xSlate: A Stiffness-Controlled Surface for Shape-Changing Interfaces

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Abstract
In this paper, we propose a new system called *xSlate*, a stiffness controlled surface for shape changing interfaces. It is enabled by a deformable frame structure that consists of linear actuators, and an elastic skin surface that can configure its stiffness by pneumatic jamming. We describe the implementation methods of xSlate and how it can be used for future applications.

CHI'18 Extended Abstracts, April 21–26, 2018, Montréal, QC, Canada.
ACM ISBN 978-1-4503-5621-3/18/04.
https://doi.org/10.1145/3170427.3186496

Author Keywords
Shape-changing Interface, Jamming, Actuated surfaces.

ACM Classification Keywords
H.5.2 [Information Interface]: User Interface — Haptic I/O

Introduction
Shape-changing interfaces aim to embody organic user interfaces that leverage humans' rich manipulation and haptic sensation[5]. Though most of the daily objects such as tools and furniture remain static, it is possible to realize tools that can deform according to situations by computational and mechanical method. It does not only widen the applications of a single tool but also improve the tool's intuitiveness by means of the shape's affordance and provide indications through tactile sensation. While various types of shape-changing interfaces have been proposed, it is still challenging to meet the requirements of flexibility for the shape-change and stiffness for bearing load applied to them. Towards this issue, we are developing xSlate (Figure 1), a shape-changing structure implementing mechanical actuators as its framework and using a stiffness-changing material as its surface. We aim to use this structure to realize objects and interfaces that change their shape to scale while sustaining stiffness.

Figure 1: xSlate before/after the shape change.

Related Work

There are two main methods for implementing shape-changing interfaces: a mechanical approach, that utilizes mechanical actuators and a material approach, that utilizes materiality. Examples of the mechanical approach include pin-array displays that use the height of each aligned actuator to generate 2.5-dimensional objects [3][1] and multiple conjunct linear actuators that change their shape in three dimensions[4][7]. In contrast, material approaches focus on the materiality such as elasticity[8] and its ability to expand and contract as ways of controlling the object's shape. Though the former method can create robust objects, displaying a high-resolution three- dimensional (3D) surface with a pin-array requires many actuators, which increase both the volume and scale of the system. The latter method can form simple and lightweight objects by utilizing the material's properties. However, owing to the material being soft, there are limits to its range of applications.

Technically, Jamming User Interface [2] is related to our research, which proposes a jamming technique to be used in tangible interfaces. Pneumatic jamming is performed by a device which has a flexible outer membrane and filled up with small particles. Once the air inside is removed using a vacuum pump, it becomes stiff as the friction increases between each particle. When the air is let in again, it returns to its original deformable state. By using this technique, it is possible to control the material's stiffness by controlling the airflow with a pump. In other research, layers of sheets are used instead of particles to design stiffness changing sheet material [6]. In these researches, the actuation method for shape change relies on the user.

xSlate

xSlate mainly consists of a frame structure that can change the size and scale using mechanical actuators, and a soft material skin structure that can change its stiffness by pneumatic jamming. Figure 2 shows the process of shape and stiffness change. xSlate has a 2D shape, and it can be kept in the desired stiffness. Therefore, it could be used as a tool that is required to have strength, such as a surface which needs stiffness to hold the weight of a placed object. When changing the shape of xSlate, the surface is softened to allow the frame structure to be actuated. Then, the surface can be stiffened again to be used which requires strength, but with a different shape.

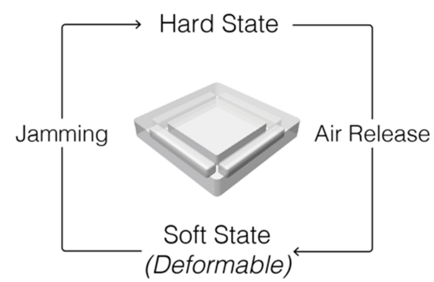

Figure 2: Process diagram of xslate.
Shape of xSlate can be changed while in soft state.

Frame Structure

The shape and scale changing function is enabled by the framework embedded into the jamming structure (Figure 3a). Linear actuators (Actuonix, L12 50mm) and 3D printed joints are used to assemble the framework. The shape and the scale can be controlled by changing the length of each linear actuators using an external control system.

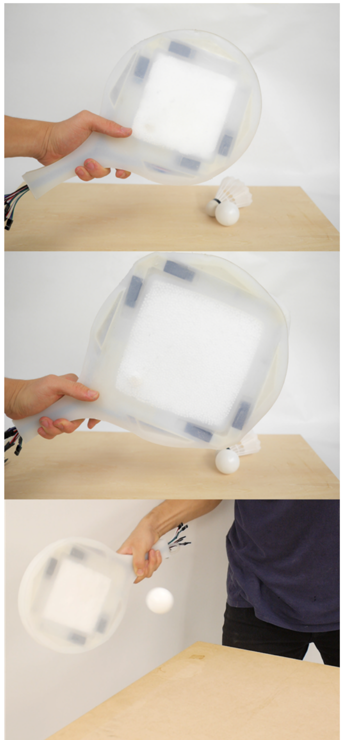

Figure 4: Size changing Racket

Surface Structure

Elastomer (Smooth-On, Ecoflex 0-10, 0-50) is used as an outer layer of xslate and also a membrane for the jamming structure (Figure 3b). Polystyrene beads are used to fill up the hollow space situated in the middle of xSlate. The space is sealed and connected to a pneumatic tube which connects to the external vacuum pump. In outer circumference of the middle space, there is one more space for the frame structure to be inserted. After it is inserted, it is sealed by a sheet of elastomer to fully cover the device by the elastomer. In order to maximize the surface area of which can be jammed, we used softer elastomer (Ecoflex 0-10) for center area and harder elastomer (Ecoflex 0-50) for surrounding area. By implementing this method, the middle part gets stretched more when xSlate is deformed by the frame actuation.

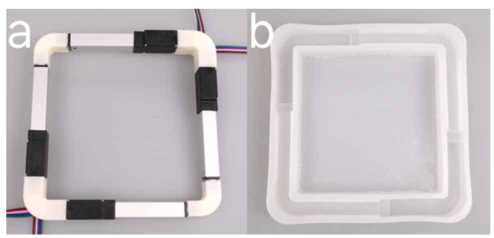

Figure 3: a) Frame structure, b) Surface structure.

Control System

xSlate requires an external control system to configure all actuator stroke and pneumatic jamming. The system is composed of a 12V air vacuum (NITTO, DP0140-X1), a 12V solenoid valve, Arduino Mega 1560 and other electronic components to control these major parts.

Application Scenarios

Size Changing Racket

We designed a size changing racket using xSlate (Figure 4). Unlike conventional rackets, users can change the size of its hitting surface according to the situation. In smallest form, it has a width of 24 cm and a height of 34cm, which is a suitable size for playing ping-pong. In its largest form, it has a width of 28cm cm and height of 40cm which is suitable for playing badminton. It can sustain enough stiffness to hit back a ping pong ball or a shuttlecock by jamming the surface. It uses 50mm stroke actuators and 3D-printed joints which also function as a grip of the racket. Electric wires and a pneumatic tube are routed to go through the grip and connected to the external system at the end of the grip.

In a future scenario, we believe this racket can be used for augmented sports. For example, it is possible to change the game difficulty by changing the size of the racket.

Shape Changing Smart Device

We also designed a smart device concept using xslate as a housing of the device (Figure 5). In the current implementation, it works as a projection display which can change the aspect ratio to suit the content projected on the surface. In a future implementation, we plan to embed a touch sensor on the surface of xSlate to enable input mechanism for xSlate.

Though it is currently necessary to project images onto the screen, in the future, it has a possibility of becoming a portable shape-changing smart device by implementing a flexible and stretchable display.

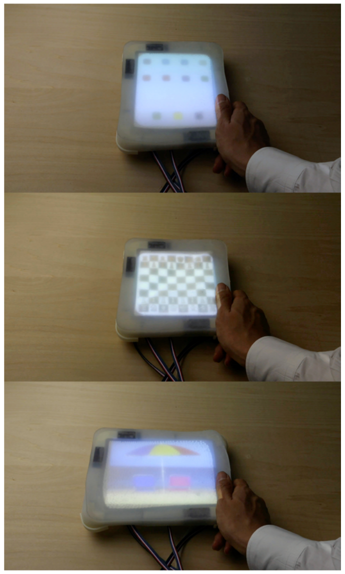

Figure 5: Shape changing smart device concept. xSlate can change its aspect ratio according to the content projected on it.

Conclusion and Future Work

In this paper, we introduced *xSlate*, a stiffness controllable surface for shape changing interfaces. This research was directed to investigate importance of stiffness changing function embedded on shape changing interfaces.

In the current implementation method, shape change and scalability is restricted to a certain extent. Firstly, shape change can be only done in the limitation of rectangular shape. In the future implementation, it can be solved by designing a joint which can change the angle between actuators. For the scalability issue, when using 50mm stroke actuators for a rectangular xSlate, maximum scale change is 170%. It is restricted by the maximum extension rate of the linear actuators. This can be improved by using a different mechanism in the frame structure. In the future, we plan to enable wider variety of shape change, as well as designing a larger device for furniture-scale applications.

Acknowledgements

This work was supported by JST ERATO Grant Number JPMJER1501, Japan.

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