A Study on Imperceptible Projection for Seamless Appearance Manipulation

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ABSTRACT

The sense of projection limits the range of application field of the projection display. This paper proposes 2-step manipulation method to increase the upper limit of the luminance for perceiving the sense of projection. The effectiveness is confirmed by comparing the proposed method to the naive one.

1 INTRODUCTION

Recently, due to the popularity of projection mapping, Spatial Augment Reality (SAR) technology has been attracting attention, which enables us to manipulate the color and texture of the real world by projection directly onto objects. However, in SAR, when a superimposed image is projected from a projector in order to manipulate the appearance of the target, we can perceive the target is illuminated with a projection pattern instead of the ambient illumination. In this study, we define the sense of projection as the sensation of perceiving the projection of lights other than ambient lights.

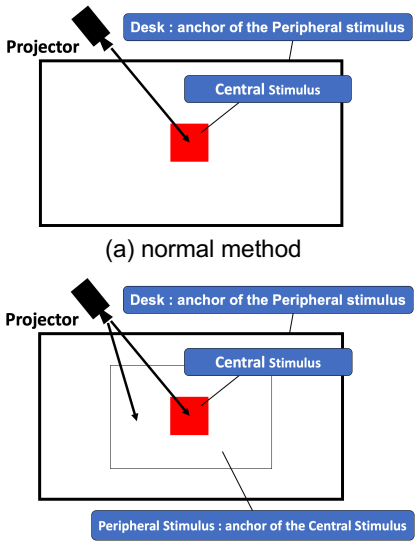
If we can achieve projection without the sense of projection, we can create a supernatural performance in amusement that is indistinguishable between the presentation of the projection and the actual pattern. In addition, it is possible to apply it to industrial applications, such as a more realistic product design assistance. In this paper, we propose a projection technique that does not give the sense of projection.

2 Methods that doesn't give the sense of projection

2.1 Realization of optically impossible operations

Although it is obvious, the sense of projection becomes less perceptible when the brightness of the projection is lowered. However, this restriction on projection narrows the color gamut and light/dark range that can be optically manipulated. Therefore, we manipulate the perception by using supplementary projection to increase the maximum radiance that is not perceived as projection(the upper limit of perceptive non-projection).

As a perceptual projection technique, Akiyama et al.[1] perceptually realized operations that are impossible to perform optically, such as manipulating to complementary colors by projecting colored light around a target and giving it a bias due to color constancy. In addition, Nagata et al.[2] induced the glare illusion by projecting the Glow pattern onto the periphery to enhance the glossiness beyond the optical limit.



(a) normal method

(b) proposed method

Fig. 1 Projection Method

Our perception does not understand optical phenomena correctly and it is influenced by the surrounding situation. Therefore, even if an operation is optically impossible, it may be possible to perceive the target operation by manipulating the surrounding environment and conditions, as in the previous study.

Regarding projection technique that do not give the sense of projection, Gilchrist et al [3] proposed anchoring decisions. Specifically, the anchor is the surface perceived to be white under the same illumination, and if it is brighter than that surface, it appears to emit light. However, there is a problem that the range of colors that can be manipulated under this condition is limited.

2.2 Methods for raising the upper limit of perceptive non-projection

Bonato et al.[4] defined the "brightness threshold" as the irradiance at which a surface appears to be self-illuminating. They found that this brightness threshold was about 1.7 times greater than the luminance of the surrounding stimulus by experiments with achromatic stimuli.

In this study, we propose a method that uses this relation of brightness thresholds to eliminate the sense of projection. For example, as shown in Fig.1(a), when the color of a target (the central stimulus) is manipulated

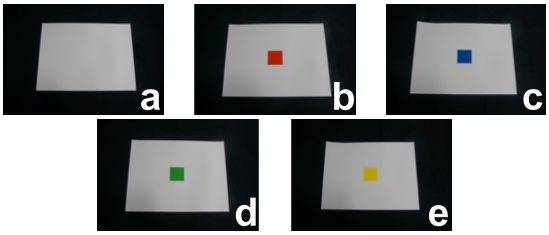


Fig. 2 Test stimuli: White reference(a) and marker of red(b), blue(c), green(d), and yellow(e).

by projection, the sense of projection of the central stimulus is perceived in relation to the radiance of desktop as the anchor. Therefore, we propose a 2-stage projection method to increase the upper limit of perceptive non-projection in which a white area is added to the peripheral part of the central stimulus, as shown in Fig.1(b).

In the projection of this test stimuli, the presence or absence of the sense of projection to the central area is determined by the difference in radiance between this area, with the white peripheral area serving as the anchor. The presence or absence of projection onto the surrounding area is determined by the difference in radiance between the two surfaces, with the desktop serving as the anchor. We attempt to take advantage of these gradual anchor transitions in order to achieve a step-by-step increase in the upper limit of non-projective perception.

3 Research of the increased amount of the upper limit of perceptive non-projection

3.1 Experimental Environments

As a white reference, we used A3 size matte photo paper with 93% ISO whiteness as shown in Fig.2(a). We used the stimuli with a red, green, blue, and yellow square of 50 mm per side were printed on the same paper by an ink-jet printer, as shown in Figure 2(b)-(e). We call the central area as “central stimulus” and the surrounding white area as the “peripheral stimulus”.

We applied appearance manipulation[5] over a range of 745 × 520 mm with 1280 × 800 resolution projector (EPSON, EB-W12) to display manipulated color on the central stimulus. Participants sit in a chair and watch the test stimulus on the desk from the front in a room lighting environment. The distance from the viewpoint to the target is 670 mm, the distance from the projector on the desk to the target is 850 mm, the radiance of the desk surface is 180 cd/m^2 under ambient lighting, and the color on the desk is white.

3.2 Procedures

We investigate the increase in the upper limit of perceptive non-projection for both the naive manipulation and the proposed 2-step manipulation method in the saturation enhancement of appearance manipulation.

In the 2-step manipulation method, the upper limit of perceptive non-projection illumination is projected to the peripheral stimulus. To determine the brightness of the white projection used as the peripheral stimulus in a 2-step manipulation, we investigate the upper limit of perceptive non-projection using the white reference beforehand.

3.3 How to research the upper limit of perceptive non-projection

First, the researcher blocks the participant's view with black paper for 10 seconds. This is because it does not allow the participant to remember the original radiance of the tabletop surface and the test stimulus. Next, the researcher places the test stimulus on the projection surface while the field of view is obstructed, and the projection is made. After 10 seconds, the black paper is removed, and the researcher asks the participant to observe the test stimulus with both eyes, and to adjust the brightness of the projection to reach the upper limit of perceptive non-projection by interleaved staircase.

Specifically, as the first trial of the research, the participant gradually increases the brightness of the projection from 0 with a keystroke. This operation is carried out until the brightness is perceived as projection, and the radiance before the perceived brightness is recorded. Then, in one more trial, the researcher maximizes the brightness of the projection after blocking the view with black paper. Avoiding the black paper, the participant sees the test stimulus again. The participant lowered the brightness gradually by pressing a key until the participant did not feel the sense of projection, and recorded the radiance that the participant did not feel the sense of projection anymore. The brightness is raised or lowered three times for each projection method. We obtain the upper limit of perceptive non-projection by obtaining the value in this way.

Because there is an insensitive zone where the sense of projection cannot be judged accurately, we use the interleaved staircase in this experiment, and we obtain the upper limit of perceptive non-projection as the middle value of the insensitive zone.

3.4 Result

The upper limits of perceptive non-projection for the white reference, the naive manipulation, and the 2-step manipulation method, were investigated in 10 healthy participants between the ages of 21 and 24 years. These results are shown in Fig. 3.

When we compare the upper limits of perceptive non-projection of the naive and 2-step manipulations, the average of all participants’ results shows that the upper limit of perceptive non-projection of the 2-step manipulation is increased for central stimuli of all colors. However, some participants did not show an increase in the upper limit of perceptive non-projection with the 2-step manipulation method. Therefore, the average increase in the upper limit of perceptive non-projection due to the 2-step manipulation remains between 3 and 15 cd/m^2.

In the proposed method, we manipulate the stimuli in

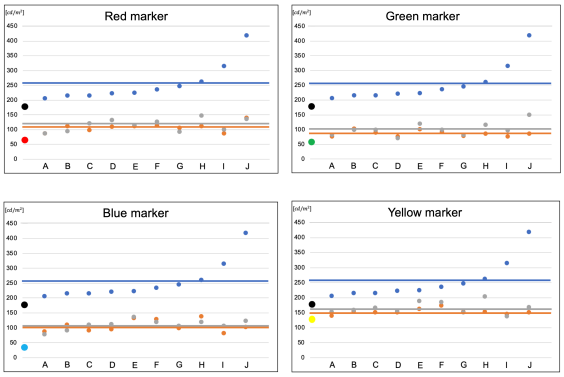


Fig. 3 Upper limit of perceptive non-projection : The horizontal axis indicates each subject from A to J. The vertical axis indicates the radiance. Each graph show upper limit radiance not perceive projection with the red, green, blue, and yellow color for the test stimulus. In each graph, the blue line shows the radiance of the upper limit of perceptive non-projection for the white reference of the subject, the orange line shows the radiance of the upper limit of perceptive non-projection for the naive manipulation. The gray line shows the central stimulus of the 2-step manipulation.

two steps: from the desk surface to the peripheral stimulus and from the peripheral stimulus to the central stimulus. This was expected to result in $1.7^2 = 2.89$ times increase in the upper limit of perceptive non-projection. However, the increase is much less than that. In each condition, the increase in the upper limit of perceptive non-projection of the 2-step manipulation was tested for significance at the 5% level of significance, and it was confirmed that the central stimulus was significant in green and yellow, but not in red and blue.

One possible explanation for the lack of an effective increase in the upper limit of perceptive non-projection by the 2-step manipulation is that the influence of the peripheral stimuli as an anchor was reduced. Specifically, it is possible that not only the radiance of the peripheral stimulus anchored by the radiance of the central stimulus, but also the radiance of the tabletop surface, the exterior of the peripheral stimulus, is a determinant of the upper limit of perceptive non-projection. Therefore, in the next section, we research the increase in the upper limit of perceptive non-projection for masked the desktop radiance condition in the same manner.

4 2-step manipulation

There are two methods to hide the radiance of the desk surface. One is to cover the desktop with a black cloth, and the other is to hide the desk from view by restricting the view. For practical use, the former can be achieved by making the background of the peripheral stimulus black. However, the latter requires the user to view through a shielding plate. In this case, the viewpoint is fixed and the viewing position is restricted. Alternatively, when allowing the viewpoints to move, wearable glasses employed liquid

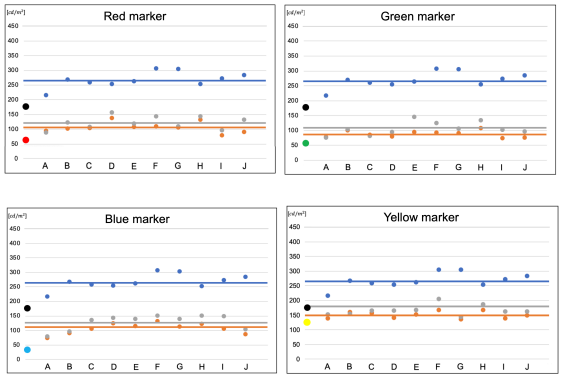


Fig. 4 Upper limit of perceptive non-projection in preventing the influence of the outer contour

crystal shutters are required. In this case, the advantage of SAR that does not require a wearable device is lost. For this reason, we adopt the method of covering with black cloth in this study.

4.1 Experimental Environments and Procedures

The test stimuli, environmental lighting, participants, and procedures used in this experiment are the same as in the previous experiment. The same spec of the projector is used, but the desktop is covered with a black cloth so that the radiance of the ambient light is not visible. For this experiment, we asked the same participants as previous experiment.

4.2 Result

The results of this research for the upper limits of perceptive non-projection for the white reference, the naive manipulation, and the 2-step manipulation are shown in Fig. 4. The vertical and horizontal axes of this graph are the same as in Fig. 3.

A comparison of the upper limits of perceptive non-projection of the naive and 2-step manipulations shows that the upper limit of perceptive non-projection of the 2-step manipulation was higher on average for the overall results for all colors. The average increase in the upper limit of perceptive non-projection across participants ranged from 15.8 to 21.8 cd/m^2. In each condition, the increase in the upper limit of perceptive non-projection of the 2-step manipulation was significant at the 5% level of significance, and it was significant for all colors.

4.3 Discussion

We can confirm that participants' results excluding H, I and J were increased in the investigation of the upper limit of perceptive non-projection of the white reference. In addition, in the results of many participants, the upper limit of perceptive non-projection increased with the 2-step manipulation, and the average increase in the overall participant's average increase was also significant. In addition, the effectiveness of the increase in the upper limit of perceptive non-projection was confirmed by the increase in the number of all colors, which was significantly different from the two colors in

Fig. 5 Saturation Enhancement Results: Appearance with white illumination(a), manipulation result with 2-step manipulation(b) and naive manipulation(c).

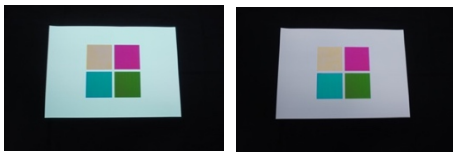


Fig. 6 Comparison of naive and 2-step manipulations (Hue Shift)

the previous experiment.

These results suggest the peripheral stimulus acted effectively as an anchor when the desktop was covered with black cloth. The reason for this is that the black cloth on the desk prevents the radiance from acting as an anchor for the central stimulus during the 2-step manipulation method. Therefore, the peripheral stimulus with increased radiance is judged as the non-projective target of the central stimulus.

4.4 Applications

As an example of the use of the 2-step manipulation, we use a sample of colors used in our research., and then apply the saturation enhancement to it. Then, we compare naive and 2-step manipulations with the same degree of saturation enhancement. In this comparison, we confirm that the 2-step manipulation is hard to feel the sense of projection of the sample that was perceived as projected by the conventional saturation enhancement.

As a confirmation procedure, we first perform the 2-step manipulation on the sample shown in Fig. 5(a) with a degree of saturation enhancement that does not give the sense of projection to any color. This result is shown in Fig. 5(b). Afterward, we change the projection method to a naive manipulation, as shown in Fig. 5(c).

When the projection of the peripheral stimulus is removed, the sample green and yellow markers are perceived as projections. We confirmed that the 2-step manipulation raises the upper limit of perceptive non-projection, and the apparent manipulation without the sense of projection is achieved by this method.

This study aims to increase the upper limit of perceptive non-projection and to expand the range of manipulation of color gamut and light/darkness. Therefore, we performed white projection on the markers in the same way as in the naive manipulation to check whether the saturation of the markers was enhanced. From the comparison of Fig. 5(b) with Fig. 5(a), we confirmed that the markers were more vivid than the white projection.

We applied the hue shift shown in Fig. 6 to the central stimulus as another application. Then we confirmed that the 2-step manipulation could provide an appearance manipulation of hue shift without the sense of projection. However, the value of the upper limit of perceptive non-projection in hue shift has not been researched. It is necessary to investigate the upper limit of perceptive non-projection for each operation method to ensure projection without the sense of projection.

5 CONCLUSIONS

In this paper, we proposed a 2-step projection method to increase the upper limit of perceptive non-projection intensity named 2-step manipulation method. The sense of projection on the central stimulus is suppressed by the white projection on the peripheral stimulus. The results showed that the upper limit of perceptive non-projection was increased by the 2-step manipulation, but the increase was not as much as expected. We considered that not only the radiance of the peripheral stimulus but also the radiance of the tabletop surface in the estimation of the central stimulus's radiance. Therefore, we covered the desktop with a black cloth so that the radiance of the desk surface is not visible, and we investigated the upper limit of perceptive non-projection of the 2-step manipulation, which is unaffected by the outer environment. The results showed a further increase in the upper limit of perceptive non-projection, confirming that preventing interference of the outer envelope can increase the effectiveness of the peripheral stimulus as an anchor.

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