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Designing LED Lights for Communicating Gaze with Appearance-Constrained Robots

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***Abstract*— Functional robots are generally restricted in appearance, thus lacking ways to express their intent. In human-human interaction, gaze is an important cue for providing information and regulating interaction. In this pilot study, we investigate how we can implement gaze behavior in functional robots since gaze communication can allow humans to read a robot's intent and adjust their behavior accordingly. We explore design principles based on LED lights as we consider LEDs to be easily installed in most robots while not introducing features that are too human-like (to prevent users from having high expectations). In the paper, we present a design interface that allows designers to explore the parameter space of an LED strip attached to a Roomba robot. We then summarize a set of design principles for optimally simulating light-based gazes. Finally, our suggested design is evaluated by a large group of participants, and their comments are discussed.**

I. Introduction

There is a trend for functional robots to be involved in our society. A real live example is the Roomba robot[1], a series of autonomous robotic vacuum cleaners that are becoming increasingly popular nowadays. However, due to the nature of the tasks such robots perform, they are generally restricted in appearance, making it hard for them to express their intent [1]. With regard to the Roomba robot, while it uses an LED display and beep sounds to indicate some of its internal states, e.g., cleaning or charging, its behavior can still be mysterious to many users. Since more and more functional robots are required to interact with, communicate to, and/or cooperate with human users, it is essential for such robots to explicitly express their intent [2].

In human-human interaction, people use multiple communication cues to express themselves. Among these cues, gaze has been suggested as important for providing information, expressing intimacy, and regulating interaction [3]. Due to its effectiveness, many researchers have tried to employ gaze as an interaction modality for social robots. Plenty of research has been done to evaluate the functionality and design principles of gaze behavior for HRI [4], [5], [6]. Unfortunately, most of it focused on human-like robots or virtual human agents. Because of an adaptation gap [7], it is suggested that applying human-like gaze (eyes) to functional robots will cause humans' expectations of such robots to exceed the real capabilities of the robots and result in a negative HRI experience. Therefore, the appropriateness of applying anthropomorphic eyes to functional robots is questionable.

To address this question of how best to apply gaze to appearance-constrained robots, a handful of previous work [8], [2] investigated light-based methods. Particularly, Szafir et al. [2] explored the design space regarding explicit robot communication of flight intentions using LED lights. They tested their four signal designs (blinker, thruster, beacon, and gaze) and found that three of them (blinker, thruster, and gaze) were effective. In particular, they reported that their participants appreciated the greater precision offered by the gaze design. Therefore, their work showed that it can be potentially effective and precise to simulate gaze communication with LED lights.

However, their work leads to several unsolved design issues. Because they did not focus on gaze signals alone, the design principles regarding how "eyes" can be simulated by LED lights were not discussed in detail. As they mentioned in the paper, they designed the signals by using measurements of the human eye. However, due to the huge difference in shape and the many other features between human eyes and LEDs, the appropriateness of such an approach can be questioned. A better method could be offering a design interface to allow designers to freely explore a design space (different combinations of parameters). In addition, color, as a key feature, can be better investigated. To be specific, different colors can be used for different parts of the eye (pupil and sclera). This allows the pupil part to be made prominent, which could lead to a better resolution regarding directionality recognition.

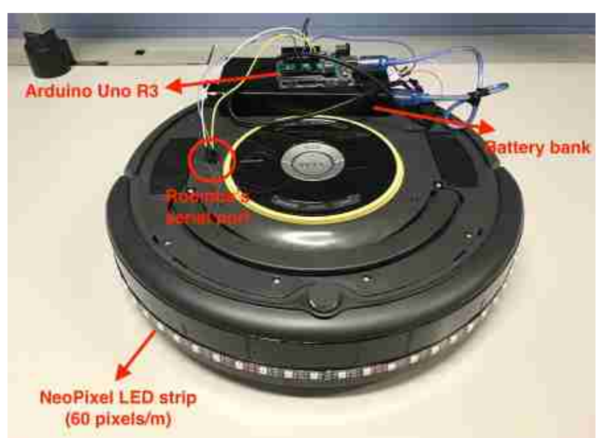

Fig. 1. Configuration of Roomba robot with LED lighting system

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[1]https://en.wikipedia.org/wiki/Roomba.

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Fig. 2. Screenshot of design interface

II. Pilot Study

Our study is aimed at exploring the design space regarding simulating gaze by using LED lights. We installed an LED lighting system (NeoPixel LED strip) on an iRobot Create 2 robot, which is a Roomba robot. Figure 1 shows the front side of the robot and the configuration of its LED lighting. To be specific, we used one meter of a NeoPixel LED strip (60 pixels). 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.

In this pilot study, we particularly examined parameter settings for simulating a gaze signal. We first developed an interface that allows designers to freely investigate different gaze designs. On the basis of the data and comments from volunteer designers, we summarized a set of (abstract) design principles that can be employed as a reference for both HRI and CHI researchers. In addition, we further hired a large sample of participants via an online survey platform to evaluate our gaze design. The participants' answers to open-ended questions provided valuable insights on how our designed gaze signal be perceived and interpreted by humans.

III. Design Interface

We developed a design interface by using Processing. As shown in Figure 2, the interface allows designers to explore a set of parameters regarding gaze simulation. Specifically, the associated parameters include *color of pupil*, *width*[2] *of pupil*, *color of sclera*, *width of sclera*, and *interocular distance*.

[2]Number of LED pixels.

The image in the upper left shows the front side of the Roomba robot with LED lighting. It provides an intuitive idea of what the robot looks like and can, explicitly or implicitly, help designers keep a correct mental model of the robot while setting parameters. The right hand side panel allows interactions between designers and the interface. Designers can freely try out different combinations of parameter values by setting the corresponding parameters. Particularly, the interface provides a candidate set of basic colors[3] in the lower right side for the designers to select. The design interface can be connected to our Roomba robot equipped with an LED lighting system. By clicking on the "Confirm" button, the interface sends the current parameter values to the Roomba (to the Arduino Uno board attached to it), which then displays the corresponding gaze signal. Designers can iterate over and optimize their gaze designs. If they finally decide on a set of parameters, they can click on the "Save & End" button to quit the design interface. The final parameter values will be saved to a local file, allowing for later analysis.

A. Design Principles

We organized a design session in which we invited six designers (one female) to join an experiment. At the beginning of the session, we showed a demo video as a tutorial regarding how to use the design interface. Later, the participants were assigned to individual design trials without any time restriction. At the end of the trials, they were asked to provide comments and opinions in a free manner. Below,

[3]http://www.creativecolorschemes.com/resources/free-color-schemes/basic-color-scheme.shtml.

we summarize a set of design principles based on the findings from this design session.

I The pupil part should be clearly identifiable. To ensure this, it is suggested that the width of the pupil be more than 1 LED pixel. In addition, the color of the pupil should contrast highly with the color of the sclera.

II The brightness of the sclera part should be much lower than the pupil part to look natural[4]. This also helps the pupil to stand out.

III The width of sclera should be sufficiently long so that the directionality of gaze, e.g., left, normal, and right, can be well recognized.

IV The interocular distance should be sufficiently long so that the two eyes can be well distinguished.

Particularly, principle II provides partial evidence of the inappropriateness of using measurements of the human eye in gaze signal design because the sclera of a human eye is, in general, much brighter than the pupil. The description of "look natural" means something different, depending on the design space to be referred to. If the task is to design an anthropomorphic eye, it could be preferable to imitate a human eye. However, with regard to designing a gaze signal with LED lights, different design principles should be relied on.

IV. Evaluation

On the basis of the findings from the design session, we decided on an example of a gaze signal that well followed the five principles. Specifically, we set the color of the pupil to bright green and the color of the sclera to dim gray. We set the width of the pupil to 2 LED pixels and the width of the sclera to 3 LED pixels. In addition, we set the interocular distance to 4 LED pixels.

We prepared two demo videos in which the Roomba robot was displaying a "scan" behavior (gazing from left to right regularly in two cycles). In one demo (a screenshot is shown in Figure 3), the robot was the only object in the video. There was nothing in front of it while it was scanning. However, in the other demo (a screenshot is shown in Figure 4), three objects were put in front of the robot. The goal of the evaluation was to find out how people would perceive and interpret our designed gaze signal that uses LED lights. Due to the mechanic embodiment of the Roomba robot and neutral shape of the LED strip, we hypothesized that people's perception of the robot would be that it is hardly anthropomorphic. As a result, it would be hard for them to interpret the light expressions as gaze signals in general. However, we hypothesized that when reference objects, or additional cues, are provided (the three objects in the second demo), people would then understand the gaze signals and attribute more agency to the robot. This actually meets a key design goal; gaze design should not introduce to much anthropomorphism as it otherwise could cause human's expectations of a robot to exceed its real capabilities.

[4]The meaning of "look natural" does not suggest that it looks more similar to human eyes. We prefer to interpret this as a lower brightness of the sclera part making people more easily perceive LED lights as a gaze signal.

Fig. 3. Screenshot of demo showing Roomba robot alone

Fig. 4. Screenshot of demo showing Roomba robot together with three objects

We performed the evaluation by using online surveys. A Japanese online crowdsourcing platform[5] was employed to recruit participants. We hired 120 participants, 60 of them for each condition (demo video). In a questionnaire, we asked two open-ended questions: 1) What was the robot doing? 2) Is it easy to understand the robot's intent?

A. Results

The results confirmed our hypotheses. In general, participants who viewed the demo showing the robot alone found it hard to understand the robot's intent. Their perceptions and interpretations regarding the robot's behavior were highly biased by the type of robot: cleaning robot. To be specific, many participants described the robot as "searching for garbage" or "cleaning (its current place)." Other participants thought that the robot was charging or waiting for commands. Such descriptions indicate that participants did not attribute agency to the robot. This suggests that, without hints regarding the functionality of the light expressions, it can be difficult for people to perceive them as gaze signals.

However, participants who viewed the demo showing objects in front of the robot found it easy to understand the robot's intent. This is not surprising since the provided objects, as an additional cue, allowed them to dramatically reduce the number of potential scenarios for guessing. An

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

analysis on the participants' descriptions of the robot's behavior clearly shows that they attributed a certain level of agency to the robot. Specifically, many participants used anthropomorphic descriptions such as "observing the objects" or "choosing among the objects." Such descriptions suggest that they interpreted the light expressions as gaze signals (scanning the objects). Importantly, almost none of the participants explicitly described the light expressions as eye-like or gaze-like, suggesting that they did not attribute too high a level of agency to the robot.

V. Design Implication

Besides the design principles we proposed, our findings offer several important design implications that can be beneficial to HRI and CHI researchers:

- Light-based gaze signals may not be explicit cues that indicate directionality. However, when a reference (objects) is provided, people can easily learn or recognize the functionality of the light expressions, similar to gaze. To be general, such reference information does not necessarily need to be an object. A robot's motion, for instance, that is coordinated to light expressions could probably help people to recognize a gaze signal too.
- Light-based gaze signals should be designed by using measurements of the human eye with caution. Some features (parameter settings) that fit the design of anthropomorphic gaze may not be appropriate for light-based gaze signals.
- Light-based gaze signals can be suitable for functional robots as they will not introduce too much anthropomorphism, which biases people to have expectations that exceed a robot's real capabilities.

VI. Next Step

The next step will be to evaluate the effect of light-based gaze signals in real HRI contexts. Because gaze can be used to indicate a robot's intent and direct people's attention [3], it is important to examine whether light-based gaze signals possess such functionalities. We will consider several evaluation methods to be applied for this purpose. Typical human-robot cooperation contexts can be designed in which task performance can be improved if a human is able to read a robot's intent (next move). Video-recorded data is needed to analyze how humans behave when reacting to a robot's gaze signals. Importantly, we will consider using a wearable eye-tracker device (Tobii Pro Glasses 2) to track people's corresponding gaze behavior on-the-fly. This will allow us to easily identify the joint-attention behavior of a person. In addition, future work could also involve gaze animation design. Gaze animations may cause people to attribute more agency to a robot. In addition, other robot shapes and arrangements of LEDs should be investigated.

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