Compensated Appearance Manipulation for Eyesight Improvement

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ABSTRACT

Pre-compensation using overlay projection decreases contrast for ill-posed inverse problem. In this paper, we propose a Compensated Appearance Manipulation that does not require pre-compensation. Through the simulation on a perceptual MTF, we confirmed the proposed method yielded more effective visibility improvements than the pre-compensation based approach.

1 INTRODUCTION

The technique of Spatial Augmented Reality (SAR) was established by the study of Raskar et al. [1], and visual assistance has been proposed as one of the applied studies of SAR. By way of an application, Amano et al. [2] proposed a visual assistance for dichromatopsia using SAR by implementing a color conversion method based on a perceptual model of dichromacy color vision in appearance control [3]. They also proposed an assistance for visual abnormalities such as cataracts and glaucoma using the same framework.

As shown in Fig. 1, the appearance control estimates the surface reflectance of the projection target, then it calculates the original appearance C_{est}. After that, the reference image R is generated with arbitrary image processing on the estimated C_{est}, and the projection image P adjusted by the controller so that the actual appearance becomes R is projected by the projector. The appearance of the target is changed to the appearance that has undergone image processing.

Visual abnormalities include not only dichromatopsia and cataracts, but also yellowing of the visual field with age, deterioration of color sensitivity, and refractive errors. The yellowing of the field of view and the decrease in color sensitivity can be roughly expressed by H as an $\mathbb{R}^{3\times3}$ color transformation matrix. This conversion can be restored to the original color by calculation. On the other hand, there is no inverse transformation to show trichromat information for dichroism because only two stimuli represent scene color. In this study, the former is called reversible deterioration and the latter is called irreversible deterioration from this viewpoint.

As a compensation method for such irreversible deterioration, we proposed a visual assistance technology for myopia and hyperopia by appearance control implemented the pre-compensation processing proposed by Huang et al. [4]. The pre-compensation technique models the blurring of the retinal image due to refractive errors by convolving the point spread function (PSF) calculated from the wavefront aberration with the ideal retinal image. When the observer looks at the pre-compensated image that has undergone the inverse transformation, unblurred image is formed on their retina in theory. However, the pre-compensated image generated by this method contains negative values, so the image cannot be presented by projection. Therefore, we added the bias with gain adjustment, but the contrast is decreased, and the significant difference with normal white illumination is not confirmed.

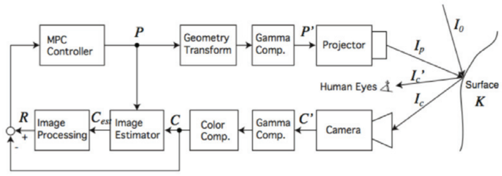

Fig. 1 Appearance control feedback processing [2]

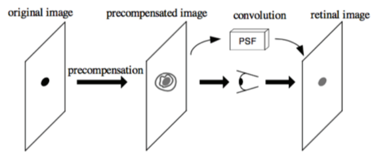

Fig. 2 Pre-compensation for eye aberration [4]

In this research, therefore, we propose a novel approach called Compensated Appearance Manipulation (CAM) that does not require such pre-compensation processing.

2 RELATED WORKS

2.1 Visual Assistance by Pre-compensation

Huang et al. [4] modeled the blurring of the retinal image caused by distortion of the crystalline lens of the eye due to refractive errors such as myopia and hyperopia with the individuals PSF. The method generates a pre-compensated image with the inverse transformation. By presenting this image on display, the observer perceives an un-blurred image on the retina (Fig. 2).

The blurred image $i(x,y)$ is represented by the convolution of the original image $o(x,y)$ and $PSF(x,y)$,

$$i(x,y) = PSF(x,y) * o(x,y) \quad (1)$$

where x and y are the coordinates of the image. Pre-compensation can be formulated as a problem to find the image $c(x,y)$ that satisfy

$$o(x,y) = PSF(x,y) * c(x,y) \quad (2)$$

Where $PSF(x,y)$ is model for refractive errors. Its solution can be obtained by

$$c(x,y) = \mathcal{F}^{-1}\{\frac{O(u,v)}{OTF(u,v)}\} \quad (3)$$

where u and v are the spatial frequencies in horizontal and vertical, $OTF(u,v)$ and $O(u,v)$ are Fourier transforms of $PSF(x,y)$ and $o(x,y)$, respectively, and $\mathcal{F}^{-1}$ denotes inverse fourier transformation.

However, Wiener filter technique is used in order to suppress the divergence due to the noise of the high frequency component as follow:

$$MTF(u,v) = |OTF(u,v)|, \quad (4)$$

$$c(x,y) = \mathcal{F}^{-1}\{\frac{O(u,v)}{OTF(u,v)}\frac{MTF(u,v)^2}{MTF(u,v)^2+\varepsilon}\} \quad (5)$$

where ε is a small constant to prevent division by zero.

When$\varepsilon$is sufficiently small, the pre-compensation process and the blurring of the retinal image due to refractive errors are compensated. However, $c(x,y)$ includes negative values and values that exceed the pixel value range. In order to avoid this problem, the gain adjustment with offset addition is applied. When we keep both peak values in the image range, we obtain correct de-blurring other than DC components, but the contrast will lost. Alternatively, if the contrast is improved by adjusting the gain, complete pre-compensation cannot be achieved by clipping.

2.2 Visual Assistance with Pre-compensated Projection

We proposed appearance control which implemented Huang's pre-compensation to provide visual assistance by projection for refractive errors. We call this method Appearance Control by Pre-compensation (ACP). In this study, we employed a Gaussian function as a PSF that represents the blurring of the retinal image for simplicity.

The standard deviation of the Gaussian function and the aforementioned primary conversion parameters for contrast improvement were obtained for each subject by a preliminary survey. Experiments were conducted using written Landolt C on the blackboard board. As a result of visual acuity evaluation under white projection and pre-compensated projection, the pre-compensated projection obtained higher average visual acuity, but no statistically significant difference was observed.

We can consider some causes for this result. The validity of the approximation of the PSF should be verified, but we think the heuristic adjustment for contrast improvement with gain and offset was a dominant factor in degrading compensation quality.

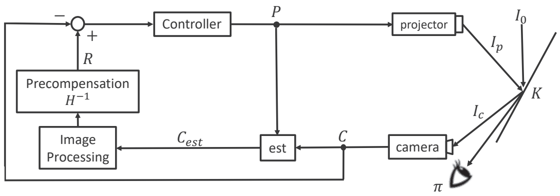

Fig. 3 Feedback process with ACP

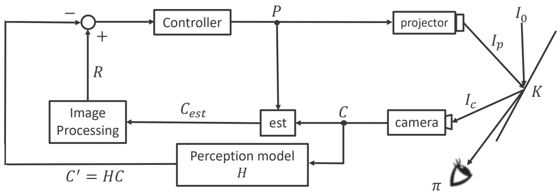

Fig. 4 Feedback process with CAM

3 METHODS

Visual assistance process using ACP is shown in Fig. 3. In this process, the desired image processing is applied to image C_{est} estimated appearance under white illumination. The pre-compensation with the overlay projection is realized by applying the pre-compensation H^{-1}, which is the inverse transformation of the visual abnormalities perceptual model H to the manipulation reference image R.

When the user sees the manipulated appearance by the overlay projection, a non-deteriorated image should be perceived as retinal image π. However, there are problems in generating H^{-1}as mentioned above. Therefore, we propose a compensated appearance manipulation shown in Fig. 4.

In this approach, the simulated perception C' is generated by applying the perceptual model H to the camera image C. The projected image P adjusted by the controller so that the deviation between C' and R is 0 is projected by the projector to change the appearance of the operation target. If $C' = R$, R is perceived in the retinal image π, and visual assistance can be realized.

In the following, we evaluate the effectiveness of the proposed method by comparing the color conversion that imitates the deterioration of color sensitivity as reversible deterioration with the blurring of the retinal image due to refractive errors as irreversible deterioration as a perceptual model.

4 EXPERIMENT

4.1 Reversible Deterioration

We investigate the difference between the control results of pre-compensation and the proposed method for the reversible perception model as saturation reduced to half, simulating a decrease in color sensitivity with aging. In the pre-compensation, the image HC that simulates the subject's perception image is output, and in the proposed method, the camera image C' to which the

Table 1 Compensated appearance manipulation

	R	G	B
Precopensation	4.251	3.839	5.813
Prposed method	3.869	3.795	5.903

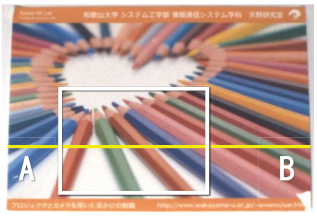

Fig. 5 Operation target

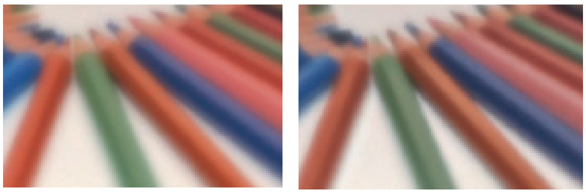

Fig. 6 Difference of Perception image between pre-compensation and proposed method: The left is the image HC with ACP. The right is the image C' with CAM.

perception model H is applied is output, and the respective images are compared. In ACP, we performed saturation enhancement that doubles the saturation to make the image HC equal to the image C' in the proposed compensation control proposed method.

Table 1 shows the MSE for each RGB component of the perception image of the pre-compensation and the proposed method with the true value as the apparently controlled camera image under white illumination. The error is in a reasonable range due to image noise. In addition, both methods have no superiority, and it can be confirmed that these methods give correct perception with the same accuracy.

4.2 Irreversible Deterioration

The difference between the two methods lies in the flow of obtaining the projection image. Since the inverse blur image cannot be accurately calculated, our previous method adjusts offset and gain so that the compensation is performed effectively. However, many efforts are required for effective compensation.

In this study, the PSF of blur due to refractive errors is approximated by a Gaussian function, similar to previous method. The standard deviation σ of the Gaussian function that represents the blur of the field of view due to refractive errors is $\sigma = 5.0$ in this experiment. The appearance control employed parameter s $(0 < s < 1.0)$ that is the mixing ratio of desired conversion and original image for R generation. When $s = 0$, no blur processing is performed, and when $s = 1.0$, the image is completely blurred. It is desirable to completely reproduce the blur assuming $s = 1.0$, that is, the blur caused by the refraction anomaly.

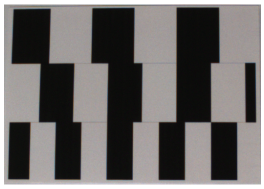

Fig. 7 Bar pattern for contrast evaluation

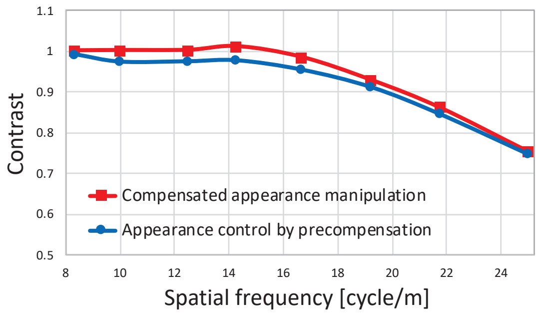

Fig. 8 MTF comparison: The horizontal axis indicates the spatial frequency. The vertical axis indicates the contrast.

However, the pre-compensation for the strong blur is not stable in control, so the value of s is changed according to the state.

When pre-compensation is applied with the overlay projection, the original appearance without refractive error is observed on the retinal image. Therefore, the HC image of pre-compensation and the C' image of the proposed method are compared as the true value with the camera image of white projection.

When s ≥ 0.9, the feedback control did not converge with ACP, and the projection was not stable. When s=0.8, the projection with ACP was stable. Therefore, we employed s=0.8 for the comparative evaluation.

Fig. 6 shows HC for pre-compensation and C' of the proposed method, in which compensatory projection was performed on the operation target in Fig. 5. From these results, the edges of colored pencils are clearer in the proposed method, and we can confirm the effectiveness of the proposed method.

4.3 Quantitative Evaluation for Irreversible Deterioration

In order to quantitatively evaluate the blur compensation of the retinal image due to the refractive errors, the MTF (Modulation Transfer Function) with the bar pattern shown in Fig. 7 was measured. MTF was measured by the ratio of the contrast

$$\frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

with the original image at each spatial frequency. Where L_{max} and L_{min} are the maximum and minimum luminance at each scan line. These results are shown in Fig. 8. For this measurement, we used 7 widths of bar patterns of 120, 100, 80, 70, 60, 50, 40 mm, and we set

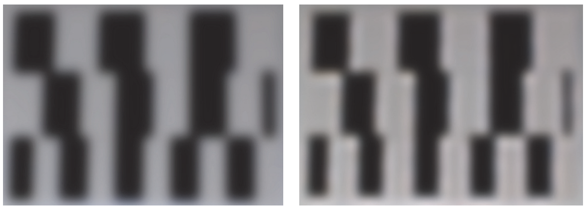

Fig. 9 Difference of edge enhancement between pre-compensation and proposed method: The left is the image HC with ACP. The right is the image C' with CAM.

$\sigma = 11$ for the Gaussian function of PSF. Fig. 9 shows HC for pre-compensation and C' for the proposed method. From these, it can be confirmed that in the perception image of the proposed method, it is clear that overshoot or undershoot occurs in the edge part of the bar pattern, and the edges can be identified more clearly.

5 DISCUSSION

5.1 Evaluation of Edge Sharpness

Fig. 10 shows the results of comparing the luminance of the line AB shown in Fig. 5 for the HC image of the pre-compensation and the C' image of the proposed method. The illuminance changes gently in the pre-compensation, whereas the edge of the illuminance is emphasized in the proposed method, and the result is closer to the true value. From this, we can confirm the contrast reduction problem in pre-compensation was solved and achieved effective compensation with the proposed method without adjusting the gain and offset parameters.

5.2 Problem on Pixel Value Clipping

Both methods produce high contrast at a spatial frequency of about 8 [cycle/m]. On the other hand, in a pattern with a high spatial frequency exceeding 24 [cycle/m], there is no luminance difference in the captured image due to blurring that cannot be compensated by either method. As shown in Fig. 8, the contrast of CAM is higher in the range 8 to 24 [cycle/m], and we can see that the proposed method has a higher compensation capability than pre-compensation.

The cause for the higher contrast with CAM is considered to be the difference in dynamic range. The pre-compensated image contains negative or excessive values that are outside the range of pixel values that can be projected from the projector. Such values are clipped at 0 or 255, and theoretically correct pre-compensation cannot be performed. On the other hand, the proposed method is presumed to automatically generate the optimal compensation image in the feedback process.

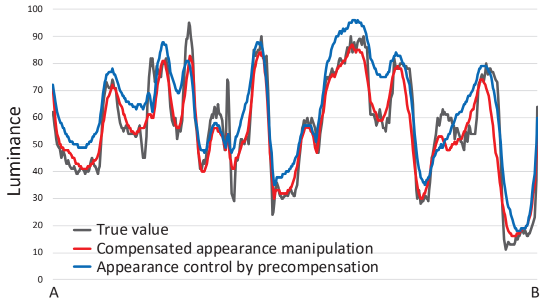

Fig. 10 Comparison of luminance on the scanline AB: The graph shows the luminance on the scanline AB shown in Fig.5 for both results shown in Fig. 6.

6 CONCLUSIONS

In this paper, we proposed a original compensatory projection method compensated appearance manipulation by introducing the user's vision model into the appearance control framework. Through the experiments for reversible deterioration, we confirmed that CAM could be compensated reversible deterioration equivalent to ACP in principle. In irreversible deterioration, the contrast reduction, which was a problem by using ACP, was improved and achieved effective compensation. In addition, it was shown that optimal compensation can be achieved simply by applying the perception model without adjusting the parameters. Subject experiments will be needed to evaluate the effectiveness of CAM for irreversible deterioration. Furthermore, We will verify the compensatory projection of other irreversible perceptual models.

ACKNOELEDGEMENT

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