Multi-Level Interaction with an LED-Matrix Edge Display

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Abstract
Interaction with mobile devices currently requires close engagement with them. For example, users need to pick them up and unlock them, just to check whether the last notification was for an urgent message. But such close engagement is not always desirable, e.g., when working on a project with the phone just laying around on the table. Instead, we explore around-device interactions to bring up and control notifications. As users get closer to the device, more information is revealed and additional input options become available. This allows users to control how much they want to engage with the device. For feedback, we use a custom LED-matrix display prototype on the edge of the device. This allows for coarse, but bright, notifications in the periphery of attention, but scales up to allow for slightly higher resolution feedback as well.

Author Keywords
Auxiliary display; casual interaction; proxemics; dot-matrix display; LEDs; edge display

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces.

Introduction

Phones are often lying around on tables [7]. Users might, e.g., arrive at their offices in the morning and place their phone down in one corner of their desk. While working, they might give the phone an occasional glance to check whether a notification has come in or when they hear an alarm or audio notification. But gathering additional information on the just received notification requires users to break their current work and devote close attention to their phone. They commonly need to reach for the phone, pick it up, unlock it, and possibly navigate through an application to get all the information they need.

But such close engagement can be problematic in some situations, e.g., when interaction with the device needs to be short. Instead, users might benefit from a way to more *casually* interact with the device [6]. In casual interaction, users can scale their engagement: picking close interaction only when more control is needed, but falling back to coarse interaction when what they need is less complicated. For example, just checking whether there is any notification should be possible with very little effort. If users need additional information, such as the number of waiting emails or the subjects of those emails, they could instead opt for closer engagement with the device. By giving users the choice of how much they need from the device in any given situation, we can enable them to only need to expend effort when really required to.

We present a prototype for interaction with notifications at different levels of engagement. By combining a distance sensor with a dot-matrix display and mounting them on the edge of a mobile device, we enable input and output in the periphery. Using individual LEDs for the display allows for sufficient brightness to make this display noticeable in the corner of the eye and using the edge ensures readability at larger distances to the device. We have designed several interaction mappings for different content sources to make use of the interaction zones in front of the device—enabling fine control close by and coarse control further away. In an evaluation, we first validate the concept in a group discussion phase. We furthermore simulate a common office scenario by giving individual participants a primary task and letting them interact with the prototype in their periphery. Our results show that participants could interact successfully and effectively.

Related Work

Augmenting the edge of mobile devices with LEDs has been previously explored by Qin et al. [8]. Instead of a single row of LEDs, we add a whole dot-matrix of LEDs, which allows us to display more detailed graphics while still maintaining the brightness levels achievable with individual LEDs.

Our prototype uses a proximity sensor to track the users' hands. This kind of sensor was previously used for around-device interactions in projects such as HoverFlow [3], or SideSight [1]. In both, our device and SideSight, the sensors are mounted on the edge. But where SideSight uses this input for control of on-screen content, we use around-device input as a lower engagement interaction channel.

We added an extra sensor below a phone to emulate future devices with built-in distance sensors on the edge. A different approach to this problem was taken in Surround-See, where a spherical lens allows the phone camera to track what is happening around the phone [9]. Such optical tracking would enable more fine-grained control and could also allow to, e.g., adapt the interface based on whether the current setting is private or public.

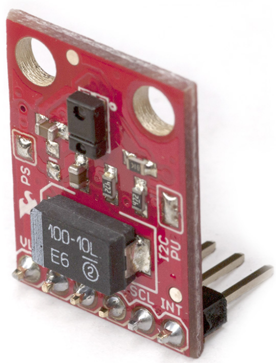

Figure 1: In our prototype, we use an Avago APDS-9960 distance and gesture sensor to measure how far the user's hand is away from the device.

Similar to our concept of varying control in interaction with a phone, previous work has explored changes in granularity for the smartwatch. Pasquero et al., e.g., discuss how users can get a coarse information fast and uncover additional details by prolonged interaction and additional user effort [4]. Similarly, Pearson et al., include granularity of displayed information as one dimension in their concept of smartwatches as public displays [5].

Prototype

Our prototype is designed as a phone attachment (see Figure 2). It contains a dot-matrix display and a proximity sensor (see Figure 1)—emulating future devices that could have such capabilities build into their edges. Samsung already builds some mobiles in their *Galaxy Edge* series with a display that slightly slopes over one edge. While our prototype contains a phone, its addition is purely cosmetic and it is not used for any interaction.

Figure 2: Our prototype consists of a dot-matrix LED display and a proximity sensor mounted underneath a phone.

We use an LED dot-matrix display to render visual feedback. This is an extension of previous work mounting strips of LEDs around a phone [8]. Using individual LEDs allows for more brightness than a backlight and aids perception of the display when it is in the periphery.

Because we could not get an LED dot-matrix display in a suitable form factor for an edge display, we reroute the light to allow for a custom pixel arrangement. As shown in Figure 3, this is achieved with glass fibers that connect individual LEDs with our final pixel locations on the edge of the device. This requires space underneath the device (see Figure 4), but allows for a height reduction of the visible part of the prototype. We used slightly larger glass fibers for ease of prototyping, but future iterations could use much finer fibers for a further reduction in height.

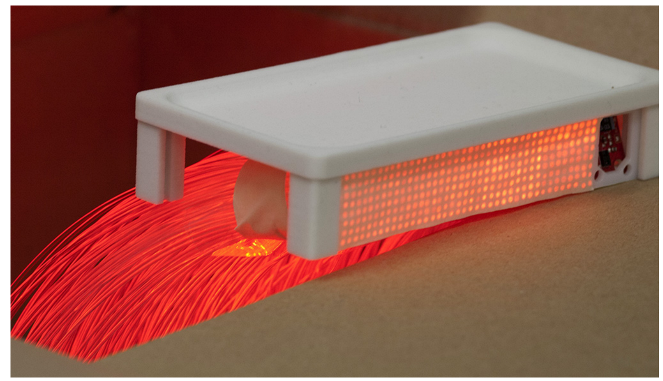

Figure 3: To achieve a higher dot density, we redirect the light from the LEDs via optical fibers. The dot-matrix display driving the final assembly sits underneath the prototype. A total of 320 strands of glass fiber connect the individual pixels. The visible display arranges the LEDs' dots in a 40×8 grid, held in place by a laser-cut acrylic stencil.

The display is driven by an Arduino microcontroller, which also collects sensor readings from the proximity sensor. However, the Arduino merely acts as a relay, passing sensor readings to a laptop, which renders the next frame for the Arduino to show on the display. This enabled faster prototyping than running all code on the Arduino itself.

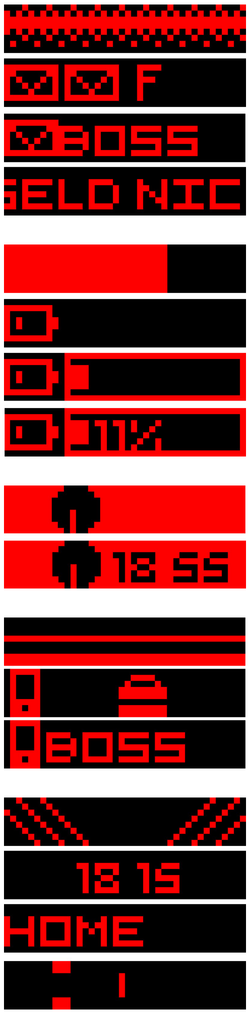

Figure 5: Display design for different notifications: messages, battery, clock, calls, alarm.

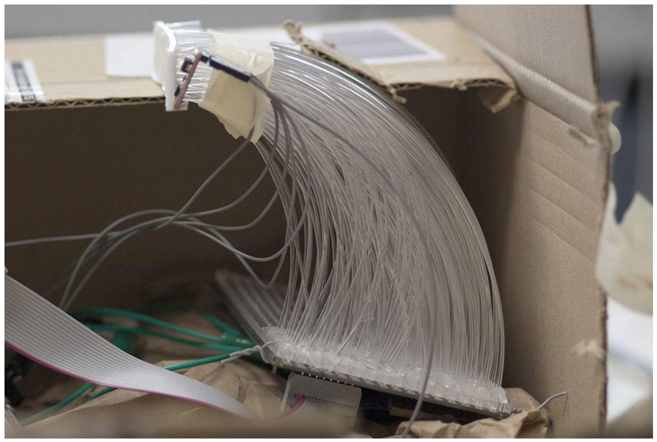

Figure 4: Glass fibers reroute the light from a large LED dot-matrix below the device to our edge display. This allows prototyping with denser LED grids than readily available ones.

Interaction Design

We designed interactions for several different notifications: incoming messages, battery level, clock, calls, and alarms (see also Figure 5). Interaction is split into four different levels, where level 0 is the default level when no interaction with the device is taking place. With increasing engagement, as the user comes closer to the device, the level increases. When no notification is active, the device defaults to clock mode and displays the time as the user approaches. Granularity here progresses from just showing a coarse watch to showing the exact time. Other modes become active once a corresponding event is triggered, such as a message coming in, an alarm triggering, or the battery depleting to a low level. In such an event, the device first plays back a notification-dependent animated icon (e.g., moving diagonal lines for the alarm). This informs the user about the type of upcoming notification and grabs attention.

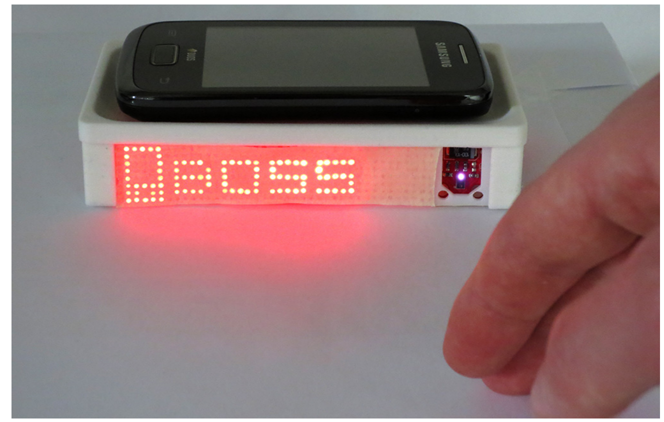

Figure 6: In call mode, users can reveal additional information about the caller by engaging more with the device. Here the name of the caller, the user's boss, is shown and the user can then decide whether to dismiss the call or accept it.

Users can delete notifications by moving their hand close to the device and holding it in position for a brief moment. This activated deletion mode where users can confirm the deletion by swiping sideways. At this point, they can also move their hand back to cancel the deletion. This, e.g., allows dismissing calls without picking up the phone (see Figure 6). When dismissing an alarm, we added an additional challenge to the deletion. Instead of just holding in place then swiping, users have to complete a short minigame. Here they have to align a bar with markings by moving their hand to the respective distance from the device. This has to be done three times (the markings move to random positions for each challenge) to finally dismiss the alarm. We made this dismissal more challenging to experiment with forcing more engagement for more impactful interactions. A user might, e.g., commonly ignore alarms and could use this dismissal mode to force herself to give alarms more attention.

Evaluation

We ran an evaluation to investigate how well the concept and prototype would be received by potential users. The evaluation was split in two phases: in an initial group phase, groups of three participants discussed the concept, while in a second phase, participants used the prototype individually. Overall, 9 participants (all male, age 23–34, $\bar{x} = 26.7$, $\sigma = 3.8$) took part in the study and were assigned to three different groups.

We explained the concept of using proximity as input for different levels of control to all participants before they engaged in their group discussions. We did not show the prototype and hence our concrete design to participants at this point, but instead tried to determine whether their designs would align with our own. In their group, participants then discussed the concept among themselves and tried to come up with possible mappings and applications for it.

All groups considered connecting to the Android notification center as source for content. One concept discussed was levels of display for time, showing only the time, only the date, or both, depending on the level of engagement. Group one brought up that this functionality could be used to control system settings such as volume in addition to showing notifications. Group two came up with a concept for message browsing. Here users can move from a coarse level, just showing message counts, to the inbox level, where message titles scroll through. Moving one level up in control, users could peek at individual messages. Overall, we saw our design concept validated by the group discussions. The idea of *"drilling into"* content was regularly brought up.

Figure 7: We asked participants to sit down at a computer and copy a text from a webpage to a document. The prototype was located in the periphery of their visual field when copying the text and occasionally displayed notifications.

After the group phase, we had participants interact with the prototype individually. We showed and explained every function of the prototype to them, but left out a description for how to dismiss the alarm to see how they would react to that. We then asked participants to sit down at a computer and copy a text from a webpage to a document with the keyboard. The prototype was placed next to them, so it would still be visible in their periphery (see Figure 7). During their engagement with the primary task, the prototype would occasionally display a notification which the participants reacted to. Afterwards, we asked them to rate their experience.

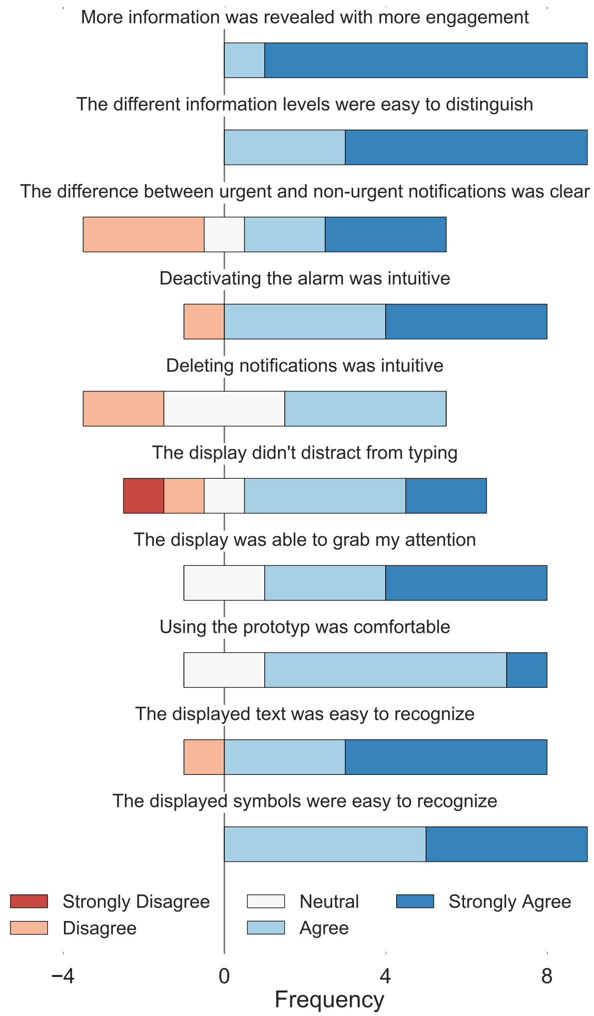

Figure 8: After participants interacted with the prototype, in a situation where they were engaged with a different primary task, we asked them to rate their experience on a 5-point Likert scale. Participants mostly rated the system favorably.

All participants were able to successfully react to and interact with the notifications. In case of the alarm, which we did not explain to them, they were slightly surprised, but figured out how to dismiss it on their own. All but one participant could see himself using such a device in their day to day life. Participants gave mostly positive responses (see Figure 8) when asked to rate several statements. Asked for possible improvements, participants noted that the text scrolling speed could be faster, allowing them to skim more notifications in a given time. They also stated that color would be a great improvement, as it would make it easier to distinguish notification sources (e.g., blue for Facebook).

Discussion

Results from the evaluation were overall encouraging. The group discussion confirmed our design while each user was also able to effectively interact with the device. Users also rated interaction and concept favorably and indicated they would be open to using such a system in a future phone. We also found that interactions are discoverable. Even missing instructions on alarm dismissal, all participants were able to figure out how to react. This is likely due to the small gesture set and the clear mapping of distance to engagement. Discoverability could be further improved through feedback on where gesturing is expected [2].

Users positive view on the concept itself might be due to how they themselves use their devices. Seven of the nine participants stated that they place their phones on the table when sitting down to, e.g., work. This indicates that having the phone available for secondary interactions, such as checking notifications, is already common. Supporting this behavior by allowing users to scale back how much engagement they need to devote to the secondary task might thus be worthwhile.

Conclusion

We have presented a concept and design for a system that allows users to scale their level of interaction with notifications. By augmenting the edge of a mobile device that is lying around, users are enabled to interact with it without needing to pick the device up. This enables more casual interactions and also empowers users to only expend as much effort as they need: if they only need coarse information, they can get it with a brief and further away interaction. Only when they require additional details do they need to further approach the device.

While our prototype is still quite large, we think such capabilities might come to future mobiles. We already see phones with one curved edge display and progress in display technology, particularly in OLEDs, could allow for much more flexible display placement. More powerful OLED technology would also be able to achieve the level of brightness we get from using individual LEDs. Integrating sensing for around-device interaction is a different challenge. However, our concept does not require precise finger or hand tracking and very coarse distance estimation would already be sufficient to enable the distance dependent interaction levels presented here.

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