Shape-Changing Mobiles: Tapering in One-Dimensional Deformational Displays in Mobile Phones

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ABSTRACT

In this paper, we present a new shape-based display technique for mobile phones: A rotatory deformation of the phone's chassis, resulting in a tapering between the phone's front and back panel. It draws on proprioceptive skills of the human hand, which we hypothesize to be sensitive to paralellism and tapering of two opposing panels.

We present a number of applications for such an actuation system: *Interactive Feedback*, *User Notification*, and *Ambient Display.* The proposed system is evaluated in a user study, which results point to certain advantages, as well as drawbacks, in comparison to other mobile actuation systems.

We conclude by discussing areas in which tapering-based deformational displays may be used advantageously, and how the proposed system may be improved in the future.

Author Keywords

Shape change, mobile phone, tapering, feedback, notification, ambient display, hand, tactile, haptic.

ACM Classification Keywords

H5.m. Information interfaces and presentation: Miscellaneous.

INTRODUCTION

Mobile interaction design has undergone several developmental trends in the past years. One of them is a constant increase of physical actuation of the device. While the vibration motor is already present in almost all mobile phones, research investigates beyond that point, exploring various styles of physical actuation.

Fig. 1: Prototype, consisting of a mobile phone, mounted to a shape-actuated box.

Haptic displays in mobile interactions are an emerging research field. This is partly due to the limited visual attention that mobile phones can be attended with: While on the go, one is often busy interacting with the environment. Furthermore, tactile displays can add to the user experience of a mobile device, and augment the interaction with it.

BACKGROUND

This section relates to existing research in the domain of tactile information techniques. It is structured into three parts: A part detailing systems based on *spatially actuated pixel matrices*, a part on *momentum-based mass actuation*, and a part about *deforming shapes.*

Actuated Pixels

Projects in the domain of actuated pixel matrices have investigated the display of information through pixels, usually laid out in a two-dimensional matrix, moving in a third dimension. The *Lumen* project [11] and the *BubbleWrap* project [3] have done so on a table surface, while the *TactoPhone* [8] project has investigated the topic in the mobile phone context. Tactile pixel matrices, especially those of high resolution, can provide the user with a lot of information at the same time. However, they need comparably high *tactile attention*, and some of them draw on abstract tactile languages that users need to decode.

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Ungrounded Force Displays

A considerable amount of work has been undertaken in the field of ungrounded force displays: Displays based on actuated momentum. For instance, in the *GyroCube* project [12], momentum is used for a directional force display. Other projects, mostly by Amemiya et al. [1, 2], investigate inertia and air-jet for this purpose.

Such accomplishments are promising for their application in mobile context, even though they can be rarely found in mobile phone sizes, and, moreover, often inefficient in terms of their power consumption.

Deforming Shapes

The *Dynamic Knobs* project [7] proposed a force-feedback button on the phone's side, which served as an input and an output at the same time. The *Inflatable Mouse* project [10] and the *Ambient Life* project [6] proposed expanding the device's casings.

A project by Hughes et al. is of particular relevance to this project: It investigates a remote vehicle operation [9], proposing a remote control with a tilting backside that would tilt according to the remotely controlled car's tilt angle. Furthermore, Horev's *inSync* hard-drive [8] introduces shape-twist as a display for data synchronization integrity.

It appears that deformation can be used as a valuable output channel. Interestingly, mobile physical displays rarely draw on the skill of the human hand to determine the angle between two surfaces of an object. This project proposes such a deformational display, which was implemented in a mobile phone prototype, and compares it to other systems, exploring various applications.

PROTOTYPES

Our prototype employs a mobile phone, mounted to a box with a moving back plate. Under the back plate, a servo motor is affixed to the front chassis, changing the backplane's angle to the device's remainder (Fig. 1). The mobile phone is connected to a nearby PC through a Bluetooth® connection, which is connected to a *Arduino* board [4], which anon drives the servo motor.

We hypothesized that it would be possible to *determine the angle of tapering* by grasping the device with one hand. Our prototype allows for tapering changes between +15° and -15°. It measured 100x60x45mm, the maximum leverage distance of the pack panel was 14mm.

APPLICATIONS

Our prototype provides a number of applications from the domains of *Interactive Feedback, User Notification* and *Ambient Display.*

Interactive Feedback

We consider those types of tactile actuation as 'Interactive Feedback' that occur in direct reaction to the user's actions on the device. As an exploration of this field, our prototype allows for one-dimensional tactile feedback while scrolling through a sequence of photographs. The phone is held in landscape format (Fig. 2); a list of horizontally laid-out photographs can be viewed by pushing either the left or right cursor key on the phone.

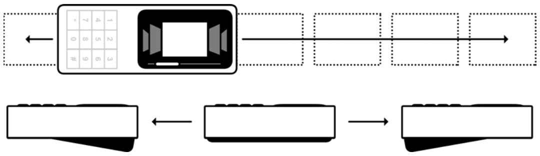

Fig. 2: Interactive Feedback: Position-in-Sequence Display.

The more photos remain on one side of the display, the thicker the phone will get on that particular side. Proceeding from the first photograph to the last will slowly tilt the phone's back plate from 'thick on right side' to 'thick on left side'.

User Notification

A second application field in which actuated geometry can be of value is user notification. While *Interactive Feedback* stands in direct (especially timely) connection to user's actions, Here, the term *User Notification* refers to the conveyance of such information that may stand in *indirect connection* to his actions, e.g. something that requires to be waited for to have happened.

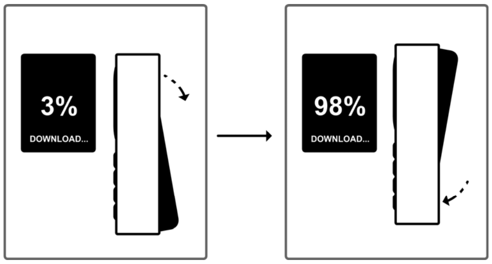

Fig. 3: User Notification: Download progress display.

Our implementation allows the shape-based display of a file download: A download will start as a tapering towards the upper end of the phone's back plate, and then, as it progresses, move towards the phone's lower end (with the phone held in portrait mode, Fig. 3). Similarly, an upload can be displayed as a movement contrary to that.

Ambient Display

The third domain of application that we explore is that of ambient displays. In this domain, the displayed data does not necessarily stand in a timely critical relationship to the users' activities, but still may be of their *interest*.

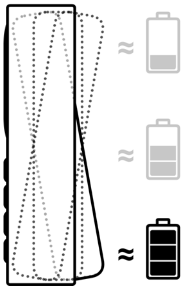

Fig. 4: Ambient Display: Battery level display.

Our prototype implements an ambient display for the phone's battery status: A fully charged battery is represented through complete tapering towards the mobile phone's top end; an increasingly discharged battery is displayed through a movement towards the 'tapering towards bottom' position.

USER STUDY

In our user study, we assessed how well users would be able to determine angular positions of the back plate on the spectrum between the 'maximum upper' and 'maximum lower' positions. Additionally, we interviewed them, asking for their impressions while interacting with the device, and, respectively, which other applications they would wish to see.

Users and Task

Users (6f, 6m, Ø 26.8 yrs.) were introduced to the system by giving them a demonstration of the 'maximum upper' and 'maximum lower' positions, as well as a demonstration of the middle ('parallel') position. Later, operating through a curtain, users were not able to see the device during the trials.

All users were engaged in 9 trials, each of which consisted of the placement of the device on the table, the servo-driven movement of the back panel into a certain angle, the users' grasp of the device, and their statement of where on a scale from -100% to +100% they estimated the currently displayed angle to be. The angles we displayed during the user studies ranged from -15° to +15°, split into 9 evenly distributed target positions. Users were presented them in a balanced, pseudo-randomized order.

Results

Users were able to determine the back plate's angle with a mean error of 2.55° (SD = 3.26°), in a mean time of 6.37s (SD = 4.83s). A repeated measures MANOVA showed no significant main effect of *Trial* on *Time* and *Error* (Pillai's Trace = .697, $F_{16,7} = 1.005$, p = .531). A univariate analysis revealed a significant main effect of *Trial* on *Time* (Greenhouse-Geisser = 357.579, $F_{5,104} = 2.527$, p = .036).

We compared the users' performance to a former study of a one-dimensional mobile haptic display, the *Weight-Shifting Mobiles* project [5], in which the accuracy in determining the device's center of weight's position was assessed, in an otherwise identical test setup.

Users performed significantly better in determining the level of tapering of the device's back plate than determining the position of the device's center of weight in terms of Error ($F_{1,22} = 32.865$, p = .000), but not in terms of Time ($F_{1,22} = .137$, p = .715).

User Statements

When engaged with the device, the participating users stated the following:

The photograph browsing application (*Interactive Feedback)* was popular among them, as it allowed for 'intuitively feeling where in the list' they were. They experienced the functionality as 'pleasing', 'fun' and 'supportive'. However, they reported also that, in the given prototype, the 'movements were too big', and the 'accuracy for interpreting such a display is probably low'.

With regard to the download display (*User Notification)*, users appreciated the 'supportive, hand-friendly' character of the interaction. They were able to interpret the device's deformation as a display of the progressing download, stating that the 'non-visual progress display would be helpful in real-life situations'.

As for the battery status display (*Ambient Display*) application, users enjoyed the, as they stated, 'possibility to check without looking at the device'. Here, some users were confused by the mapping in the presented prototype: 'Up' may be either represented through a 'thicker upper end' of the device, while it may at the same time be displayed by a 'tapering towards the upper end' (which is the mapping we used).

General comments included that a 'thicker bottom'-shaped device felt 'safer' in their hand, while a 'thicker top' would result in a feeling of 'instability, as it would be easier to accidentally drop the device'.

DISCUSSION

Tapering, as a type of shape-based actuation in mobile phones seems to be a supportive means for mobile tactile actuation. It has advantages in the areas of subtle user information, but seems less suitable for direct and factual information display. In the three application scenarios that were presented, users quickly adopted the proposed interaction techniques, pointing out their advantages and disadvantages.

The results of the quantitative study indicate that the human hand is sufficiently sensitive to tapering-based displays as we propose them. This sensitivity might, as the results also indicate, be trained throughout usage.

An initial comparison to our previous work on one-dimensional haptic displays through weight-shift enabled mobile devices revealed accuracy advantages of the system proposed in this paper, which might, however, result from the device's size. The size of our prototype was a point of critique many users raised: Users felt able to determine smaller changes in the tapering of the device than we assessed in the test.

CONCLUSION

The proposed system draws on a capability of the human hand to determine the tapering of a shape of a hand-held item, an ability that has rarely explored as a means of mobile interaction.

From the findings of our study, it can be concluded that a system, as we proposed it, is generally suitable; it has advantages (e.g. in terms of accuracy of position estimation) over other tactile actuation systems, but also its specific drawbacks (e.g. mapping issues) – depending on the application, one may be more adequate than the other.

In our particular prototype, the implementation is, as the users stated, comparably large, and needs to be miniaturized. The results of our quantitative study indicate, however, that a flatter version of the system would also be suitable for a considerable number of angles to be distinguished.

FUTURE WORK

The work presented in this study is one of several studies in the area of physically actuated mobile devices. Future work may investigate *curvature* as a type of display (which can be felt with only the fingers on one side of the device) in mobile phones, and also how shape change can also be used as a means of input, as proposed in the *Dynamic Knobs* [7] project.

The human hand is able to sense and act beyond what current mobile phones allow for, and the authors would like to encourage further research that pushes this boundary.

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