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Gaze Guidance in the Real-world by Changing Color Saturation of Objects

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Abstract

In this study, we propose a method for real-world gaze guidance by projecting an image onto a real-world object and changing its appearance based on visual saliency. In the proposed method, an image of the object is first acquired. Next, the image is changed such that the visual prominence of the object is increased and the image is changed so that the visual prominence of other parts of the object is decreased. Finally, the modified image is re-projected onto the object itself. Consequently, the object's appearance and visual prominence are altered, and the user's gaze is focused on the desired object. In this study, we propose an image processing method that changes the saturation of an object. We call this the "saturation filter." A coaxial projector-camera system was used to apply the proposed gaze guidance method proposed in this study to a 3D object. The coaxial projector-camera system does not need to be recalibrated when an object moves. In this study, two experiments were conducted to verify the effectiveness of the proposed method in guiding a viewer's gaze. As a result, it was confirmed that the proposed method can achieve the effect of gaze guidance.

CCS Concepts

• ***Human-centered computing*** → ***Human computer interaction; Displays and imagers;*** • ***Computing methodologies*** → *Mixed/augmented reality;*

1. Introduction

Figure 1: *The concept of real-world gaze guidance.*

When people go shopping, there are many products in the same category, and it is difficult to know which one to choose. Manufacturers want to direct customers' attention to their products by, for example, using colorful packaging. Stores may also direct customers' eyes to specific products by attaching special sales pop-ups, such as newly arrived items or today's sale items.

This type of eye guidance is also common in electronics markets. There are many visual stimuli when accessing such electronic marketplace web pages, such as color changes and flashing lights. However, it has been reported that customers feel annoyed by such "overt" visual stimuli because they are forced to shift their gaze. In contrast, Hata et al. [Hata et al.(2016)] and Azuma et al. [Azuma and Koike(2018)] proposed more natural eye guidance using image filters such as Gaussian blur and color shift, respectively. They showed that these image filters can guide the user's gaze to a specific position even when the user does not notice subtle changes in the displayed image. If such subtle changes in appearance can be applied to real objects, it might be possible to guide the user's gaze without noticing or bothering the user. However, how can such image filtering effects be applied to real objects?

This paper describes a method for guiding a viewer's gaze in the real world using projection mapping technology. In particular, a coaxial projector-camera (procam) system is used to achieve precise pixel-by-pixel projection mapping, which enables subtle viewing changes. The contributions of this study are as follows.

- A method to provide visual effects, similar to image filtering for

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digital images, to real-world objects was proposed by using a coaxial procam.
- A saturation filter and a shift filter were implemented using the procam.
- Appearance change of the real-world objects was confirmed.
- Gaze guidance effect for the real-world objects was confirmed by user experiments.

2. Related Work

2.1. Gaze Guidance on Computer Displays

Several methods have been proposed to guide the viewer's gaze by changing the appearance of the content on a computer display. In this study, we refer to these methods to guide the viewer's gaze by changing the appearance of real objects. Hagiwara et al. [Hagiwara et al.(2011)] proposed gaze guidance by changing the color of an image to change its visual saliency. Mateescu et al. [Mateescu and Bajic(2013)] proposed gaze guidance by changing the orientation of a part of the image to create a difference from the surrounding edge direction distribution. Hata et al. [**?**] proposed gaze guidance using unnoticed Gaussian blur. Azuma et al. [Azuma and Koike(2018)] proposed gaze guidance using an artificial color shift, which is sometimes observed in printed documents.

2.2. Gaze Guidance Using a Projector

Several existing gaze guidance methods for projection onto real objects have been proposed. Butz et al. [Butz et al.(2004)] proposed a method for assisting search and other tasks by projecting a spotlight onto a user-specified object with AR markers. Pinhanez et al. [Pinhanez(2001)] proposed guiding a user by projecting signs and characters onto the floor or wall depending on the situation. Booth et al. [Booth et al.(2013)] proposed gaze guidance that projects a blinking light onto objects and then stops the projection when the user's gaze is on the target object. Adcock et al. [Adcock and Gunn(2015)] proposed a method for projecting information onto three-dimensional objects in order to support an on-site worker. Takimoto et al. [Takimoto et al.(2019)] used a procam system to change the appearance of a planar object such as a picture based on visual saliency for gaze guidance in the real world. Takimoto's method is similar to the method proposed in this paper, but the method proposed in this paper is different in that it can change the appearance of three-dimensional objects.

2.3. Appearance Control by Spatial Augmented Reality

Many SAR techniques [Bimber and Raskar(2005)] have been used to change the appearance of real objects by using projection. However, to the best of our knowledge, there has been little research on gaze guidance. Shader Lamps [Raskar et al.(2001)], a computer graphic technique based on pioneering SAR research, have been used to change the visual appearance of real objects. Amano et al. [Amano and Kato(2010)] proposed appearance control using projection with a technique known as model predictive control. They applied such appearance control to the properties of paper documents. Jones et al. [Jones et al.(2013)] proposed a system that extends the visual experience beyond a television screen by using a projector that covers a wide area of the surrounding physical environment. Shimana et al. [Shimana et al.(2016)] proposed an omnidirectional appearance control for three-dimensional objects using multiple procams. Kawabe et al. [Kawabe et al.(2016)] proposed a projection technique called deformation lamps, which adds realistic dynamic effects to real static objects. Fujimoto et al. [Fujimoto(2018)] proposed a method for enhancing the perceived deliciousness of food using a procam.

3. Proposed Method

This section describes a method for real-world gaze guidance that changes the appearance of an object using proximity.

Figure 2 shows the outline and data flow of the proposed method. First, the real world (original image) was captured by the camera and transformed into the coordinate system of the projector. Next, an image filter was applied to this (transformed) image to obtain a new image with increased visual prominence in the target region and decreased visual prominence in the surrounding regions. The final image was then accurately projected onto a real-world object using a projector in the procam. The core components in this approach are a saturation filter and a coaxial procam.

3.1. Saturation Filter

A saturation filter increases or decreases the saturation of a captured live action image. The saturation filter increases the saturation of the desired areas in the captured image and decreases the saturation or inverts the colors in the other areas. When an image is projected onto an object, the user's eye is directed to the areas of high saturation.

In this study, the saturation filter is implemented using formula 1, which is a simplified version of the saturation change algorithm [Amano and Kato(2010)], where *src* is the original image, *dst* is the projected resultant image, *gray* is the original image converted to grayscale, and s is the saturation change parameter. When $s = 0$, the original image remains the same, and as s increases, the image saturation increases. Conversely, if s is negative, the saturation decreases, and at $s = -1$ the image becomes a grayscale image. When $s < -1$, the color is close to the opposite color of the original image. In this way, the surface color and the projected color cancel each other out.

$$\begin{aligned} gray &= \frac{1}{3}(R_{src} + G_{src} + B_{src}) \\ dst &= \max(\min(s * (src - gray) + src, 255), 0) \end{aligned} \tag{1}$$

3.2. Coaxial Procam

Typically, a procam setup requires a fixed projection surface because the camera and projector are separate. In contrast, in a coaxial procam, the camera and projector have the same optical axes. There is no need for geometric recalibration even if the object moves.

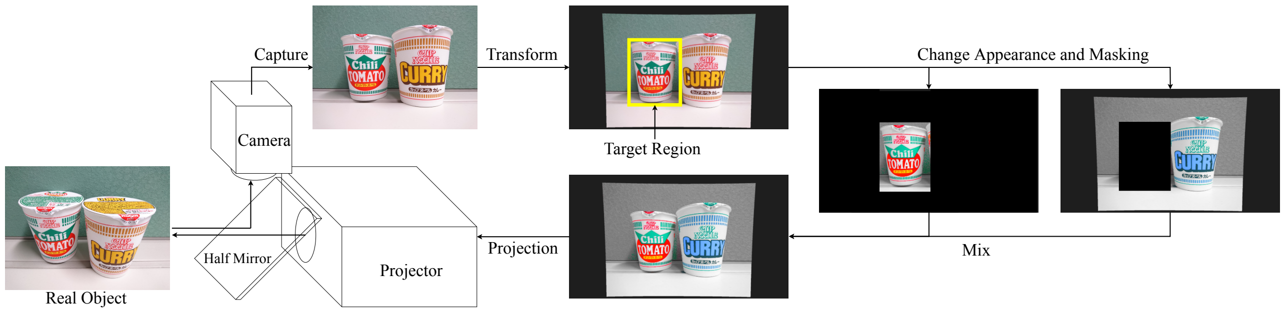


Figure 2: *The data flow of the proposed method.*

Therefore, in this case, we used an Acer H6510BD † projector and an FLIR Grasshopper 2.0 MP Color FireWire 1394b ‡ camera.

Figure 2 shows a schematic of the procam. Because the optical axes are aligned, the object can be easily captured and reprojected, even if it moves. Figure 3 shows an example of a real object (12 cup noodles) to which the proposed method is applied. The top image in Figure 3 shows the real object captured by the camera on the procam. The lower image in Figure 3 shows a real world object on which each of the images in the upper row is projected. This is what the user perceives.

4. Experiment 1

Two experiments were conducted to verify the effectiveness of the proposed method for eye guidance. In Experiment 1, we compared gaze guidance effect of the saturation filter proposed in this study with an existing real-world gaze guidance method, the shift filter [Miyamoto et al.(2018)], projecting the original image.

4.1. Apparatus

Three types of objects (a set of 12 cup noodles, a set of 8 paperback books, and a set of 12 stuffed animals) were used as examples of real-world objects (Figure 4). The subjects sat on a desk in front of the objects. A chin rest was attached to the desk to ensure the accuracy of gaze measurement. The subjects' gazes were recorded using a pupil gaze tracker §. The coaxial procam was placed under the desk such that the subject could not see it during the experiment. Figure 3 shows the experimental setup. Room lighting was always on, and the position of the object and the subject were carefully chosen so that reflections of room lighting on the object surface would not directly reach the subject's eyes. The parameters of the saturation filter s were set for each target region to the minimum value such that the visual prominence of that region was the highest highest within the entire object. To simplify the conditions, the absolute value of s is shared between the target and other regions. In other words, $s > 0$ was determined, and the saturation was changed using s for the target region and $-s$ for the other regions. The shift filter parameter, d, was empirically set to eight pixels. This was approximately 3 mm to the left and right of the subject's surface.

4.2. Participants

Fifteen subjects (14 males and 1 female, age 20-42) participated in the experiment, each using their own contact lenses or glasses to correct their vision as needed. The subjects were not told anything about the image filter and were simply asked to look at objects freely.

4.3. Procedure

After calibration of the eye-tracking device, the subjects were asked to close their eyes to prevent them from seeing the switch to the projection phase. They were then instructed to look at the object for 10s, with and without the image filter. After the trial, the subjects were instructed to close their eyes again. For each trial, three different objects were placed on a turntable and rotated so that the subjects would not notice any differences from the previous trial (Figure 4.1).

This trial was performed once for each object in the set using a saturation filter and a shift filter, and two trials with the original image were performed in the case of measurement failure. Additionally, two dummy trials were conductec. In addition, two dummy trials were conducted and the entire set was shifted and desaturated such that counting the number of trials would not predict the experiment. However, these dummy trials were not included in the analysis. In other words, the number of trials for the cup noodle and stuffed animal sets was $12 \times 2 + 2 + 2 = 28$, and the number of trials for the paperback book set was $8 \times 2 + 2 + 8 = 25$, with 8 additional dummy trials not used in the analysis to match the number of trials in the other sets.The order of $28 \times 3 = 84$ trials is fixed, with the first trial for all subjects being a cup of noodles, the second a paperback book, the third a stuffed animal, and the fourth a cup of noodles again. The order of the trials in each set was random. The parameters did not change during each trial in this experiment.

4.4. Hypotheses

In this experiment, the following three values were calculated from each line-of-sight measurement data. For the trajectory that pro-

† https://www.acer.com/ac/ja/JP/content/model/MR.JFZ11.00G
‡ https://www.flir.com/
§ https://pupil-labs.com/products/core/

Figure 3: *Examples of the shift and saturation filters. (a): an original image taken using a procam camera. (b): an image with the saturation filter applied, increasing the saturation of one object and inverting the colors of the other objects. (c): real objects on which the original image (a) is projected. (d): a real-world object on which the saturation-filtered image (b) is projected.*

jected the original image, the following values were calculated for each object in the set as the target object:

- Entry time: First time of the gaze fixation for 240 ms [Taylor et al.(1960)] at the target object.
- Continuous time: maximum time during the gaze stayed continuously at the target object.
- Total time: total time the gaze stayed at the target object.

These values were calculated from the corresponding gaze measurements. These values were compared among each set of saturating filters, shift filters, and the original image to verify the gaze guidance effect. In other words, the null hypothesis that we reject in this experiment is as follows:

- $H_{null}1$: There is no difference between the saturation filter, shift filter, and original image in (entry time, continuous time, and total time).

4.5. Result

4.5.1. Noodle Cups Set

As shown in Figure 6, these three values may not be normally distributed. Therefore, as shown in Table 1, the Friedman test was performed and all three values were significantly different ($p < 0.001$). Thus, we rejected the null hypothesis $H_{null}1$ for the cup noodle set.

The average ranks in Table 1 are the same set of subjects and the same set of objects, with trials differing only in the projected image. The calculated values are compared, and the ranks are ranked in ascending order of the calculated values. In Experiment 1, the smaller the rank, the shorter the input time, and the larger the rank, the longer the continuous and total times.

The results of Scheffe's multiple comparison test are shown in Table 2. This table shows that there was a significant difference between the original image and the two filters for all three values. The average ranking in the table shows that the two filters rank

Figure 4: *The three types of objects on the turntable as used in Experiment 1. The AR markers are used for the gaze tracker.*

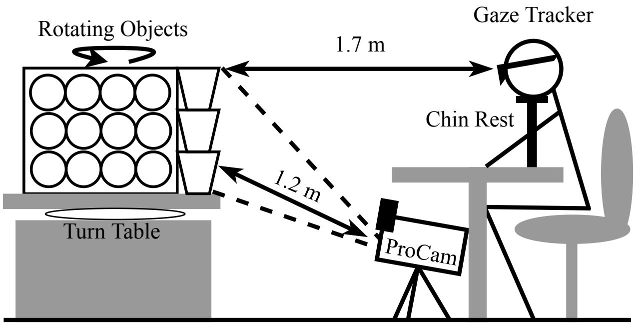


Figure 5: *The setup of Experiment 1.*

better for all three values, confirming the eye-guidance effect of the saturation and shift filters. The histogram shown in Figure 6 indicates that the saturation filter and shift filter had more trials with shorter input times and more trials with longer continuous and total times than the original. It can also be seen that there is a large difference between the saturation filter and shift filter in terms of continuous time and total time. Furthermore, the shift filter had a higher average rank. Therefore, the shift filter appeared to be more effective for cup noodles.

4.5.2. Paperback Books Set

As already shown in the cup noodle set, Tables 3 and Table 4 show that there was a significant difference between the original image and the image with the two filters applied. The filtered image was ranked better than the original image. Thus, the Bunko set confirmed the eye-guidance effect of the saturation and shift filters. There was also a significant difference between the saturation and

Table 1: *Friedman test results for noodle cups set.*

	Noodle Cups		
	Entry Time	Continuous Time	Total Time
	Average Rank		
Saturation Filter	**1.86**	2.10	2.11
Shift Filter	**1.89**	**2.28**	**2.31**
Original Image	2.26	1.62	1.58
	Friedman Test		
$\chi^2(2)$	19.9	44.2	52.4
p-value	**p<0.001**	**p<0.001**	**p<0.001**

Table 2: *Scheffe's multiple comparison test results for noodle cups set.*

	Noodle Cups		
	Entry Time	Continuous Time	Total Time
	$\chi^2(2)$ (p-value)		
Saturation - Shift	0.156(0.925)	6.52(**0.0383**)	7.47(**0.0239**)
Saturation - Original	32.0(**p<0.001**)	43.0(**p<0.001**)	51.5(**p<0.001**)
Shift - Original	27.7(**p<0.001**)	83.0(**p<0.001**)	98.2(**p<0.001**)

shift filters in terms of the input time and total time, indicating that the saturation filter ranks better than the shift filter. Therefore, we believe that the saturation filter is more effective for Bunko sets.

4.5.3. Stuffed Toys Set

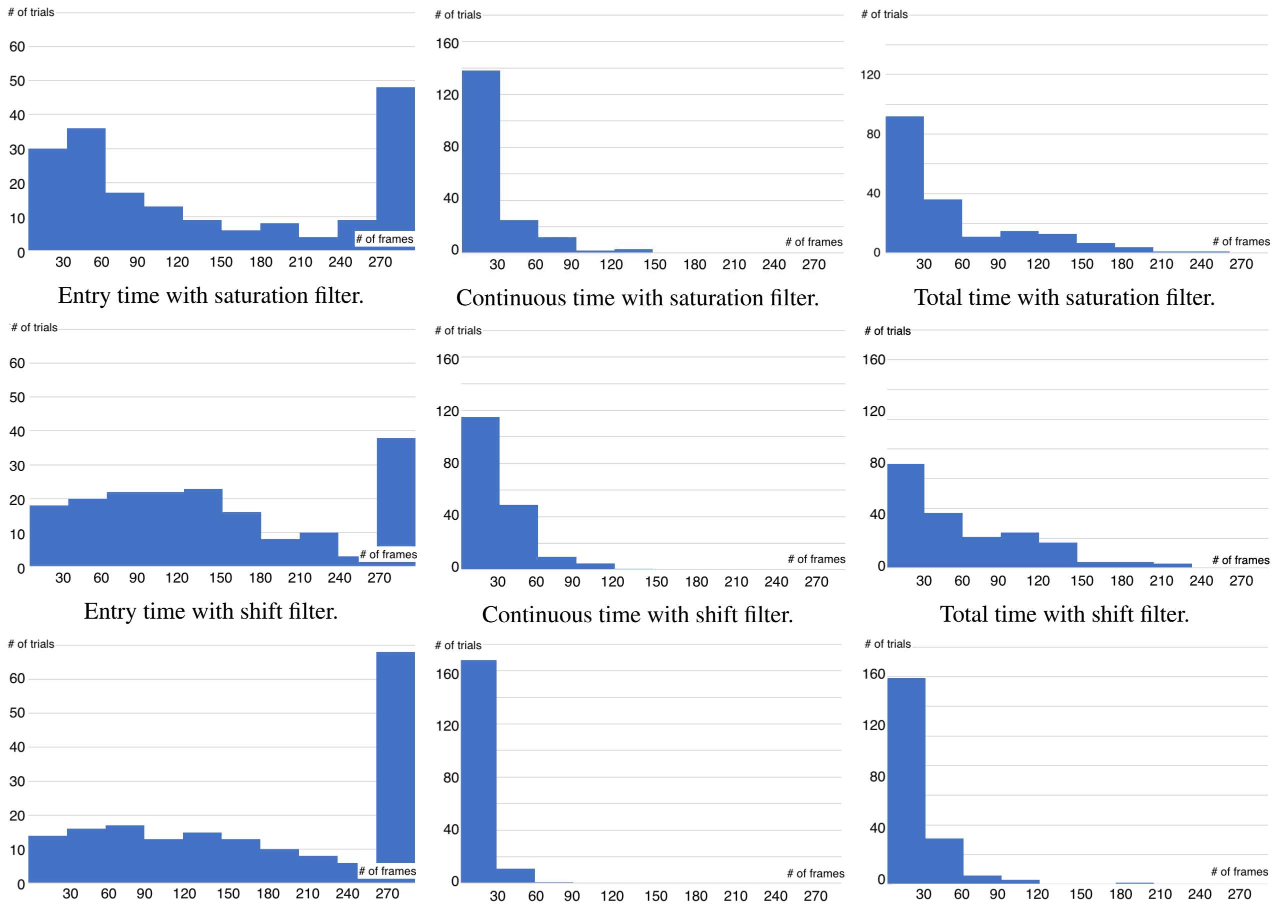
As shown in Table 5, there were no significant differences between any of the three values. Therefore, the plush-toy set cannot demonstrate the eye-guidance effect of the proposed method. The main reason for this may be that the stuffed toys used in this experiment were made of shiny material that reflected the projected light and reduced the change in appearance. Based on this consideration, we conducted an additional experiment 2 using different stuffed toys.

5. Experiment 2

In Experiment 2, the eye-guidance effect of the saturation filter on stuffed animals was verified by quantitatively comparing it with the original image projected on the stuffed animals. The shift filter was not compared because the results of the projection on the stuffed animals used in the experiment beforehand showed little difference between the original image and the shift filter.

Table 3: *Friedman test results for paperback books set.*

	Paperback Books		
	Entry Time	Continuous Time	Total Time
	Average Rank		
Saturation Filter	**1.73**	**2.28**	**2.37**
Shift Filter	2.00	2.08	2.09
Original Image	2.27	1.63	1.54
	Friedman Test		
$\chi^2(2)$	17.8	27.7	44.1
p-value	**p<0.001**	**p<0.001**	**p<0.001**



Entry time with saturation filter. Continuous time with saturation filter. Total time with saturation filter.

Entry time with shift filter. Continuous time with shift filter. Total time with shift filter.

Entry time with original image. Continuous time with original image. Total time with original image.

Figure 6: *Histograms of three values calculated from the gaze measurement results of each filter and original image in the noodle cups set (horizontal axis: number of frames of gaze tracker (30 fps), vertical axis: number of trials).*

Table 4: *Scheffe's multiple comparison test results for paperback books set.*

	Paperback Books		
	Entry Time	Continuous Time	Total Time
	$\chi^2(2)$ (p-value)		
Saturation - Shift	8.90(**0.0117**)	5.00(0.0822)	9.55(**0.00843**)
Saturation - Original	35.6(**p<0.001**)	52.8(**p<0.001**)	85.1(**p<0.001**)
Shift - Original	8.90(**0.0117**)	25.3(**p<0.001**)	37.6(**p<0.001**)

Table 5: *Friedman test results for stuffed toys set.*

	Stuffed Toys		
	Entry Time	Continuous Time	Total Time
	Average Rank		
Saturation Filter	2.01	2.05	2.06
Shift Filter	2.02	1.89	1.88
Original Image	1.96	2.07	2.07
	Friedman Test		
$\chi^2(2)$	0.675	3.79	4.31
p-value	0.713	0.150	0.116

5.1. Apparatus

Four stuffed animals were used in the experiment. The subjects sat on a chair in front of a plush object. The distance from the subjects' eyes to the objects was 1.7 m. The distance from the objects to the procam was 1.3 m. Figure 7 shows the scene of the experiment. The room lights were always on. The parameters of the saturation filter were determined as in Experiment 1.

5.2. Participants

Forty subjects (35 males and 5 females, aged 21-29 years) participated in the experiment and corrected their vision with their own contact lenses and glasses as needed. Forty subjects were divided into two groups. The first 20 subjects participated in the experiment using the original projected object. The remaining 20 subjects participated in the experiment using an object with a saturating filter.

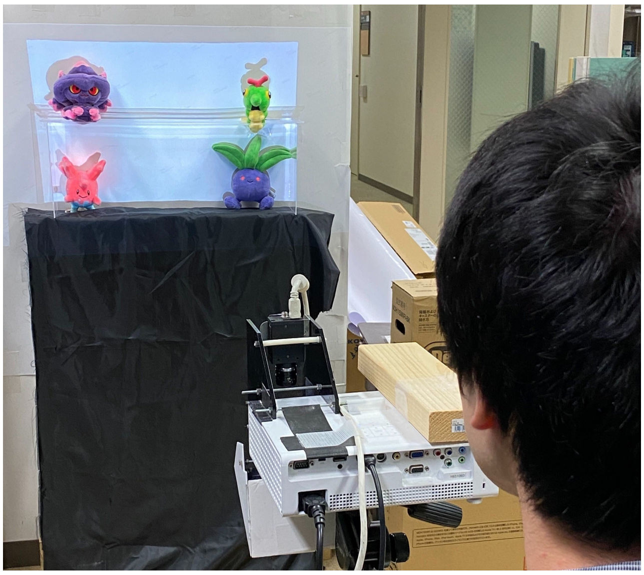


Figure 7: *A scene of Experiment 2.*

5.3. Procedure

Initially, the objects were hidden behind a board with a mark at the center. The subject sat down and adjusted his chair such that his eyes were in front of the mark. This mark is located in front of the center of the object itself. The subjects were instructed to close their eyes while maintaining their posture. During this time, the board was removed and an image was projected onto the object. Finally, the subject opened his eyes and verbally answered which of the four stuffed animals he saw first.

The trial was administered to 20 subjects with the original object projected. The responses have been tabulated. The same trial was then conducted with the remaining 20 subjects, using a saturation filter to guide their gaze to the stuffed animal with the fewest responses (top left).

5.4. Hypothesis

In this experiment, the eye-guidance effect was tested by comparing the distribution of responses given for the image to which the saturating filter was applied with the distribution of responses given for the original image. In other words, the null hypothesis that we reject in this experiment is as follows:

- $H_{null}2$: There is no difference between the saturation filter and the original image in the distributions of objects that subjects initially look at among the four stuffed toys.

5.5. Result

Figure 8 shows the actual appearance of the objects used in this experiment and the distribution of the responses. Fisher's exact test of these responses showed a significant difference ($p = 0.021$), thus rejecting the null hypothesis $H_{null}2$. Thus, the gaze induction effect of the saturation filter was confirmed for the plush toys used in the experiment.

Figure 8: *The actual appearances of the objects used in Experiment 2 and the numbers of answers of each stuffed toy.*

6. Discussion and Future Work

The effectiveness of the proposed method in guiding a viewer's gaze was confirmed through two experiments. However, for the set of cup noodles, the existing method, that is, the shift filter, was more effective in guiding the eye gaze. As mentioned earlier, Experiment 1 discussed the difference between the two filters, taking into account the different methods for determining the parameters of the two filters and their conditions.

Because the shift filter acts on the edges of the image, it is thought that the eye-guidance effect was greater for cup noodles with characters that have many edge components on a bright background. On the other hand, because the saturation filter changes the saturation of objects, it is thought that the eye-guidance effect was greater for the paperback book set with many highly saturated areas and the stuffed animal used in Experiment 2. From the above, it is necessary to use different image filters depending on the object that is the target of the eye guidance.

6.1. Limitations

In Experiment 1, we attempted to reduce the subject's learning effect by placing an object on a turntable and rotating it in each trial. However, comments obtained from the subjects after the experiment indicated that they remembered the differences from the previous trial because they had seen the same object several times. To verify the gaze guidance effect of the proposed method more rigorously, it is necessary to increase the number of subjects and the types of objects as well as to reduce the number of trials with the same object as much as possible.

The proposed method in this study uses a coaxial procam, which does not require recalibration, even if the object moves slightly. However, the procam itself cannot be constantly moved. Even if the optical axis of the procam is the same, the focus adjustment and calibration must be performed each time depending on the distance to the object. In addition, because the proposed method cannot change the view of an object outside the camera's shooting range, the procam and the user are assumed to view the object from the proximity direction.

6.2. Future Work

Applications of the proposed method include the natural appeal of products in the store and buffet dishes, support for specialized tasks such as machine assembly and maintenance, and spatial learning such as driving training and disaster training. To realize these applications, dynamic projection and parameter adjustment according to the user's line of sight, and automatic recognition and tracking of objects are necessary.

7. Conclusion

In this study, we proposed a real-world eye guidance method. In the proposed method, an object is photographed and a saturation filter is used to increase the saturation of the target area and decrease the saturation of the surrounding area. The appearance of the object was then changed by re-projecting the processed image onto the object itself using a coaxial procam, and gaze guidance was performed. Two experiments quantitatively confirmed the effectiveness of the proposed method in guiding the viewer's gaze by comparing it with the existing methods. Several applications will be implemented in future research.

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