Augmenting Elastic Displays with Active Vibrotactile Feedback

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Figure 1: Screenshot of the prototype (left) and schematic hardware setup (right)

ABSTRACT

Within the last years, several use-cases for Elastic Displays have been explored, showing the potential for this novel technology. However, one of the shortcomings of this type of interface is that it is not possible to provide active haptic feedback to the user. This feature is limited to actuated displays, which in turn are much more complex to build, more expensive, less robust and portable. In this paper, we describe another approach to provide basic active haptic feedback for Elastic Displays by using vibration motors. We explore different options for vibrotactile feedback and describe the results of a student project in which some of the concepts were realized as part of a small game prototype.

KEYWORDS

Shape-Changing Interfaces, Elastic Displays, Interaction Design, Interaction Metaphors, Tactile Feedback

1 INTRODUCTION

Novel interface technologies such as **Shape-Changing Interfaces** [1, 13] blend the physical and the digital world and allow to create innovative interaction concepts, which address multiple sensory channels. **Haptics** is one of the sensory channels which is not really addressed by traditional user interfaces. One aspect of haptics deals with materiality and how the user perceives an object when touching it. Texture, weight, and temperature are some aspects well known from product design. A more recent research field deals with non-rigid, interactively deformable materials, providing additional haptic sensation when an object changes its shape. However, the material properties for deformation usually provide only passive haptic feedback in regard of friction, surface tension or physical resistance. For interactive surfaces, an active deformation that reacts to the user's actions is still not easy to achieve and often requires a very sophisticated mechanical construction.

In this paper, we describe an approach for providing limited active haptic feedback for an interactively deformable surface by using vibration motors. We describe some design considerations regarding motor types, placement, vibration patterns and perception of these stimuli. Based on this and former use cases related to **Elastic Displays**, we developed some concept ideas and finally describe a showcase as result of the explorative research on **vibrotactile feedback** as part of a student project.

2 RELATED WORK

In this paper, we focus on **Elastic Displays**, a subclass of **Shape-Changing Interfaces**. These displays do not change their shape actively, but can be deformed by the user and always return to their initial state when not being touched. According to the taxonomy of Rasmussen et al., **Elastic Displays** change their form and neither orientation, volume, texture, viscosity, or spatiality, and therefore

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maintain their topology [13]. Input and output are combined in a direct interaction. In contrast to **Actuated Displays**, they provide only passive haptic feedback based on the surface tension and material resistance. However, **Elastic Displays** can be realized without the mechanical complexity of **Actuated Displays**, resulting in an more portable setup, higher durability and more cost-efficient hardware components.

The basic technological idea was introduced with the *Khronos Projector* [2] and was adapted by several researchers since (e.g. [12],[15]). Novel use cases have been explored, utilizing materiality and specific characteristics of **Elastic Displays** (e.g. [5],[7],[9]). In order to consolidate knowledge about interaction design for these displays, Troiano et al. have proposed interaction models and gestures [16]. Furthermore, a general model for tasks and applications for this type of interface has been proposed (cf. [6]).

Passive haptic feedback is often used in virtual environments by incorporating physical objects as proxies for interaction [4]. Other than active haptic devices, these objects are not controlled by a computer [8]. Hinckley et al. show how these "props" can aid in mastering manipulation of objects in 3D [3]. Other classifications focus on the user for the difference between active and passive haptics. Rodríguez et al. distinguish between cutaneous and kinesthetic passive and haptic feedback, where both can involve the user's active movement or exploration or passive sensations [14].

Elastic Displays thus provide a specific environment for passive haptics in the current setup with an active kinesthetic exploration of the user. Although the deformation of the surface is not controlled by a computer, it can be deformed and thus gives varying force-feedback based on the amount of deformation. Combinations of passive and active haptic feedback have been explored, e.g. by [19] with their weight-shifting dynamic passive haptic proxy.

3 CASE STUDY: ESCAPE ROOM GAME

We started exploring the idea of **vibrotactile feedback on Elastic Displays** by experimenting with the existing hardware and some vibration motors. To get a first impression we did some low-fidelity prototyping, by manually adjusting placement, vibration patterns and intensity while interacting with the deformable surface. Using the setup depicted in Fig 2, we tried to explore if and how the fabric transports vibration and how the perception of some basic vibration patterns work on an elastic surface. After this first experiments, we asked a group of students to do further investigations, especially in regard to different placement of vibration motors and use cases as part of a semester project.

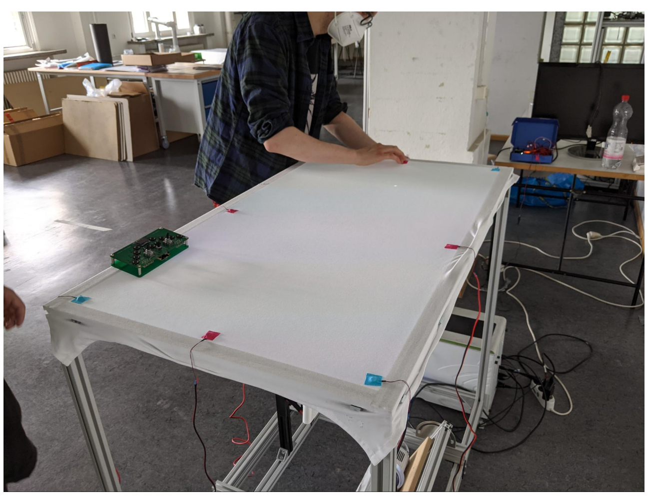

Figure 2: First prototypical setup to explore the feasibility of using vibration motors on an Elastic Display

3.1 Technology

We used a tabletop setup (cf. Fig. 1, right) for our **Elastic Display** with a translucent, elastic fabric (*Lycra*). The fabric is fixed on the aluminium frame. Due to its material properties, it preserves it's shape even after strong pushes. The table has a height of 97 cm and the interactive surface measures 67 cm by 100 cm. We use an *Optoma GT1070Xe* short-throw projector with a resolution of 1920 x 1080px for visualization via rear projection from below the surface, so that hands do not cast occluding shadows. A *Microsoft Azure Kinect DK* depth camera captures the deformation of the elastic textile with a resolution of 512 x 512px at 30 frames per second. The distance between the sensor and the surface is 46 cm. Accordingly, the maximum deformation of the surface is around 40 cm. The detection of deformations starts at a minimal depth of 3 cm.

To provide vibrotactile stimuli we used *ERM (Eccentric Rotating Mass)* vibration motors. These can be driven with a DC signal and hence don't need a special driver IC. The voltage level and can be generated via pulse width modulation (PWM). In this prototype we used cylindrical and coin type ERMs, where the former can provide higher vibration amplitudes due to the higher rotating mass. Hence, they can actuate a larger area of the table surface. However, the cylindrical ERMs produce audible noise. There are different options for placing the vibration motors along the frame of the **Elastic Tabletop Display**. In order to provide a uniform vibration effect over the whole surface, we decided to place four cylindrical motors next to the frame, one in the middle of each side. Additionally, we mounted four smaller coin motors along the two long display sides, one right and one left in the middle between the display edge and the cylindrical motor (cf. Fig. 3). Using this placement, the cylindrical motors cover nearly the whole surface, and the coin motors can support or enhance the basic vibration.

3.2 Design Considerations

Vibrotactile signals can be used for different purposes on touch devices. One common approach is to provide **feedback** for a successful interaction, e.g. when pressing a button or to support the execution of gestures, either by simply providing a haptic signal for successful detection of the gesture, or for different phases of the gesture, e.g. the start and end of a *drag* operation. Regarding **Elastic Displays**, there are some additional concepts for **feedback**: One option is to trigger short vibration pulses when the user reaches a certain depth. This effect could be used to differentiate between depth layers and support layer navigation (cf. [11]). Vibration strength can also be dynamically adjusted to the current depth to enhance the perception of the spatial interaction.

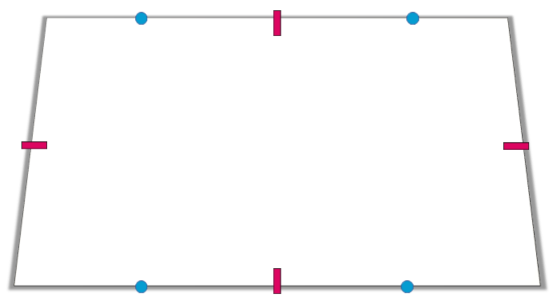

Figure 3: placement of the vibration motors. Cylindrical motors are red, coin motors are blue.

In a more physical way, vibrations can be used to simulate the collision with virtual objects when touching the borders of interface elements on the interactive surface (cf. Fig. 4). Depending on the visualization, this could be triggered based on the lateral finger position, or based on the current depth, or both. This *tactile resistance* could also be used to communicate errors or invalid interaction attempts.

Another use of vibration could be to provide **feed forward**, that means to notify the user about possible interactions or to guide the user's attention into a certain direction. A simple notification could be a vibration pattern based on the proximity to an interactive object. Again, this can be either a predefined pattern or dynamically adjusted to the remaining distance. In this case, **feed forward** can also be combined with the **feedback** when reaching the interactive object. In theory, also user guidance could be realized with vibration patterns to point into a specific direction or location. One option is to use different motor types, positions and signal intensities so that the user can feel the maximum effect of the vibration at a specific position (cf. Fig 5). Another approach is to use dynamic patterns to encode a movement effect, e.g. by sequentially modulating the signal of vibration motors aligned along the display frame from left to right.

As a broader distinction, **vibrotactile feedback** could be used as abstract information and stimuli to provide realism. In terms of interaction the former can be used to mediate *knowledge of result*, e.g. "you reached the object" or "task completed". In contrast, motion-coupled **vibrotactile feedback** can be used to provide *knowledge of performance*.

A second effect is that vibration motors also generate an acoustic **feedback**. When placed on the aluminium frame of the tabletop, the resulting sound effect is rather intense. Based on the use case, the noise can be reduced by placing the motors away from the frame, so that the fabric absorbs the acoustic noise of the vibrations. However, a certain sound will still be noticeable when vibration motors are active. As different intensities and motor types produce different sounds, there is also some variety in the options for the use of (spatial) sound effects.

3.3 Concept and Implementation

Our goal was to explore different forms of **vibrotactile feedback** in combination with different **interaction metaphors**. In the context of a student project, we worked on different concepts. The concept ideas included:

- A *hidden object game*, in which vibrations are used as **feed forward** to provide hints about the location of hidden object(s) and trigger specific vibration patterns as **feedback** when the correct object was identified.
- An edutainment-focused used case for a *learning geography quiz*: Searching for countries / cities / rivers or other geographical elements on a blank map could be supported by vibrations. Again actively guiding the user depending on the difficulty, depth interaction could be used to explore layered maps and/or to adjust the level of assistance needed.
- A specific version of *Point-and-Click* adventures for **Elastic Displays** could use the depth interaction to zoom into or beyond objects in a virtual scene. Vibration could be used

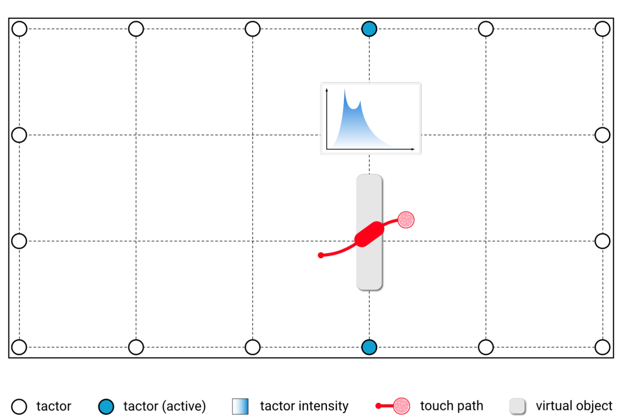

Figure 4: Modulating the vibration intensity when crossing as virtual border

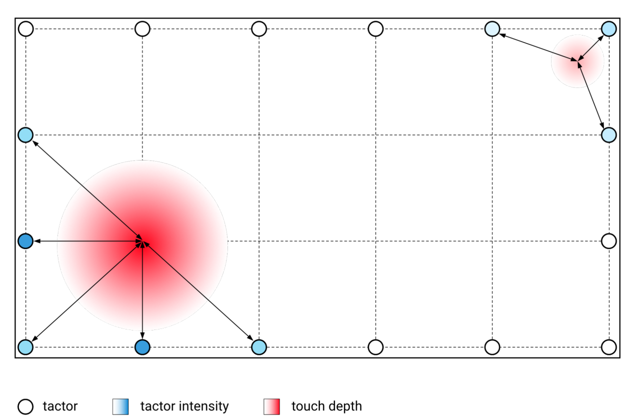

Figure 5: Using different Motors to specify a location on the elastic surface

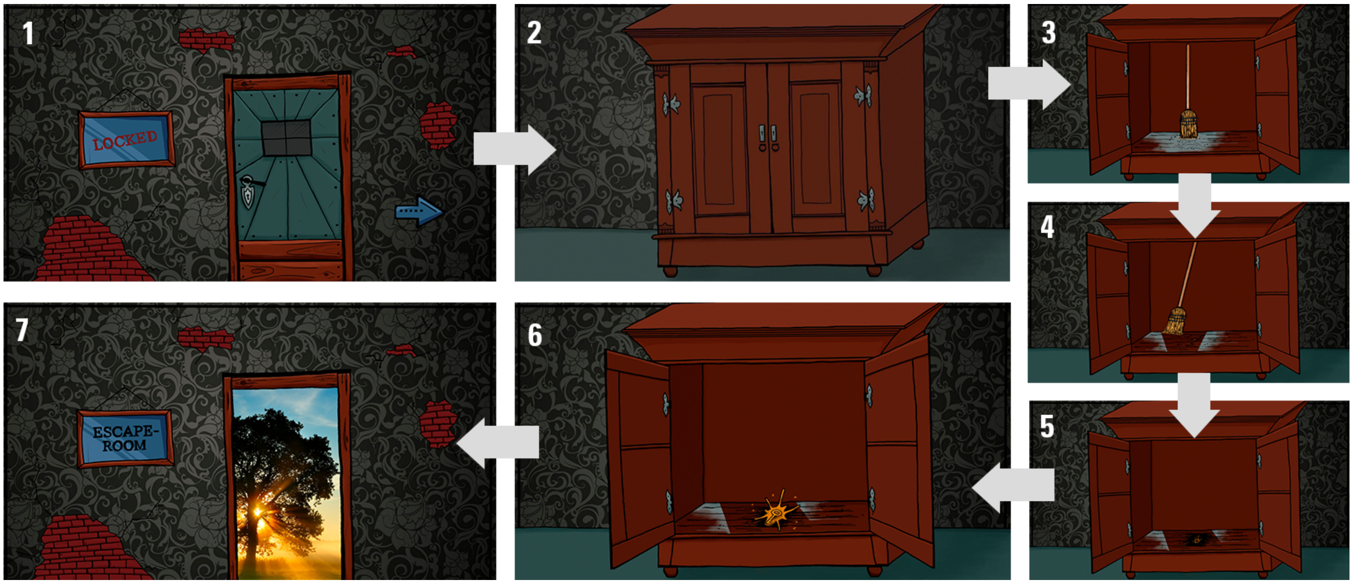

Figure 6: Storyboard of the application: To unlock the door (1) the user turns to the closed wardrobe (2), inside he finds a broom (3) and cleans the floor (4) which reveals a crack on the bottom (5). Breaking this reveals a key (6) which is used to unlock the door and escape (7).

for collisions, determining important objects and **feedback** for executed actions.

- *Haptic support to convey emotions*: use vibration patterns and intensities to express danger, critical timing, stress or other emotions in a virtual environment.
- *Tactile situations*: use vibration patterns and intensities to intensify the atmosphere in a virtual environment, e.g. supporting the visualization of waves on the beach by waves of vibrations across the screen, or mimic wind by small modulated vibrations.
- Provide *guidance for blind people* when interacting with the screen. Vibration patterns could be used to point to certain areas on the screen, **vibration feed forward and feedback** for proximity to, and interaction with screen elements, in addition to acoustic descriptions.

which in the the end were combined in a small escape room game. The idea was to combine **Natural Interaction metaphors** and use **vibrotactile feedback** to enhance the physical sensation of the virtual environment. For the scenario, five gestures have been specified:

- *Touch*: slightly pushing into the surface at the position of a virtual object,
- *Push*: deep push into the surface,
- *Swipe*: slightly push into the surface and move the hand into one direction. The detection of the *Swipe* gesture is using a temporal threshold for executing the gesture as well as a positional threshold for the minimal distance of the movement,
- *Pump*: do several *Push* gestures sequentially in a short amount of time and
- *Pull* the surface towards the user.

The mini-game consists of the following stages (cf. Fig. 6):

(1) the game starts in a room with a closed door
(2) the user *touches* the door, but it is locked
(3) turning to the right, there is a wardrobe
(4) the wardrobe can be accessed by *swiping* the doors open
(5) inside there is a broom and the baseplate looks dirty
(6) using the broom with a *pumping* movement cleans the dirty base,
(7) revealing a crack in the floor
(8) firmly *pushing* into the floor to break it and reveal something inside
(9) *pulling* partially unknown object reveals a hidden key and places it in the inventory
(10) turning back to the door
(11) the user now can *touch* the door again to open it with the key
(12) with the door open, the user can leave the room

We used different vibration patterns to guide the user and support the interaction. Executed actions or state changes are indicated by short vibration pulses. When trying to open the locked door, there was a "rumbling" vibration as feedback, indicating that the door cannot be opened. The pumping gesture is supported by short vibrations on the turning points of the gesture to indicate, that the amount of pressure was sufficient. When trying tho break the bottom of the wardrobe, the intensity of the vibrations increases with the amount of force applied to break through the floor.

The prototype was developed using our **ReFlex** framework (cf. [10]), which provides a client-server-approach to decouple the tracking and interaction from the visualization in the client application. The **ReFlex** server broadcasts the detected interactions via *WebSocket protocol* to the *Vue.js* client, which updates the application

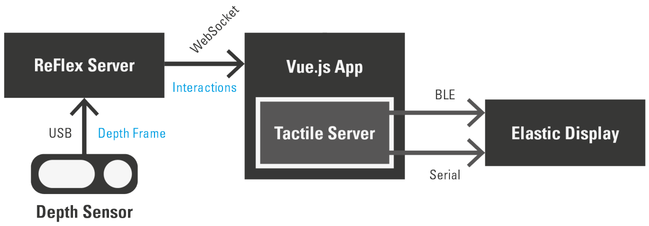

Figure 7: Architecture diagram of the main components of the prototype.

logic and calculates vibration patterns. The client app includes a tactile server component which uses the **TactJam** framework (cf. [17], [18]) to control the vibration motors via *Bluetooth LE* and *Serial communication* (Fig. 7).

4 LESSONS LEARNED AND FUTURE DIRECTIONS

With the case study described in this paper, we started to explore the possibilities for augmenting the **Elastic Display** with active haptic feedback using vibration motors. This first prototypical implementation gave us important insights on the feasibility and limitations of this approach. On the one hand, it was pretty easy to bring the existing frameworks **ReFlex** and **TactJam** together, and first results were achieved pretty quickly. The **vibration feedback and feed-forward** integrated nicely into the user experience when interacting with the **Elastic Display**. However, the current implementation can serve only as a showcase, and the interplay between the gestures and finger movement on the elastic surface with tactile vibrations need to be studied to a further extend in order to derive general facts on the benefits and drawbacks of the technology. We did many preliminary observations, which should be analyzed and verified in future research. So did the perception of the vibration nearly vanish when moving the fingertips, making it difficult to support movements with dynamical feedback or provide **feedback** when executing a gesture. The perception of vibrations was not consistent over the surface, which may be related to differences regarding surface tension. We therefore mostly used the center of the surface for interaction to have a consistent experience. As locating the vibration was rather difficult, we did not use this in our prototype. Again, it should be studied which type of motor may be appropriate for guiding the user, and which vibration intensities and patterns can be used for this task. Furthermore, the location of the actuators was not tested thoroughly, as there are many possibilities, that we could not study so far: different motors with different capabilities, housing and mounting of the vibration motors are subject to future studies. After this first exploratory prototype showed the potential of the concept of **vibrotactile feedback**, we plan to do a more structured and basic research especially to get a more precise description of the surface and material properties and how vibrations physically are transported over the surface. We are currently doing extensive measurements, which hopefully result in a precise model on how to use vibration for conveying a haptic sensation on fabrics with specific deformation characteristics. Furthermore, we continue our work on use cases for **Elastic Displays** and plan to do a study comparing the use of this technology with and without **vibrotactile feedback** in a real-world scenario, in order to understand which impact it has on the interaction with **Elastic Displays**.

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