Take me by the Hand: Haptic Compasses in Mobile Devices through Shape Change and Weight Shift

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ABSTRACT
This paper compares two novel physical information displays, both of which allow for haptic, non-invasive, non-audiovisual information display: a shape-changing device and a weight-shifting device. As for their suitability in mobile navigation applications, the two haptic systems are compared against each other, and also against a GUI-based solution, which serves as a baseline. The results of the study indicate that the shape- and weight-based displays are less accurate than the GUI-based variant, but may be suitable for simple directional guidance (e.g. walking ahead, or turning left or right) and beneficial in terms of reaction times to visual cues (e.g. traffic lights). This paper concludes with an outlook towards potential future research activities in this field.

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

General terms: Design, Human Factors

Keywords: Physical displays, navigation, weight shift, shape change, handheld, mobile phone

INTRODUCTION

Current developments in mobile devices are accompanied by growth in the devices' functional repertoires – one area of applications that has made particular advances in the recent past is spatial navigation.

In this field, the inclusion of new input channels (e.g. GPS receivers and magnetometers) into devices' hardware has enabled handheld navigation to be location-aware and, in more recent developments, also direction-aware.

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Fig. 1a, 1b, 1c: Directional indication through shape change-based, weight shift-based and GUI-based cues.

As for the available output channels, navigation has, for a long time, been solely relying on audiovisual cues. In cars, for instance, speech-based direction indication has established itself as the status quo, while in handheld navigation, devices based on visual cues are commonly found.

This is a surprising circumstance, as handheld navigation devices are often used while walking – an activity that requires visual attention by itself [10]. Hence, the usage of tactile cues for pedestrian spatial navigation is researched with eager – an overview of these activities will be given in the following section.

BACKGROUND

Physical directional indication for pedestrians is an active research field. Works in this area include directional cues given through actuators in the user's clothing and accessories, in dynamically reacting environments, and in handheld devices themselves.

Directional Guidance in Clothing and Accessories

Actuated items that are worn close to the body, e.g. as demonstrated in the FeelSpace project's vibration-based compass belt [9], are often beneficial as they can be used without an involvement of the user's hands. Other examples include Frey's CabBoots, which provide directional information to the user's feet [3], and Kojima's Pull-Navi, which exerts directional forces on the user's ears [6].

While these approaches cleverly leverage the human ability of perceiving directional information at various body sites, such devices may face acceptance issues and scalability hurdles when approaching everyday clothing practice: Integrating a directional haptic display into a mobile phone may hence be worth exploring as an alternative.

Directional Displays in Dynamic Environments

Another option for providing directional information to users is to augment the environment (e.g. through public displays) with the necessary cues. Such displays may be located on fixed screens, as investigated by Müller [8], or on location-aware signs, as in Kray's proposal [7], or on the floor, as in Rukzio's 'Rotating Compass' project [11]. Augmented environments are beneficial in terms of their unobtrusiveness: they are easy to ignore for users, if undesired, and they can, in many cases, be used in a hands-free fashion. At the same time, such types of display may remain unnoticed easily, and addressing information towards single, individual users can be problematic.

Physical Directional Cues in Handheld Devices

Mobile devices provide fruitful ground for navigation support – they allow for individual information display and are commonly accepted among users.

Recently, Amemiya proposed a inertia-based actuation system [1, 2], based on a rotatable linear accelerator. This system leverages on the asymmetry of human inertia perception, utilizing a cycling rhythm of abrupt, easily perceivable actuation into one direction, and a subtle (and thereby vanishing) movement into the other direction. Sakai's GyroCube [13] utilizes a torque-based system, which is suitable for three-dimensional directional actuation – such research provides insights into potential future ways of directional guidance. Other projects, such as Sahami's work on integrating multiple vibrators into one device [12], utilize the commonplace vibration actuators, being, even though mostly solitarily, available in many phones that are currently on the market. At the same time, inertia, torque and vibration may be perceived as intrusive by users – an alternative approach might be of benefit.

The Research Gap

The related work reviewed in this section points to a necessity for further research into non-intrusive, tactile wayfinding assistance. An approach of potential benefit may be the actuation of a handheld mobile device's physical properties, such as its distribution of weight, or its geometry. Recently, we proposed a set of new haptic displays for integration into mobile phone chassis: A shape-changing mobile [4] and a weight-shifting mobile [5]. In these studies, results indicated that users' estimations regarding the *intensity* of the weight shift or shape change were more error-prone than estimations regarding their *direction*. Therefore, the proposed display techniques may be particularly suitable for providing users with wayfinding cues.

To date, it has not been researched in how much these haptic displays may be suitable for mobile navigation, compared to each other, and compared to existing visual, GUI-based solutions. This paper reports a user study that seeks to shed light on this issue.

IMPLEMENTATION

Similar to earlier implementations [4, 5], the shape-changing device includes a motor that exerts a directional force onto a tilting plate on one of the device's sides (Fig. 1a), while the weight-shifting device includes a lead mass, mounted to a servo motor (Fig. 1b). Additionally, a gyroscope sensor was attached to the systems.

The shape-changing actuator measured 72mm x 72mm x 50mm, being able to extend one edge of its back plate by 3mm, resulting in a tilt angle of 5.5° towards this edge. The weight-shifting actuator measured 90mm x 90mm x 45mm and weighed 146g, including the internally moving mass (20g). The control condition, the visual system, consisted of a Sony Ericsson W880i mobile phone that was also attached to the gyroscope, displaying an arrow into the indicated direction. All components were connected to a nearby PC that controlled all stimuli during the experiment and recorded all user inputs.

USER STUDY

In the study, users were assessed in their ability to turn according to a directional cue given by the aforementioned handheld devices. We compared three types of display: Shape change-based, weight shift-based, and visual direction indication.

Users and Task

In three trials, 12 users (6f, 6m, Ø 31.3 yrs.) were seated in a rotatable office chair and handed one of the three devices. They were instructed to follow its directional cues, turning towards the indicated direction. Users were free to decide in which hand they would hold the apparatus.

As a simultaneous secondary task a traffic light was displayed on a nearby projection wall (Fig. 2). Users were instructed to press a key on a wireless presenter, which they held in their other hand, as soon as the traffic light switched from green, via yellow, to red. In a pre-test, the users' field of vision was tested; all users had a field of vision of at least 135°.

After a training session, users engaged in all three conditions (weight-based, shape-based, and visual), for 2-minute trials. The conditions were tested in pseudo-randomized order. In the shape change and weight shift conditions, the devices were masked with paper, as to avoid visual cues.

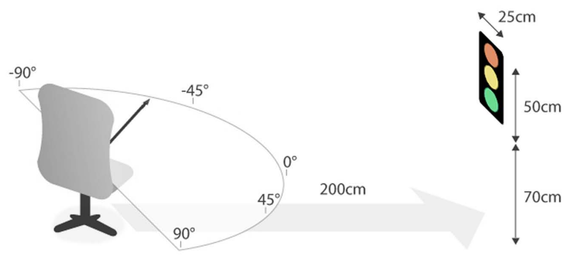

Fig. 2: User test setup, rotatable office chair and projected traffic light.

The measured values were *directional error* (accumulated over the duration of each trial, sampled every 0.5s), and the *reaction time* to the traffic light change.

It was hypothesized that users would perform worse in the secondary task in the visual display condition than in the weight shift-based and shape change-based conditions.

RESULTS

Using the shape change-based system, users followed the directional cues with a mean error of 57.56° (SD = 40.19°). As for the weight shift-based system, the mean error accumulated to 52.36° (SD = 39.80°), and 33.53° (SD = 34.62°) for the visual system (Fig. 3).

Here, we found significant differences in the users' performances between the three conditions ($F_{2,20}$ = 17.62, part. $?^2$ = .638, p = .000), and, through a Scheffé test, also between all three conditions in the aforementioned order (p = .000).

As for the secondary task, users required on average 1.29s (SD = 0.98s) in the 'visual display' condition, while they required, on average, 1.23s (SD = 1.18s) using the shape change-based system and 1.05s (SD = 0.72s) using the weight shift-based system (Fig. 4).

We also found a significant difference in these performances ($F_{2,22.18}$ = 2.99, part. $?^2$ = .213, p = .035). A Scheffé test revealed the 'weight-based' actuation to be significantly quicker than the 'visual' condition (p = .006) and also, yet only at a borderline significance niveau, quicker than the 'shape-based' variant (p = .051).

DISCUSSION

Interestingly, users either preferred, as they found it less stressful and thereby comforting, the 'clarity of the visual cues' or the 'subtlety of the haptic systems'.

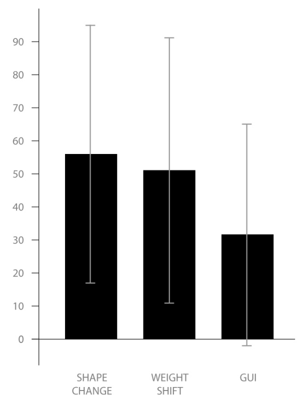

Fig. 3: Mean values (°) and standard deviation for *directional error* in shape change-based, weight shift-based and visual conditions.

The fact that we found differences between the visual variant and the proposed haptic displays, in terms of their accuracy and in favor of the visual condition, underlines that a visual display can have clear advantages over haptic displays, particularly in terms of accuracy. However, the mean error for all three proposed display techniques allows users to differentiate at least three directions: Left, right, and straight ahead. This might qualify all three display mechanisms to be suitable for haptic navigation tasks.

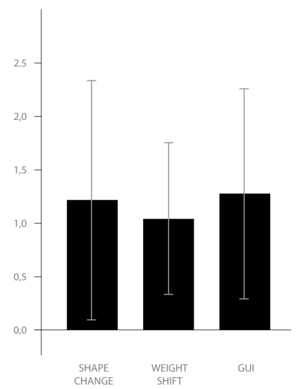

Fig. 4: Mean values (s) and standard deviation for *reaction time* in shape change-based, weight shift-based and visual conditions.

However, the differences in users' reaction times towards the traffic light projection indicate that a visual display may be inappropriate in mobile pedestrian navigation, and that a haptic version, be it weight-shifting or shape-changing, could offer a suitable alternative.

CONCLUSION

Walking navigation is a task that requires only few directional cues. Haptic displays utilizing weight shift and shape change may represent an elegant solution to provide users with such information in a non-intrusive way. Besides mobile navigation, such styles of display may provoke thought about novel ways of making information available to us.

OUTLOOK

As the study was conducted seatedly in an office chair in the lab, future studies will have to investigate the generalizability of the results, and how well the proposed mechanisms will work in actual street and traffic situations.

Further research in this area should investigate the factors that determine the accuracy at which the proposed haptic stimuli can be perceived. Such factors could, for instance, be the overall weight of the device and its contrast to the shifting weight on its inside, or, respectively, the size of the device and its contrast to the shape change that the actuation causes. Movement patterns may also turn out to be fruitful ground for future research, as quick changes in the device's distribution of weight or its geometry may be perceived more easily, while more subtle movements could be used as a means of ambient information display.

In the user study, users showed different strategies to determine the weight's position and the shape's tilting angle: They ran their fingers over the edges, slightly tilted the device, and also moved the device to get a feeling for the currently indicated direction. Researching these strategies in depth may provide valuable insights for future developments. If we can integrate interactive systems into our everyday spatial experience, leveraging on skills of the human hand, we may soon be able to interact with computers in rich and yet non-intrusive ways. These may be lessening cognitive burden and make the digital world more intuitively accessible.

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