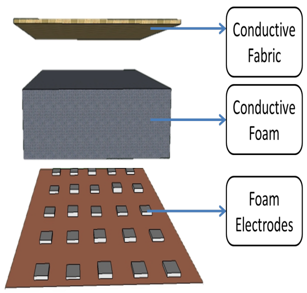

Figure 2: Prototype 1 Layer model

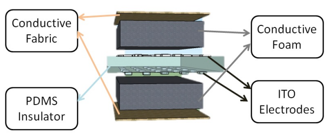

Figure 3: Prototype 2 Layer model

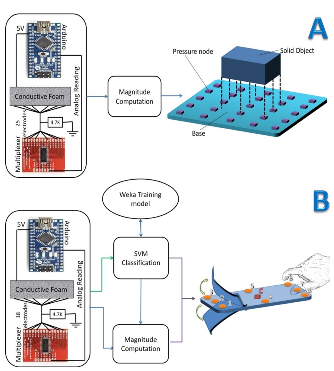

Figure 4: SOFTii - equivalent circuit: A) Prototype 1, B) Prototype 2.

Nevertheless, the volume-sensitive feature provides passive haptic feedback on the hand with air pressure. The second prototype of SOFTii is inspired by shape changing interpretation to provide a pressure-based local bending input metaphor.

SOFTII - System Design

SOFTii utilizes a layer configuration of non-conductive and conductive soft materials. This combination produces a distinct elastic and conductive behavior which can be used to measure shape deformation. The distributed pressures are employed to provide a pressure-based soft input metaphor for 3D topography design and video game applications.

Hardware Prototypes

Two prototypes of SOFTii have been fabricated to perform topography design with coarse silhouette and continuous control with pressure-based deformable input (Figure 1).

Prototype 1 - Coarse Silhouette Sensing

This prototype consists of conductive foam with distributed electrodes underneath one side, while the other is covered by conductive fabric (Figure 2). This configuration allows capturing the imprinted surface deformation. The conductive foam performs as a soft pressure sensor and provides passive haptic feedback simultaneously.

Prototype 2 - Local Bending Sensing

This prototype is constructed by mirroring two conductive foam layers through a PDMS insulator. The device is wrapped around by conductive fabric (Figure 3). The ITO coated PET films offer thin, flexible electrodes which are suitable for the construction of flexible device (0.175mm thick, $50\Omega/in^2$ resistivity). PDMS[1] is selected because of the flexible, soft, and non-conductive properties. The electrode grid supports tracking local pressures on both surfaces. In this study, we hypothesize that users often apply pressure on both sides to bend the prototype. This hypothesis is applied for the training process with the SVM algorithm.

Sensor Evaluation

In both prototypes, the readings are managed by voltage divider via analog multiplexors (CD74HC4067 16-Channel analogous multiplexer), then processed by an Arduino microcontroller[2] (ATmega328, clock speed 16MHz). Therefore, the local pressure resolution is customizable for the purpose. The conductive foam (Open Cell Polyurethane, density $50lb/cuft$, tensile strength 25 psi) provides a flexible, tactile and responsive layer. We hypothesize that connecting a wire directly to the foam is not effective in distributing the voltage across its porous structure. Thus the conductive fabric is used as a voltage distributer (surface resistance: $< 5\Omega/in^2$, thickness 0.45 mm, 78% nylon and 22% elastomer). We perform point pressure tracking test and pressure-based bending test to evaluate the discretely distributed electrodes (Figure 5). The test results indicate that it is visible to capture coarse shape outline with imprinting mechanism. Also, it is possible to identify local deformation (location, direction, and magnitude) using surface distributed pressures.

Computational Model

In this section, we introduce our computational models for the prototypes and their applications.

[1] http://web.mit.edu/6.777/www/matprops/pdms.htm
[2] http://www.arduino.cc

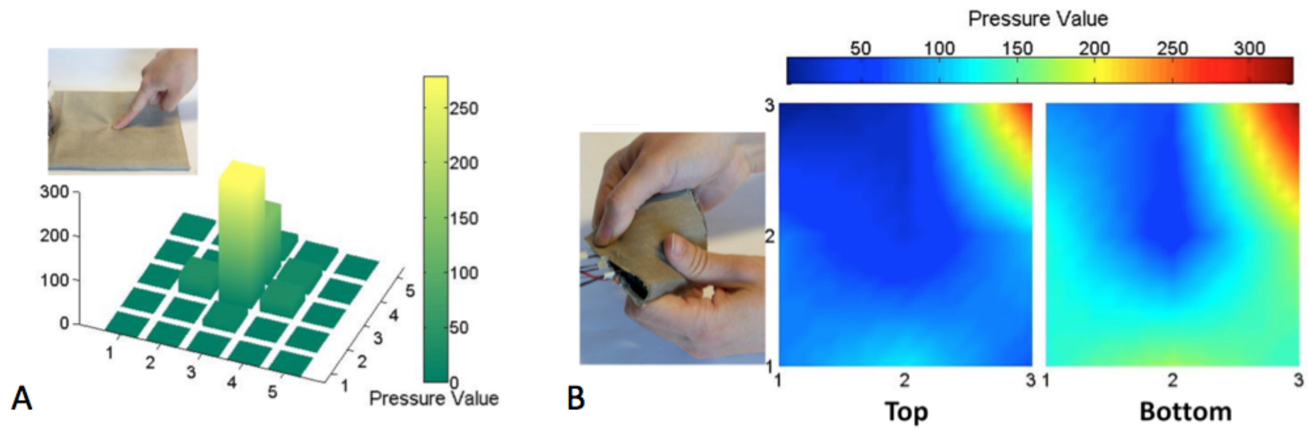

Figure 5: Point pressure experiments on different locations on the surface of SOFTii: A) Pressure observations from pointing finger in the middle part for Prototype 1, B) Pressure-based bending in counter-clockwise direction of top-left corner for Prototype 2.

The First Prototype - Sensor Interpolation

In this setup, the deformation of the conductive foam is recorded with 25 electrodes. These pressure readings are used to derive the coarse shape outline that causes the deformation from the top of the conductive foam. We employ bilinear interpolation to interpolate the sensor values over the active surface. We observed that pressure readings from a sensor diminishes as the point of load is moved away from the sensor. Additionally, loads applied directly on the sensor has negligible affect on the nearby sensors. The interpolated values at each vertex is linearly mapped to the mesh deformation. Moreover, the current setup can run in a single touch tracking mode by estimating the position of touch event. Assuming single-touch input, we calculate the weighted average of all the sensor reading using the following relation:

$$\overline{x} = \frac{\sum_{j=1}^{n}\sum_{i=1}^{m} P_{i,j}x_i}{\sum_{j=1}^{n}\sum_{i=1}^{m} P_{i,j}} \quad \overline{y} = \frac{\sum_{j=1}^{n}\sum_{i=1}^{m} P_{i,j}y_i}{\sum_{j=1}^{n}\sum_{i=1}^{m} P_{i,j}} \tag{1}$$

The Second Prototype - Bending Estimation

The bending magnitude levels are computed using the polynomial regression model:

$$y_j = \sum_{i=0}^{n} a_i x_j^i + \epsilon_j \tag{2}$$

The difference in readings between the upper and the bottom layer represents the local deformation at the

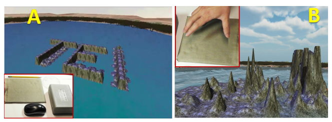

Figure 6: Topography design using everyday objects and hands

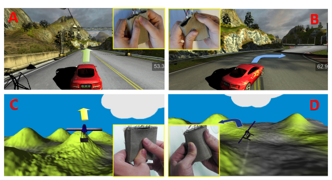

Figure 7: Flexible game controller, based on bendable input: A) Car speed control with direct force input, B) Drifting with flexible force input, C) Airplane altitude control with direct force input, D) Turning with flexible force input.

corresponding node. They are plotted against the magnitude levels to derive the polynomial trend line. A range of 90 degree in each direction is mapped to the bending angles. Thus, an accuracy of 91% is obtained from our polynomial model. *SVM Training:* In this setup, SOFTii is trained with 17 different patterns of local bending states using SVM algorithm via Weka[3] library. These patterns include 8 nodes with 2 bending directions (clockwise and counter-clockwise) for each node, plus a stationary resting position. We obtain a clearly classified training data result by adopting 4 different intensities for each bending state. In this paper, the location and the direction of the bending states are obtained from the patterns of 18 analogous readings.

Interactions

We put effort in utilizing SOFTii as a multimedia input device. The purpose is to provide an intuitive tangible interface between user and computer via force input domain. These interaction methods serve as our proposed ideas for developing application scenarios for Softii.

3D Topography Design with everyday objects

Design Motivation: Here, SOFTii is implemented as a tool for detecting coarse shape silhouette based on the pressure distribution. The system imitates the stamping metaphor to recognize the coarse shape outline. The pressure readings are interpolated. Here SOFTii performs the task using convex objects. The physical objects can be employed directly as the pointer to generate various shapes for the task (Figure 6).

Flexible Game Controller

Traditional personal computer (PC) system games, are currently handled by a combination of key pressing-and-releasing. SOFTii, however, can be customized as a flexible input device for various games. Here, we implement the flexible SOFTii game controller with car racing and flight controlling. The tactility and flexibility of the materials provide pressure-based and deformable input method (Figure 7).

Flexible E-book Reader

Electronic book (e-book) technology is developing rapidly due to its convenience and security. However, the interaction design still has not caught up with the graphical effects. We use the flexible and distributed pressure readings in flipping e-book pages to further improve the tangible experience in e-reading. The direct mapping between the bending angle with the flipping effect allows using SOFTii as a proxy for the pages to be flipped. Two of the bendable corners support manipulating the top most page on each side of an opened e-book (Figure 8).

Local bending recognition

We implement SOFTii as a novel input device to precisely recognize local bending. The ability to distinguish location, direction, and magnitude of local deformation provides a direct interface for shape manipulation. In this paper, the bending magnitude is directly mapped to the virtual deformation to provide precise control using equation 2. The location and direction of the bending is classified and identified by the SVM algorithm (Figure 9).

Future work

In order to obtain a more accurate shape outline with high details, the SOFTii system needs more sensors per unit length. Concurrently, the interpolation model can be further improved with the two-dimensional Gaussian function. Gaussian approach holds the potential to

[3] http://www.cs.waikato.ac.nz/ml/weka/

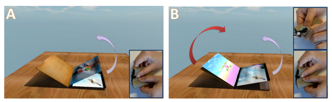

Figure 8: E-book reading by mimicking the page flip motion with bendable input device: A) Turn to next page by bending top right corner in CCW direction, B) Turn to previous or next page by bending top left corner in CW direction or top right corner in CCW direction.

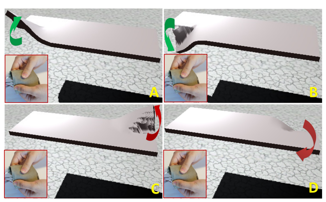

Figure 9: Local bending: A) Left-upper corner in CW direction, B) Left-upper corner in CCW direction, C) Left-upper corner in CCW direction, D) Left-upper corner in CW direction. Magnitude is being controlled by the amount of bending

simulate the "pull effect" of the deformation on the surface with greater accuracy. The flexibility of the system can be ameliorated by reducing the thickness of each layer. In order to improve the sensitivity of SOFTii, some potential materials are waiting to be tested including conductive rubber or conductive PDMS to replace the current conductive foam.

Conclusion

In this study, we introduced SOFTii, a soft interface input device for 3D topography design with everyday objects and continuous control of virtual objects via external force input. Two prototypes of SOFTii have been fabricated with layer configuration. The layer configuration of the soft conductive and non-conductive materials provides a unique tangible interactive experience. The first prototype of SOFTii was able to detect coarse shape silhouette with the imprinted pressure metaphor, where the pressure value is used to generate the height of the topography. The second prototype performed as a deformable input device via external force for video game applications. Additionally, the SVM classifying algorithm assisted in detecting local bending of the device for continuous shape modelling.

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