A review of Shape-changing interfaces and their use in input and output

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ABSTRACT
Shape change is being increasingly used in user interfaces particularly with the rise of Ubiquitous computing. We did a review of existing work on shape-changing interfaces by comparing and contrasting the work and finally tried to find open research questions in the design space of Shape-changing interfaces.

Author Keywords
shape changing interface; flexible displays; review; survey; gesture; bend gesture

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation (e.g. HCI): User Interfaces

INTRODUCTION
Shape-changing objects play an important role in design, in architecture and other fields. As exemplified by Rasmussen et al. [10], the Southern white-faced owl enlarges its body to scare enemies or shrink it to camouflage with the tree. This is shape changing to express an output. We have picked Flexible displays and shape changing as our topic of interest to perform a review of work that is being done in this field. The reason we chose this area is its application in Ubiquitous computing, which is reviewed in this article by Coelho and Zigelbam [1].

We have observed that there has been work done by Rasmussen et al. [10] to classify design purposes in shape changing interfaces and also an analysis of why studying user experience with shape changing interfaces is important. The aim of this paper is to use these findings in classifying design purposes of research that has been done and submitted for CHI sessions 2012 and 2013, in this area.

We have chosen papers from CHI 2012 and 2013 in this field, as a starting point and went ahead exploring the papers cited by them to prepare this review. Based on this review, we discuss some open research questions and under-researched areas in the field of Shape changing interfaces. The benefit of working on this paper is that we have gained insights into research being done in this field.

CLASSIFICATION OF BENDING GESTURES
With the advent of flexible displays, we have the prospect of using different gestures but not just touch gestures. One of them, that would appear to be most intuitive, is the use of bending gestures. For example, a flip of a page can be easily represented by a user bending screen like he/she is flipping a page in a physical book and a zooming context can be achieved by a user folding a screen towards him. With all these independent degrees of freedom, there is a need to find which would be the most appropriate classification ways to classify bending gestures so as to associate it with contexts.

Warren et al. [12] have worked on studying how users perform bends to identify well distinguishable bend gestures. They started off with identifying some parameters on which they would like to distinguish gestures viz., Location, Direction, Size of bent area, Angle, Edge, Speed of bend and Duration of Bend. These parameters can be classified into Kinetic Parameters using the classification proposed by Rasmussen et al. [10]. Out of these, after an initial pilot study with users, they narrowed down the criteria to Location, Direction Size and Angle. The participants were asked to perform 36 unique bending gestures in 3 sets. These 36 bending gestures can be called different combinations of each criteria for example, small size bend up at the top corner.

We can summarize the findings of this paper as:

- Bending the device down(away from user) is more difficult that bending it up, mostly due to ergonomic design of device.
- Users were able to distinguish between small bends and large bends easily while they had difficulty with medium sized bends.
- Users prefer bends on the top and side location than the bottom corner.

These findings were applied to suggest some guidelines to associate bending gestures to different contexts. It was suggested that frequent users functions be mapped to top corner as they felt comfortable with bending the top corner. It was also suggested to use only two sizes as they weren’t able to distinguish medium size clearly. Using adaptable classification system would help even more as the classifier can be trained to suit particular user.
In this paper on classification, one point that remained unanswered was the effect of user’s handedness on the classification of gestures. The interaction in this paper can be classified as Direct interaction, where we have shape changing input with implicit output, as per classification of interaction proposed by Rasmussen et al. [10].

SHAPE MEMORY ALLOYS AND THEIR APPLICATIONS
Shape memory alloys (SMAs) are metals that change shape in response to heat, are a popular solution precisely for their light weight and flexibility, these can be used as creative crafting materials by combining them with paper, The authors Jie Qi and Leah Buechley [9] presented mechanisms for moving paper with SMAs along with a set of design guidelines for achieving a movement. They studied various mechanisms such as folding flap, parallelogram, curling flap, clam shell with these SMAs as shown in Figure 1.

One example is the programmable matter project, in which they have an array of custom made SMA hinges helped providing a movement to a sheet to fold autonomously into various forms [5]. These in a form of a wire and contracts to ten percent of its original length upon heating and can be controlled electronically which makes them feasible to be used in programmable interfaces.

The experiment conducted in the paper design an origami crane as shown in Figure 2, where they decouple the muscle wire to give curling wings to the crane. A survey from participants revealed, that the greatest challenge was to get the desired motion for the curling wings which are caused due to the contraction of the muscle wire. The experimental results SMAs can be used in the introductory electronic workshops.

With these techniques and approaches from the paper we move forward on to the next level of the shape changing materials and their properties.

Does the shape memory alloys have any constraints on their resolution? What properties do they exhibit? Answering these questions the authors et al. [11] defined the ten different forms of a shape resolution based on the Non-Uniform Rational B-splines (NURBS) principle with. According to Coelho’s properties [1] shape changing devices require power to memorize their shape changes, the author’s concentrate on the shapes the object can adopt rather than the material of it. Here are the properties listed: area, granularity, porosity, amplitude, zero-crossing, closure, stretchability, strength, speed. Based on the above properties they proposed a self-actuated flexible mobile device called Morphees, which has the ability to transform itself into shapes as desired.

Morphees exhibit tactile and force feedback, as they change shapes during the interaction with the user, a few examples are to:

- Mimic a console: asking the user to grab it.
- Top edges curl inwards: comfortable to hold and type a password.
- Gun trigger: while playing video games

These could be built but have certain limitations, building a high shape resolution touch, which can be overcome by either avoiding the display and touch layers to restrict the shape changing layer or by considering the touch as a tile in the Morphees-couture. These features make it to be predicted as next generation mobile by the authors.

‘MorePhone’ is one of the applications, where the shape deformations are used for the study of effective way of communicating various notifications to the user. Traditional phones
have a plain screen and have notifications on the top of the screen. The authors [3] studied various shape actuations for both haptic and visual notifications on the mobile.

MorePhone uses shape memory alloys to achieve the actuation of the surface display as well as the corners, and has a thin-film E Ink display. The experiment was conducted with 14 participants where they studied the urgency of notifications and the areas of the phone display they would like to receive notifications, which of the visual-tactile or just visual notifications are better. The type of notification (1-corner, 2-corner, 3-corner or all corner bends) for each urgency. After the study users stated that there was no significant difference between act of visual-tactile or visual only notifications, 4/6 participants actually tried looking at the notifications when the screen was curled in the tips and most of them just touched the screen instead.

The future studies on the phones could be customizing the shape notifications by the users. Two more of such applications are the Light changing cloth and Mimic tiles which are discussed further in this paper.

INTERACTION USING OPTICAL FIBER CLOTH
We have discussed so far about usage of shape changing physical items as input and output. But, in ubiquitous devices, physical input or output would not be the way of human interface. Light is another major form of input/output in these systems. Hashimoto et al. [4] discuss a prototype design where optical fibers are used in conjunction with a light pen to change the color of the optical fibers as per input from the pen.

Light Cloth [4] is a fabric made of optical fibers tied together, with LED and light sensors on one end of the fiber each. There is also a pen that can emit infrared light to provide input to the optical fibers about the color of light user wants the chair to be. The researchers targeted furniture design with the Light cloth prototype they made and developed a prototype chair where a user can sit and choose the color of chair (one among 8 combinations) with an infrared pen while sitting on the chair.

The ability of changing the color of the cloth with invisible light as discussed in the paper can be used in storing design in space i.e., an invisible laser light can be displayed on a ramp and when model with light cloth dress passes the light the color of the dress changes. This pen can be used in surface computers where users can point at a location on light cloth to highlight or use that part.

One of the missing aspects with the paper, is that it has no experimental observation to support their hypotheses about the aesthetic benefits of this system.

VARIABLE STIFFNESS DEFORMABLE USER INTERFACE FOR MOBILE DEVICES
Mobile devices offer very limited input methods and even lesser methods for output feedback. The output feedback in mobile devices is restricted to features like display and vibration functions. Several approaches have been tried to overcome these limitations in output methods. This paper proposes to solve input problems by enabling flexible and intuitive user interaction by actions which are familiar to user and output problems by providing haptic feedback to inform the user along with vibration function.

The basic design of Mimic Tile, devised by Nakagawa et al.[8], comprises of two important aspects viz., deformation-based gesture recognition and variable stiffness for haptic feedback. Three basic types of deformation that are chosen to be performed are Bending Downward, Bending Upward, Swing. These gestures are chosen because of high user preferences[6]. Haptic feedback is given to the user by encouraging user to use device flexibility for input and by changing the stiffness of the input device the haptic feedback is provided to the user.

The main components of a Mimic Tile are two Shape Memory Alloy (SMA) wires, silicon rubber sheet, heat resistant pulleys, a polycarbonate plate and acrylic plate. As SMA wires work as sensors as well as actuators the relative size of the Mimic Tile is much smaller than the devices used previously because general actuators like servo motors which are very heavy are not used here. The stiffness of these wires is set using Pulse width Modulation (PWM) which reduces energy consumption by the wire working as actuators [7]. For sensing function, the difference in resistance between two SMA wires placed in front and back of device is used this difference is then mapped with the angle at which the device is bent. Wavelet transformation is applied to data collected form sensors which is used to easily detect time varying gestures like swing.

Experiments have been performed on Mimic Tile in order to test input through gesture, haptic feedback and usability. In experimentation, deformation based gestures are accurately recognized by the device and feedback is provide to the user through haptic feedback. Although the proposed device is extremely simple and easy to extend it does not address the problem of dissipation of heat generated by the SMA wires.

DYNAMIC PHYSICAL AFFORDANCES THROUGH SHAPE AND OBJECT ACTUATION
Follmer et al.[2] have developed InFORM- a shape changing user interface at the Media Lab in Massachusetts Institute of Technology. The architecture of this system is as shown in Figure 3. The system focuses on incorporating the advantages of Graphical User Interface to a a Tangible User Interface. InForm is made up of pins which are vertically actuated. Based upon the user’s interaction these actuated pins form different 2.5 dimensional shapes.

The user’s movements are tracked by a Microsoft Kinect motion sensor. All the pixels above the computed dynamic background model and threshold image are sought which are manipulated using OpenCV to compute contours of the threshold image. The shape is generated using bed of motorized polystyrene pins. Pin height and its stiffness are represented as 8-bit height map in the software.
Follmer et al. mainly focus on three basic functionalities which are needed in dynamic UIs: to facilitate through Dynamic Affordance, to restrict through Dynamic Constraints and to manipulate passive objects. For facilitating dynamic physical affordance, the inFORM system provides physical elements that the user is able to touch. Some of the implementations are buttons, one dimensional input, two dimensional input and handles. For restriction functionality the system can sense the way physical object interacts with constraints and it can dynamically modify their parameters to adapt to the input, for example Wells act as containers and slots can control the direction in which an object can move. Manipulation of objects is facilitated by functions like lifting and tilting angle through computational control. The objects can be maneuvered on X-Y axis by movement of pins in Z-axis.

There is a wide scope for usage of inFORM system. It can range from a simple usage as Marble Answering Machine to providing haptic feedback to visually impaired individual. Moreover it can be efficiently used in Computer Aided Design domain. The major advantage being physical interaction with a solid model created and dynamically changing parameters of the solid model. Some of the issues which can be encountered are overlapping of pins during rapid maneuvering and size of pins may prove to be limitation for the system to display curved contours.

DISCUSSION AND CONCLUSION

We have reviewed 8 papers from CHI 2012 and 2013 in sessions Hot Moves: Shape-Changing & Thermal Interfaces and Flexible Displays respectively, and were then led to 2 journal articles and 2 papers from other ACM conferences. Papers were analyzed by keeping the classifications proposed by Rasmussen et al [10]. We also drew comparison between papers on how research in one is related to, as an application, in another.

We have discussed various purposes to which designers design shape-changing interfaces. We have observed that shape-changing interfaces are drawn up similar to some daily life activity. But what is the purpose of this, apart from being a design inspiration? There is no systematic approach towards classifying all shape-changing interfaces and finding combinations of purpose, input/output configurations and shapes to arrive at new interfaces. There should also be research done on evaluation of users’ reaction to the interfaces. As per Rasmussen et al.’s research, there are about 10 papers that they reviewed working on the same. But this percentage of research wouldn’t be enough in the field which is growing exponentially along with ubiquitous computing. A key objective for future research in this area is to generate more data on the user experience with shape-changing interfaces. Rasmussen et al. have also suggested two ways of collecting such high quality data. These are some open research questions we found.

Though our review contains wide variety of aspects in Shape-changing interfaces, this wouldn’t give a holistic view of this field.

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