Weight-Shifting Mobiles: Two-Dimensional Gravitational Displays in Mobile Phones

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Abstract
In this paper, we present a novel type of haptic display for usage in mobile phones. It changes the gravitational properties of the device by shifting an internal weight along two axes. Its utility is explored in a performance study, in which users were estimating positions of the device's actuated center of gravity. The users also participated in qualitative studies: A questionnaire that assessed the perceived quality of interacting with the device, and an interview in which they described their experiences with the weight-shifting mobile. Furthermore, this paper suggests three domains of application in which the system may be of benefit: Augmenting digital content with physical mass, ambient displays, and haptically augmented wayfinding.

Keywords
Weight-shift, mobile phone, haptic display, navigation

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

General Terms
Design, Human Factors

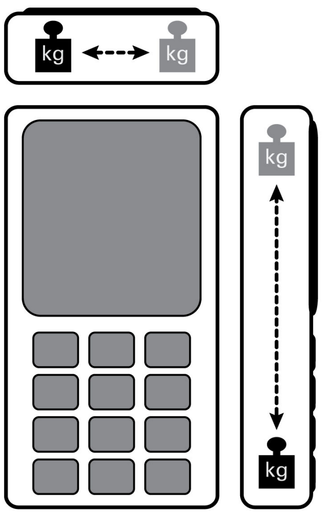

Fig. 1: Two-dimensional weight actuation.

Fig. 2: Prototype. Weight-augmented box, containing an iron weight mounted to two motor faders.

Introduction

Recently, Dourish proposed 'Embodied Interaction' [6] as a new paradigm of Human-Computer Interaction (HCI). He argues, following earlier argumentations by Ishii [10] and Winograd [16], that HCI is increasingly physical and social, and therefore based on everyday knowledge. Following these theories, it can be hypothesized that designing the ways in which we interact with computers, based on things that humans are able to do inherently well, may prove to be fruitful ground for future HCI studies.

With regard to mobile HCI, it appears worthwhile to investigate the capacities of the human hand that the design of mobile interactions could rely on.

Background

This section presents work that appears relevant to this field of research: Works that investigate the physical representation of digital content. It is structured into three subsections: Force-feedback displays, vibrotactile actuation, and mass-based displays.

Force-Feedback Displays

Force-based displays offer rich sensomotory feedback across a broad range of interactions. Research in this field has yielded results allowing 3D feedback on the basis of motorized arms [12], frame-mounted wires [11] and airflow [1]. These systems, while being flexible in their output, are usually not mobile.

Vibrotactile Actuation

In mobile applications, the vibration motor is widely used for tactile actuation. It can be found across many current mobile phones, and its utility has been the subject of various research projects. In such activities, it has been used to display contents inside of a device [15], provide directional information [13], as tactile feedback in touch-screen applications [4], for the display of metadata [3] and as a means of communication [5]. All of these profit from their feasibility: Mobile phones are commonly equipped with the necessary actuator, a vibration motor. However, it may be criticized that vibration is an unnatural tactile event, and may also be perceived as disturbing.

Mass-Based Displays

Mass actuation is a novel and less extensively researched field of haptic displays. Works in this area have investigated inertia-based directional displays [2] and lever simulations [14] in Virtual Reality environments. These systems are promising in terms of their mobility, but lack expressivity: Often, such systems are limited to a single dimension of display that is, at its best, rotationally alterable.

Recently, we proposed Weight-Shifting Mobiles [8], a mass-shift based system for haptic actuation in mobile phones. The general idea seemed applicable for a variety of applications, however, being one-dimensional, this system was limited in its expressivity. The project reported in this paper seeks to investigate the utility of a two-dimensional variant of such a device (Fig. 1). Employing individually controllable X and Y axes appears worthwhile: It might allow for augmenting the entire body of a device with actuated mass, the simultaneous display of two data points, and also for the directional indication of entities outside of the device. While these may seem to be plausible reasons, their verification in practice has not taken place yet. This is the research gap that this paper attempts to close.

Fig. 3: Augmentation of digital content with mass.

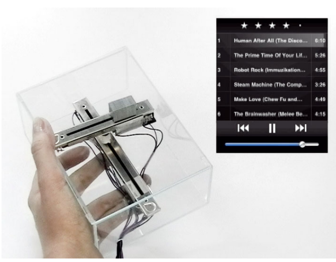

Fig. 4: Simultaneous, ambient display of two data points (playhead position, playlist progress).

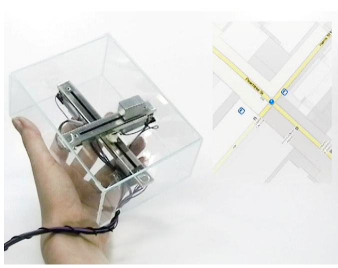

Fig. 5: Haptic compass. Display of directional and distantial information.

Prototype

To explore possible interactions, this project involves a physical prototype of the proposed actuation system. It consists of a weight-augmented box that employs two orthogonally mounted motor faders with a plumbum weight affixed on top (Fig. 2).

The prototype measures 150x60x115mm and weighs 215g, 72g of which accounting for the plumbum weight, and 45g for the small fader that was moved along the Y axis. In consequence, the weight moving along the Y axis sums up to 117g.

Applications

We propose three types of applications for weight-shift augmented mobile devices: GUI augmentation, ambient display, and haptic pointing.

GUI Augmentation

In GUI augmentation applications, the contents of the device's screen are physically augmented with mass. This appears to be a worthwhile endeavour, as physical mass is already – virtually – simulated in modern GUIs, often in the form of inertia simulation (e.g. in list scrolling UI elements) (Fig. 3).

Ambient Display

Another type of application that may be of utitlity in the context of two-dimensional weight-shift may be ambient display. We hypothesize that the subtlety of a weight-shifting device (as compared to a vibrating device, for instance) may be supportive for such applications that do not require users' direct attention (Fig. 4).

Haptic Pointing

Besides applications that represent data inside the device, or metadata that is independent of the device's screen contents, two-dimensional weight shift may be utilized as to point towards things that are outside of the device (Fig. 5).

Users and Task

12 users (6f, 6m, Ø 28.0 yrs.) participated in a user study that assessed how precise and how quickly users were able to determine the position of the weight in the device. After a visually supported training phase, they were, while wearing headphones, handed the device behind a curtain, estimated the position of the weight, and indicated it through a mouse click on a laptop computer. All users performed the click with their non-preferred hand, while holding the device in their preferred hand. Users were not in contact with it while the weight was moved, as only the absolute position was of interest in this primary study.

Besides this quantitative part, users took part in a questionnaire that assessed the perceived quality of interactions involving weight-shift. The questionnaire assessed the pragmatic and hedonic quality of the prototype [7], and its results were compared to those from a similar study, conducted in the *Shape-Changing Mobiles* project [9]. After taking part in the performance test and the questionnaire, users were interviewed, as to which novel applications they would imagine for such a system.

Results

Users were able to determine the position of the weight inside the device with an average error of 28.9mm (SD = 22.1mm) on the device's X axis, and with an average

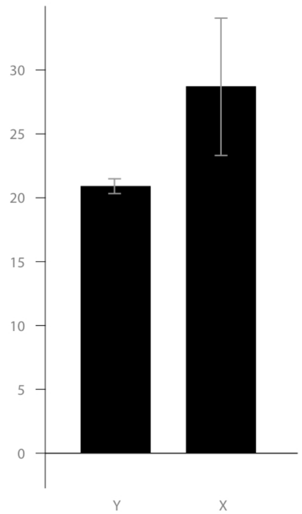

Fig. 6: Mean error and standard deviation on X and Y axis.

error of 21.0mm (SD = 19.2mm) on the device's Y axis. The average time they required for this task was 6.31s (SD = 5.17s).

We found a difference between the mean error in estimating the weight's position on the device's X axis (M_X = 28.9mm, SD = 5.32mm) and the mean error in estimating the weight's position on the device's Y axis (M_Y = 21.0mm, SD = 0.67mm) (Fig. 6).

As for the 'Hedonic Quality: Stimulation' scale, no significant differences were found ($T_{11} = 0.491$, $p = .633$). In terms of the 'Pragmatic Quality' scale, users preferred ($T_{11} = 2.548$, $p = .027$) the shape-changing mobile (M = 4.10, SD = 0.71) over its weight-shifting counterpart (M = 3.52, SD = 0.57).

Users noted that they found the interaction 'calm', 'subtle' and 'clear'. Users criticized that the prototype was too large to be held comfortably in their hands, and was too heavy, as well. As they reported, it would be a good addition to explore 'movement patterns'. Users generally appreciated the functionality, especially with regard to the system's 'ambient display style'.

Discussion

The accuracy at which users could determine the position of the weight inside the device appears sufficient to utilize weight-shift as a mobile information display. Feeling the weight moving in the device (and therefore being provided the previous position as a reference point) could increase the accuracy. In our study, the device was placed on the table while the weight was moved.

The circumstance that users were more accurate in estimating the weight's position on the device's Y axis could be due to the greater weight (resulting from the X-axis fader) moving along this axis. Also, the greater length of this axis may have led to more distinguishable positions (e.g. off the hand, resulting in a greater lever).

When comparing the questionnaire results of the presented system to its shape-changing counterpart, it seems that both appear equally new to users (hence their similarity on the 'Hedonic Quality: Stimulation' scale). In terms of the pragmatic scale, users preferred the other system, which may, however, result from the oversized dimensions of the prototype they were given for the weight-shifting mobile.

Still, it appears that weight-shift, as proposed, is generally suitable for mobile information display: Users could perceive the displayed data – the position of the weight inside the device – at a rate that allows for certain applications. Due to the perceptive accuracy our study indicated, applications should be designed in a way for which low-resolution output is sufficient.

Conclusion and Outlook

Weight-shift is a type of haptic display that may not be found in market-ready devices in the immediate future. But as technology gets smaller and lighter, such types of display may be of growing interest. Picking up specific abilities of the human hand may, in the end, provide a suitable ground for the design of interactions that are particularly tailor-made for their users: Human beings.

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