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Evaluating the Effectiveness of Physical Shape-Change for In-pocket Mobile Device Notifications

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ABSTRACT

Audio and vibrotactile output are the standard mechanisms mobile devices use to attract their owner's attention. Yet in busy and noisy environments, or when the user is physically active, these channels sometimes fail. Recent work has explored the use of physical shape-change as an additional method for conveying notifications when the device is in-hand or viewable. However, we do not yet understand the effectiveness of physical shape-change as a method for communicating in-pocket notifications. This paper presents three robustly implemented, mobile-device sized shape-changing devices, and two user studies to evaluate their effectiveness at conveying notifications. The studies reveal that (1) different types and configurations of shape-change convey different levels of urgency and; (2) fast pulsing shape-changing notifications are missed less often and recognised more quickly than the standard slower vibration pulse rates of a mobile device.

Author Keywords

Mobile devices; notifications; shape-change;

ACM Classification Keywords

H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces—Haptic I/O.

INTRODUCTION

The increasing array of applications available for mobile devices has resulted in a steady rise in the number and frequency of notifications pushed to users. Some of these notifications are urgent (incoming phone calls, diary appointments), while others are less worthy of immediate attention (application updates, game progression). Missing high-priority notifications is at best annoying, but can also lead to more serious consequences.

Current mobile devices use audio and vibrotactile channels to attract the user's attention. Unfortunately, many scenarios arise where these two channels collectively fail to alert the user. Typically this happens in noisy and busy environments (where the user fails to hear the audio notification) and/or when physically active (failing to feel the vibrotactile notification). Shape-change is one alternative for providing notifications, for example Hemmert et al's backplane tapering for in-hand information transfer [5]; Gomes et al's display bending for ambient (visual) notifications [4] and; Horev's actuated pixel matrices [6].

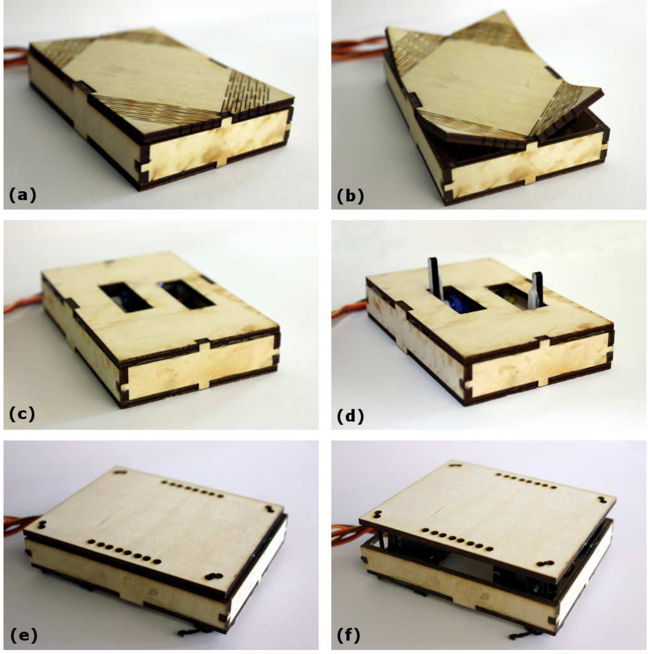

Figure 1: Shape-changing notification devices. (a) Inactive Corner Bending (b) Four corners bent (c) Inactive protrusion (d) Maximum protrusion (e) Inactive Volume Expansion (f) Full volume expansion

By augmenting audio feedback with shape-change (or, in silent mode, replacing vibrotactile feedback) mobile devices may provide more reliable event notifications. However, we do not yet understand the effectiveness of this new modality for attracting users' attention when the phone is in their trouser pockets (which is common among males [7]).

In this paper, we evaluate the effectiveness of three shape-changing devices for providing notifications. We implemented devices capable of delivering variable-urgency notifications while in the user's pocket (see Figure 1). Through two user studies we evaluate the efficiency of shape-change for attracting a user's attention, understand

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factors that influence urgency, and compare our devices against traditional techniques. The primary contributions of this paper are: 1) The development of three shape-changing devices; 2) A user study evaluating the efficiency and urgency conveyed by different configurations of these devices and; 3) A user study comparing shape-change to vibration for notifications in noisy environments.

RELATED WORK

Mobile Device Notifications

Audio and vibrotactile channels are typically used to provide notifications on mobile devices. Audio provides 'public', attention-demanding notifications that are often perceived as inappropriate [8]. Vibrotactile notifications provide a personal (effectively silent) channel to alert the user, with Tactons defining a structure for non-visual communication using time- and intensity-based patterns [2]. Visual-only cues are typically not used as a primary alerting function as they are likely to be missed if the display does not have the user's full attention [9].

Mobile Shape-Changing Interfaces

There is growing interest in developing mobile-sized shape-changing interfaces to provide an additional information channel to the user. To describe such interfaces, Coelho categorised technological properties [3], Rasmussen et al. high-level shape-change descriptors [10] and Roudaut et al. a low-level shape-describing framework [11].

Several point-designs in this space already exist. Hemmert using back-plane tapering [5] for in-hand information transfer finding users could estimate the angle between the device's front and back planes. Horev [6] used a matrix of actuated pixels to convey in-pocket dynamic information. Several examples also combine visual displays with mobile shape-change. Alexander et al. [1] employed display module tilt to add an additional information channel; Gomes et al. [4] demonstrated that flexible display bending can successfully convey ambient notifications (with whole device bending considered more urgent than corner bending); and Roudaut et al. describe a range of actuation implementation strategies [11]. We use these previous designs as inspiration for deriving three shape-changing devices suitable for in-pocket notifications.

SHAPE-CHANGING NOTIFICATION DEVICES

We constructed three shape-changing devices suitable for in-pocket testing. They cover a range of prototypes suggested in the literature and implement four of Rasmussen et al's types of shape-change [10] (noted in brackets):

Protrusion (form, texture)

The protrusion device is conceptually based on Horev's actuated pixels [6]. A small arm protrudes from the device having the effect of physically 'poking' the user (Figure 1c–1d). The urgency and intensity of notifications are configured by adjusting: the protrusion height (10mm or 15mm) and the type of protrusion (static, slow pulse, or fast pulse). In static protrusion, the arm moves immediately to its final position (taking 200ms); slow pulses move to the protruded position (200ms), pause for 500ms, return to the rest position (200ms) and pause for a further 500ms before repeating and; fast pulses continually move between protruded and rest position. These terms are also used to describe the movement in the remaining devices.

Volume Expansion (volume)

Based on Hemmert et al's phone-tapering [5], the back-plate expands from the base to increase the device's volume (Figure 1e–1f). In full expansion mode, the whole back-plate moves away from the device; in tapering mode, one end moves away from the base. The urgency and intensity of notifications are configured by adjusting: the operation mode (full expansion or tapering), the height of the expansion (5mm or 10mm), and the type of expansion (static, slow pulse, fast pulse).

Corner Bending (orientation, form, volume, texture)

Drawing from MorePhone [4], Morphees [11] and Tilt Displays [1], each of the four corners of the device can individually, or in any combination, bend away from the base's corner (see Figure 1a–1b). Notifications are configured by adjusting: the number of corners actuating (1–4), the tip of the bend's height (8mm or 12mm), and the type of movement (static, slow pulse, fast pulse).

Our devices were constructed using laser cut 3mm wood, actuated by servo-motors, and controlled by an Arduino microcontroller. They were 70mm (W) × 105mm (L) × 20mm (H), approximately the size of a mobile device, meaning they could easily fit into participants' pockets (Volume Expansion was slightly larger, W = 85mm).

USER-STUDY 1: EVALUATING THE EFFICIENCY AND URGENCY OF SHAPE-CHANGING NOTIFICATIONS

To understand the influence of device configuration, we aimed to: (1) Determine the efficiency (recognition time, missed notifications) of in-pocket shape-change to gain the user's attention and; (2) Understand the urgency afforded by different types and configurations of shape-change.

Experimental Task

Tasks are conducted with one of the devices placed into the participant's preferred front trouser pocket with the shape-changing components facing their body. A notification on the device is randomly triggered within a 4sec window and the participant presses a physical button held in their dominant hand when they feel the device move, stopping a timer. The notification lasts for 10sec; if it's not recognised within this time it is deemed 'missed'. The participants then provide an urgency rating for that notification (1 = Not at all urgent, 5 = Very Urgent). If participants fail to recognise the notification within 10sec it is deemed 'missed' and the next task is then attempted.

Experimental Setup

We conducted a within-subjects study where each participant completed tasks with all three devices (previously described) in a variety of device-specific configurations. This allows us to form a greater understanding of the individual devices. The configurations tested were:

- Corner Bending: *number of corners* (1, 2, 3, 4), *expansion height* (8mm, 12mm) and *corner movement type* (static, slow, fast).
- Protrusion: *protrusion height* (10mm, 15mm) and *protrusion movement type* (static, slow, fast).
- Volume Expansion: *expansion type* (full expansion, tapered expansion), *expansion height* (5mm, 10mm) and *expansion movement type* (static, slow, fast).

To assess only the effectiveness of the notifications, participants stood still and wore headphones playing white-noise to avoid recognition through sound made by the device's servo motors. Participants used the devices in the above listed order, testing all possible configurations.

Participants

Sixteen volunteer participants (6 female, 10 male) between the ages of 22 and 33 (mean 24 years) took part in the study. Half of the participants wore jeans and the other half looser pants. They placed the devices in their preferred front trouser pocket: 10 in the left and 6 in the right.

Results

Corner Bending

Participants missed 33 of the 384 notifications. All occurred during the 8mm bending for a variety of corners and movement types. An ANOVA identified a significant difference in response time by factor *number of corners* ($F_{3,45} = 8.12$, $p < 0.01$). Bonferroni-corrected paired t-tests (evaluated at $\alpha = 0.002$) showed differences between corners (slowest listed first): 1 & 2 ($t(95) = 5.36$, $p < 0.001$), 1 & 3 ($t(95) = 3.54$, $p < 0.001$), and 1 & 4 ($t(95) = 5.31$, $p < 0.001$).

The larger 12mm corner expansion was recognised significantly faster (1.5sec) than 8mm (1.7sec, $F_{1,15} = 14.22$, $p < 0.05$). There was also a significant effect of movement type ($F_{2,30} = 93.77$, $p < 0.01$). A post-hoc Tukey test found an HSD of 665ms ($\alpha = 0.01$) showing slow pulsing movement (2.2sec) to take significantly longer for recognition than static (1.3sec) and fast pulsing movement (1.3sec).

Participants' urgency ratings did not show a difference between the number of corners used, but showed a significant difference between the larger 12mm extrusion (mean 4.0) and the smaller 8mm extrusion (mean 2.0, $\chi^2 = 178.3$, $p < 0.01$). Movement type also significantly impacted on urgency, with static movement least urgent (mean 2.5), followed by slow pulsing movement (3.0) and fast pulsing movement (3.6, $\chi^2 = 113.08$, $p < 0.01$).

Overall, the corner bending device effectively communicates urgent notifications using four corners, with a large extrusion in a fast pulsing manner. Using a small bend extrusion leads to missed notifications.

Protrusion

Participants recognised all 96 notifications from this device. ANOVA confirmed that the larger 15mm protrusions were recognised significantly faster (1.4sec) than the smaller 10mm protrusions (1.6sec, $F_{1, 15} = 6.86$, $p < 0.05$). There was a further significant difference based on protrusion type ($F_{2, 30} = 93.20$, $p < 0.001$). A post-hoc Tukey test gave an HSD of 338ms ($\alpha = 0.01$) indicating slow pulsing (2.1sec) is significantly slower than static (1.3sec) and fast pulses (1.2sec). There was no interaction between protrusion and speed. Participants' urgency rankings showed both high-speed pulses ($\chi^2 = 9.95$, $p < 0.05$) and larger protrusions ($\chi^2 = 46.02$, $p < 0.001$) to have higher urgency ratings.

Overall, the protrusion device creates reliable notifications, with low-urgency transmitted using small protrusions in a static position and high-urgency using high-frequency pulses of large protrusions.

Volume Expansion

In total, participants only missed 2 of the 192 notifications using this device. There was no significant difference in response time between full expansion and tapered expansion. An ANOVA confirmed 10mm expansion was recognised more quickly (1.5sec) than 5mm expansion (1.6sec, $F_{1,15} = 7.11$, $p < 0.05$). There was a significant different in recognition time based on movement type ($F_{2,30} = 145.43$, $p < 0.01$). A post-hoc Tukey test revealed an HSD of 359ms ($\alpha = 0.01$), indicating slow pulsing (2.1sec) was significantly slower than static (1.3sec) and fast pulsing (1.3sec). There were no further time-based interaction effects.

Participants' urgency rankings showed full expansion (mean 3.9) to be more urgent than tapered expansion (mean 3.2, $\chi^2 = 23.3$, $p < 0.01$); 10mm expansion (mean 4.25) more urgent than 5mm expansion (mean 2.8, $\chi^2 = 68.3$, $p < 0.01$); and urgency increasing from static (mean 2.8) to slow pulsing (mean 3.5) to fast pulsing (mean 4.25, $\chi^2 = 81.0$, $p < 0.01$).

Overall, Volume Expansion creates reliable notifications, with high-urgency transmitted using fast-pulsing, large-depth, full expansion. Less urgent notifications can use static, tapered expansion with a shallower depth.

Summary

All of the devices were successfully able to convey notifications, with different configurations conveying differing urgency. Greater protrusion and fast pulse rates created more quickly recognised and higher urgency notifications. Participants indicated their overall preferences as: Volume Expansion (8), Protrusion (7), and Corner Bending (1).

USER-STUDY 2: COMPARING SHAPE-CHANGE TO VIBRO-TACTILE FEEDBACK

We believe that physical shape-change notifications will be most effective when audio is not available (when in 'silent' mode, or in noisy and busy environments). To validate this assumption and to compare to the status-quo of vibrotactile feedback (the current best method for communicating non-audio, non-visual mobile notifications), we conducted a study where participants were walking and unable to hear the audio from the device.

Notification Devices and Configurations

We choose the most efficient notification configuration of each of our three devices to compare with the vibrotactile feedback on a mobile device. The devices were as follows: (1) Protrusion, 15mm, fast pulses, (2) Volume Expansion, full expansion, 10mm, fast pulses, (3) Corner Bending, four corners, 12mm, fast pulses (4) Samsung Galaxy S3 default vibration mode (1.6sec pulse/pause cycle).

Experimental Setup and Participants

We conducted a within-subjects study with a single independent variable, *device,* with the four levels described above. Notifications were provided to simulate a phone call, so lasted for 20sec. To simulate a noisy/busy environment, users walked in a figure-of-eight with marker distances 2.3m apart and wore headphones playing white noise. Participants pressed a physical button whenever they felt a notification from the device in their pocket. Each device provided five notifications, with the order counterbalanced.

Ten participants (4 female, 6 male) between the ages of 22 and 27 (mean 24) took part in the study. Three wore tight jeans and the remainder wore looser pants. Half placed the devices in their right front pocket, the rest in the front left.

Results

Participants missed 25 of the 200 notifications (12.5%). 21of the missed notifications were from the mobile phone in vibration mode, the remainder from the Corner Bending device. There was a significant difference in response time between devices ($F_{3,27} = 24.471$, $p < 0.01$); a post-hoc Tukey test showed an HSD of 2.2sec ($\alpha = 0.01$), showing the vibration alert (6.3sec) was recognised significantly slower than the three shape-changing devices (Protrusion = 1.4sec, Volume Expansion = 1.7sec, Corner Bending = 2.0sec). There were no other differences between pairs.

DISCUSSION AND LIMITATIONS

Our user studies have established that in-pocket shape-changing notifications are effective, complementing previous findings on their use as ambient notifications [4]. In real deployment, these devices should be augmented with audio output, allowing notifications to still be received when the device is out of sight. The biggest limitation to deployment of such devices is power. Our shape-changing devices with multiple motors under load (i.e. when in a tight pocket) can require peak power of over 1A.

While we were able to simulate a noisy/busy environment with physical movement and white noise, a true 'in the wild' study is still required to prove their effectiveness over longer periods of time and under real-use conditions (including a variety of clothing styles). Further investigation is also needed to understand the influence of pulse rate when comparing vibrotactile and shape-change notifications.

CONCLUSION

We implemented three shape-changing devices and conducted two user studies to evaluate their effectiveness for in-pocket notifications. Shape-change can successfully alert the user and be configured to output a range of variable-urgency notifications. In busy/noisy environments, shape-change provides alerts that are missed less often and recognised faster than the traditional vibration of a mobile phone.

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