Managing Smartwatch Notifications through Filtering and Ambient Illumination

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Abstract
The ongoing development of smart, wearable devices opens up a new range of possibilities with respect to human-computer interaction. Recent research has confirmed that smartwatches are primarily used to visualize notifications. However, the limited screen size is at odds with the ever-growing amount of information. Often, explicit interaction is needed to get an overview on the currently available information. We provide an aggregation/filtering approach as well as several displaying concepts based on a self-built, power-efficient smartwatch prototype with twelve full-color LEDs around a low-resolution display. In a user study with twelve participants, we evaluated our concepts, and we conclude with guidelines that could easily be applied to today's smartwatches to provide more expressive notification systems.

Author Keywords
Notifications; smartwatch; LED; notification filtering

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
In the last 2-3 years, the importance of smart wrist-worn devices for the mass market has rapidly increased. Besides fitness trackers, more sophisticated devices such as

the Apple Watch or those of the Samsung Gear series are especially responsible for this development. Although the on-going miniaturization of components provides more and more powerful devices with more advanced in- and output modalities, it is questionable whether people can benefit from this development. In addition, the battery service life of these devices is still problematic, not least because of their computational power and their displays.

Apart from displaying the time, it was shown smartwatches are used primarily to visualize notifications [11]. The wrist has turned out to be an optimal location for users to notice changes in an effective and quick manner [1, 4], so a smartwatch can be considered as an ideal device for displaying notifications. Shirazi and Henze [12] analyzed notifications shown on different mobile devices and found that whether or not a notification should be displayed not only depends on its importance, but also on the respective output device.

However, comparatively little research has been done to enhance how notifications are presented and how people interact with them. Currently, there are no concepts in place for prioritizing/filtering out (types of) notifications; they are typically shown one by one, and switching between multiple notifications requires explicit interaction. While more sophisticated interaction techniques are under investigation (e.g. [7, 10]), current devices typically use simple gestural input (e.g. turning one's wrist) or require the use of the other hand either for touch input or utilizing additional mechanical input controls [6]. Although simple gestural input may seem favorable, the risk of false positives should not be underestimated, resulting in the need for a delimiter gesture such as [8]. In our work, we try to target the problem from another perspective: Instead of improving the handling of (possibly unnecessary) notifications, we aim at reducing the overall amount and improve the way they are presented. We contribute to this field of research in two ways: We developed a custom-built, energy-efficient smartwatch prototype that focuses on the current main use of smartwatches, i.e. displaying time as well as notifications through a low-resolution display and a frame consisting of twelve full-color LEDs. Based on our prototype, we carried out a user study to evaluate our concepts, i.e. filtering/prioritizing incoming notifications as well as varying visualizations of them. Based on our results, we present guidelines for notification presentation that could easily be transferred to current off-the-shelf devices.

Related Work

While today's commercial smartwatches typically feature high-resolution LCD, OLED or eInk displays, scientific prototypes also examined other output concepts. Hwang et al. [5] developed a system providing rich tactile feedback by simultaneously using vibration motors of different interconnected devices and worked out nine different tactile patterns. Lee and Starner evaluated wrist-worn wearable tactile displays (WTDs) [9], which should provide a better perception accuracy than regular smartphones. Instead of forcing the user to take out his smartphone to read an incoming notification, three vibration motors and 24 vibrating patterns were used to convey information.

Fortmann et al. [2] examined the integration of LEDs into jewelry to discreetly display simple information about notifications – a concept that Samsung also picked-up recently with its new lifestyle band Charm[1]. Harrison et al. presented sets of light behaviors, i.e. ways for devices to communicate their state using light and informational states [3]. The authors showed that point light sources can convey more information than expected.

[1] http://bit.ly/24Pn5pA, last retrieved June 24th, 2016

Figure 1: Smartwatch prototype

Xu and Lyons [13] proposed a design for ordinary watches which are augmented with four LEDs as icons for phone, calendar, messages and one for other applications. For messages, five colors could be assigned to different people to have the LED indicate who sent the message. To show the number of missed calls, the phone icon is pulsed for the respective number of times. In their second prototype, Xu and Lyons attached an RGB LED circle behind a translucent watch face to support a larger range of applications.

We continue in the same direction as Xu and Lyons, but we not only consider the visualization possibilities on a wrist-worn device, but also address the topic of pre-filtering and aggregating notifications to simplify notification handling and help the wearer to distinguish important notifications which really require interaction. To assess the filtering mechanism as well as different visualization approaches, we conducted a user study with twelve participants based on our self-built prototype.

Concept and Implementation

Typically, notifications are arranged in a timeline and consist of a title and a content text, often accompanied by the icon of the respective application. Although we focus on Android as the operating system here, our concepts are easily transferable to all kinds of notification systems. Starting with Android 5.0, one can completely block notifications for a given app, allow the system to show all notifications, or select a range of applications which may send notifications even when the device is put in a "do not disturb" mode. Hence, fine-grained filtering, i.e. by person or message content, is not possible. Furthermore, no centralized notification settings are available, but each app could provide its own settings. As a consequence, no filter like "Only show notifications with high priority on my smartwatch" is possible, although such a priority value is currently available.

To solve these shortcomings, we provide a notification filter concept based on preconditions and effects. If the preconditions are fulfilled, the filter matches and its effects are applied. The preconditions contain a target app (or a wildcard to match all apps) and can contain further criteria such as a minimal priority or a string to match against. Effects are visual or tactile cues created by the smartwatch or the mobile phone when a filter matches. This opens up a broad range of possible actions, such as vibro-tactile patterns, showing something on the display, or activating LEDs.

In our hardware prototype, we focus on visual output with a low-resolution display and twelve RGB LEDs arranged around it. This setup gives us the possibility to not only rely on temporal patterns, like blink patterns, but also to use spatial patterns, such as different LED positions, as well as combinations of both. Also, different LED colors and light intensities can be used to differentiate several states and to convey more information. As an example, consider three incoming emails: A possible visualization consists of three successive LEDs, while their color could imply the type (email) or represent the sender(s). Alternatively, a single LED could be activated steadily and only be turned off and on again three times within a short time interval. A steadily illuminated LED at the three o'clock position could also represent the number of emails.

To test our filtering and visualization concepts, we developed a smartwatch prototype (see Figure 1) as well as a smartphone application. Our hardware prototype features twelve RGB LEDs placed in a clock-face manner around a low-power black-and-white display; it can connect to the smartphone via Bluetooth. The printed circuit board is self-designed and assembled with the goal to achieve a prototype of similar size to a state-of-the-art smartwatch (size of the 3D-printed housing is $4 \times 4 \times 1$ cm).

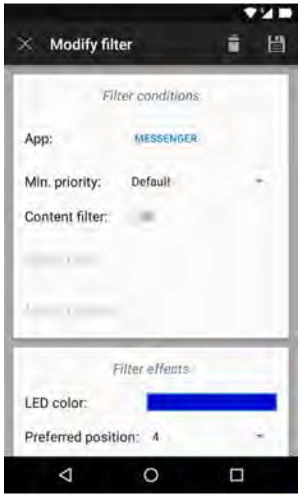

Figure 2: Filter settings

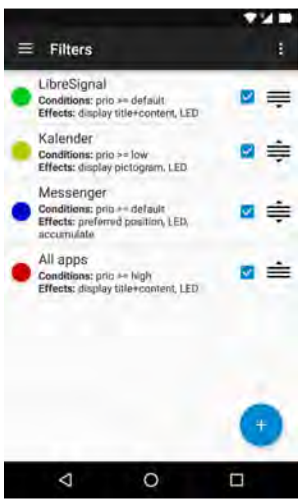

Figure 3: Filter list / priority

The smartphone application consists of two background services (for Bluetooth communication and notification filtering) and a GUI as status indicator and control interface. For the filter effects, LED color, LED position and blinking frequency can be defined (see Figure 2). It can further be defined whether the display should show information such as the notification's title. As notifications could possibly be matched by several filters, filters can be ordered by priority, i.e. the first matching filter is applied and all following filters are not considered (see Figure 3). To ease the filter creation process, the *Unfiltered messages view* displays the ten most recent non-matching notifications, which can easily be used as a template to create a new filter.

User Study

We recruited twelve participants (three female) aged between 21 and 38 years (average age 25 years) all of whom had a background in computer science and prior experience with touch-enabled devices. Five of the participants also had prior experiences with smart wearable devices, i.e. body-worn devices that are able to display notifications.

Notification filter/prioritization system

The aim of the first part of the user study was to assess our concept of filtering notifications. We thereby wanted to analyze whether the concept is understood and how its usability is perceived. We started with a pre-session questionnaire to assess the participants' background w.r.t. smartwatches and notifications, continued with guided practical tasks and concluded with a post-session questionnaire to analyze the usefulness of our concept and the participants' subjective opinion. We prepared 14 tasks that led the participants through the functionality of our filtering system and the prototype. To give a specific example, consider the following task "*Set up a filter for a new notification, filter by content, set LED color to green and make it blink fast*". In the post-evaluation questionnaire, we asked questions from the After Scenario Questionnaire and further questions directly related to the completed tasks. To conclude the user study, the participant was given the System Usability Scale (SUS) questionnaire to assess usability aspects.

Results

The pre-session questionnaire revealed that all but two participants were interested in having a clearer way of displaying multiple notifications. The participants mentioned ideas such as combining multiple notifications from one app, or aggregation based on the sender; prioritization was also one of the desired extensions. All but one participant agreed that meta-information such as the sender's name is already sufficient to estimate the relevance of a notification.

Considering smartwatches as an extension to smartphones w.r.t. notifications, eight people stated that when using a smartwatch, there is no need to retrieve the phone from a pocket to read notifications and further, it is possible to retrieve notifications in a more discreet way. All five smartwatch owners tended to be rather unsatisfied with how their watches deal with showing multiple notifications and were interested in a better way to represent notifications on their smartwatch. In contrast to notifications on smartphones, four out of the five smartwatch owners found it to be harder to directly determine at a glance whether the notifications on their watch are important. Three candidates blamed the fact that the smartwatches do not show an overview of all notifications, so that they "need to swipe back and forth to see the different notifcations".

Based on the post-session questionnaire, all participants were satisfied with the ease of completing the scenarios as well as the required task completion times. On a scale from -3 (not satisfied at all) to +3 (completely satisfied), the highest rating was achieved eight (min=+1, max=+3) and seven

S1: Five new emails
+ Five LEDs of the same color.
+ One LED is active, then turned off and on five times.

S2: One message by Alice and one by Bob
+ Two LEDs with different color indicating the person.

S3: One email and one instant message
+ Two LEDs with different color depending on the application.

S4: Showing the time – hours and minutes
+ Differently colored arcs for hours and minutes.
+ Two differently colored LEDs for hours and minutes.

S5: Alarm in ten minutes
+ One LED at 10 minutes (2h).
+ Two consecutive LEDs.

S6: Important interruption, for example for a call
+ All LEDs are blinking.

S7: Alarm in ten minutes and receiving a call
+ One LED at 10 minutes and a chaser overriding it.

S8: Progress of a download
+ An arc as percentage indicator; the full circle means 100%.

times (min=+2, max=+3), respectively (median=+3 for both questions). Regarding understanding of the concept, eleven participants gave the highest rating, whereas the last one assigned +2. All participants liked the concept (8× +3; 4× +2, median=+3) and complimented the straightforward way to create and modify filters as well as the immediate reaction of the prototype to changes made in the app. Several participants commented that they like that the filters allow them to give notifications a more personal note and that they have the feeling of having greater influence on the messages they receive. The overall usability (assessed with the SUS questionnaire) was rated with an average score of 87.3 (median 87.5).

LED frame visualizations
For the second part of our study, the participants first got a brief introduction into the possibilities of the LED frame, namely displaying RGB colors, blinking with different frequencies, coarse fading and pulsing. After that, a questionnaire consisting of two tasks was handed out. In the first task, eight scenarios, e.g. an incoming notification on the phone, were presented, for which the participant should propose their ideal visual representation on the LED frame. In the second task, several example proposals for each scenario were given and the participant had to rank them by their adequacy. Finally, the participants had to insert their proposals in the ranking. This way, we hoped to get an idea of good visualizations using a multi-color LED frame.

Results
From the most preferred visualizations (see sidebar), one can see that participants were more comfortable with LEDs displaying discrete numbers instead of only a rough estimate. In contrast, higher numbers could be displayed by assuming that each LED stands for a multiple of a certain number, e.g. the LED at the five minute position would represent the number 5. Another possibility would be to make use of the "round" nature of the LED frame and use it as a percentage indicator (cf. **S8**). Participants commented that when displaying the exact number is irrelevant, using properties like light intensity or blink frequency could be appropriate. However, a change in the light intensity was named only infrequently for notifications with lower priority and if so, the blink frequency was required to be rather low to not distract. Several participants mentioned that they perceive fading as less distracting and that it could be used to display persistent information, while blinking was perceived as more aggressive, and appropriate only for actions requiring interaction (cf. **S6**). When events need to be depicted in parallel, e.g. in **S7**, the participants accepted that important information could (temporarily) override other information. Whenever more than one person or app was involved, participants preferred using different colors over different positions to distinguish between them (**S2** and **S3**).

For most scenarios, the proposals the participants came up with earlier, strongly matched the later presented visualizations. For example, in scenario **S1**, seven of the participants suggested lighting up five LEDs in a row. In comparison, for **S4** and **S5**, participants proposed different approaches. For them, having 5-minute steps was not precise enough, so they suggested adding light intensities, colors or increasing fading speeds for the LEDs.

Guidelines for Smartwatch Notification Systems
Based on the findings of the user study and the participants' comments, we establish the following guidelines:

- A mechanism to filter unnecessary notifications on smartwatches should be provided.
- Users should be able to define in what way (audio, vibration, visual) they want to be notified.
- Notifications should be visible at a glance.

- Notifications should be filterable by person.
- Discrete numbers are preferred over rough estimates, especially for small numbers.
- Symbols and colors should be preferred over text.
- Similar notifications should be grouped.

Conclusion and Future Work

Our results show that users prefer to have more control over whether and how notifications are displayed. Hence, we derived a number of guidelines that should be kept in mind when defining notifications for wearable devices.

As next step, we plan to implement an Android Wear watch face to present our concepts to a larger audience and to be able to run in-the-wild studies. Long-term evaluations – either with the watch face or our prototype – are also of importance for assessing our approach. In this sense, a quantitative evaluation, e.g. regarding response time, should also be taken into consideration; in addition, different form factors, e.g. for fitness bands – resulting in a different LED arrangement – are worthy of investigation.

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