Exploring Notifications in Smart Home Environments

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Abstract
Notifications are a core mechanism of current smart devices. They inform about a variety of events including messages, social network comments, and application updates. While users appreciate the awareness that notifications provide, notifications cause distraction, higher cognitive load, and task interruptions. With the increasing importance of smart environments, the number of sensors that could trigger notifications will increase dramatically. A flower with a moisture sensor, for example, could create a notification whenever the flower needs water. We assume that current notification mechanisms will not scale with the increasing number of notifications. We therefore explore notification mechanisms for smart homes. Notifications are shown on smartphones, on displays in the environment, next to the sending objects, or on the user's body. In an online survey, we compare the four locations in four scenarios. While different aspects influence the perceived suitability of each notification location, the smartphone generally is rated the best.

Author Keywords
Notifications; Reminder; Ambient Display; Peripheral Display; Wearable Display; Smart Home; Online Study

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

Introduction

Notifications on current computing systems are used to make the user aware of incoming messages, updates, or upcoming appointments [10]. Especially on mobile devices, the number of notifications is constantly growing due to an increasing amount of applications that make use of notifications. The ongoing advancements in the smart home sector may lead to a dramatic increase of notifications due to an increase in embedded sensors (cf., Dohr et al. for an overview of potential sensors [3]). Future smart homes will have sensors or actuators integrated in most home appliances, that will be capable of notifying the user about events.

With the increasing number of notifications in an environment such as a smart home, current notification mechanisms will not scale and will result in information overload. Further, smart environments will create notifications that are very different from what users receive today. We envision that in the future, different types of notifications will be presented in different locations. These locations can be the user's mobile phone, a central display in the home, a wearable display on the user's clothing, or directly in the sensor's or object's location. All of these notification locations have their inherent benefits and drawbacks.

In this work, we explore the user's preferences regarding the location of smart home notifications. We hypothesize that the *perceived suitability of a notification location is related to the urgency of the notification. Users should prefer closer notification locations for notifications with a higher urgency.* In an online survey, we compare four types of notification scenarios with different urgency levels that are displayed at four different locations. We analyze five aspects of the notifications and generate a model which shows that these aspects have an influence on location suitability.

Notification Locations

We envision four different locations with different distances to the user for displaying notifications generated by smart home appliances. In some cases the notification location is next to the user. In other cases the notification location is placed in a fixed positions.

Body. A possibility for presenting notifications is using on-body displays such as display-augmented body parts [8] or garment based displays [6]. Another example of this category are wearable gadgets that provide visual feedback such as smart jewelry [4].

Smartphone. Today, users receive most of their notifications on smartphones (cf., [9]), which are often near the user (cf., [12]). Most smartphones visualize an incoming notification using a pop-up message on the screen.

Display. Central displays placed in the environment of the user can be utilized to present smart home notifications. Müller et al., for example, visualized different kinds of information with ambient light displays [7] and Consolovo et al. used a display to present health information, intake of medicine or food, and activities [1].

Object. Smart home appliances could display notifications on the device, for example by using low-cost displays (e.g., E-Ink) or ambient projection [11]. Garcia Macias et al. created an augmented reality application which shows the watering state of the plant on the plant pots [5].

Scenarios

Our focus in this work is to find out where people prefer to receive their smart home notifications. Therefore, we chose four different scenarios with different urgency levels. In these scenarios, smart home appliances will notify the user about from moderate importance to urgent events.

Figure 1: Four examples of scenarios and locations as shown in the online survey.

Entrance door. The smart home system recognizes visitors at the entrance door and sends a notification to the user. Immediate reaction is required, otherwise visitors might assume that nobody is at home.

Closing a window. It starts snowing while a windows is opened for ventilation. To prevent snow from getting into the room, the system notifies the user by presenting a notification. In this case, the urgency level is rather high and the user should react in the next few minutes.

Taking medicine. The user needs to apply eyelid ointment every evening. The smart home system detects that the ointment should be applied and informs the user. In this case the user should react soon.

Watering a flower. The smart plant pot detects that the winter rose needs to be watered and sends a notification. The urgency level of this notification is rather low and the user should react to it within the next hours.

Online Survey

We conducted an online survey to evaluate where users prefer to receive smart home notifications and how they assess the different notification locations. Participants were presented with 16 consecutive images (in a randomized order), one for each possible combination of scenario and notification location (see Figure 1 for examples). For each image, participants answered a questionnaire consisting of six items, each on a 7-point rating scale. The first item required participants to rate how suitable the notification location was for the particular scenario. Next, participants responded to five semantic differentials, i.e., rating scales between two bipolar adjectives. The adjective pairs were: bad – good, disturbing – not disturbing, not easy to perceive – easy to perceive, not useful – useful, and complicated – simple. These pairs were selected on the basis of informal interviews conducted prior to the survey [2]. They were chosen to capture the diversity of aspects that were expected to influence participants' evaluation of the notification locations. Afterwards, we asked participants for each scenario to rate whether they would want to be notified in this scenario. Additionally, the participants ranked the four notification locations according to their preference. Lastly, participants could comment on the notification locations and the scenarios. In total, 183 people participated in our online survey (110 female, 73 male). Participants were between 18 and 76 years old ($M = 23.83$, $SD = 5.44$).

Results

Relevance of Scenarios

For the question if the participants wanted to be notified in the given scenarios, we conducted a one way repeated measures ANOVA (sphercity assumed, Huynh-Feldt corrected). We found that participants differed in how relevant they considered the scenarios, $F(2.63, 480.40) = 94.36, p < .001$. Overall, most participants agreed that they would like to receive notifications for *taking medicine* ($M = 5.84$, $SD = 1.42$), followed by *watering a flower* ($M = 4.81$, $SD = 1.72$), *closing a window* ($M = 4.24$, $SD = 1.88$), and *opening the entrance door* ($M = 3.25$, $SD = 2.05$).

Semantic Differentials

Each participant rated each combination of scenarios and presentation location using five semantic differentials. We conducted six 4 x 4 repeated-measures analyzes of variance (ANOVA) with the factors notification location and scenario, one for each semantic differential, as well as one for the suitable location ratings (LSR). Results are reported in Figure 2. The main effect of location was significant in all six cases, indicating that ratings differed with the notification location. This effect was further modulated by the scenario,

scenario	df_M	df_R	F	p
simple	2.80	513.27	6.59	$< .001$
easy to perceive	2.86	522.99	2.83	$= .041$
not disturbing	2.98	545.55	1.58	$= .194$
good	2.83	517.64	28.96	$< .001$
usefulness	2.83	517.35	34.86	$< .001$
LSR	2.63	487.95	24.30	$< .001$

sphercity assumed, Huynh-Feldt corrected

(a) scenario

location	df_M	df_R	F	p
simple	2.44	445.86	19.49	$< .001$
easy to perceive	2.84	520.00	95.02	$< .001$
not disturbing	2.94	537.19	128.87	$< .001$
good	2.86	522.45	33.26	$< .001$
usefulness	2.99	547.03	19.63	$< .001$
LSR	2.76	512.92	42.52	$< .001$

sphercity assumed, Huynh-Feldt corrected

(b) location

interaction	df_M	df_R	F	p
simple	8.78	1,606.05	1.71	$= .084$
easy to perceive	8.53	1,561.19	8.37	$< .001$
not disturbing	8.71	1,593.42	20.64	$< .001$
good	8.34	1,525.90	8.20	$< .001$
usefulness	8.27	1,513.38	21.75	$< .001$
LSR	7.92	1448.36	16.29	$< .001$

sphercity assumed, Huynh-Feldt corrected

(c) interaction

Figure 2: The results of the inferential statistics.

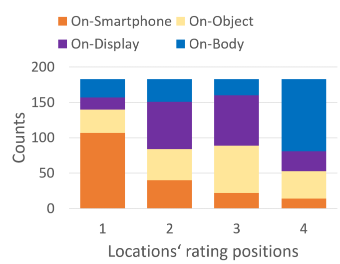


Figure 3: The overall ranking of the presentation location.

as indicated by the significant interaction term (except in the case of rating non-disturbances). We conducted a series of post-hoc comparisons (paired-samples t-tests as reported in the following) to further investigate effects of particular interest. Only if significant, the p-values were adjusted for multiple comparisons using Bonferroni corrections. Mean ratings are shown in Figure 4 and Figure 5. Error bars represent 95% confidence intervals (i.e., overlapping error bars indicate non-significant differences between means).

Simple. Disregarding the influence of scenario, participants' ratings were highest for smartphone and lowest for on-body (phone vs. object $(t(183) = 4.04, p < .001)$, object vs. display $(t(183) = 14.65, p < .001)$, display vs. body $(t(183) = -10.98, p < .001)$).

Easy-to-perceive. Disregarding the influence of scenario, notifications presented closer to the user were rated as easier to perceive (body vs. object $(t(183) = 3.82, p < .001)$, body vs. display $(t(183) = 8.81, p < .001)$, phone vs. object $(t(183) = 12.91, p < .001)$, phone vs. display $(t(183) = 9.18, p < .001)$).

Non-disturbing. Disregarding the influence of scenario, participants' ratings for on-body were much lower than for the other notification locations (body vs. phone $(t(183) = -12.55, p < .001)$, phone vs. display $(t(183) = -0.09, p = .930)$, display vs. object $(t(183) = -4.27, p = .001)$). On-body ratings for the least urgent condition, flower, were lower than ratings for the most urgent condition (flower/on-body vs. door/on-body, $t(183) = -5.37, p < .001$).

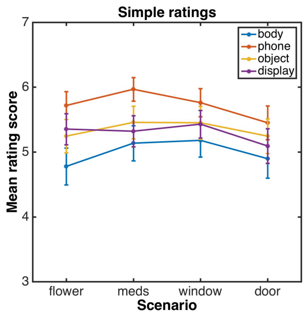
Good. Disregarding the influence of scenario, participants' ratings were highest for smartphone and lowest for on-body (phone vs. object $(t(183) = 6.49, p < .001)$, object vs. display $(t(183) = -0.40, p = 0.690)$, display vs. body $(t(183) = 3.40, p = .002)$). Disregarding the influence of location, ratings were lowest for door (door vs. flower $(t(183) = -4.38, p < .001)$, flower vs. window $(t(183) = -1.30, p = .195)$, window vs. medicine $(t(183) = -3.67, p < .001)$.

Useful. Disregarding the influence of scenario, participants' ratings were highest for smartphone and lowest for on-object (phone vs. body $(t(183) = 4.97, p < .001)$, body vs. display $(t(183) = -0.15, p = .884)$, display vs. object $(t(183) = 2.29, p > .04)$. Notifications on the object were judged least useful in the two urgent scenarios (window/object vs. flower/object $(t(183) = -1.64, p < .103)$, window/object vs. medicine/object $(t(183) = -6.70, p < .001)$, door/object vs. medicine/object $(t(183) = -10.46, p < .001)$, door/object vs. flower/object $(t(183) = -5.01, p < .001)$).

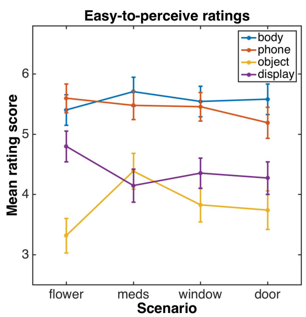
Location Suitability Ratings (LSR)

Disregarding the influence of scenario, participants' LSR were highest for smartphone and lowest for on-body (phone vs. object $(t(183) = 6.93, p < .001)$, object vs. display $(t(183) = -0.53, p = .599)$, display vs. body $(t(183) = 4.25, p < .001)$. Disregarding the influence of location, LSR were lowest for door (medicine vs. window $(t(183) = 5.40, p < .001)$, window vs. flower $(t(183) = -0.25, p = .803)$, flower vs. door $(t(183) = 3.65, p < .001)$).

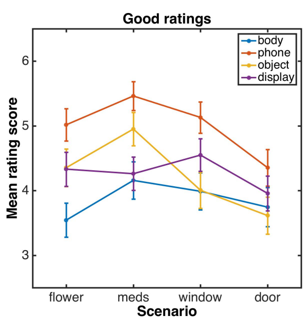
To test whether urgency had an effect on the LSR, we performed four linear mixed effects analyzes, one for each notification location. As the fixed effect, we entered the scenarios in increasing order of urgency and as the random effect the participants. p-values were obtained by using a likelihood ratio test of the full model with a null model without the fixed effect. We hypothesized that the LSR would increase for more urgent scenarios when notifications were displayed close to the user (i.e., smartphone and on-body) and decrease when displayed in a location of un-



(a) simple



(b) easy to perceive



(c) good

Figure 4: Ratings per scenario and location for simple, easy to perceive and good

defined distance to the user (i.e., display and on-object). This hypothesis was partially verified. While LSR increased moderately for on-body notifications it decreased for the other three notification locations (on-body: $\chi^2(1) = 13$, $p < .001$, increases LSR by 0.15 ± 0.04 (SE) per level of urgency; phone: $\chi^2(1) = 16$, $p < .001$, increases LSR by -0.17 ± 0.04; on-object: $\chi^2(1) = 55$, $p < .001$, increases LSR by -0.39 ± 0.05; display: $\chi^2(1) = 16$, $p < .001$, increases LSR by -0.07 ± 0.04). Thus, urgency is not the only factor determining participants' LSR.

We performed a linear mixed effects analysis of the relationship between the LSR and the ratings of the five semantic differentials. The latter were entered as fixed effects into the model (without interaction terms). As random effects, we entered participant, notification location, and scenario. p-values for each semantic differential were computed using a likelihood ratio test of the full model against an alternative model without the semantic differential of interest. Results show a positive relationship between location fit and the ratings of each of the semantic differentials (non-disturbing: $\chi^2(1) = 195$, $p < .001$, increasing the rating of non-disturbing by 1 increases suitable location ratings by 0.18 ± 0.01 (SE); useful: $\chi^2(1) = 189$, $p < .001$, increases location fit ratings by 0.19 ± 0.01; easy: $\chi^2(1) = 128$, $p < .001$, increases location fit ratings by $0.14 \pm .01$; simple: $\chi^2(1) = 8$, $p = .004$, increases location fit ratings by 0.04 ± 0.01; good: $\chi^2(1) = 618$, $p < .001$, increases location fit ratings by 0.43 ± 0.02).

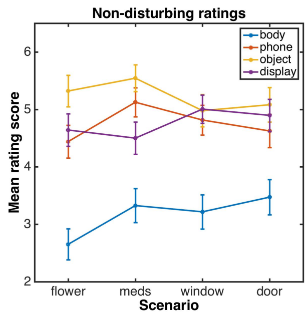
Notification Locations

Figure 3 shows the order of the notification location according to the participants' preferences. The *smartphone* was placed most often on the first position. Also, *on-display* and *on-object* were most often placed on the second and third position. The *on-body* location was mostly positioned last.

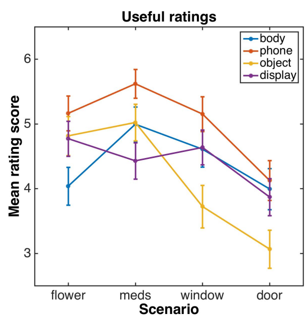
Discussion

Participants perceive the smartphone to be the most suitable location for notifications and rate the smartphone as simple, easy-to-perceive, and useful. Possible reasons for this are that participants are familiar with this technology [comment by participant P105] and their smartphone is usually with them (e.g. [P117]). The on-body notification location that is also close to the user was generally not well received. Though on-body notifications were rated to be easily perceptible, they were also distracting and they received low ratings concerning their suitability as a notification location. The perception of on-body notifications as distraction was more pronounced for the less urgent scenarios. A reason for that could be that people do not want to wear notifications on their bodies where they are perceptible to others, in particular when notifications do not require immediate attention and therefore might have to remain on the body for some time. The display and on-object notification locations received low ratings for ease of perception. A reason could be that the user is not always close to these notification locations, e.g. the entrance door [P9]. These two locations received intermediate ratings in most other regards with the exception of on-object notifications being rated as being not very useful in urgent situations.

We find some support for the hypothesis that the urgency of the scenario determines the perceived suitability of a location for notifications. Notification locations that are at a distance from the user were judged to be less suitable as urgency increased. In contrast, on-body notifications, which are within immediate reach of the user, were judged as more suitable as urgency increased. However in the case of smartphone notifications, we also found an effect opposite to the one predicted. This indicates that factors besides urgency determine the perceived suitability of a location. For instance, we found that the chosen scenar-



(a) non-disturbing



(b) useful

(c) location suitability

Figure 5: Ratings per scenario and location for non-disturbing, useful and location suitability ratings

ios differ not only in terms of their urgency but also in how relevant participants consider them. For example, the entrance door is rated very low – people do not consider it a scenario, in which they would like to receive notifications. Lastly, we showed that suitability is also a function of how simple, good, easy-to-perceive, non-distracting, and useful a location was rated.

Conclusion

In this work, we explored the user's preferences regarding locations for notifications in smart homes. We compared the locations *smartphone*, *display*, *object* and *body* using four scenarios. While different aspects influence the perceived suitability of each notification location, the smartphone was rated as the most suitable. The results provide first insights into the increasingly important topic of ubiquitous notifications. In future studies, we plan to observe different notification locations in the wild and over a longer period. Future work should also focus on the design of ambient notifications and their representation. Non-trivial information encoding could decrease users' privacy concerns and thereby enable notifications beyond personal devices.

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