Weight-Shifting Mobiles: Motion and Tilt in One-Dimensional Gravitational Displays

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***Abstract*—In this paper, we propose motion and tilt as an input technique for Weight-Shifting Mobiles, a recently proposed mobile interactive system that employs a moving center of gravity as an output channel. We present a prototype that combines weight actuation with accelerometer input. We discuss how motion- and tilt-based applications in current mobile devices can be enhanced through weight actuation, and, on the other hand, how weight-based output can be augmented through motion and tilt input. Furthermore, we point to new application spaces that arise from the proposed combination. We present a study in which we compared a button-based input technique and the proposed accelerometer-based input style for a weight-actuated system. We present three application scenarios: A supportive technique for graphical user interfaces, a gesture support scenario, and a balance actuation system. While the conducted user study did not reveal any quantitative differences in button- and accelerometer-based input, user comments indicate that motion and tilt are suitable, and in some cases even preferable, as an intuitive input for weight-based mobile interactions.**

Keywords - Weight-shift, tangible interface, gravity, mobile phone, accelerometer, gyroscope.

I. Introduction

Recently, we proposed Weight-Shifting Mobiles [1], a novel actuation system for mobile phones. It employs a moving center of weight, resulting in a change of the device's gravitational properties: It becomes heavier on one side. The proposed applications for Weight-Shifting Mobiles were: Interactive Feedback while interacting with the device through buttons, User Notification about internal processes, and the system's usage as an Ambient Display.

The proposed applications make use of buttons, internal processes, or external data as input – but none of them draws on the device's motion. However, taking motion and tilt into account as an input seems promising. This paper will review related literature, describe the proposed system, report a conducted user study, and discuss its implications for research in this field.

Figure 1. Prototype, consisting of mobile phone, weight-actuated box and accelerometer.

II. Background

In this section, we will review the relevant related work for this project. It is structured into two parts: The first part details the state of the art in accelerometer-enhanced mobile interaction, while the second part describes current developments in mobile tactile actuation.

A. *Accelerometer-based Mobile Interaction*

Research activities in mobile interaction are often concerned with new input techniques. Increasingly, accelerometers are included in off-the-shelf mobile phones; their application range is steadily increasing. Accelerometers are currently used for various purposes in the area of input, including, tilt input, gesture input, and spatial awareness.

1) Tilt Input

Tilt is an input method popular in mobile interaction design, as it allows for *intuitive control* of the device. Applications in this area include buttonless input for games [2], musical expression [3] and content browsing [4].

2) Gesture Input

Besides using motion and tilt directly as an input, gestural input – which is often based on an *abstract* or *symbolic* relation to the activity at hand – has been explored for usage in education [5], art [6] and authentification [7].

3) Spatial Awareness

Besides utilizing motion and tilt as direct means of input, accelerometers and gyroscopes enable mobile phones to augment graphical user interface (GUI) operations in the *background* with spatial awareness [8]. Applications in this area include, for example, portrait/landscape switching [9], depending on the device's orientation.

Eyes-free interaction [10] is an emerging topic in mobile interaction design, and accelerometers, which draw on embodied knowledge for their execution, are a step into this direction. In this domain, where motion serves as the input, tactile actuation plays a central role as the feedback channel.

B. Tactile Actuation in Mobile Devices

Various approaches are being explored as for the physical, tactile actuation of handheld devices.

1) Shape-based Actuation

Altering the device's shape is a suitable means for mobile tactile actuation, as shape is a *high-bandwidth*, *non-visual* channel of communication that can often be intuitively interpreted. Projects in this field include dynamic buttons on the phone's side [11] and actuated pixel matrices [12]. These provide often suitable notification, but are often challenging in terms of their mechanical engineering.

2) Temperature-based Actuation

Another modality that may be addressed to inform the user is temperature. Research has investigated mobile temperature-based notification [13], however the human sensing capability in this field seems to be *limited in terms of perceptive accuracy* and *timely responsiveness*.

3) Momentum-based Actuation

Other approaches have followed a momentum-based approach: These proposals included excitatory displays [14] and the simulation of buttons through directed momentum [15]. These explorations are promising, as they provide *subtle information* to the user, however their *noticability is timely limited*: For continuous information display, the actuation has to be repeated.

This project seeks to investigate the recently proposed concept of *Weight-Shifting Mobiles* [1] in more depth: It is hypothesized that its combination with a motion- and tilt-capable input increases the spectrum of possible applications and adds both to the application range of accelerometer-based and weight-shift-based interactions.

III. PROTOTYPE

Our prototype consists of a mobile phone, mounted on a 'weight-actuated' box containing a servo-motor, tied to a lead weight (Fig. 1). The apparatus also holds an accelerometer. The motor is connected to an Arduino [16] board, which communicates with a nearby PC. The PC is connected to the mobile phone through a Bluetooth® connection. The box, including the accelerometer and mounting material, measuring 130x60x45mm, weighs 70g; the motor, including the additional weight, weighs 63g; the phone weighs 70g.

Three applications were developed to explore suitable fields of usage for this setup. We present them in the following.

A. GUI Support

One possible application context for motion- and tilt-sensitive weight-shift based interactions is the senso-motoric support of graphical user interfaces (GUIs). GUIs draw often on visual representations of physical entities, and weight-shift can augment these with additional realism. *Content Spatiality* plays a vital role in many GUIs; weight-shift in combination with motion- and tilt-sensitivity appears to be a promising means of input for systems that are concerned with the navigation of spatially laid out content.

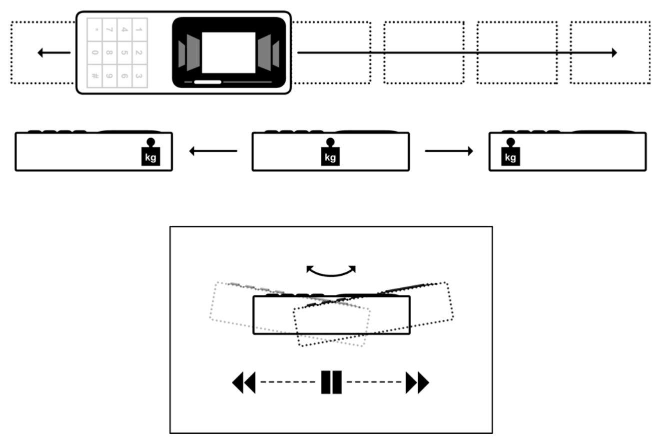

Figure 2. GUI support: Tilt-controlled, weight-augmented browsing of sequential content.

We implemented a 'photo-viewer' application (Fig. 2), in which a strip of photos is navigated by tilting the device. Depending on how many photos are left on one 'side' of the display, the device's center of weight moves correspondingly far to that side.

B. Gesture Support

Gesture-based interfaces are currently emerging in mobile HCI. In such interactions, in which the device is moved to perform a gesture, *feedback* is often a critical component. Relying on visual or acoustic feedback is often worthwhile, however not always appropriate, as for its attentive needs, and social acceptability. The tactile channel provides a more subtle possibility for feedback – and weight-shift might offer an intuitive and broad spectrum of tactile signals for the user. We present a simple gesture-based interface (Fig. 3), augmented through a weight-shift based feedback channel: In a messaging application, the user can send an e-mail message of 5MB size.

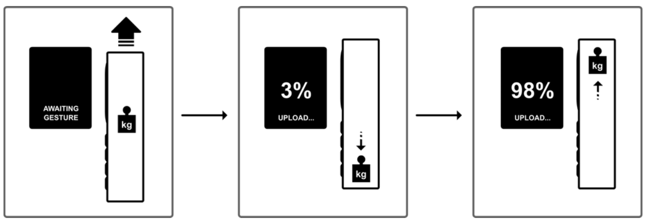

Figure 3. Gesture support: Weight-augmented e-mail upload; triggered through a 'throw' gesture.

The user sends the message by performing a 'throwing' gesture. As soon as the device recognizes the gesture, it quickly moves its center of weight to its bottom (where it indicates a '0%' progress of sending the message), and then progressively towards its top (indicating that the message has been sent entirely).

C. *Balance Actuation*

Besides the augmentation of otherwise GUI- or gesture-based interactions, weight-shift actuation in combination with an accelerometer can lead to an application space of its own. For instance, it can be used to change the 'balancing behavior' of a device. As the center of weight is often a critical element for balancing the device while held in hand, (especially when its keys are placed far towards its bottom), investigating *active balancing* appears worthwhile.

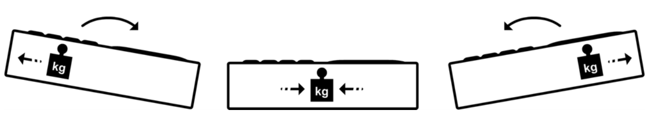

Figure 4. Balance actuation: The device's actuated weight counter-balances tilting of the device.

We implemented a system that, as soon as the device tilts into one direction, moves its center of weight into the opposing direction, resulting in a counterbalancing act, for instance when the device might otherwise fall out of the user's hand (Fig. 4).

IV. USER STUDY

We conducted a user study that consists of two parts: Firstly, we assessed the differences between button-based and accelerometer-based input for weight-shift actuated systems in a small quantitative study. Secondly, we conducted a qualitative inquiry in which we presented the aforementioned applications to users and assessed their experiences with them in a later, semi-structured interview.

A. *Users and Task*

12 users (6f, 6m, Ø 27.1 yrs.) participated in the study. All users were introduced to the system and allowed to experiment with it in an initial training phase.

Each user took part in 18 trials. In the experiment, in each trial, users were asked to move the weight on the device's inside to a certain target position. They were able to do so through one of two methods: either by tilting the device, or by pressing the device's up/down buttons. The input methods were switched after 9 trials; half of the participants started with button-based input, the other half with accelerometer-based input. Time and error were the measured values. After the training phase, users were introduced to the 9 target positions that were used in the experiment; these were equally distributed from the device's bottom to its top.

After the quantitative part, users were introduced to the three applications described above. They were encouraged to freely explore the proposed interactions and were then interviewed about their experiences while interacting.

B. *Results*

Using buttons, users were able to place the weight into the desired position in a mean time of 10.6s (SD = 9.7s), with a mean error of 24.1mm (SD = 31.8mm). Using the accelerometer, users were able to position the device's center of weight in a mean time of 11.5s (SD = 9.51s), with a mean error of 18.9mm (SD = 20.7mm).

A MANOVA revealed no significant main effect of Input Method on Time and Error (Pillai's Trace = .026, $F_{2,9} = .120$, $p = .888$).

C. *User Statements*

As for the different applications we presented to the users, they reported the following:

Regarding the *GUI Support* application, users stated that the, moving the weight together with the photo strip, the 'device responds as expected', it would be 'more fun', and that they would know 'intuitively about the list position'. On the other hand, users criticized that the weight feedback would not be 'necessary for this visual application'.

With regard the *Gesture Support* application, users appreciated the 'combination of the gesture input and weight feedback', especially with regard to the 'non-visual character of the feedback'. Some users, however, preferred the 'visual feedback for its accuracy' and disliked the gesture because it may be 'triggered unintentionally'.

As for the *Balance Actuation* application, some users criticized that the feeling of a counterbalancing device was 'strangely alive' and even 'useless'. Others, however, liked the functionality, describing the interaction as 'well fitting the hand', 'grasping back', and 'comfortable for typing text messages or taking a self-portrait'.

V. DISCUSSION

The results of the presented study indicate that accelerometer-based input is suitable for weight-shift-actuated mobile interactions. While our quantitative evaluation revealed no significant differences in terms of performance, the participants' comments point to differences in the user experience. Most users experienced the proposed motion- and tilt-based system to be generally more 'fitting' for a weight-actuated system than the button-based variant, even though such a preference is hardly generalizable and should be viewed as application-dependent.

What especially raised our interest were the users' notions of the underlying metaphor. The mental models of such a system seem to vary: Some users expected the photo stream to 'slide' through the device, while others assumed that the phone's display would 'point' to a photo on that stream – which would let them expect an inverse control scheme.

The three different application spaces we presented to the users were generally appreciated, yet not without critique. It appears that more investigation in this field is necessary, as to explore further how a combination of classical UI elements (e.g. buttons), motion- and tilt-based input, and weight-shift can be used adequately in mobile interactions.

VI. CONCLUSION AND OUTLOOK

We presented a combination of weight-shift actuation and motion- and tilt-based input in mobile device interaction. The presented applications were appreciated by the users in the test group, and even though no significant main effect of Input Method on Time and Error was found, their comments in the interviews point to a more natural style of interaction through motion and tilt.

Future work in this field may shed more light on how physical, weight- and momentum-based input and output can seamlessly combine, and so make the physical actuation of the mobile phone an advantageous addition to a connected life.

VII. ACKNOWLEDGEMENTS

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