Effect of Expressive Lights on Human Perception and Interpretation of Functional Robot

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CHI'18 Extended Abstracts, April 21–26, 2018, Montréal, QC, Canada.
ACM ISBN 978-1-4503-5621-3/18/04.
https://doi.org/10.1145/3170427.3188547

Abstract
Because appearance-constrained robots lack expressiveness, human users often find it hard to understand their behavior and intentions. To address this, expressive lights are considered to be an effective means for such robots to communicate with people. However, existing studies mainly focus on specific tasks or goals, leaving the knowledge of how expressive lights affect people's perception still unknown. In this pilot study, we investigate such a question by using a Roomba robot. We designed two light expressions, namely, green and low-intensity (GL) and red and high-intensity (RH). We used open-ended questions to evaluate people's perception and interpretation of the robot, which showed different light expressions as a way to communicate. Our findings reveal that simple light expressions can allow people to construct rich and complex interpretations of a robot's behavior, and such interpretations are heavily biased by the design of expressive lights.

Author Keywords
Expressive lights; color psychology; appearance-constrained robot; human-robot interaction (HRI)

ACM Classification Keywords
H.5.m. [Information Interfaces and Presentation (e.g., HCI)]: User Interfaces - Theory and methods

Introduction

People are explanatory creatures. Due to our tendency to form explanations of things, we build mental models, our conceptual models of the way objects work or people behave, of those things and use the models to help us understand our experiences and handle unexpected occurrences [13]. Therefore, we naturally adapt our social skills and exhibit similar social behavior when we first meet a human-shaped robot. However, a large number of robots currently in use for applications such as search and rescue and domestic cleaning are neither anthropomorphic nor zoomorphic. When we first encounter such robots, the lack of appropriate mental models and knowledge with regard to these robots can lead to unsmooth or even failed interaction [11]. Therefore, there is a significant challenge in finding effective ways for these robots to successfully interact with human users.

Existing approaches mainly focus on motion cues [12, 4, 3, 14]. Unfortunately, such methods suffer from low expressibility and are hard, if not impossible, to apply in many application scenarios such as places that have restricted space. Alternatively, previous research [2, 15, 5] showed that expressive lights, as a dynamic vision cue, can be used for robots to communicate with humans. Basically, expressive lights have been shown to be effective in various human-robot interaction (HRI) contexts such as indicating internal states [2], communicating intent [15], and expressing emotion [5]. In general, a commonality with regard to most of these studies is that they focused on specific tasks or goals. Therefore, it is still unknown how expressive lights affect people's interpretation of a robot in general.

In this work, we investigate this research question. On the basis of color psychology theories and related literature, we designed two light expressions, namely, *GL* (green and low-intensity) and *RH* (red and high-intensity). We designed an experiment to study people's perception and interpretation of a Roomba robot's behavior in different expressive lights conditions and employed open-ended questions for evaluation. Findings from this pilot study reveal that simple light expressions can allow people to construct rich and complex interpretations of a robot's behavior, and such interpretations are heavily biased by the design of expressive lights. This is supported by Joseph's claim [10] that "...single bit of communication can leverage an enormous amount of social, cultural and emotional capital, giving it a significance far greater than its bandwidth would seem to suggest."

Expressive Light Design

Color psychologists have intensively investigated various aspects of color, including color vision, color symbolism and association, and color effects on psychological and biological functioning [7]. Particularly, red has been shown to be a critical color and has thus garnered the majority of research attention. Red is the color of blood, and dynamic variations in visible blood flow on the face and body can indicate fear, arousal, anger, and aggression [1]. Red is also a term that appears in almost all lexicons and, moreover, in many sayings such as "in the red." Besides red, the color green has been intensively studied as well. It has positive links in the natural realm, for example, green foliage and vegetation [9].

Studies on hue color associations suggest that color meanings can be grounded in two basic sources: learned associations that develop from repeated pairings of colors with particular concepts or experiences and biologically based proclivities to respond to particular colors in particular ways in particular situations [8]. For instance, a specific red-danger association can be generated from experiences with regard to (life-threatening) situations such as viewing blood, an angry face, traffic lights, and/or warning signals

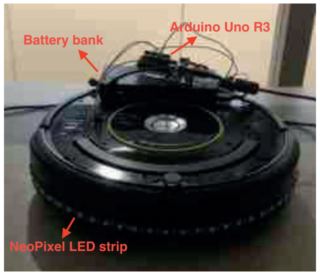


Figure 1: Configuration of Roomba robot with LED lighting system

Figure 2: NeoPixel LED strip (60 pixels)

and sirens [9]. Similarly, green can be associated with positive meanings, e.g., approach and pleasure, due to experiences with green traffic lights and the general image of being the color of nature.

On the basis of the above survey on color psychology, we decided to focus on two colors: **green** and **red**. They produce opposite effects on human psychological functioning. Basically, green can be associated with weak and positive affect and induce approach-like behaviors in a human. In comparison, red can be associated with strong and negative affect and induce avoidance-like behaviors. Besides color, two more parameters, waveform and intensity (frequency), needed to be decided on to design expressive light patterns. In particular, Terada et al. [16] studied color and dynamic parameters for representing emotions. They found that a rectangular waveform with a high frequency represents intense emotions, while a sinusoidal waveform with a low frequency represents weak emotions. On the basis of their work, we decided to combine a sinusoidal waveform and a low frequency with green to enhance the effect of the color green. Similarly, we combined a rectangular waveform and a high frequency with red to enhance the effect of the color red.

Pilot Study

We conducted an experiment in which we installed an LED lighting system on an iRobot Create 2 robot, which is a Roomba robot. Roomba is a series of autonomous robotic vacuum cleaners used in indoor environments. It perfectly fits the definition of an appearance-constrained robot and has very limited ways to express itself, e.g., moving forward/backward and spinning. Figure 1 shows the configuration of the robot with LED lighting. We used one meter of a NeoPixel LED strip (60 pixels, Figure 2). The LED strip was controlled by an Arduino Uno R3 board, and both the strip and the board were powered by a 5-V, 3-A portable powerbank. The same board was also used to control the movements of the robot.

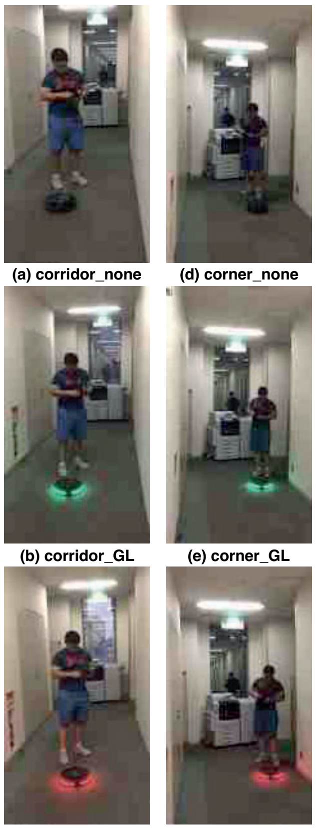
By using expressive lights, we are effectively enabling a robot to modify its appearance as a method of communicating with humans and, moreover, providing additional cues to assist humans in interpreting the robot's true intentions. We expect that the simple light expressions we designed can allow people to construct rich and complex interpretations of the robot's behavior and that such interpretations will be heavily biased by the design of the expressive lights (GL or RH).

Procedure

We designed two similar practical HRI contexts, *corridor* and *corner*, which are common for indoor autonomous robots [2]. Specifically, the Roomba robot moved along a narrow corridor (corridor context) or approached a corner of the corridor (corner scenario). In the two cases, the robot encountered a person and stopped before it ran into the person. While stopped, the robot further showed GL, RH, or simply no lights (see Figure 3). We presumed that the robot's intention, i.e., what it was doing, in such contexts would be ambiguous and thus could be interpreted in various ways. We presumed that the added expressive lights could significantly affect and bias people's perception and interpretation of the robot's behavior and its intention.

The experiment had a between-participant design, where each person viewed two videos belonging to the same condition (none, GL, or RH). A Japanese online crowdsourcing platform[1] was employed to recruit participants. We initially hired 180 participants, 60 for each condition. In a ques-

[1] Fastask: https://www.fast-ask.com. The website is only available in Japanese.



(a) corridor_none (d) corner_none
(b) corridor_GL (e) corner_GL
(c) corridor_RH (f) corner_RH

Figure 3: Screenshots of each video clip (condition)

tionnaire, we asked three open-ended questions: 1) What was the robot doing? 2) Did the robot want to communicate something to the person? If yes, what information did the robot want to communicate? 3) Do you think that the robot was friendly?

Results

After filtering out unreliable data, we had 40 participants from the *none* condition (11 females, $\text{M}_{age} = 39.9$, $\text{SD}_{age} = 7.6$), 40 participants from the *GL* condition (14 females, $\text{M}_{age} = 42.3$, $\text{SD}_{age} = 9.3$), and 40 participants from the *RH* condition (14 females, $\text{M}_{age} = 43.6$, $\text{SD}_{age} = 8.6$). We analyzed all their answers and observed interesting findings. We summarize the key findings below.

I In the **RH** condition, 15 out of 37 participants (41%) used negative words, such as *warning* or *hostile*, to describe the robot and its behavior. No participants (0 out of 40, 0%) in the *none* condition and only 1 participant (1 out of 42, 2%) in the *GL* condition used such descriptions.

II In the **RH** condition, only 8 out of 37 (22%) participants described the robot as a cleaning robot. However, half of the participants (20 out of 40, 50%) in the *none* condition and almost the same number of participants (20 out of 42, 48%) in the *GL* condition explicitly described the robot as a cleaning robot.

III In the **GL** condition, a majority of the participants (32 out of 42, 76%) perceived the robot as friendly. In comparison, half of the participants (19 out of 40, 48%) in the *none* condition, and, in particular, only 12 participants (12 out of 37, 32%) in the *RH* condition perceived the robot in the same way.

IV Participants showed different levels of **imagination** when explaining what was happening in the videos. Specifically, participants in the *none* condition showed a low level of imagination. They generally described the robot's behavior in three different ways: the robot was *cleaning*, *moving (tele-operated)*, and *approaching the person (intended)*. However, participants in both the *GL* and *RH* conditions showed a high level of imagination (described the robot's behavior in 5 and 6 ways, respectively). People in the *GL* condition described the robot as *cleaning*, *moving (tele-operated)*, *approaching the person (intended)*, *communicating to the person*, and *playing*; people in the *RH* condition thought the robot was *cleaning*, *moving (tele-operated)*, *approaching the person (intended)*, *warning the person*, *patrolling*, and *malfunctioning*.

V On average, participants used less words to answer the three open-ended questions in the *none* condition (83.9 words/person). In comparison, participants in the *GL* and *RH* conditions used 91.7 w/p and 90.9 w/p, respectively.

Discussion and Future Work

Our findings show that RH expressive lights can have a particularly strong negative bias on people's perception of a robot. People tend to interpret the robot's behavior in a negative way. In comparison, GL expressive lights can have a positive bias on people's perception of a robot. Interestingly, in general, people tended to interpret the robot's behavior as **goal-directed** when it showed either GL or RH. This indicates that they perceived the robot as having intent (beliefs and desires). As summarized in finding II, far fewer participants, especially in the *RH* condition, described the Roomba robot as a cleaning robot, suggesting that they anthropomorphized the robot in both the *GL* and *RH* conditions more than in the *none* condition. Therefore, we infer that social HRI is more likely to be established when a robot shows expressive lights as a means of communication.

Further, we found that expressive lights can affect how a person perceives the friendliness of a robot. Summarized in finding III, most participants perceived the Roomba robot as friendly in the *GL* condition, and on the contrary, the lowest number of participants thought so in the *RH* condition. This can be explained by referring to findings I and IV. Finding IV particularly lists how participants imagined and interpreted the scenarios in the videos. Besides the common interpretation that the robot was *cleaning*, *moving (tele-operated)*, and *approaching the person (intended)*, participants in the *GL* condition additionally imagined that the robot was either trying to communicate to the person or playing. These interpretations are positive in general, which is probably why people interpreted the robot as friendly. On the contrary, both findings I and IV clearly suggest that participants in the *RH* condition thought that the robot was giving warnings and was hostile. It is thus not surprising that they treated the robot as less friendly.

Claimed by Joseph [10] that a single bit of communication can leverage an enormous amount of social, cultural, and emotional capital, our study further shows that simple communication based on expressive lights can lead people to creatively imagine and interpret a robot's ambiguous behavior. Moreover, such imagination and interpretation is heavily dependent on the design of expressive lights. In addition, it can also depend on the contexts and person's particular knowledge and experience in interacting with robots.

We believe that this work can open up opportunities for further investigation on simple communication methods that can be applied to various HRI contexts. Instead of focusing on specific tasks and goals, this simple method, using expressive lights, relies on people's imagination and can affect their perception and interpretation of a robot at a high level (positive vs. negative). Therefore, future work is needed to investigate different HRI contexts and observe how people's perception and interpretations differ with regard to the context. It is also necessary to explore different designs of expressive lights, and their effects on people should be evaluated. In this pilot study, we did not intend to treat the parameters (color, waveform, and intensity) as independent factors. However, we suggest future studies should do so to avoid interaction effects among them.

Acknowledgements

This study was partially supported by JSPS KAKENHI “Cognitive Interaction Design" (No. 26118005).

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