ABSTRACT
In the field of interface surface research, the idea of the ‘softness’ of a surface medium is one significant factor in determining a suitable means of interaction with the user. With direct touch input, for example, the degree of surface softness allows for the generation of various touch sensations and tactile feedback. Additionally, the softness also affects the shape of the surface: a soft surface will allow the user to deform the surface at will while a hard surface will maintain its shape easier. In many traditional flexible surfaces to date, this element has been considered static and thus unchangeable. This project, in contrast, considers the softness of a surface to be dynamic and thus further explores the interaction possibilities with this type of surface. We demonstrate the possibilities of dynamically changing surfaces and their derived user interaction.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation]: User Interfaces

General Terms
Input devices and strategies

Keywords
Interactive Surface, Tabletop, Dynamic Softness Control

1. INTRODUCTION
For a long time, solid planar surfaces have been commonly used for computer displays. Recently, there have been many attempts to provide a flexible element with the display surface to extend possibilities of interaction by utilizing many flexible materials, such as elastomer, sand or clay [1]. However, in many traditional flexible displays to date, this softness element has been considered as an unchangeable, static element. Thus, traditional flexible surfaces limit the possible interaction that is supported on each surface due to the interactive element being strongly dependent on the physical/chemical properties of display material.

In order to address this problem, we proposed the idea of Dynamic Flexibility for the display medium and developed a novel interactive surface with the capability of dynamic flexibility control. The main features of this surface are as follows: Firstly, the user can use the display as both a traditional rigid/planar display and also a flexible/non-planar display. Secondly, the surface of the display is able to perform gradual dynamic translation of its properties from soft to hard and vice versa. In addition, the user or the system can quickly switch the surface softness state at anytime.

2. DYNAMIC SOFTNESS CONTROL
In order to develop the surface that has such dynamically changing softness properties, we looked into the application of small particle materials together with a particle density control technique. Polystyrene particles exhibit liquid-like behavior due to its lightweight and low friction characteristics. However, if you seal these particles into an airtight plastic bag and extract the air from the bag, the particles trapped within are compressed and the bag will gradually harden. If the pressure approaches vacuum pressure levels, the surface container (the plastic bag) will become completely rigid. Based on this technique, we developed an tabletop system. Figure 1 shows the relationship between internal particle density and softness of the surface. At first, when the pressure of the table is at atmospheric pressure, the surface behaves as a soft surface. In this state, the surface provides soft touch sensation like sand or clothing, and enables the user to change the shape easily with simple hand manipulation or with tools. The surface will gradually become harder when the vacuum pump starts to reduce the pressure within the volume. In the median state, the user can deform the surface with his/her hands like clay (Figure.1(left)). Furthermore, once the internal pressure approaches the maximum level determined by the degree of vacuum, the surface becomes hardened and its current shape is fixed (Figure.1(right)).
3. IMPLEMENTATION

Figure 2 describes hardware configuration of our prototype system.

![Image of hardware configuration](image)

**Figure 2: System Hardwares**

3.1 System Hardware

Table is composed of 495mm x 330mm x 50mm box that is filled with 1mm expanded polystyrene particles and covered and sealed with non-breathable spandex material. A vacuum pump (ROBINAIR 15800L), a pneumatic sensor (XPFM-100KPGW), an electromagnetic valve(CKD 3PB) and a digital electro pneumatic regulator(CKD EVT500) are also attached to the system to control internal particle density. A depth camera (Microsoft Kinect) used for touch detection, together with a visible light projector (Epson EMP1710) are fixed 80cm above the table to cover whole area of the system. The softness of the surface reflects the internal particle density of the surface medium controlled by a vacuum pump. This pump is connected to electromagnetic valves and a regulator which are controlled by an Arduino microcontroller. The surface can be changed with this vacuum pump (Robinair 15800K, 3.3 10-6MPa maximum degree of vacuum, 187L/min displacement (50Hz)) from soft to completely hard in under 3 seconds. In the completely hardened state, the surface can maintain its current shape. Additional air displacement valves were installed to increase recovery responsiveness from pressure manipulation.

3.2 Touch Detection

At the first step of touch detection, the camera captures the background depth image of the table surface. The region of 1.0-3.5cm above the surface is then binarized by subtracting background and current depth image (Figure 3). Next, labeling is performed to the regions in the binarized image to detect finger position. These regions are also tracked by finding the nearest region in the previous frame. By using these steps, multiple users’ fingers can be detected and tracked on the non-flat surface at a rate of 30fps.

3.3 Softness Control

We took two requirements into consideration when developing the softness control system. Firstly, the system should be able to set and regulate any softness state between the hard and soft extremities. Secondly, the system should be able to control the rate of softness change. For example, rapid change is required to reduce the input latency if the user changes the softness with GUI, such as a button or a slider. On the other hand, the user can feel the gradual transition of softness, when the speed change is slow. In order to satisfy these requirements, a pneumatic sensor and electromagnetic valve are employed to monitor and set/keep internal pressure. And to dynamically control the power of the vacuum pump, an electro-pneumatic regulator is also installed.

4. APPLICATION

A 2.5 dimensional modelling and texturing application was developed to demonstrate this functionality. The user can form a 2.5D model by using a variety of hand movements such as “scooping” or “pulling and tugging” while experiencing the touch sensation of a dynamically-changing material. Additionally, once the model is in a fixed state, he/she can instantaneously paint a texture onto the surface with direct touch input. Furthermore, this application has another mode that enables the user to interact with his/her original characters that he/she has made via modeling tool through direct touch input. If the user creates a shape on the table with his/her hands, facial features (eyes, nose and mouth) are projected on the shape. This face will then react to user’s touch input. Once the interaction is complete, the character can be removed through the use of a “delete” button on the display.

5. DISCUSSION AND FUTURE WORK

In this current implementation, the use of a depth camera (Microsoft Kinect), on an overhead mount brought about a couple of issues. The first issue is that due to the overhead mounting, occlusion occurs during hand detection. The second is that there is a latency issue with the current technology. To address this problem, sensor-based touch detection can be used for input instead of computer vision. This can be done by attaching a capacitive sensor array on the back of the surface cloth. Another issue is that there is only a single vacuum pump to control the pressure inside the particle volume. This pump has enough power to harden the particle surface, however, it lacks a suitable level of air displacement to quickly change the softness. Two types of vacuum pumps can be suggested to rectify this issue; a pump that allows for higher air displacement can be used to accomodate prompt softness change, and a pump that has higher maximum level of suction can be used to increase the rigidity of the surface. For the following prototype, another suggestion is to employ a more flexible cloth. This will increase the level of moldability, enabling the user to create more complicated shapes on the table. We also want to reduce the latency in softness control and develop a faster softness changing technique to give an improved tactile sensation feedback.

6. REFERENCES