BendID: Flexible Interface for Localized Deformation Recognition

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BendID: Flexible Interface for Localized Deformation Recognition

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Figure 1: BendID: (a) Layer configuration, (b) Finished Prototype, (c) Localized shape bending, (d) Game controller

ABSTRACT

We present BendID, a bendable input device that recognizes the location, magnitude and direction of its deformation. We use BendID to provide users with a tactile metaphor for pressure based input. The device is constructed by layering an array of indium tin oxide (ITO)-coated PET film electrodes on a Polymethylsiloxane (PDMS) sheet, which is sandwiched between conductive foams. The pressure values that are interpreted from the ITO electrodes are classified using a Support Vector Machine (SVM) algorithm via the Weka library to identify the direction and location of bending. A polynomial regression model is also employed to estimate the overall magnitude of the pressure from the device. A model then maps these variables to a GUI to perform tasks. In this preliminary paper, we demonstrate this device by implementing it as an interface for 3D shape bending and a game controller.

Author Keywords

Soft interface; soft input device; PDMS; ITO; conductive foam; localized surface pressure; 3D partial bending.

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.

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INTRODUCTION

The benefits of physical activities and creative play for cognitive development have been suggested by psychologists and educators [14]. Nonetheless, the educational system currently tends to omit the important role of physically interactive activities after kindergartens [20]. In academic environments, specifically with engineering students and researchers, people are encouraged to perform 3D modeling using Computer-Aided Design (CAD) software, such as Google Sketchup[1] or SolidWorks[2]. Recent developments in 3D modeling software provide users with intuitive interfaces for creative design [4]. However, these tools rely on mouse, keyboard or touchscreen which, while being widely accepted input device, do not provide appropriate metaphors for physical modeling or control.

Inspired by the concept of Tangible User Interfaces (TUI) by Ishii and Ullmer [8], and Weiser's vision of computers that "weave themselves into the fabric of everyday life" [22, p. 94], we seek a method to directly and intuitively manipulate virtual 3D shapes with a deformable, tangible tool.

We introduce BendID, a bendable input device for real-time 3D bending manipulation. BendID leverages the material's physical properties and conductive sensitivity coupled with its computational algorithm to precisely manipulate 3D bending from user defined deformation. The underlying algorithm consists of a supporting polynomial regression model and a SVM classification scheme to capture user intent.

RELATED WORK

Recently, shape-changing interfaces have been developing swiftly along with the seamless tangible interaction because of their dynamic properties [15]. Coelho [2, p. 171] discusses the feasibility of building up deformable devices for "recording the user's action and applying it in some other

[1] http://www.sketchup.com/
[2] http://www.solidworks.com/

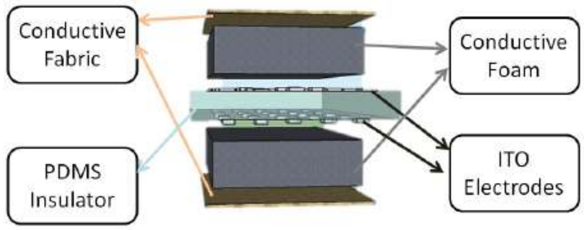


Figure 2: BendID prototype - layering configuration

place or context". The bending interface has been suggested to employ flexible materials for direct and continuous control method [1, 19, 11]. However, these interfaces either rely on bend sensors and force sensors or are not completely flexible because of the hardware attached. The PrintSense system supports pressure sensing for continuous control [5]. But the stiffness of the materials is not capable of producing pressure-based tactile feedback. The inflatable mouse is capable of detecting volume change for novel interactive techniques [10]. This design provides continuous control with tactile feedback. However, the limitation of the traditional "point and click" paradigm reduces the intuitiveness in 3D applications.

Therefore, researchers have been exploring force inputs with deformable soft materials. "A kit-of-no-parts" from craft textile demonstrates various soft materials have their conductivity varied with their deformation [13]. Designers can mix different materials so that the number of internal electrical connections are increased when squeezed, thus, lowering the resistance between electrodes. Similarly, the Skweezee system is employed for gesture recognition using surface pressure and integrating it with a SVM algorithm [21].

Our BendID system borrows this metaphor to classify localized bending effects of physical shapes using an SVM algorithm. The classified patterns are then combined with the magnitude of bending registered from surface pressure values to produce precise control over bending. Daily objects that are turned into touch sensitive input devices have been suggested by Sata [18]. Similarly, Makey Makey [3] allows users to turn various objects into an touching input device with a natural-based interface. BendID draws its inspiration from this user interface ideology, where we designed it as a pad with conductive foam covered by conductive fabric.

BENDID - DESIGN RATIONALE

- *Tactility:* Materials were selected to provide a natural somatosensory response to the user. We used Polydimethylsiloxane (PDMS), ITO (Induim Tin Oxide) coated PET films, conductive foam and fabric. The integration of ITO and PDMS provides a pathway to explore fabricating transparent electronic pads with low cost. The ITO coated PET films offer thin, flexible electrodes which are suitable for the construction of flexible device.
- *Understanding Intents:* We employed a SVM classification algorithm to understand the direction of bend. A polynomial regression mathematical model also estimates the overall magnitude of pressure from the array of electrodes. These algorithm, at the back-end, are clearing out the irrelevant data (noises) to derive user-intent out of the readings.

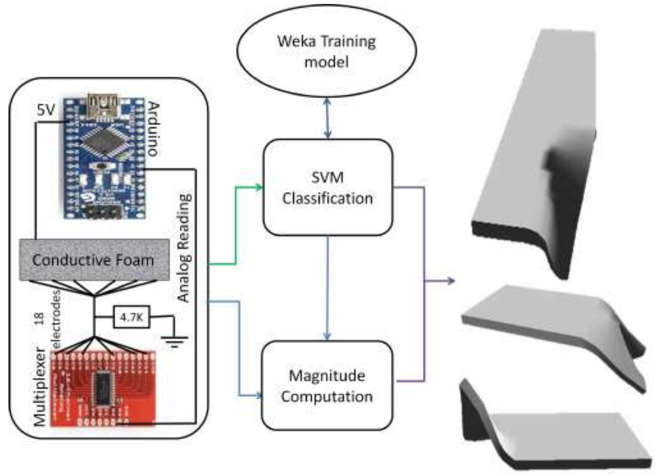


Figure 3: BendID - Schematic workflow

Table 1: BendID prototype hardware configuration.

Objects	PDMS	Conductive foam	Electrodes
Perimeter (inch)	2.5 x 2.5	2.5 x 2.5	0.5 x 0.5
Thickness (inch)	0.6	0.5	1/16
Quantity	1	2	18

BENDID - SYSTEM DESIGN

BendID consists of four layers - (a) PDMS layer, (b) ITO electrodes array, (c) conductive foam and (d) conductive fabric (Figure 2). The array of ITO electrodes (PET films) are laid on the PDMS sheet. This is then sandwiched between two conductive foams and this entire configuration is wrapped by a conductive fabric.

ITO coated PET films are transparent, flexible and favor good electrical properties (0.175mm thick, $50\Omega/in^2$ resistivity). They were laid on a PDMS sheet, which forms the structural backbone of the device. This when integrated with the conductive foam (Open Cell Polyurethane, density $50lb/cuft$, tensile strength 25 psi) provides a flexible, tactile and responsive device. We hypothesis that by connecting a wire directly to the foam, will not distribute the voltage effectively because of its porous structure. Thus we employ the conductive fabric cloth to evenly distribute the voltage (surface resistance: $< 5\Omega/in^2$, thickness 0.45 mm, 78% nylon and 22% elastomer). Table 1 explains in detail the hardware configuration.

This configuration allows localized surface pressure tracking on the top and the bottom layer simultaneously, while the size allows BendID to be used as a handheld device. The distributed resistance values (interpreted as pressure) gathered from the top and bottom ITO electrodes are then used to compute the user intent by a SVM classification scheme and a polynomial regression model. The SVM estimates the bending direction whereas the overall magnitude of pressure is derived from the regression model.

The deformation induced by the user's hand on the conductive foam surfaces read by the ITO electrodes translates to pressure readings. These readings are processed by

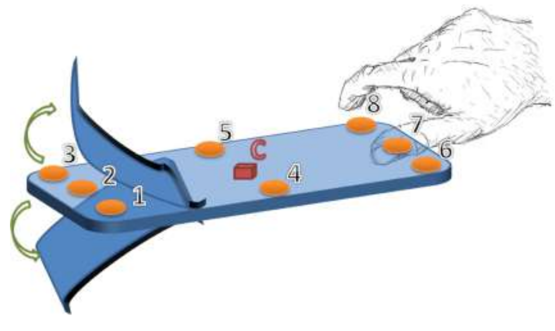


Figure 4: Pattern recognition via bending with 8 nodes

an Arduino Nano microcontroller[3](ATmega328, clock speed 16MHz) and stored in the form of patterns through analog multiplexers (CD74HC4067 16-Channel analogous multiplexer). These patterns are passed to the SVM training model, which uses the Weka library[4] for real-time recognition and classification of the correct localized bending. Simultaneously, these patterns are transferred to the magnitude mapping model to compute the appropriate magnitude of the bending action (see workflow in Figure 3). The classified pattern and the magnitude are then visualized and animated by the Unity3D game engine[5] for real-time visual feedback.

SVM Training model

We categorize 16 patterns, based on the location of 8 nodes, where each node consists of 2 electrodes (top and bottom). Two patterns are generated for each node (clockwise and counterclockwise directions - Figure 4). With addition to a stationary resting position, we train the SVM model with 17 different patterns (Figure 5). In our training model, one pattern consists of four different intensities of bending which represents the angle of bend between 0 to 90 degree. Each intensity level included 300 samples of analog readings. These intensities help us develop a comprehensive training data set, which when applied to the recognition algorithm for the entire device outputs bending values from 0 to 180 degree.

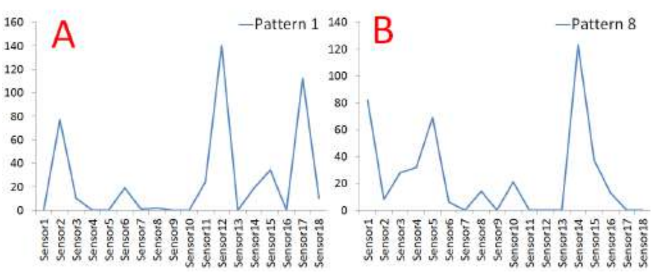


Figure 5: Pattern samples of localized bending (one sample): A) Upper right corner CW, B) Bottom left corner CCW

Pressure tracking

We performed initial tests with single finger press on different locations on the device's surface. This was done in order to investigate the capability of ITO electrodes in recording changes in resistance on the conductive foam surface. The space between each pair of electrodes is 0.75 inches. The results (Figure 6) suggest that the readings from the ITO electrodes can be used to derive the magnitude of the deformation as well as the localized position of the contact point.

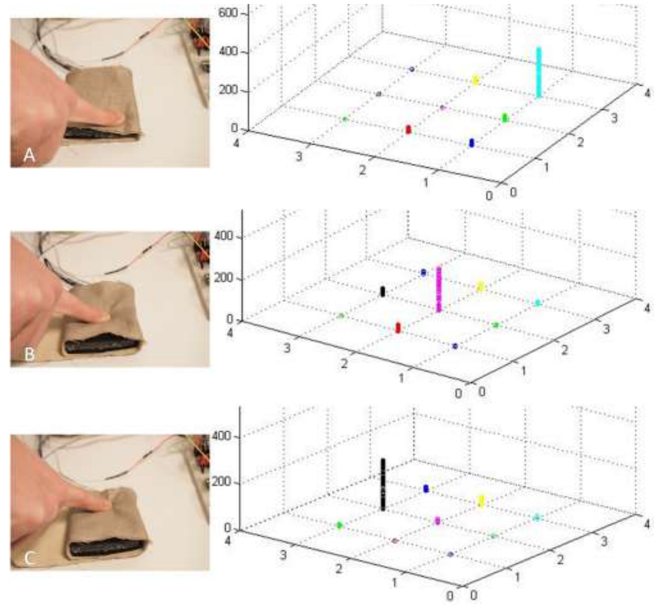


Figure 6: Pressure magnitudes on (a) lower right corner (b) middle (c) upper middle

Magnitude Computation

The bending magnitude levels are computed using a second-order polynomial regression model. The subtractions between upper and bottom nodes (independent variables) were plotted against the levels of magnitude (dependent variables) for developing the trend-line in the regression model (Figure 7). The subtractions are employed since they represent the mechanical deformation in corresponding area. From this regression model, we could calculate the magnitude of pressure applied and bending angles between 0 (normal position) to 180 degree. With the concurrent use of SVM classification process, BendID can visualize the location and magnitude of bending in real time. In this preliminary study, the system to understands the user-intent via soft touches rather than strenuous hard bending.

The Polynomial Regression Model:

$$y_j = \sum_{i=0}^{n} a_i x_j^i + \epsilon_j \tag{1}$$

The model accuracy was 91% by a second order polynomial regression model. The plot (Figure 7) showcases the distribution and the quadratic equation developed in the model.

IMPLEMENTATION

Trained flexible tangible interface

In an attempt to explore various applications for BendID, the input device is used as a flexible input device for 3D shape bending and a game controller for car racing (Figure 8),

[3]http://www.arduino.cc/
[4]http://www.cs.waikato.ac.nz/ml/weka/
[5]https://unity3d.com/

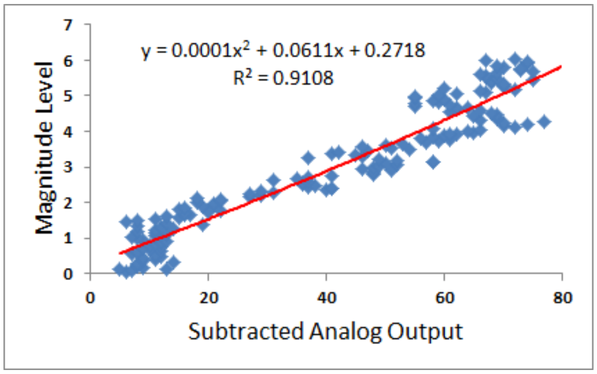
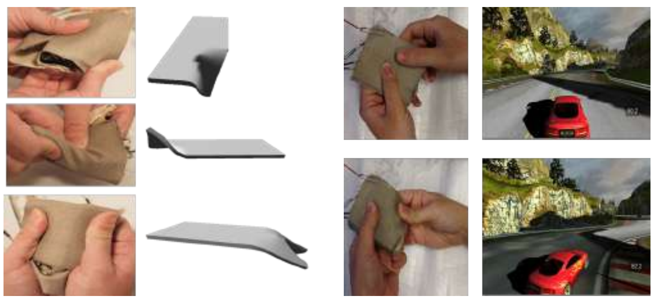


Figure 7: Second order polynomial regression model



(a) Shape bending with magnitude (b) Game controlling with pressure

Figure 8: BendID - Applications

where the amount of bending is mapped to the virtual shape deformation or to the steering of the car. It is expected that this interface improves maneuverability of virtual shapes directly and efficiently. The purpose of tangible ubiquitous computing is to put the human mind and computer as a coupled information processor [6], where the computer is more at a listening and understanding position. One approach for implementing the idea of flexible control device is to allow users to train their own device and decide the outputs. We expect that a trained flexible input device helps reducing cognitive load during tasks such as 3D modeling or gaming. The direct control method with tactile feedback can supply user with intuitiveness and freedom in control.

Scalability

The bendable nodes on BendID surface can be increased by attaching more ITO electrodes for higher resolution of sensing. Another method for implementing the idea on larger surface is by using multiple of such devices as patches. These patches will be distributed over the surface more effectively to gather inputs (pillow, pads etc). Nonetheless, during real time manipulation, sometimes unintended inputs are triggered from the user's hand. This makes the SVM classification produce wrong outputs to the magnitude mapping model. Thus, the system shows wrong results compared to the user intent. In our pilot test, the SVM model gave an output with an accuracy of 95.4% in detecting the 17 patterns. This lingering problem restricts us to design a large scale prototype of the device, rather use multiple of such as patches distributed over the area.

IMPLICATIONS

The BendID system offers a tactile tangible input experience to the user. Its portability and intuitive control is complimented by somaesthesia and lower cognitive load, making this system an ergonomic and a ubiquitous system.

Ubiquitous System

In the tangible ubiquitous computing paradigm, it is crucial to design a natural user interface so that the cooperation between the physical and virtual tools can be utilized [16]. Due to its small size and simple hardware configuration, BendID can be used as a tabletop or a handheld device. Furthermore, when ubiquitous computing is becoming extensive and invisible in user's practices, it is important to consider interoperability with respect to physical devices as well as users [17]. We believe that BendID can work well with various hardware platforms such as desktops, tablets or mobile phones. Also, it is feasible to set up BendID as a networked input device to share tasks between users.

Somatic Sensation

Interaction design benefits from some level of tactility [12]. With our BendID design, users can experience state-of-the-art interactions in modeling or game controlling with somatic sensation from the soft material configuration of BendID. Passive tactile feedback from the soft material provides users the ability to control the device easily and accurately. In tangible ubiquitous computing, semantic mapping between digital data and physical devices plays an important role [7]. This mapping also improves the intuitiveness of BendID.

FUTURE WORK

The method of using Bluetooth® to provide serial communication will enable system portability. Along with the hardware configuration, we are also working on investigating new applications for BendID such as freeform 3D modeling or 3D sketching. The hit rate of the magnitude computation can be increased by adjusting our model with either group mean performance (GHR) or individual subjects' performance (IHR), as mentioned by Kessler [9].

CONCLUSION

In this study, we introduced BendID, a soft tangible device to perform localized bending operations in 3D modeling process. The input device is capable of classifying and recognizing 17 different bending types with precise magnitude sensing. The layer configuration of conductive soft materials provide robustness and tactile feedback for new tactile experience in 3D shape modeling and game controlling. The combination of the SVM training algorithm and the magnitude computation model provides a novel experience in continuously manipulating digital information. However, a deeper study and an user evaluation is needed in order to further investigate the promising features and applications as well as a more user-centered design for BendID.

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