Designing Effective Human-IoT System Communication

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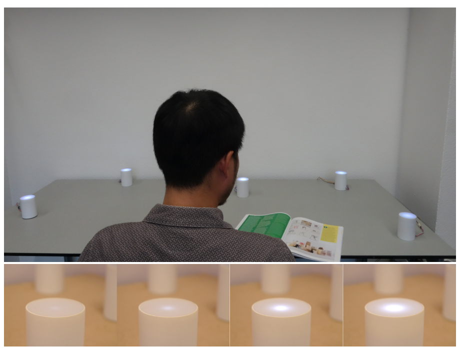

Figure 1: In this study, we developed a distributed system with five devices to investigate the effectiveness of communication with the feedback designs. Top: The setup of the experiment. Bottom: The variants of light behaviors displayed on the top of individual device. The video demonstration could be accessed via: Group behavior–https://vimeo.com/209322399; Individual expression–https://vimeo.com/209322460.

ABSTRACT

Connected devices and automatic systems are becoming popular and ubiquitous, but they seldom provide informative communications on their status or intents of behaviors. In this paper, we utilized the low-cost point LED and speaker to design alternative lighting behaviors and sounds for expressing a system's intentions. We then recruited 16 participants to investigate how likely those designs could be intuitively interpreted. It was found that the six group light patterns developed in our study could effectively communicate the intended messages and provide users high degree of situation awareness. With the auditory accompaniments, in most cases they enhanced the messages and enabled peripheral interactions. We demonstrated how to design effective communications for providing users' awareness on artifacts individually and in aggregate to understand the intelligibility of the system.

KEYWORDS

Peripheral Interaction, Feedback, Feedforward, Internet of Things, Situation Awareness

INTRODUCTION

Smart products and connected devices are becoming popular and ubiquitous. Some advanced systems (e.g. [7]) can anticipate users' needs and proactively assist people's daily activities, such as in a smart home or factory. Unlike traditional products, connected devices and intelligent systems are able to sense users' needs and trigger specific functions without physical interactions. On the one hand, this

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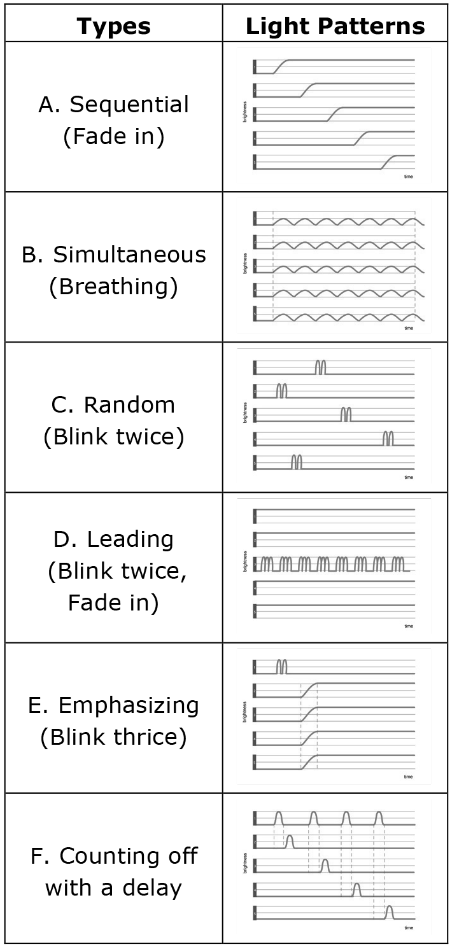

Figure 3: The six group behaviors composed by variants of individual point light patterns with the animation principles of staging and timing[13].

intangible nature provides a certain flexibility for implementation and usage. On the other hand, however, these smart artifacts offer little cues than users are used to [3]. When something unexpected happens, due to a lack of situation awareness [4], users often feel frustrated because they do not know where was the problem from [9][14].

To support intelligibility in a complex system [1], most manufacturers provide GUI software to report the system status or errors on users' computer or mobile devices, e.g., [12]. Although such applications can convey explicit information about the system, they are thought of as too obtrusive in the way they interrupt users' daily activities [8]. Based on the interaction-attention continuum[11], we knew that users were overwhelmed by those fully focused interactions. In fact, not all of the communications needs the users' full attentions. Some of the messages could be delivered through the peripheral or ambient interactions, such as the active status or exchanging information among the devices [2]. In this paper, we demonstrated how could we design the expressivity with the visual and auditory feedback that could provide effective communications for the human-IoT system interactions.

METHODS

Designing the Lighting and Auditory Feedback

Since the LED (light-emitting diode) was successfully commercially adapted to the market in the 1970s, it has been widely embedded in electronic products to provide feedback at very low cost. In this study, we focused on the design of feedback via point LED light. Specifically, we utilized variations in intensity and timing to create variant expressiveness of light behaviors shown on multiple devices. Building on Harrison et al. [6] and Pintus' [10] studies on the expressivity of point lights, we first defined nine basic individual patterns (see Figure 2), such as variants of fading and blinking. Secondly, we developed a virtual system consisting of five devices to simulate an Internet of Things (IoT) system. In order to investigate the communication issue, we chose seven communication vocabularies from [2], including booting, joining, broadcasting, synchronizing, notifying, showing problems, and triggering functions. We also used those vocabularies to define a scenario of human–IoT system interaction (see Table **1**). Thirdly, we applied the animation principles of staging and timing [13] to explore the

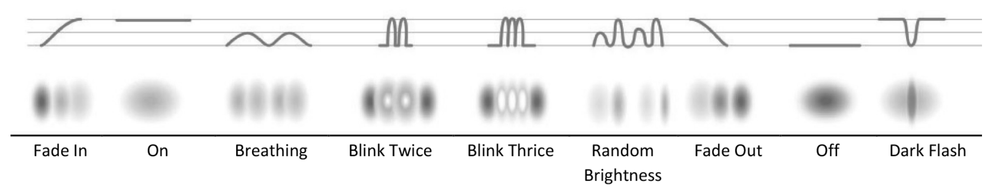

Figure 2: The visualization of the nine light behaviors of a single point light.

variants of group behaviors with different individual lighting patterns. Through conducting a pilot survey on evaluating the design qualities with six interaction designers, we identified six designs (see Figure 3) that users felt consistent and most meaningfully associated with the intended vocabulary. Finally, we developed the auditory accompaniments based on the events defined in the scenario of task.

Table 1: The five tasks in the scenario of the human-IoT system interaction defined in this study. For each task, we identified the needed vocabularies[2] to develop the light behaviors. The ones shown in this ta-ble were the most matching designs concluded from the pilot study.

Task	Vocabulary	Light Behavior	
		Individual	Group
1. Waking up the system	Welcome, Booting, Waking up everyone	Fade in	Leading
2. Adjusting the settings of the system	Broadcasting, Synchronizing	Blink twice, Pulse	Leading, Simultaneous
3. Joining a new device to the system	Joining, Confirmed	Fade in, Pulse	Sequential, Counting off with a delay
4. Checking the devices and the system	Detecting problems, Alerting	Blink twice, Solid on	Random
5. Removing a defective device	Disconnecting	Fade out	Emphasizing

User Study

We conducted a study to investigate how likely it would be that the users could successfully perceive and interpret the message through the alternative light or light and auditory feedback and feedforward. We used Wizard-of-Oz approach to execute the experiment in two separated rounds. The user first experienced the interactions with only the light feedback. After a break, they tried the same interaction with the light and auditory feedback. To simulate usage in real environments, we spread out the five prototypes on an office table (200 X 80 cm), with some placed outside of the user's visual attention field (see Figure 1). In this way, we aimed to investigate the interactions with a ubiquitous system. Because we focused on the effects of the first two levels (perception and comprehension) of situation awareness on the interaction, we used the SAGAT probe [5] approach to query the participants' perceptions and interpretations during the operation. For each of the five tasks, after noting down the user's intuitive interpretations, we revealed the message that was intended to be conveyed through the designs and asked the participant to rate how clearly it was perceived on a five-point Likert-scale, from 1 (not clear at all) to 5 (very clear). Meanwhile, because the goal of this study is to investigate the subtle expressions of the lighting and auditory designs, we purposely recruited 16 designers (average age 28.4, seven females) from our department to evaluate the designs.

RESULTS

Overall, the participants felt that they perceived the light behaviors (SA Level 1) and had comprehensive understanding of the system's behaviors as it intended to communicate (SA Level 2). For instance, in the first task: *waking up the system*, 15 participants noticed that after the first device was booted up, it triggered the other devices to wake up. Meanwhile, for the most complicated case of Task 3: *joining the system*, 15 users could describe the process of how the new device joined the system, although five of them used "connecting" instead of "joining."

Regarding the participants' ratings of how clearly the system's messages were conveyed through the light behaviors, the means of the five tasks of the first round were between 4.13 and 4.88 (out of 5, see Table 2). The standard deviations were less than 0.70, excepting 1.26 for the fifth task, *removing a device from the system*. In this case, two participants rated the design below 2, i.e., unclear. One user mentioned that "because [in the end the device] had a dimmed light, I felt that it was still connected to the system. If the light was entirely off, I might feel that it was completely disconnected from

Table 2: Statistical results of the participants' ratings of clearness in conveying the message in different tasks.

Light Behaviors Only					
Task	1	2	3	4	5
Mean	4.56	4.75	4.31	4.88	4.13
SD	0.51	0.68	0.70	0.34	1.26
Light Behaviors plus Auditory					
Task	1	2	3	4	5
Mean	5	4.63	4.63	4.81	4.50
SD	0	0.62	0.62	0.54	0.73

the system" (P9). Those two users' ratings improved to 3 and 4 in the second round, when auditory feedback was also provided. The same user, P9, stated, "The auditory feedback is simple and helps me to understand the message better."

Comparing the results of the two rounds, we saw that the auditory accompaniments enhanced the users' understanding of the system's behaviors in three tasks. But the users felt the message less clear in the second and fourth tasks, especially the former: *adjusting the system's settings*. In that instance, three users rated the combination feedback with a score of one point less, i.e., changing from 5 to 4, compared to the light only session in the first round. Although most of the participants appreciated that the starting sound helped to confirm that their input was received by the first device, due to the lack of an ending sound when the other devices synchronized with the settings, they felt the communication was not completed. One of them stated, "Due to the lack of a responsive audio feedback from the other devices, it felt as if the devices were less synchronized than I experienced with the light behavior [blinking altogether] in the first round" (P15). Originally, we thought that if whenever a user adjusted a setting, all of the connected devices would play a sound in response, it might be felt to be too obtrusive in the daily environment. Therefore, we arranged that all the devices would show blinking light behaviors with a precise timing just after the starting sound was finished. Although the participants saw the correspondence between the two modalities provided in the prototype, they were waiting to perceive the ending of the sound feedback. Instead of substituting a feedback in the middle, designers need to provide seamless transitions, such as fading out sound, to fulfill users' comprehension of the feedback.

CONCLUSION AND FUTURE RESEARCH

Overall, our study showed that the expressivity of group light behaviors could already convey IoT systems' behaviors to the users directly in the peripheral and physical context. The additional auditory accompaniments could enhance their situation awareness and understanding of the communications, especially when the devices were distributed inside and outside a user's attention field. During the study, we also collected many valuable suggestions that could be developed further to improve user experiences of complex IoT systems. For instance, colored lights could more directly alert; multiple lights could display the processing of actions. While most of the participants appreciated that the sound feedback increased the perception of the system, it might be a bit too obtrusive to have to hear so many sounds whenever interacting with the system. This opens up interesting challenges on how to design the coordinated feedback and feedforward with multiple modalities that could provide high situational awareness and unobtrusive interactions at the same time.

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