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

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Abstract

This paper presents a novel haptic actuation system for mobile phones: Two-dimensional tapering through an actuated back plate.

It proposes this type of shape-change for various applications, e.g. for ergonomically actuating the shape itself, displaying internal contents, and pointing to entities located outside the device. The paper reports a user study in which the accuracy of perceiving the two-dimensional tilt of the phone's back plate is measured, as well as results from a questionnaire and a user interview.

The results indicate that two-dimensional shape change may be a suitable addition to existing mobile phone technology.

Keywords

Shape-change, mobile phone, haptic display, physicality, form, content, navigation

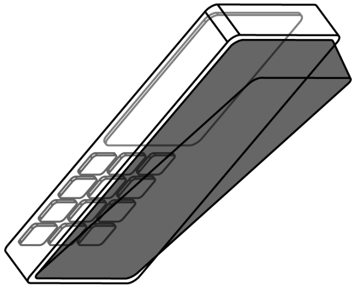

Fig. 1: Concept. Shape actuation on back of mobile phone.

Fig. 2: Prototype. Shape-change augmented box, driven by four servo motors.

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Design, Human Factors

Introduction

Previously, it has been argued that human-computer interaction should be based on embodied skills of humans [2]. This argumentation is sound, but taking it into practice is an activity that still needs to be explored further.

The human hand is a primary means of human-computer interaction, and picking up on its specific abilities may, beyond leading to interesting schemes of interaction, provide insights into how embodied interaction could be developed in the future.

A particular skill of the human hand is the perception of the shape of hand-held objects [10].

Background

Shape-change has been investigated in various contexts, in both mobile and non-mobile applications. This section reviews works relevant to this project in the following fields: Extendedness, surface and angle. The three of these usually perform in a dynamic interplay, and can hardly be separated, but such a categorization may help to see emergent gaps:

Extendedness Actuation

Similar to the FlashBag USB drive concept [9], in the Dynamic Knobs [7] project, extendedness was investigated as a means of interaction on mobile phones. The proposed solution is a knob that extends from the phone's side, as to display information and be used as a means of input at the same time. The usage of a button is simple and intuitively understandable, but, in its one-dimensionality, limited to a rather narrow interaction space.

Surface Actuation

Horev's Tactophone [8] investigates, similarly, the utility of a surface change-based display in mobile applications. Coelho proposed changing surfaces [1] as well, in order to display information ambiently to users. It should be noted, though, that these proposals seem hard to be implemented on an actual mobile phone. They also operate on a symbolic representational layer, and may require prior knowledge to be interpreted. Harrison's [3] dynamically changing projection screen allows for altering of the interaction surface, depending on internal statuses – however, it does not provide a mobile solution.

Angle Actuation

In the 'Talking to the Hand' project [8], an external hard disk was proposed that displayed its synchronization level through a twist in its chassis. Besides these explorations by Horev, actuating the angle between parts of a device has apparently not been the main focus of any research.

Recently, we proposed Shape-Changing Mobiles [5], which investigated one-dimensional, tilt-based shape change as a means of display for off-screen contents in a mobile phone. This follow-up project investigates the potential of using two-dimensional tilt operations (Fig. 1), as it may be of advantage in communicating more data to the user, in a more accurate way, and in closer

Fig. 3: Actuation of the shape itself, dynamic ergonomics.

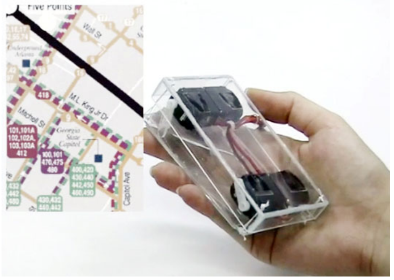

Fig. 4: Display of internal, yet off-screen content through thickness.

Fig. 5: Directional information towards targets outside of the device.

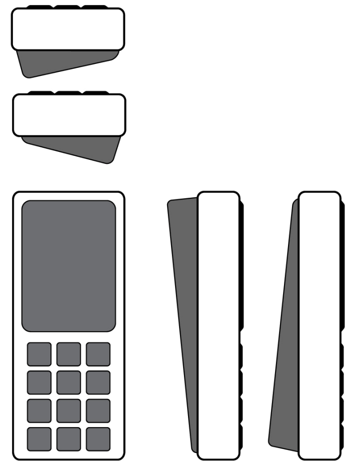

Fig. 6: Two-dimensional angular actuation.

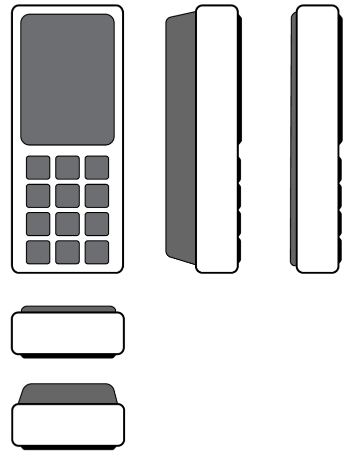

Fig. 7: Thickness actuation.

relation to, usually two-dimensionally laid out, screen contents. We present a prototype (Fig. 2).

Applications

The proposed system allows for various applications: Such that operate on the level of device shape itself (e.g. being thin in the pocket and thick, tapering downwards, while held in hand) (Fig. 3), internal content (e.g. providing digital content with physical volume, displaying off-screen elements through device thickness on the respective edges) (Fig. 4) and external entities (e.g. pointing towards a destination in a navigation scenario) (Fig. 5).

Prototype

The proposed prototype consists of a mobile-phone shaped box. The box is enabled to change its geometry via four servo motors which are placed in its corners. The resulting movement is a tilt of the back plate, around two rotational axes (Fig. 6). The back plate is affixed to the chassis with rubber connectors and pushed out by the servo motors' levers – a circumstance that, besides changing the device's angular properties, also allows for changing the device's thickness (Fig. 7). The prototype, in its smallest state, measures 110x20x60mm and allows for tilting of its back plate by 10° into each direction, extending by up to 15mm in depth.

Users and Task

12 users (5f, 7m, Ø 28.8 yrs.) participated in a study that assessed how precise users were able to determine the angle between the device's front plate and its back plate. In a training phase, they were introduced to the minimum and maximum X and Y tilt angles of the back plate, alongside intermediate positions. After that, they were asked to estimate a series of 15 pseudo-randomized tilt positions, marking a reference point on a nearby computer, showing a graphical representation of the prototype. This reference point was determined by the proportion of the current tilt, compared to the maximum of 10°, on each the X and Y axis.

During the test, all subjects were wearing headphones and had no visual contact to the device, operating through a curtain. They also put down the device after each trial: Users were not in contact with the device while it changed angles.

In this performance task, the measured items were time on task and error. Users also filled out a questionnaire, assessing the pragmatic and hedonic

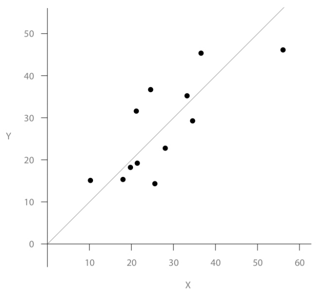

Fig. 8: Errors on X and Y axis.

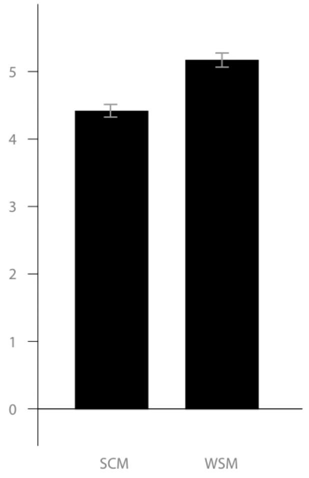

Fig. 9: Attractiveness ratings for *Shape-Changing Mobiles* and *Weight-Shifting Mobiles* prototypes

qualities of the proposed system [4] and took part in a semi-structured interview.

In the same test, all users were introduced to an alternative system: A weight-shifting mobile [6]. The test results were compared between both prototypes.

Results

Users were able to determine the angle of the back plate with an average error of 5.46° (SD = 5.33°) on the device's X axis, and with an average error of 5.47° (SD = 4.96°) on the device's Y axis. They did so in an average time of 7.01s (SD= 4.71s).

A T-Test revealed no significant differences between the accuracy on the X axis and the accuracy on the Y axis (T_{11} = .030, p = .485). We did find a positive correlation between X error and Y error (Pearson's r = .781, N = 12, p = .001) (Fig. 8). No significant differences were found in comparing the percental accuracy of the weight-shifting mobile and the shape-changing variant (T_{11} = .685, p = .508).

As for the results from the questionnaire, we found significant differences on the 'Attractiveness' scale (T_{11} = 3.823, p = .003): The shape-changing prototype was rated significantly more attractive (M = 5.09, SD = 0.58) than its weight-shifting counterpart (M = 4.42, SD = 0.74) (Fig. 9). Also, on the 'Hedonic Quality: Identification' scale, we found differences (T_{11} = 3.422, p = .006) in favor of the shape-changing system (M = 4.69, SD = 0.56), compared to the alternative proposal (M = 4.39, SD = 0.69).

During the interviews, users pointed out that they preferred the 'ergonomic activeness' of the system, and its 'distinguishability just by feeling the edges', and especially the 'clarity of edge and center positions'. They particularly asked for the possibility to 'use the shape as a manipulative input, as well'.

Discussion

The average error rates reported above indicate that estimating the angle between the device's back and front plates is feasible for users at a level that allows its usage as a means of information display. This accuracy and the considerably high average time required for the estimation might be influenced by the fact that users did not feel the movement of the plate – perceiving the transitions, as it would be the case in many real-world scenarios, may have an effect on time and accuracy, as the previous position could serve as a reference. While users performed similarly well on the device's X and Y axis, we found a correlation between the X and Y error. This circumstance might qualify the proposed method of shape-based display especially for *directional* information: When users misjudged the X position, they also misjudged, in a similar amount, the Y position. The angle was therefore estimated rather correctly, while the offset from the center was estimated rather wrongly.

When comparing the shape-based system to its counterpart from the 'Weight-Shifting Mobiles' project, we found no differences in the accuracy of position estimation, but in subjective ratings of the quality of interaction, in favor of the system presented in this paper. However, this might be due to the prototypes themselves and differences in their size and weight: The weight-shifting prototype was about twice the size and weight of the shape-actuated one.

Some users found it easier to determine the set angle by feeling the distance between the edges, rather than between the surfaces. This strategy may serve as an inspiration for future haptic display techniques.

These results indicate that tapering-based shape-change is a suitable means for information display in mobile interactions. The accuracy that users were able to perceive the angle at points to an applicability of the system for the support of everyday usage, especially when screen real-estate is limited or, due to other visual tasks (such as navigation) visual interaction is not appropriate.

Conclusion and Outlook

Operating a shape-changing device seems to require an acclimatization phase, and the proposed system is rather visionary than a market-ready implementation. Shape-change may be influential in the future of HCI, and experiencing such systems today can be helpful in guiding this development towards a convenient, supportive and humane style of interaction.

Future investigations in this field should investigate how input and output could be combined in shape change, and how the interplay of hands, device shape, and screen can be used to provide a rich experience of interacting with devices while on the go.

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