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Experimental Study for Revising Visual Noise Measurement of ISO 15739

***Akira Matsui*[1]*, Naoya Katoh*[1]*, Dietmar Wueller*[2]**
[1]*Sony Imaging Products & Solutions Inc., Tokyo, Japan,* [2]*Image Engineering GmbH & Co. KG, Kerpen, Germany*

Abstract

Visual noise is a metric for measuring the amount of noise perception in images taking into account the properties of the human visual system (HVS). A visual noise measurement method is specified in Annex B of ISO 15739, which has been used as a useful measurement metric over the years since its introduction. As several issues have been questioned recently, it is now being investigated for revision involving changes to the CSF, color space used for rms noise value measurements, and visual noise formula combining rms values in three color channels. To derive visual noise formula involving color noise weighting coefficients representing HVS sensitivity to noise, subjective experiments using simulated luminance and color noise images were done. The improvement of calculation stability and HVS correspondence was verified using simulation and real camera images under various conditions. Finally, subjective experiments using real camera images were performed to validate the revised method and update the color noise coefficients considering practical measurement cases.

Introduction

The latest 3rd edition of ISO 15739 [1] published in 2017 specifies visual noise measurement method in Annex B, which was carried over, with minor revision, from the 2nd edition published in 2013, when it became a normative part. This annex specifies a calculation procedure for visual noise that takes into account the human visual system (HVS) response to noise in images, and it has been used as a useful metric over the years after its introduction. The framework for the current version of the visual noise measurement is based on the spatial sCIELAB work of Wandell [2], Johnson and Fairchild [3], and others in combination with some studies from Konica Minolta [4] and Image Engineering [5].

Visual noise is measured for gray patches in images of an OECF chart [6], and some important aspects of the visual noise calculation procedure are as follows: apply contrast sensitivity function (CSF) in opponent color space representing HVS spatial frequency response; measure rms noise standard deviation values in L*u*v* color space; derive visual noise values using visual noise formula, which is a linear combination of three rms values with color noise weighting coefficients representing HVS sensitivity to noise. The procedure is shown in the upper path of Figure 1.

Some issues concerning the visual noise measurement were questioned recently, and a revision of ISO 15739 was requested in ISO/TC42/WG18. Meanwhile, the IEEE Camera Phone Image Quality (CPIQ) group developed a visual noise measurement method [7][8], where some issues found in ISO 15739 were partly addressed. However, there exists a different issue that the color noise weighting coefficient for the b* channel used in the visual noise formula combining L*a*b* rms values is a negative value, which is unrepresentative of the HVS property in general cases.

Revision concept

Several issues raised were as follows: it is possible that negative XYZ values, introduced during the calculation procedure by the large CSF peak in the achromatic channel, may influence the visual noise calculation accuracy for dark and noisy patches; involving a division calculation in the u*v* derivation potentially makes the visual noise calculation unstable in darker cases; using a linear combination of rms values for visual noise formula is different from a statistically general way of combining rms values as sum of variances.

To address these issues, the following was proposed for incorporation, shown in the lower path in Figure 1:

1. Reduce the CSF peak in the achromatic channel from three to one by normalization to avoid negative XYZ value occurrences.
2. Change rms measurement space from CIELUV space to CIELAB space, a color space that is more commonly used in the imaging industry. CIELUV space is currently used for better perceptual uniformity for small color differences, but CIELAB space is known to have better uniformity for larger color differences. This is important in measuring larger noise values possibly assumed for recent cameras with higher ISO sensitivity settings. Additionally, calculation of noise at darker levels in CIELAB space is much more stable than in CIELUV space, as the former does not involve unstable division in its calculations.
3. Adjust the color noise weighting coefficients in the visual noise formula to closely match the HVS sensitivity. Also investigate whether a visual noise formula based on a linear weighted sum of rms values or the square root of weighted sum of variances better describes the visibility of noise.

In order to psychophysically determine the color noise coefficients for the visual noise formula combining L*a*b* rms values, we first performed subjective experiments using simulated luminance and color noise images [9][1]. Then, the improvement of negative XYZ issue was examined using simulated and real camera images. Thirdly, the validity of revised method for HVS correspondence was confirmed using a range of color noise simulation images with different saturations. Finally, subjective experiments using real camera images were

[1] The third subjective experiment out of the three experiments reported in [9] is referred to and discussed in detail in this paper, based on which the following validations were examined. The color noise coefficients have been modified with an inadequacy in calculation found.

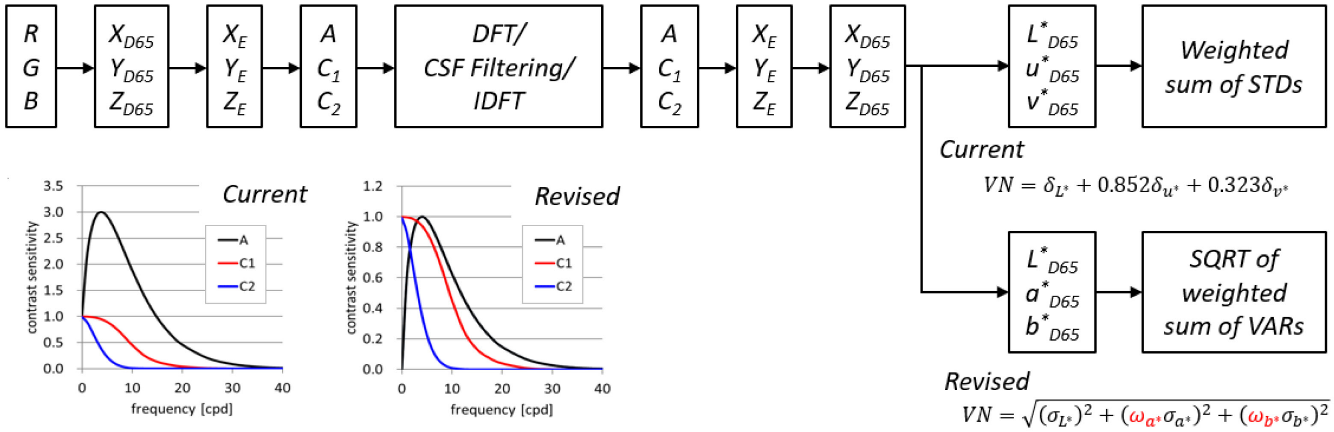


Figure 1. *Visual noise calculation procedure. In the right side of the procedure, the upper path represents the currently specified procedure, and the lower path shows the revised procedure. CSFs of the current and revised versions are shown in the lower left.*

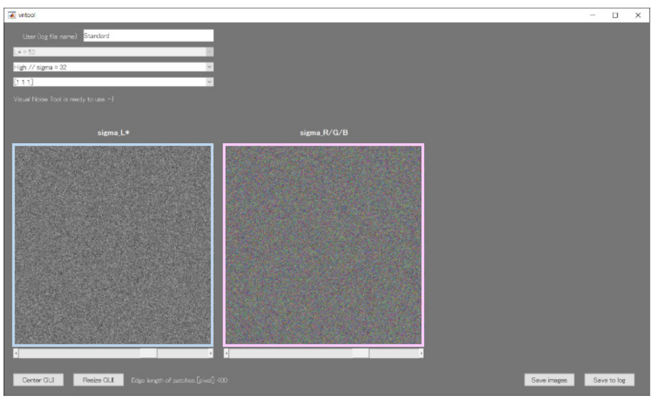


Figure 2. *Subjective experimental tool. A color noise patch appears at the center, and a luminance noise patch appears in the left side. Noise level of the luminance noise patch can be changed using the slider. (The patches' boundaries are colored for visibility in this Figure. The redundant right area is for showing an additional patch in different experiments.)*

done to validate the revised method and update the color noise coefficients taking into account practical measurement cases.

Experiments

Subjective experiment using simulated images

Method

A subjective experimental tool was prepared to investigate the HVS response to noise between different color channels. Figure 2 shows the tool window as displayed on a computer screen. A flat field gray patch with color noise appears at the center, and a gray patch with luminance noise appears in the left side. The noise level of the luminance noise patch can be changed using a slider, and each observer adjusts the slider in such a way that the noise levels of the two patches are perceptually similar. The luminance noise levels adjusted by subjects for different color noise patches appearing in turn are logged. Here, simulated noise images were used for both the luminance noise patch and the color noise patch (400 × 400 pixels), whose average levels were L*=50 and noise properties were white, i.e. having flat noise spectra.

For the luminance noise patch, rms value of L* can be adjusted between 0 to 16 with a step size of 0.25. For the color noise patch, noise was applied in sRGB color channels in order to have similar noise property to real camera cases where, generally, image sensors have RGB Bayer color filter array pattern, and signal processing is also performed in RGB channels. We used 24 color patches for normal cases and 18 patches for extreme cases, where "normal/extreme" represented the degree of difference in noise level between the color channels. Here, base noise rms level varied between 8, 16, and 32. Then, for the normal cases, rms values of none, one, two, or three channels were attenuated by 1/3. For the extreme cases, rms values of one or two channels were suppressed to zero.

Thirty-one subjects at three sites in two countries joined this subjective experiment. The results for the normal cases were used to derive color noise coefficients giving a revised visual noise formula, and the extreme case results were used to check the validity of the derived formula.

Results

The averages of the results of all the subjects for the normal cases were analyzed to derive color noise coefficients for the visual noise formula combining L*a*b* rms values. An unweighted linear regression was performed for the difference between the variances of the luminance noise factor in the luminance noise patch and the color noise patch as a function of the two chrominance noise variances, with the intercept forced to zero.

For the squared sum formulation:

$$VN = \sqrt{(\sigma_{L^*})^2 + (\omega_{a^*}\sigma_{a^*})^2 + (\omega_{b^*}\sigma_{b^*})^2} \qquad (1)$$

the derived coefficients were as follows:

$$\omega_{a^*} = 0.222, \omega_{b^*} = 0.266 \qquad (2)$$

with the coefficient of determination r^2=0.83. For the linear sum formulation, linear regression was similarly performed with r^2=0.49. The square sum formulation was selected for the revised method because the formulation models the results of the experiments better. Hereafter, we refer to the revised metric with Eqs. (1) and the coefficients in (2) as VN_tentative, and the currently specified metric in the third edition as VN_ed3.

The extreme case results were also confirmed to show good matching between the two patches using the VN_tentative metric, similarly to the normal cases.

Validation for negative XYZ issue

Method

To examine the influence and improvement of the negative XYZ issue, simulated noisy dark images were first generated and investigated where this issue may happen. We generated dark patches with average luminance L*=15 and luminance noise varying between 9.6, 19.2, 28.8, 38.4, and 48.0 in sRGB rms values. These are referred to as conditions #1 to #5, respectively. The reason for using luminance noise here, instead of color noise, is that luminance noise should give the same behavior as visual noise values between VN_ed3 and VN_tentative, so it is easy to specify whether such an issue is happening.

Additionally, some dark patches in a real camera image were investigated, where the shooting condition was set to be ISO 12800 and the noise reduction for high sensitivity deactivated. Average luminance levels of the three patches observed were L*=53, 32, and 11.

Results

Figure 3 shows the ratio of the number of pixels with negative XYZ value(s) to the total number of pixels. While some negative XYZ pixels were observed for VN_ed3, there were no negative XYZ pixels for VN_tentative by the effect of CSF modification. Figure 4 shows VN values for VN_tentative and VN_ed3. For ease of comparison the gain in noise rms value, due to differences in the CSF, was cancelled by normalizing the data with the luminance noise value corresponding to condition #1. VN_ed3 was measured to be smaller than VN_tentative, since negative XYZ pixels (relatively larger noise pixels) were omitted in rms calculation as specified in the calculation procedure of the standard.

In the real camera image patches, negative XYZ were observed in 2%, 14%, and 29% of pixels respectively in the VN_ed3 case. In the VN_tentative case, negative XYZ pixels only appeared in the darkest patch with 0.004% ratio. Luminance CSF peak being normalized at one does not necessarily ensure that occurrences of negative XYZ values are fully eliminated, but its probability can be suppressed very close to zero.

Although visual noise calculation works well in general cases, as described above it was confirmed that modification of CSF solves the negative XYZ issue and contributes to accurate rms measurement leading to fair visual noise measurement in darker and noisier cases.

Validation for HVS correspondence

Method

A range of saturated color noise simulation images were prepared to validate improvement in terms of HVS correspondence under different noise properties. Here, we generated 12 color noise patches in which the color noise levels and saturations were different. Color noise rms values varied between 16, 24, and 32 and were applied in sRGB space. The saturation level of the color noise was also varied between none, small, medium, and maximum by changing the cross-correlation between the noise in the three channels. The average luminance level was L*=50.

Firstly, the visual noise values of the patches for VN_ed3 and VN_tentative were calculated. Then, all the 12 patches were ordered according to the calculated visual noise values by either of the two metrics and observed to check whether the images were well ordered according to perceptual noise level order.

Results

Figure 5 shows the measured visual noise values for the 12 images using the two metrics. It is noted that the ratio of the two metric values seems to be dependent on color noise saturation level. Correlation coefficient of these plots is 0.78.

Figure 6 shows the patches ordered according to the measured visual noise values. VN_ed3 is shown in Figure 6-1 and VN_tentative in Figure 6-2. The patches are displayed in ascending order from left to right and top to bottom. All the experts who viewed the results confirmed that they were ordered according to perceptual noise order better in the VN_tentative case than in the VN_ed3 case, which means that the former is a metric that reflects the HVS property in a better way. The order for VN_ed3 suggests that color noise is weighted somewhat more heavily relative to luminance noise.

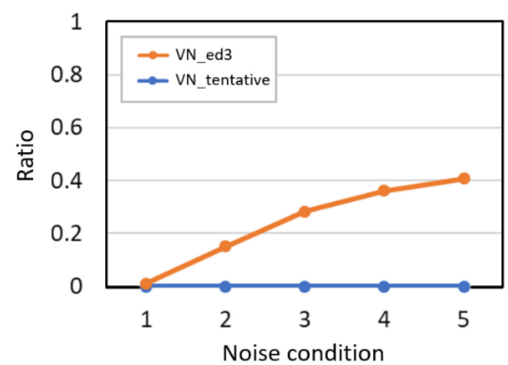


Figure 3. *Ratio of the number of pixels with negative XYZ value(s) to the total number of pixels. While some negative XYZ pixels are observed for VN_ed3, there are no negative XYZ pixels for VN_tentative.*

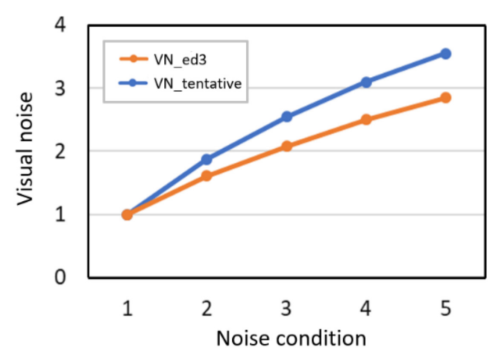


Figure 4. *Visual noise values for VN_tentative and VN_ed3 with normalization by the value corresponding to condition #1. VN_ed3 is measured to be smaller than VN_tentative caused by omission of negative XYZ value pixels in measuring rms values.*

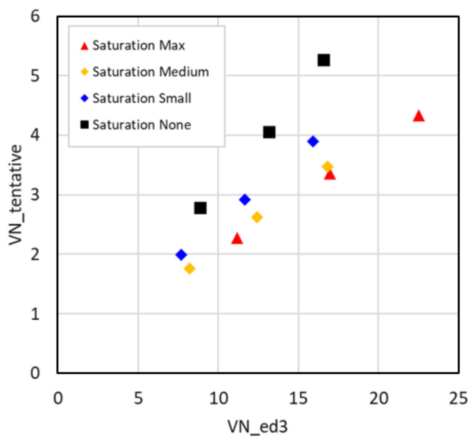


Figure 5. *Visual noise values of the 12 images using VN_ed3 and VN_tentative. It is noted that the ratio of the two metric values seems to be dependent on color noise saturation level.*

Subjective experiment using real camera images

Method

In order to more closely validate the visual noise formula of VN_tentative and update the color noise coefficients, subjective experiments using real camera images were done. In this experiment, real camera images were prepared and used for color noise patches in the experiments, in a similar way to the experiment using simulation images already described. This enabled us to validate the visual noise formula taking into account practical measurement cases. The luminance noise patches using simulation images with a slider were the same as in the previous experiment.

Four cameras with different sensor sizes, including a smartphone, were used to capture 72 raw formatted images in total. Three different average luminance levels (L*=25, 50, and 75), three different ISO sensitivity settings (different according to the cameras), and two illuminants (A, D65) were used for shooting with each camera. These were developed using PC development software with simple settings (no noise reduction, no edge enhancement, bilinear interpolation for demosaicking, and white balance adjusted to gray), and the visual noise values of the images were computed.

From the 72 images, 36 images that covered the distribution range in visual noise values well were selected to be used in the subjective experiments. In addition, reducing the number of images meant that the experiment could be performed in a reasonable amount of time. A similar experimental tool to the previous experiment was used, where patches of these camera images appeared at the center of the tool instead of simulated color noise images. The experimental procedure was the same as in the previous experiment. The viewing conditions were controlled to conform to Annex E of ISO 15739, where recommended practical viewing conditions are given, and ISO 3664 [10] with a little modification for relaxation.

Fifty-four subjects at six sites in three countries participated in this experiment. The averages of the results of all the subjects were used to validate VN_tentative and derive updated color noise coefficients representing practical measurement cases.

Results

Firstly, the degrees of variation in the experimental results between the subjects, and also between the experimental sites, were confirmed. The mean of the relative standard deviations between the subjects was calculated over the 36 images and found to be 0.25. This is a reasonable value, and any evident systematic deviation dependent on the sites was confirmed to not be seen.

In Figures 7 and 8, visual noise values of all the 36 images for VN_ed3 and VN_tentative, using the averaged experimental results between all the subjects for each image, are shown respectively. The horizontal axis represents visual noise values of color noise patches, and the vertical axis corresponds to visual noise values of luminance noise patches. The VN_tentative plots are confirmed to be closer to the diagonal line, which means the metric represents HVS property better than VN_ed3. The mean over the images, of relative error (ratio of the absolute value of the difference between visual noise values of color/luminance noise patches to a visual noise value of a luminance noise patch) was 0.487 for VN_ed3 and 0.136 for VN_tentative, which confirms improvement in HVS correspondence.

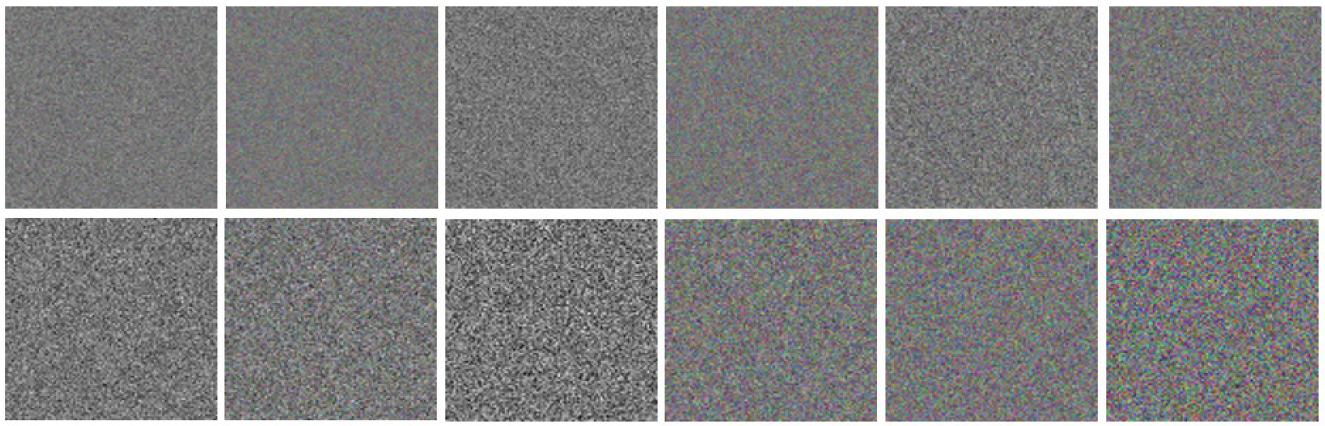
In Figure 9, the visual noise values shown were calculated using the updated formula with color noise weighting coefficients derived by regression using the results of these experiments. The derived color noise weighting coefficients were:

$$\omega_{a^*} = 0.338, \omega_{b^*} = 0.395 \quad (3)$$

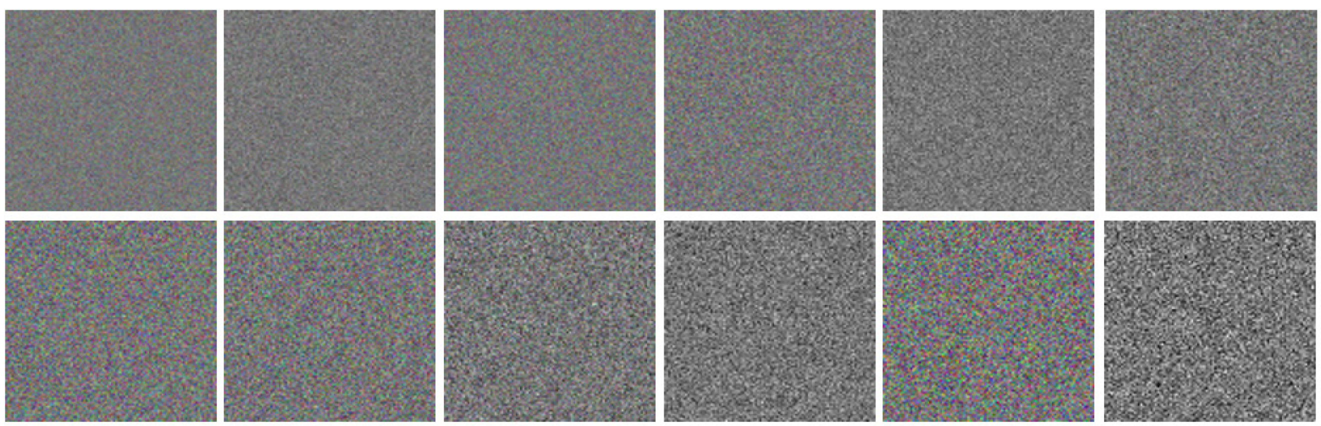
with r^2=0.95. The mean of the relative error for these plots is 0.060. This shows that the updated formula gives better matching to visual perception in practical measurement cases.

One major reason for the factor of 1.5 increase in the color noise coefficients, in both color channels, from Eq. (2) to Eq. (3), is presumed to be the difference in spatial frequency distribution of noise between the two experiments. In the previous experiment, both the luminance and color noise patches contain white noise. On the other hand, the color noise patches, used in this experiment, have a specific noise spectrum that is somewhat attenuated at higher spatial frequencies, in all the color channels, due to the camera signal processing. As for assumable HVS properties related to spatial frequency, the major factor described as the CSF, the HVS ability to detect low contrast pattern stimuli, is incorporated in the visual noise calculation procedure. However, it is known that lower frequency noise is generally perceived as more annoying, and such a perceptual factor may have influenced the responses of the observers in the psychophysical experiments.

The measured values for VN_ed3 and VN_tentative were compared, and it was noted that VN_tentative values were a couple of times smaller than VN_ed3 values. This is mainly caused by the CSF peak reduction in the achromatic channel, by which luminance noise rms values are calculated as smaller values to be reflected in the measured visual noise values. This is important difference to be noted when the revised method is used in future edition.



(6-1)



(6-2)

Figure 6. *Twelve noisy patches having different color noise level and saturation, ordered according to visual noise values, VN_ed3 in (6-1) and VN_tentative in (6-2), in ascending order from left to right and from top to bottom. It can be confirmed that the images are better ordered according to perceptual noise order in the VN_tentative case than in the VN_ed3 case. Visual noise values: 7.7, 8.2, 8.9, 11.2, 11.7, 12.4, 13.2, 15.9, 16.6, 16.8, 17.0, and 22.5 (VN_ed3); 1.8, 2.0, 2.3, 2.6, 2.8, 2.9, 3.4, 3.5, 3.9, 4.1, 4.3, and 5.3 (VN_tentative).*

Conclusions

Between several proposed changes for revision of visual noise measurement method specified in ISO 15739, color noise weighting coefficients in visual noise formula were needed to be determined psychophysically. Subjective experiments using simulation images were done first, giving these coefficients as tentative values. The negative XYZ issue was confirmed to be addressed by the revised method, using simulation and real camera images in dark and noisy cases. Improved HVS correspondence under various noise properties was proven using a range of saturated color noise simulation images that were evident for perceptual confirmation. Finally, subjective experiments using real camera images were done to validate the revised method and update the color noise coefficients in practical measurement cases. The derived coefficients are reasonable values, which is a requirement for the CPIQ measurement method.

Additional experiments are ongoing to validate these results and fix the revised visual noise measurement method to be reflected in the ISO 15739 4th edition.

Acknowledgement

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Author Biography

Akira Matsui received BS and MS degrees in mechano-informatics technology at the University of Tokyo, Japan. He is a Senior Imaging Engineer at Sony Imaging Products and Solutions. He has been developing camera signal processing algorithms and LSIs implemented in many digital still cameras, video cameras, and smartphone cameras over the past 25 years. He is actively involved in ISO/TC42 standardization and serves as a co-PL for the revision of ISO 15739.

Naoya Katoh received B. Eng. degree in precision mechanics in 1987 from Kyoto University, Japan. In the same year, he joined Sony Corporation. He received an MS degree in color science in 1997 from Rochester Institute of Technology, USA, and Ph.D degree in 2002 from Chiba University, Japan. He was awarded "Sony Outstanding Engineer" in 2003 and 2006. He is now a Principal Engineer at Sony Imaging Products and Solutions and is involved in color imaging for digital cameras. He is an active member of ISO/TC42 and IEC/TC100/TA2 and received "IEC 1906 Award" in 2006.

Dietmar Wueller studied photographic technology at the Cologne University of applied sciences. He is the founder of Image Engineering, an independent test lab that tests cameras for several photographic and computer magazines as well as for manufacturers. Over the past 20 years the company has also developed to one of the world's leading suppliers of test equipment. Dietmar Wueller is the German chair of the DIN standardization committee for photographic equipment and also active in ISO, the IEEE CPIQ (Cellphone Image Quality) group, and other standardization activities.

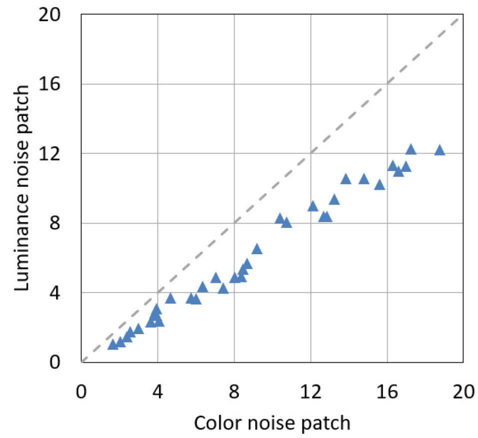

Figure 7. *Plots of visual noise values for VN_ed3. The horizontal axis represents visual noise values of color noise patches, and the vertical axis corresponds to visual noise values of luminance noise patches.*

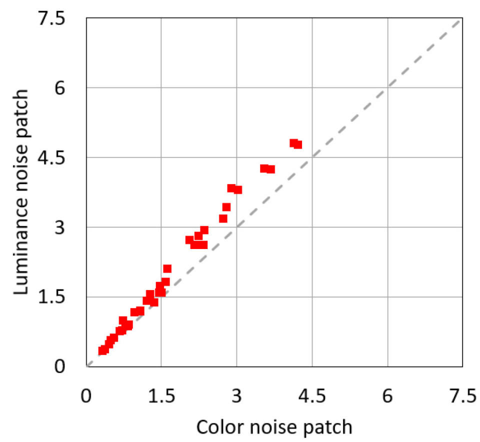

Figure 8. *Plots of visual noise values for VN_tentative. VN_tentative plots are closer to the diagonal line, which means the metric represents HVS property better than VN_ed3.*

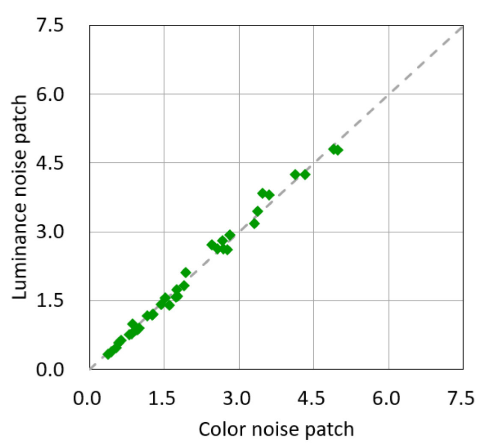

Figure 9. *Plots of visual noise values using the updated formula. This shows the updated formula gives better matching to the visual perception in practical measurement cases.*

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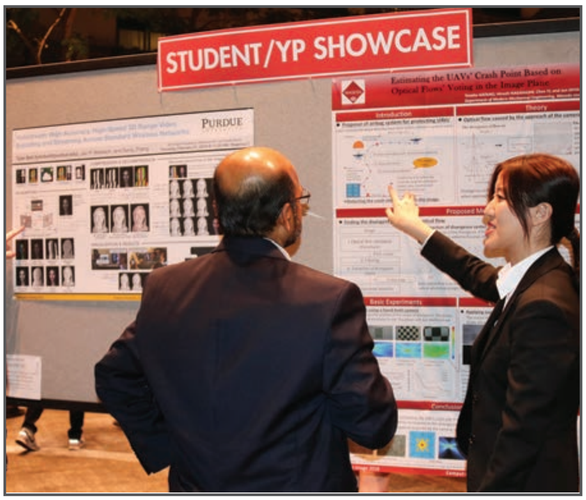

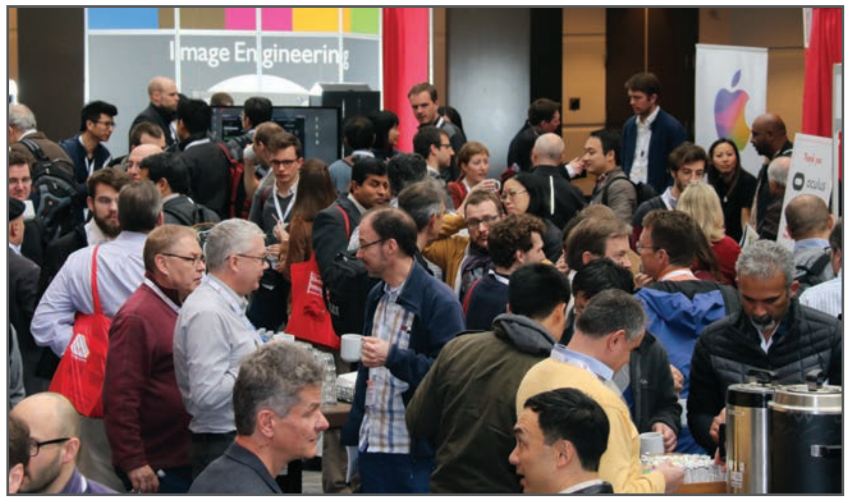

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