The effect of Peripheral Augmented Feedback on System Understanding

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ABSTRACT

The quantity of smart homes is increasing enormously. The decisions taken by the smart home are difficult; every decision is based on many variables. Smart systems are getting smarter every day and they almost perfectly integrate into human life. Most of the times a smart home is a closed system; the user is not able to see the background decisions made by the system. Communicating system statuses to the user could potentially enhance the user experience of the system. In order to understand the effect of peripheral augmented feedback on system understanding, we designed an artefact that shows the status of a part of a smart system through lighting. We deployed this artefact in two environments for three weeks, and conducted a qualitative interview before and after this period. Our findings show that using lighting as a peripheral augmented feedback medium is an effective way of transferring system statuses to a user, provided that they fully understand the mapping used in the artefact.

Author Keywords

Peripheral; Seamless Interaction Design; Augmented Feedback; Smart Thermostat; Internet of Things; System Understanding; Calm Technology;

INTRODUCTION

The amount of 'smart homes' is rising significantly; the quantity of Internet of Things (IoT) devices has passed 25 billion at the end of 2015 [1]. A house can be called a smart home if two or more IoT devices are sharing data with each other [2]. Internet of Things devices can be used in many different situations. The most obvious option is the smart home, where people want to make their house more pleasant to live in, or try to make their living situation more energy efficient for example. On the other side, IoT is also used at professional organizations. Heijmans and Philips, two large Dutch companies, for example started working on digitizing the infrastructure in Eindhoven [3]. By replacing existing technological devices with internet connected (IoT) devices, they try to create a smart city infrastructure. In all these cases the technology is present in order to take over some users' decisions, so they can focus on other things in life.

Taking over decisions from an already existing system is hard. Every decision is based on several other decisions. For example, before a person turns on their light, they will first check if it is dark enough outside. Then they will subconsciously check if there are not any other lamps powered on in the same room which already generate enough lighting. Finally, they would start thinking about the intensity of the lighting. All these processes depend on many variables and even more important: personal preferences. These preferences change from day to day; tomorrow someone can have a day where they tolerate less light than today. The digital system should also anticipate on these changes.

But what if the system is able to anticipate on these decisions (almost) perfectly? Then there still is another problem that is not thought of. When, for example, a smart thermostat system with geo-fencing (a system that detects when someone comes home [4]) starts heating because someone enters the home, the person is not able to see that the system has detected them, since geofencing is an invisible process. Therefore, they do not know that the system already started heating the house, and needs to check whether the system anticipated on the presence. In reality the system was already heating the house, resulting in a time waste. Even more important, the user cannot fully trust the automated system, which leads to confusion. Therefore, the whole idea of an autonomous (self-thinking) smart system is reduced.

Based on this problem we will discuss the aspects of augmented feedback in the periphery of someone's attention and how this contributes to the understanding of automated systems in this paper. We did this through a purposely developed artefact, in the form of a wooden frame with acrylic plate. This plate is illuminated from the back, which results in an artefact which looks like a painting (further discussed in system overview section). The lights show the system statuses of a smart thermostat system, where it will show red, blue or green pulsing colours. These colours represent the heating, cooling or steady state of a smart thermostat in a smart home. With the help of this artefact, we hypothesise user would receive augmented feedback on the system status in the periphery of their attention.

We started the research with a user test, in order to validate the artefact. Then, we continued with a deployment in a real life situation. The duration of the deployment was approximately three weeks. Data was gathered at the beginning and ending of this period.

THEORETICAL BACKGROUND

Nowadays, systems mostly cover the two extreme ends of attention abilities; focused and implicit interaction [5]. We want the interaction to be in the periphery of their attention, since otherwise it would take up too much of their valuable time. People perform multiple activities in the periphery of their attention, for example the perception of what the weather is like. In addition, we are also easily able to focus on these type of activities [6]. Unfortunately, interactions with technological devices usually require focused interaction [6]. Technology is becoming way more important, therefore the need increases to seamlessly fit interactions with technology into the everyday lives [5]. This can be achieved by transferring focused and implicit interactions to the periphery of someone's attention; this type of interaction is called 'peripheral interaction' [6]. In this study we will show the effect of showing system statuses of a smart thermostat system in the periphery of someone's attention.

We intend to create this peripheral interaction with the use of lighting. Light influences the psychological mood of a human [7]. Besides, colours also result in different mood effects on people [8]. Research on using ambient coloured lighting used for communication showed that the effect of ambient lighting is enhanced by making use of pre-existing colour associations [9]. So therefore we chose to stick to these associations.

RELATED WORK

Yang and Newman show disadvantages of a smart system, most of them are focused on the shortcomings in adaptiveness of smart home systems on the users' life [10, 11]. For example, these researchers conclude that the systems' intelligent features were not perceived as expected, due to the systems' inability to understand the user's behaviour [11]. It is suggested that such an intelligent system requires improved intelligibility and an improved manner in which users can provide input to the system [10]. This is all focused on the intelligence of the smart home; making the smart system even smarter and evaluating the smartness. We focus on increasing the user experience of a smart system, so that is a new research topic as far as we could find.

Furthermore, using peripheral visual feedback results in higher detection of unexpected events, without interfering the efficiency of the main task of a person [12]. Potential applications are suggested, such as improving designs by adding peripheral visual feedback to an existing system [12]. How and why is not discussed. Not much work is known in this area of peripheral interaction [5].

SYSTEM OVERVIEW

Here we describe the design and technical details of the artefact used in this study, including the different materials to create it, and how it works. The artefact (figure 1) is an IoT-based device which is able to visualize the system status of a smart thermostat system. It communicates the actual system status through different lighting patterns to the user. The artefact receives information from a smart thermostat, which is connected to the artefact using several online services and a microprocessor. The technical details are discussed later on. We wanted the artefact to be in the periphery of the attention of our participants, so we chose to design it in the form of a 'painting'. We chose to do this, because a painting fits the home environment's ambiance and therefore is easier to blend into the periphery of the attention of a user.

Figure 1. Final research artefact showing the heating status (red) of a smart thermostat

Technical Details and Appearance

The development started with the creation of two identical wooden frames made out of MDF, since MDF is an affordable material which is easy to process. The dimensions of the prototype are 80x30x2.3 centimetre, a size which we assume is not too large but still noticeable on the wall in a room. A sheet of semi-transparent Akyprop (70% translucent) plastic is placed in front of the frame in order to diffuse the light emitted by the LEDs. Later on, the MDF was stained to give it an appearance which is more natural.

Inside the wooden frame we placed a Wemos D1 Mini V3 [13], which is a breakout board of an ESP8266 chip. The Wemos D1 Mini V3 also consists of a CH340 USB to serial converter, which enables it to be programmed using the Arduino software. We wanted to use an Arduino compatible device, since Arduino is an easy to program, open source environment [14]. The ESP8266 is an affordable WiFi chip which enables data transmission over the internet [15].

The microprocessor is connected via cables to a SPI-I2C-UART bi-directional logic level converter. This device is used to convert the 3.3V signal created by the ESP8266 to a 5V signal [15]. This signal is necessary for the WS2812B LEDs, placed on a strip, used in our prototype [16]. We chose to use this type of LEDs, because they are easily programmable in Arduino and only one cable is used to send the data to all the LEDs. Besides, the WS2812B all have a chip embedded in the LED and are therefore individually addressable [16]. This opens the opportunity to set more than one static colour. The LEDs will show a pre-programmed pattern and colour. The different colours and patterns are discussed in the next section.

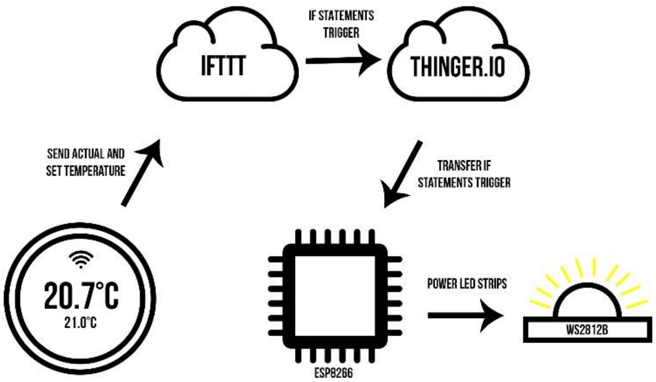

Figure 2. Visualization of the artefact's data transfer with a smart thermostat

Implementation Details

We chose to focus on a smart thermostat in this study, since we thought this is the best example where users desire a visualisation of the system status (as exemplified in the introduction). The process of transferring information from the thermostat system to light coming from the artefact (figure 2) starts with an IFTTT Applet. IFTTT is an online platform which can be used to connect different apps and (smart) devices with each other [17]. In our case we wanted to connect a smart thermostat (e.g. Google Nest) to Thinger IO (explained later). IFTTT will request two variables from the smart thermostat: current temperature ($T_{current}$) and desired temperature ($T_{desired}$). IFTTT then runs three different equations:

- $T_{current} > T_{desired}$ *Cooling*
- $T_{current} < T_{desired}$ *Heating*
- $T_{current} == T_{desired}$ *Neutral*

When an equation is triggered, IFTTT will send a signal to Thinger IO via an HTTP Post with the result of the equation defined in the message. Thinger IO is also an online platform which can be used to connect different apps and (smart) devices [18]. We had to use two different online environments, because IFTTT was not able to connect with an ESP8266 and Thinger IO was not able to make a connection with a smart thermostat. Thinger IO has one simple task: transferring the trigger to the ESP8266. So this is what is being done by the environment: when Thinger IO receives a trigger from IFTTT, it sends the same trigger to the ESP8266.

When the ESP8266 receives the signal it uses a library to convert it into a lighting change. The library is called FastLed, which is a fast, efficient, easy-to-use Arduino library for programming addressable LED strips and pixels such as the WS2812B [19]. We chose to use a animation which looks like flowing, rotating light (figure 3). We chose to use non-static lighting since we thought it would represent the activity of the system. The only variable in the lighting at the different situations is the colour:

- *Cooling* Blue colour
- *Heating* Red colour
- *Neutral* Green colour

We decided to use these colour mappings because it is commonly believed that blue-ish colours relate to cold feelings and red-ish colours relate to warm feelings [20, 21, 22, 23, 24]. We chose green as a neutral colour because green is exactly in in the middle of the colour spectrum, with red-ish colours on the right and blue-ish colours on the left. The ESP8266 is coded via Arduino software, an open-source program to write code which is Java-based. The Arduino code only transfers the incoming triggers into a digital signal which sets the LEDs to the desired colour and pattern using the FastLed library.

Figure 3. Artefact's lighting pattern, heating state (red)

As earlier defined, the artefact needs to be in the periphery of the participant's attention. In order to make this happen, the artefact needs to blend into the surrounding area; it needs to draw as little attention as possible. Therefore, the luminance level of the lighting is very important. The uniformity of luminance describes the difference between luminance levels in a certain area [25]. There is no real standard for home situations, so we decided to take a recommendation from Zumtobel lighting solutions. As defined in *The Lighting Handbook* by *Zumtobel* the luminance uniformity of lounge areas needs to be 0.4 [26]. This is why we chose to adapt the luminance levels of the artefact to the specific home situation. The FastLed library offers us a way to change the luminance of the LEDs [19]. How we adapted the luminance levels to the specific deployment situations will be discussed in the next section.

THE STUDY

This is a three week qualitative study of one household and company in the Netherlands. All the participants live in a house with a working smart home system. The study involved two interviews for every participant, one at the beginning of the period and one at the end.

Participants

Five participants. from one household and company participated in the qualitative study. One company with four workers and one single family home were used during the three week long deployment (table 1). An additional single person household was used for a pilot study of two days, in order to test the technology and avoid some bugs. No data was obtained during this period. The household and company were recruited through social media. These participants were all acquaintances of the authors of this paper (opportunity sampling).

Participant	Situation	Age	Hardware
A	Household 1	35-40	Tado V2
B	Company 1	30-35	Honeywell Lyric T6
C	Company 1	30-35	Honeywell Lyric T6
D	Company 1	40-45	Honeywell Lyric T6
E	Company 1	30-35	Honeywell Lyric T6

Table 1. Overview of participants, age and hardware specifications

To be eligible for the study in this paper, each deployment address had to have a working smart home system with smart thermostat. They needed to use the smart thermostat for at least two years, since the thermostat would then have had time to adapt to the participants' living situation.

Procedures

The deployment started with the installation of the artefact in the participants' household/company, this took approximately 0.5 - 1 hours. No explanation was given to the participant during this period, since we did not want to influence the understanding of the system. The luminance was measured using a Konica Minolta LS-110 Luminance measurement device. The desired luminance of the artefact was then calculated using the luminance uniformity defined in the *implementation details* section. Finally, the Arduino code was adapted to the desired luminance and the participants' network (WiFi) credentials.

At the start and end of the deployment an interview was held. Using an interview booklet several questions were asked to all the participants and the results were noted by the interviewer. A large part of the questions is open-ended in order to stimulate a discussion. Each interview with a single participant took approximately 10 - 15 minutes. The most important topics of the first interviews were: participants' understanding of the smart thermostat and smart home system in their environment and how often and why the participant uses the smart thermostat. The most important topics of the final interviews were: participants' understanding of the smart thermostat and system changes; participants' opinion on design related aspects; the artefact understanding (colour mapping etc.).

At the end of the interview, the participants were asked to fill in the User Experience Questionnaire (UEQ) [27]. This questionnaire was translated to Dutch by Adriaan Dekker and can be obtained from the official website [28]. The UEQ was designed as a quick and reliable questionnaire to measure the user experience of interactive products. It consists of 26 items arranged in six scales: attractiveness, perspicuity, efficiency, dependability, originality, and stimulation. The pragmatic quality of the artefact is of interest to us, which is defined by the perspicuity, efficiency, and dependability [28]. The perspicuity defines whether or not the functioning of the artefact is easy to learn and understand, and if it is ambiguous [28]. The efficiency relates to the amount of effort the user has to put in, and whether the artefact is quick and effective to use [28]. The dependability shows whether the user feels in control of the interaction and can predict the system's behaviour [28]. These aspects give insights in whether or not the participants felt like the artefact was seamlessly integrated in their lives, and if they could interact with it within the periphery of their attention [28].

During the deployment of the artefact, the participants were not able to ask questions about the function of the prototype, because they should be unbiased. Every 3-5 days we contacted the deployment address to ask them if the system still was operational.

Analysis

Bias is the wide range of tendencies for participants to respond inaccurately or falsely to questions [29]. An example of response bias is demand characteristics, the type of bias where participants alter their response to the desired answer of the research [30]. Since this research is focused on the question if peripheral augmented feedback increases the system understanding, we tried to deceive the participants by adding questions about other aspects of the design to decrease the demand characteristics. We also added the same question formulated in different ways to the questionnaire, in order to compare the answers to these questions, to gather the most reliable data. This will be done by visualizing the answers to the different open, closed and Likert based questions. After analysis of this visualizations we can conclude what the effect of peripheral augmented feedback is on system understanding. Through this paper the participants are defined by a pseudonym (table 1).

RESULTS

In order to get an understanding of the effects of the artefact on system understanding of the participants, we analysed the interviews which we held before and after the three week deployment of the artefact. We started the analysis by writing down all the quotes and answers from the participants, the qualitative part of the study (figure 4.a). This resulted in a total of 82 different quotes/answers from the five participants in this study. For readability purposes, we translated the quotes ourselves from Dutch to English.

We continued the analysis by filtering the quotes which did not relate to our research question (figure 4.b). For example participant A said: "The thermostat is doing well overall. I hope the overshoot will go away, since it is a self-learning thermostat.". This quote is more related to the choices the system makes; how *smart* the thermostat is. In this study we focus on communicating the status of the system. We double checked the irrelevance of these quotes by asking each team member if they agreed with the choice.

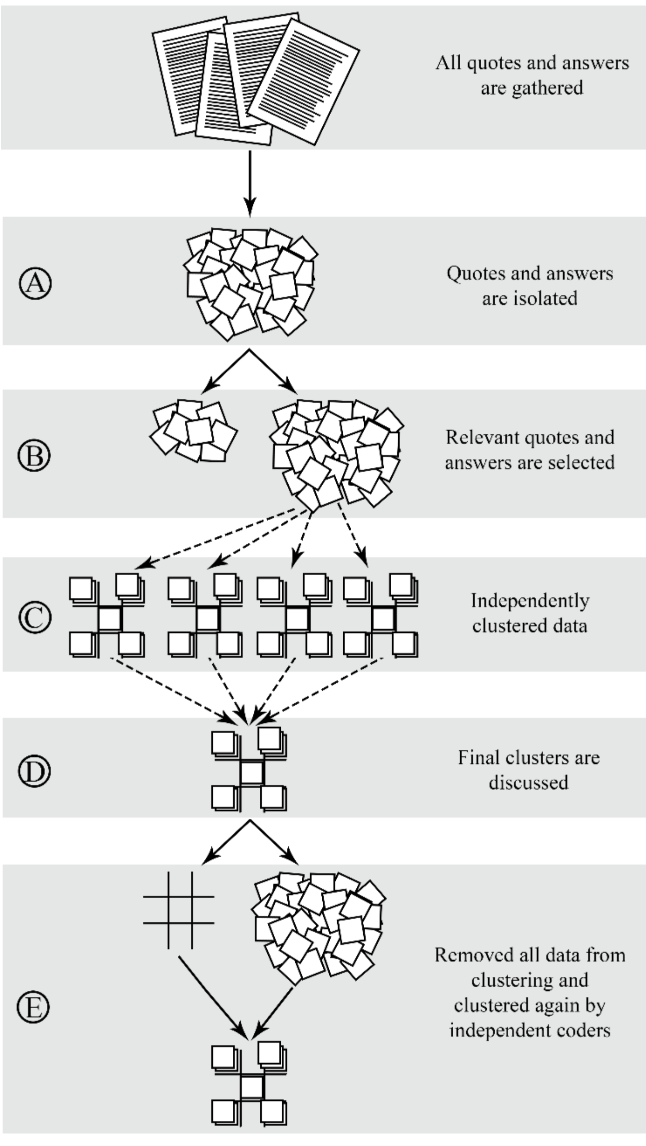

Figure 4. Clustering process of this research

Since the amount of quotes and relevant answers was small (72 items), we chose to do the clustering all individually: every researcher clustered all the quotes independently to increase the reliability (figure 4.c). The four different cluster groups were then compared and discussed with all four researchers. Then, we came with a set of five final clusters: comprehension, confusion, automation, appearance and peripheral interaction (figure 4.d). We did plan to give all the quotes to randomly chosen independent *coders*. They should then divide all the quotes and answers under the different clusters, which needed to be compared by us afterwards (figure 4.e). Unfortunately, due to time shortage we needed to do stick with the combinations we have made ourselves in a stadium (the step in figure 4.d).

When looking at the comprehension and confusion of our artefact, three out of five participants indicated that they understand the represented system status. For example when we asked participant D, without any explanation beforehand: "How does the artefact show when the smart thermostat system changes state and starts heating the house?", she answered, "When the colour and pattern changes to pulsing red I knew that the thermostat was going to heat my house." Not everybody understood this immidiatly, for example participant C said: "I didn't understand the colours and patterns in the beginning, but after a few days my colleague explained them, then it was all clear to me.". Also, participant A was not completely sure about his thoughts: "I thought something is happening when seeing the pulsing motion, but that was not entirely clear.".

The participants did know our research topic beforehand, but we wanted to prevent them from giving desired answers (bias). Therefore, we added questions on the automation of the system. For example we asked: "Does the device help with understanding why the system makes a certain decision?". Four out of five participants answered that the artefact only shows the current system status, for example participant A said: "I didn't see what happens inside the system, I only see the status of what is going to change in my environment.". On the other side, participant A said: "Yes, the device also helped me with understanding why the system is doing it.". Unfortunately, the researcher did not ask which property of the artefact was connected to the understanding of the system decisions.

Some small remarks were made on the appearance of the artefact. Four out of five participants liked the size of the artefact, for example participant E said: "I like the size of the artefact, it is just like a painting.". On the other side participant C indicated that the size of the artefact was way too big. When looking at the brightness, Participant A indicated that it was too bright when it was dark outside. Finally, four of the five participants said that the artefact did not match the interior of the company, for example participant D said: "The artefact didn't match with the surroundings.".

In terms of peripheral interaction, all the users indicated that the device was noticeable but not distracting. For example participant C said: "The device wasn't annoying, but it wasn't placed in full sight either.".

The results from the User Experience Questionnaire can be seen in the table 2. The scale ranges from -3 (horribly bad) to +3 (extremely good). However, scores below -2 or above +2 are extremely unlikely due to participant's different opinions and answer tendencies, such as avoiding extreme answer categories. Scores between -0.8 and +0.8 are considered to be neutral.

UEQ Scales		Pragmatic and Hedonic Quality	
Attractiveness	0,556	Attractiveness	0.56
Perspicuity	1,167	Pragmatic Quality	0.97
Efficiency	1,083		
Dependability	0,667		
Stimulation	0,667	Hedonic Quality	1.00
Novelty	1,333		

Figure 5. User Experience Questionnaire results from deployment during this study

One participant was removed from the UEQ analysis due to the many inconsistencies. For example, this person rated "not understandable", "easy to learn", and "complicated" all towards the high end of the spectrum. There were other inconsistencies in the Stimulation and Novelty qualities as well.

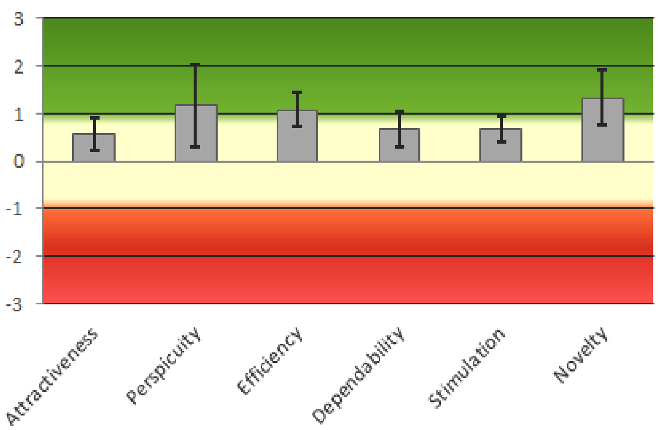

Figure 6. User Experience Questionnaire results from deployment during this study

DISCUSSION

This paper describes a study looking at the effect of peripheral augmented feedback on system understanding. An artefact was deployed three weeks in two environments. The study shows that using coloured lighting patterns in the periphery of someone's attention can transfer the system status information to the user. In this section we are going to consolidate our insights, limitations and future possibilities.

At the beginning of this paper we said that we wanted to look into a possible solution for an upcoming problem when using a smart home system. Everyday smart homes get smarter and more decisions are taken away from the user in their living environment (as discussed in introduction). We stated that these systems are getting too smart and the users are not receiving feedback of what is happening in their environment, especially the statuses that are relevant to the user. We clarified this problem by taking a smart thermostat as an example, where people desired feedback on when their house is heating or cooling. As provided in this study, a coloured lighting artefact served as an option for giving feedback in this specific situation.

When comparing the five pre- and post-interviews we saw that overall the artefact made the smart thermostat status clear to the user. Sometimes the user needed some additional explanation, this was given by other participants. When the users understood the mapping and changes in colour and patterns, they used this as a feedback mechanism without putting their attention into this process. This could suggest that the feedback was provided and received in the periphery of the participant's attention. In conclusion, we have found that the effect of peripheral augmented feedback on system understanding in a smart thermostat system is that people understand the system status. Nevertheless, they first need to know what the different colours and patterns of the artefact's lighting mean. Not all participants did map the pre-existing colour associations to the correct statuses, as we thought they would earlier in this paper.

The data analysis of the User Experience Questionnaire shows that the artefact is perceived as positive (see figure 6). As defined in the study setup, the perspicuity, efficiency, and dependability are most important to answer our research question because they relate to the understanding of, and the interaction with the artefact. These three scales combined are also defined as the pragmatic quality, which has a score of 0.97, which is relatively positive. The perspicuity has a score of 1.17, which means the participants see the artefact as something that is quite easy to learn and understand. The efficiency has a score of 1.08, so the participants feel like they don't have to put a lot of time and effort into using the artefact. The dependability has a score of 0.67, which is relatively lower than the other scores. However it is still perceived as positively neutral, which means the user feels somewhat in control of the interaction and moderately knows how to predict the system's behaviour. A way to increase this score might be to make the artefact a little smaller and less bright, so users have full control of the interaction and don't feel like the artefact is obtrusive at times. Another way might be to make personal adjustments to the system's behaviour (e.g. change of colours) so that the users can better predict this behaviour.

However, we note some potential limitations to this study. The first limitation is the amount of participants who participated in the study. We only used five participants in this study, such amount has a large margin of error [31]. Therefore, it would be better to have a sample size as big as possible, preferable above 100. As discussed earlier, the second potential limitation is the way we conducted our interviews. All the participants were known by the interviewers, as well as the field. This could potentially result in a situation where the participant gives desired answers to the questions. This could be prevented by doing a blind study, where both the participant and the interviewers do not know the purpose of the study and do not know each other. Finally, in this study we chose to give no explanation about the artefact while deploying it in the environments, because we did not want to influence the results. This choice resulted in people who did not understand the colour mapping to the different statuses. Fortunately other participants in the same environment explained the mapping, but it could be useful to explain it before the deployment and see if this gives any differences in the results.

A possible approach for other researchers is to explore other media which can be used to transfer the smart home's system status through the periphery of someone's attention. We only focused on coloured lighting patterns, but there are many other possibilities. For example sound, movement and scent. The user study presented in this paper is focused on the effect of peripheral augmented feedback in specifically smart home systems. Researchers could also try to implement such system in other areas where peripheral feedback would be beneficial, for example a feedback system on difficult processes in companies or computers. Finally, HCI researchers could try to find a coloured lighting pattern that is easily understandable for the user, without any additional explanation.

CONCLUSION

The aim of this study is to look at the effects of augmented peripheral feedback on system understanding. We focused on a smart thermostat system. We designed an artefact which used coloured lighting patterns to communicate the different statuses: heating, cooling and a steady state. We deployed the artefact for three weeks in two environments, and conducted a qualitative interview before and after this deployment. We concluded that with the help of the artefact we were able to communicate the system status to the participant, but only when the fully understood the different coloured lighting patterns; they needed to know what these meant. Provided that the participants fully understood the coloured lighting patterns things they did not focus on the artefact when receiving this data, they interacted with the artefact in the periphery of their attention.

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