# Weight-Shifting Mobiles: Automatic Balancing in Mobile Phones

**Fabian Hemmert**
Deutsche Telekom Laboratories
Ernst-Reuter-Platz 7
10587 Berlin, Germany
fabian.hemmert@telekom.de

**Susann Hamann**
Deutsche Telekom Laboratories
Ernst-Reuter-Platz 7
10587 Berlin, Germany
susann.hamann@telekom.de

**Matthias Löwe**
Deutsche Telekom Laboratories
Ernst-Reuter-Platz 7
10587 Berlin, Germany
matthias.loewe@telekom.de

**Josefine Zeipelt**
Deutsche Telekom Laboratories
Ernst-Reuter-Platz 7
10587 Berlin, Germany
josefine.zeipelt@telekom.de

**Gesche Joost**
Deutsche Telekom Laboratories
Ernst-Reuter-Platz 7
10587 Berlin, Germany
gesche.joost@telekom.de

---

*CHI 2010*, April 10–15, 2010, Atlanta, Georgia, USA.
ACM 978-1-60558-930-5/10/04.

## Abstract

This paper presents a new type of interaction support for mobile phones: Automatic balancing through weight-shift. It proposes that weight-shift in mobile phones could be used as to change the device's balancing behavior. The question that this technology can help us to explore is how our interaction with mobile phones in everyday life could change, once devices were able to actively change the way we hold them in our hands.

Various levels of interaction are proposed: Balancing based on angular tilt and counter-balancing of button-clicks, and, for a future implementation, balancing, supported through grasp recognition. We report a user study that assessed in how much such a system may help users to balance the a device equipped with the proposed system. It concludes that actuated balancing may be helpful in mobile interactions, but that it needs to be designed carefully.

## Keywords

Weight-shift, mobile phone, haptic display, balance

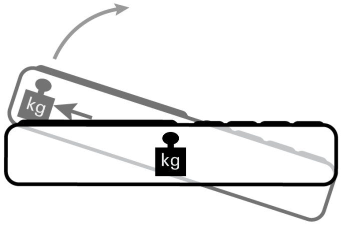

Fig. 1: Weight actuation, self-balancing.

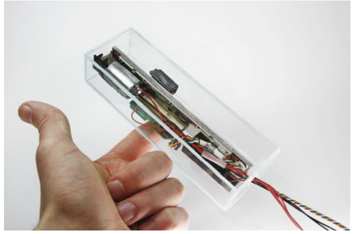

Fig. 2: Prototype, balanced on index finger.

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

## General Terms
Design, Human Factors

## Introduction
Weight-shift in mobile devices has been previously proposed as a novel type of information display [4], and utilizing it to change the gravitational behavior of a mobile phone offers a broad new space of interaction design. The ability to perceive information through this channel has been the objective of previous studies, but utilizing balance itself seems to be inadequately explored.

## Background
This section reviews the literature that is related to this work, structuring it into the following subsections: Balance actuation and grasp-reactive mobile devices.

### *Balance Actuation*
Recently, Amemiya proposed a mass-shifting device, as to exert directional inertia on a walking user's hand [1]. Another recent example for balance actuation can be found in robotic systems [6] – a system that has also found its application in the Segway personal transporter [2]. However, in mobile devices, balance actuation can be found only rarely.

### *Grasp-Reactive Mobile Devices*
Grasp reactivity is a novel addition to mobile device research. Recent works by Lee [5] and Wimmer [7] propose systems that change modes in the device's software depending on grasp.

Combining the two of these domains of research may provide a basis for a novel type of interactivity: Smart devices that prevent letting them fall, by balancing themselves (Fig. 1).

## Prototype
The presented prototype consists of a weight-actuated box (Fig. 2), measuring 155x33x48mm, enabled to sense motion and tilt through an accelerometer. The motor-driven mass on its inside weighs 20g, while the entire apparatus weighs 107g. The 100mm motor fader that drives the weight is able to move the weight through the device at various speeds, two of which we compare in the study described below.

## Applications
We propose three explorative applications for the reported system. These include an angle-determined variant, a click-counterbalancing variant, and a grasp-reactive variant.

### *Tilt by Angle*
Moving the weight according to the angle of the device may allow for a simple counter-balancing of tilt movements, e.g. if the device is bound to tilt over and fall out of the user's hand (Fig. 3).

### *Click Counterbalancing*
Operating on touch screens usually involves the exertion of a force onto them. This may cause an out-balancing of the device. Weight-shift may provide a way to counter-balance these actions, and furthermore provide a haptic feedback (Fig. 4).

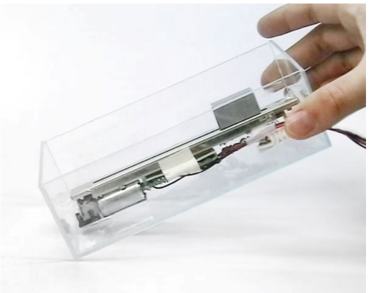

Fig. 3: Angle determination through tilt.

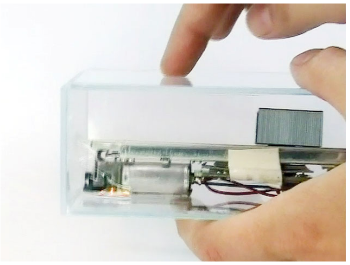

Fig. 4: Counterbalancing clicks.

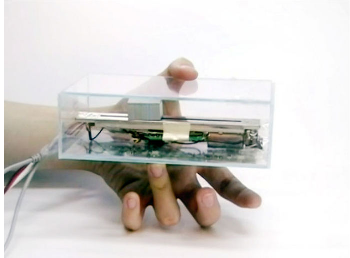

Fig. 5: Reacting to grasp.

*Grasp Reactivity*

This proposal adds another layer of hardware: A touch-sensitive bottom. This bottom may be used to have the internally moving weight place itself over the user's hand or finger. Adjusting the device's center of gravity to where it is held may lead to improved balancing behavior, and may therefore change the way how we manually interact with devices, just in the way we hold them (Fig. 5).

Single-handed operation of a mobile device is often desirable, and a balancing device may be helpful in this context: The thumb could be used for input across the entire device, while it balances itself on the remaining fingers. This is especially the case when the keyboard of the device is located particularly far towards its bottom.

## User Study

Prior to answering the bigger questions of how such technology may change the way we interact with mobile devices, it appears necessary to clarify its boundaries. A pilot user study was carried out to assess this matter.

12 users (5f, 7m, Ø 28.8 yrs.) participated in the study. They were handed the mobile phone-shaped prototype that allowed for the proposed actuation. In the study conducted, users were instructed to run their finger over a path, projected on a wall in front of them, with the device balanced on this particular finger. In the pre-study, in which users completed 20 movements, the measured items were error rate (each dropping of the device was considered a error; the device was loosely affixed to the users' wrists) and time on task.

The pre-study indicated that having users decide the speed of following the path themselves might leave too many variables uncontrolled. The task was then adjusted in that a moving target was now projected on the wall, following a path (Fig. 6), which the users had to track with their fingers, balancing the device. The animation was played in two speed conditions, MOV2 (2s duration) and MOV4 (4s duration), each of which intermittently was the first to be presented to the users.

The prototype was tested in three conditions: SLOW, FAST and OFF. In OFF mode, the weight remained in the device's center, regardless of the angle it was tilted to. In SLOW mode, the weight moved at 20.1cm/s, in FAST mode, it moved at a speed of 25.7cm/s. In both FAST and SLOW modes, the weight moved to a position that was determined by the device's angle to the ground. The maximum angle before it fell off a single balancing finger was, in OFF mode, 40°, and in SLOW and FAST mode 60°.

Users were introduced to the system and its modes in a training phase, in which they were asked to balance the device on one finger. One third of the users started the experiment with the automatic balancing deactivated, while the other two thirds started the experiment with the functionality enabled, respectively in SLOW and FAST mode. All users completed six trials, combining each speed condition with each mode in pseudo-randomized order. Users completed 20 movements along the path, the measured item was error rate. After each trial, users filled out a questionnaire that assessed the hedonic and pragmatic quality of the system [3]. They were interviewed afterwards, and asked for their experiences with the device.

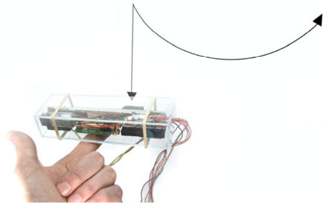

Fig. 6: Task illustration. Balanced prototype and projected path.

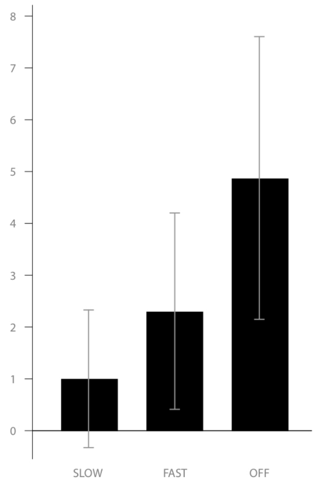

Fig. 7: Mean error and Standard Deviation for MOV2 condition.

## Results

We compared error frequencies between the SLOW, FAST and OFF modes, for each of the speed conditions. For the MOV4 (low speed) condition, no significant differences were found between the three modes ($X^2_{df = 2, N = 12} = 1.632$, $p_{1\text{-tailed}} = .232$). For the MOV2 (high speed) condition, a significant difference was found through a MANOVA ($X^2_{df = 2, N = 12} = 12.67$, $p_{1\text{-tailed}} = .001$), SLOW being the least error-prone mode ($M_{SLOW} = 1.00$, $SD = 1.34$), before FAST ($M_{FAST} = 2.33$, $SD = 1.92$) and OFF ($M_{OFF} = 4.92$, $SD = 2.75$) (Fig. 7).

We found differences in the scales for 'Hedonic Quality' between FAST and OFF ($T_{11} = 3.644$, $p = .004$), with higher ratings for FAST ($M = 4.57$, $SD = 0.76$) than for OFF ($M = 4.00$, $SD = 0.78$). For the comparison between SLOW and OFF, we found significant differences on the scales for 'Pragmatic Quality' ($T_{11} = -3.424$, $p = .006$) and 'Hedonic Quality' ($T_{11} = 4.244$, $p = .001$). Users favored, on the pragmatic scale, the OFF condition ($M = 4.69$, $SD = 0.80$) over the SLOW condition ($M = 3.94$, $SD = 0.98$), and responded inversely on the hedonic scale, favoring the SLOW condition ($M = 4.55$, $SD = 0.47$) over the OFF condition ($M = 4.00$, $SD = 0.78$).

In the interviews, users stated that they would prefer a 'more calm style of movement' for the system, the interaction should be more 'unobtrusive'. Other users reported that they 'did not trust the device' in its balancing actions, and that 'mobile phones do usually not fall out of the hand'. Users appreciated that the interaction was, reportedly, 'proactive' and 'potentially useful' in situations in which holding the phone can be paid only little attention, and also when placing the phone on a non-even surface. Besides varying levels of trust towards the device, users typically fell into one of two groups: One group had the opinion that being supported by the device took away their competence, the other group appreciated the support.

## Discussion

The error frequency comparison revealed differences between the three modes the device was tested in. The speed of the weight moving in the device seems to have an impact on the performance, with the SLOW mode, in our case, leading to lower error rates than the FAST mode. The OFF mode was the most error-prone, which indicates that the functionality indeed helped users in performing the task.

The questionnaire results indicate that the 'moving weight' modes (SLOW and FAST) are differently accepted than the non-moving mode (OFF). Users were appealed by the moving conditions, but perceived the OFF mode, even though they performed worse, more useful. This may be due to acceptance issues towards the system.

It appears that users generally appreciated the functionality, even though they may have difficulties in attuning to the feeling of a automatically balancing device.

## Conclusion and Outlook

The system allows for supportive interventions in mobile phone haptics, and exploring such technology seems worthwhile in the light of technology advancing. As for the proposed system, it appears necessary to investigate which ratio of responsivity and accuracy is appropriate: A too quickly reacting system may feel too hectic in hand, while a too smoothly reactive system may be perceived as ineffective. Automatically balancing devices need to be designed carefully, as to promote their adoption among users. What remains is the question whether technology should act fully automatically, or only support us in our actions.

## Acknowledgements

We would like to thank Ina Wechsung, Stefanie Lange, Sarah Diefenbach and Marc Hassenzahl for their help with the statistical part of this work.

## References

1. Amemiya, T., Ando, H. and Maeda, T. Lead-me interface for a pulling sensation from hand-held devices. *ACM Trans. Appl. Percept.*, *5* (3). 1-17.
2. Argall, B., Gu, Y., Browning, B. and Veloso, M., The first segway soccer experience: towards peer-to-peer human-robot teams. in *HRI '06: Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction*, (Salt Lake City, Utah, USA, 2006), ACM, 321-322.
3. Hassenzahl, M., Burmester, M. and Koller, F. AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität *Mensch & Computer 2003*, B.G. Teubner, Stuttgart, 2003, 187-196.
4. Hemmert, F., Hamann, S., Löwe, M., Wohlauf, A. and Joost, G., Weight-Shifting Mobiles: One-Dimensional Gravitational Displays in Mobile Phones. in *Adjunct Proceedings of UIST'09*, (2009).
5. Lee, H., Chang, W., Park, J. and Shim, J., New mobile UI with hand-grip recognition. in *CHI EA '09: Proceedings of the 27th international conference extended abstracts on Human factors in computing systems*, (Boston, MA, USA, 2009), ACM, 3521-3522.
6. Nagarajan, U., Kantor, G. and Hollis, R., Human-robot physical interaction with dynamically stable mobile robots. in *HRI '09: Proceedings of the 4th ACM/IEEE international conference on Human robot interaction*, (La Jolla, California, USA, 2009), ACM, 205-206.
7. Wimmer, R. and Boring, S., HandSense: discriminating different ways of grasping and holding a tangible user interface. in *TEI '09: Proceedings of the 3rd International Conference on Tangible and Embedded Interaction*, (Cambridge, United Kingdom, 2009), ACM, 359-362.