The Perception of Chromatic Noise on Different Colors

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Abstract

A paired comparison psychophysical experiment was conducted to investigate the perception of chromatic noise. Interestingly, chromatic noise on a grey patch was less visible than on chromatic patches. Among chromatic patches, chromatic noise on a purple patch was the most visible and chromatic noise on orange, yellow, or green patch was less visible. Then a heterochromatic brightness matching experiment was conducted and it was suggested that this perception of chromatic noise could be explained by the Helmholtz-Kohlrausch effect. The gradient of the luminance of the same brightness was shown to have a correlation with the chromatic noise visibility. Thus the chromatic noise was perceived not only as chromatic noise but also as brightness noise that should be more sensitive for the human vision. Due to the dependency of the Helmholtz-Kohlrausch effect on hue and chroma, the visibility of chromatic noise should depend on the colors of the patches.

INTRODUCTION

Digital still cameras have been used widely for the last ten years and their technology has developed dramatically. The resolution of consumer digital still cameras increased year after year [1]. Today, even a digital camera with a 16 M or more pixel image sensor is not uncommon on the market. This enables users to print pictures from these cameras in large format. As a consequence, the user demand for high quality image capture is increasing. However, increasing resolution resulted in a decrease in pixel size [2]. Recent development of the image sensor will make it possible to shrink the pixel size as small as 1.0μm [3]. But a smaller pixel captures a smaller amount of photon energy increasing the likelihood of noisy images [4]. Thus the noise reduction filter plays an important role in the image processing chain. The bilateral filter [5] can effectively reduce small amplitude fluctuation that is the main component of noise while keeping edges and lines sharp when the parameters are set properly. In order to optimize the noise filter parameters and algorithms, understanding of the human visual perception of noise is crucial. Recently, it was reported that the perception of chromatic noise depended on the colors of the patches [6]. A bilateral filter whose parameters were tuned according to the different perception of noise on color was also proposed [7]. These researches conducted psychophysical experiments and found the dependency of the visibility of noise on different colors, but its mechanism is not obvious.

In this research, two psychophysical experiments were conducted to investigate the dependency of chromatic noise perception on different colors and its mechanism.

PSYCHOPHYSICAL EXPERIMENT OF CHROMATIC NOISE

A forced choice, paired comparison experiment was conducted to investigate the dependency of the perception of chromatic noise on different colors. An EIZO CG221 LCD monitor was used to display the stimuli. The 22.2" LCD is 1920 × 1200 pixels. It was calibrated according to the sRGB standard [8]. Thus the white point was 80 cd/m^2 and CIE D65. A screen shot of the experiment is shown in Fig. 1. One achromatic and sixteen chromatic base colors were used as shown in Fig. 2. Two levels of Gaussian white noise was added to them and one noiseless achromatic patch was also used, totaling 35 patches. Thus the observers had to compare 595 pairs for one session. The noise model was an additive chromatic noise and the CIE $L^*a^*b^*$ values of i-th patch at the position (x,y) were,

$$L_i^*(x,y) = 52, \quad (1)$$

$$a_i^*(x,y) = \bar{a}_i^* + n_{a^*}(x,y), \quad (2)$$

$$b_i^*(x,y) = \bar{b}_i^* + n_{b^*}(x,y), \quad (3)$$

where $\bar{a}_i^*$, $\bar{b}_i^*$, n_{a^*}, and n_{b^*} are the chromatic coordinate of noiseless base color, and additive noise terms of a^* and b^*, respectively. The additive noise $\vec{n}$ was defined as,

$$\vec{n} = (n_{a^*}, n_{b^*}) = (r(\sigma)\cos\theta, r(\sigma)\sin\theta), \quad (4)$$

where the θ was a uniform random value ranging from 0 to 2π and the $r(\sigma)$ was a Gaussian random value whose standard deviation σ was set as 3 or 6. These patches were displayed on the LCD surrounded by grey background whose L^* was 50. The dimension of the patch was 256 × 256 pixels. The observers were instructed to see the LCD at the distance of 50 cm (∼ 1.6 ft). In general, the chromatic noises were marginally seen by the observers when the σ was 3.

Figure 1. *A screen shot of chromatic noise experiment.*

RESULTS AND DISCUSSIONS

Seven observers took part in the experiment that contained 595 comparisons for one session and each observer completed

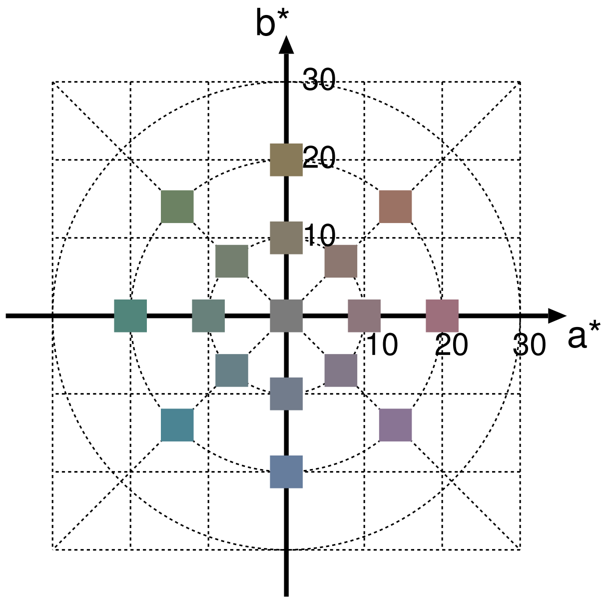

Figure 2. *Chromatic coordinates used for the experiment.*

two sessions. They were instructed to choose the one that they thought contained larger noise. Using Thurstone's law of comparative judgment (Case V) [9], interval scales were derived as shown in Fig. 3 and 4 as the size of the cross symbols. Interestingly,

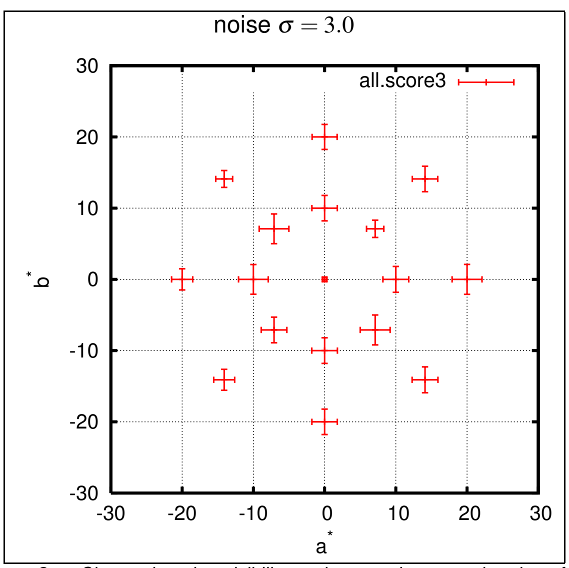

Figure 3. *Chromatic noise visibility scales are shown as the size of the cross symbols. (Noise amplitude $\sigma = 3$)*

the perception of chromatic noise was the smallest for the achromatic color, thus the chromatic noise on a grey is the least visible. Chromatic noises on chromatic colors were more visible, but the visibility depended on hue and chroma. When the additive noise level was $\sigma = 6$, the chromatic noises on the patch whose hue $h^*_{ab} = 315°$ were perceived largest. The chromatic noises on the hue $h^*_{ab} = 180°$, $225°$, $270°$, $0°$ and chroma $C^*_{ab} = 10$ were also perceived larger than the others except on the patch whose hue $h^*_{ab} = 315°$. The chromatic noises on the hue $45°$, $90°$, and $135°$

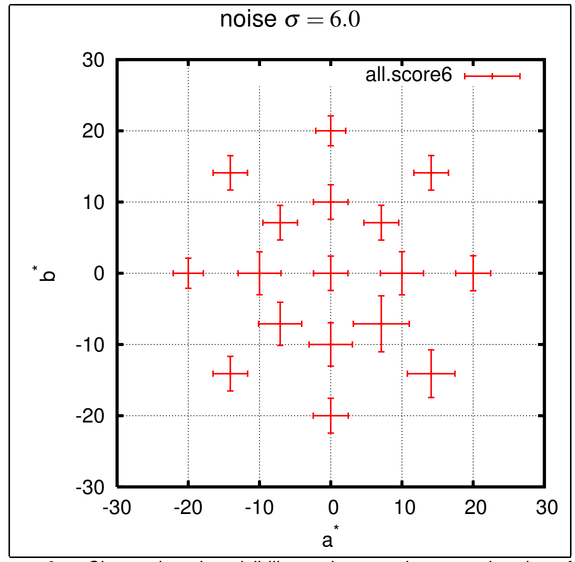

Figure 4. *Chromatic noise visibility scales are shown as the size of the cross symbols. (Noise amplitude $\sigma = 6$)*

or chroma $C^*_{ab} = 20$ (except $h^*_{ab} = 315$) were less visible than the others. When the additive noise level was $\sigma = 3$, the dependency of the visibility of chromatic noise on hue and chroma was not so obvious. But chromatic noises on the hue $h^*_{ab} = 135°, 180°, 315°$ and the chroma $C^*_{ab} = 10$ and the hue $h^*_{ab} = 0°$ and the chroma $C^*_{ab} = 20$ were perceived larger than the others of $\sigma = 3$ and their perception was almost equivalent to the noise level $\sigma = 6$ on the hue $h^*_{ab} = 90°, 180°$ and the chroma $C^*_{ab} = 20$.

The visibility of chromatic noise was shown to be different depending on the color of the patches. When the additive noise level was $\sigma = 6$, chromatic noise on cyan, blue, and purple patches were more visible than on yellow or green patches, based on the interval scales calculated from all results. Looking into the results of each observer, there was a variation. Depending on the observers, the hue on that they saw noise larger varied from cyan, blue, purple to red. But no observer saw noise on the yellow patches larger than other chromatic patches. According to this behavior, it was assumed that this dependency was caused by the Helmholtz-Kohlrausch effect [10]. The Helmholtz-Kohlrausch effect is the effect that the chromatic stimuli appear brighter than the achromatic stimuli of the same luminance. This effect also depends on hue and chroma and it is marginal for yellow and green. Thus it would be possible that the variation of chroma and hue due to the chromatic noise could be perceived as the variation of brightness even if the luminances were the same. Due to the higher spatial visual resolution of brightness component, the chromatic noise could be perceived as "brightness" noise as well as "chromatic"noise as illustrated in Fig. 5. This perception of brightness variation should depend on chroma and hue because the Helmholtz-Kohlrausch effect depends on chroma and hue. In order to confirm this assumption, a heterochromatic brightness matching experiment was conducted. Twenty four chromatic patches shown in Fig. 6 were compared to a reference achromatic patch. The observers were instructed to adjust the luminance of the chromatic patches so that they were appeared to be the same brightness with the reference. The same seven observers took part

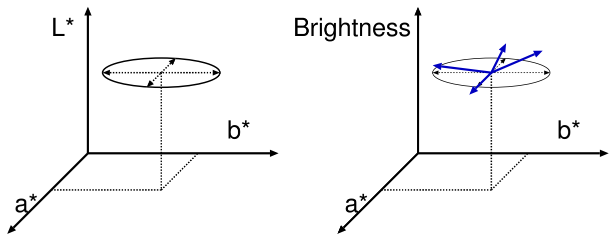

Figure 5. Chromatic noise is the variation in a^*b^* plane with fixed L^* (left), but it would be perceived not only as chromatic noise but also as brightness noise (right).

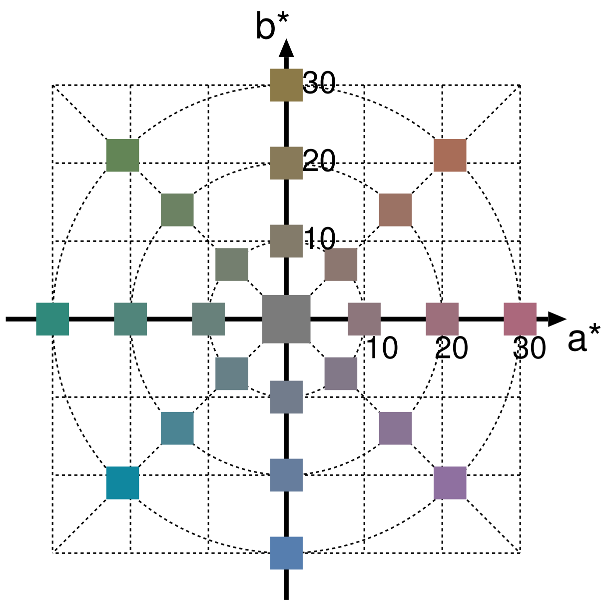

Figure 6. Chromatic coordinates used for heterochromatic brightness matching.

in this experiment and the result is shown in Fig. 7, where the horizontal axis is the hue angle of test patches and the vertical axis is the chroma. The differences of the luminance between the reference ($L^* = 51.56$) and the chromatic patches when the reference and the test had the same brightness are shown as vertical offsets from the chromatic coordinate (h^*_{ab}, C^*_{ab}) of the patches. For example, for the test patch of $h^*_{ab} = 0$ and $C^*_{ab} = 10$, it appeared to have the same brightness with the reference when luminance was smaller by 2.0, For the test patch of $h^*_{ab} = 0$ and $C^*_{ab} = 20$, the difference became 2.2, and for the test patch of $h^*_{ab} = 0$ and $C^*_{ab} = 30$, the difference became even greater to be 2.6, The difference of the luminance is greater at larger chroma in general. But there is little difference for the hue $h^* = 90°$ and $135°$. The result shown in Fig. 7 is consistent with the Helmholtz-Kohlrausch effect [10].

In order to confirm the assumption that the chromatic noise could be perceived as “brightness” noise as well as “chromatic”noise, the gradients of the luminance of the same brightness were calculated and compared to the interval scales of the visibility of chromatic noise. As the gradient, the averaged luminance gradient to the four perpendicular directions from a sample was used. The luminance gradient between two sampling points

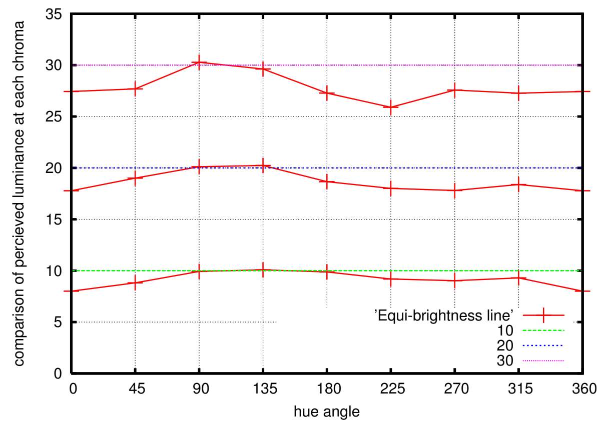

Figure 7. The result of heterochromatic brightness matching. The differences between the horizontal lines $C^*_{ab} = 10, 20, 30$ and the red lines are the differences of luminance when chromatic and achromatic patches had the same brightness.

was calculated by,

$$g_{i,j} = \frac{|L^*(a^*_i, b^*_i) - L^*(a^*_j, b^*_j)|}{\sqrt{(a^*_i - a^*_j)^2 + (b^*_i - b^*_j)^2}}. \quad (5)$$

Then, as illustrated in Fig. 8, the gradient G_0 at (a^*_0, b^*_0) was defined as,

$$G_0 = \frac{1}{4}\left(g_{1,0} + g_{3,0} + g_{p,0} + g_{q,0}\right), \quad (6)$$

and $L^*(a^*_p, b^*_p)$ and $L^*(a^*_q, b^*_q)$ were linearly interpolated values from $L^*(a^*_1, b^*_1)$ and $L^*(a^*_2, b^*_2)$ or $L^*(a^*_4, b^*_4)$. Due to the fairly sparse sampling at higher chroma, the gradients at $C^*_{ab} = 20$ (shown as “×” in Fig. 9) might be less accurate than the gradients at $C^*_{ab} = 10$ (shown as “+”). The relationship between the inter-

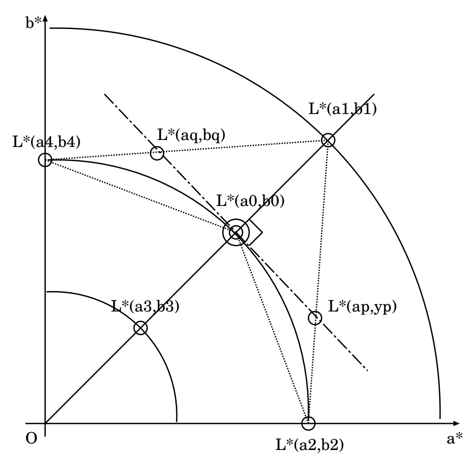

Figure 8. Sampling geometry when calculating the gradient of the luminance of the same brightness.

val scales of the visibility of chromatic noise and the gradient of the luminance of the same brightness is shown in Fig. 9. Though it is not strong but there is a correlation between them. Thus it can be said that the visibility of chromatic noise is affected by

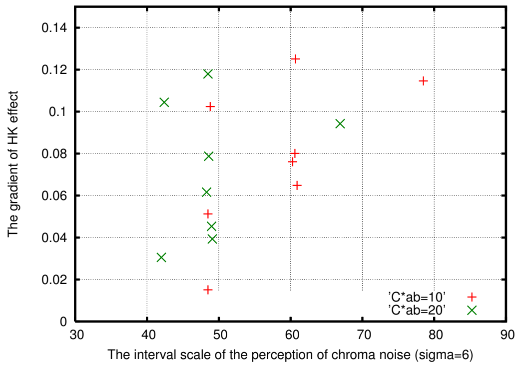

Figure 9. *The correlation of the interval scales of chromatic noise ($\sigma_{ab} = 6$) and the gradient of brightness. The "+" signs were values at $C^*_{ab} = 10$ and the "×" signs were values at $C^*_{ab} = 20$.*

Helmholtz-Kohlrausch effect and the chromatic noise is perceived as "brightness" noise as well as "chromatic" noise. Recalling that the $V(\lambda)$ is based on minimum flicker [11], it is reasonable that the same L^* values do not always give the same brightness perception for spatial patterns. This gives an interesting suggestion for a noise reduction filter. Considering visual performance, a noise reduction filter is applied to luminance and chrominance components [12]. The filter smoothes the chrominance components more strongly than the luminance component. One reason of this is that human visual system captures most of the fine detail information from luminance component and smoothing the luminance component degrades sharpness greatly. But another reason is that chrominance noise is considered to be unnatural and better to be eliminated while the luminance noise sometimes is said to be "film grain"-look and natural. The most important and difficult task of a noise reduction filter is to eliminate unnatural chrominance noise while keeping sharpness perception and natural look. As the chromatic variation is perceived as "brightness" variation, a noise reduction filter that converts and modulates chromatic variation into luminance variation when smoothing chrominance components will be able to accomplish this. But more elaborated research is needed because it was suggested that the heterochromatic brightness matching depended on the spatial frequency [13].

CONCLUSIONS

The perception of chromatic noise on different colors was investigated through a paired comparison psychophysical experiment. Interestingly, chromatic noise on a grey patch was less visible than on chromatic patches. Among chromatic patches, chromatic noise on a purple patch was the most visible and chromatic noise on orange, yellow, or green patches was less visible. In order to explain this noise perception behavior, a heterochromatic brightness matching experiment was conducted. The dependency on chroma and hue of the luminance for the same brightness (Helmholtz-Kohlrausch effect) was shown by the result of this experiment, and the gradient of the luminance of the same brightness and the noise visibility scale was shown to have a correlation. Thus it was suggested that chromatic noise was perceived not only as chromatic noise but also as brightness noise. Due to the higher spatial visual resolution of brightness and color dependent contribution of the chromatic noise to the brightness, the visibility of chromatic noise depends on the colors of the patches. These results can be utilized to improve a noise reduction filter performance.

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