Visual Noise Revision for ISO 15739

Dietmar Wueller[1], Akira Matsui[2], Naoya Katoh[2]
[1]Image Engineering, Kerpen, Germany, [2]Sony IP&S, Tokyo, Japan

Abstract

With the publication of the second edition of the ISO 15739 Standard [1] in 2013 the measurement of "visual noise" became a normative part of the standard. Over the years the algorithm has proven to be useful and reliable for the judgement of the visibility of noise in images captured by digital cameras. Nevertheless a few aspects of the measurement procedures were questioned by some experts like e.g. the relation of the contrast sensitivity function (csf) for the luminance and the two chrominance channels. And the resulting weighting factors for the three channels also depend on the csf relation. In addition, some experts would like to use the more common CIELAB space instead of CIELUV.

For these reasons the responsible ISO technical committee 42 working group 18 is looking into a revision of the visual noise section of the standard. This paper describes the procedure the group is undertaking to solve the remaining issues in the upcoming revision.

Introduction

The second edition of the ISO 15739 noise measurements standard that has been published in 2013 contains Annex B that specifies visual noise measurement. This Annex describes a way to determine the visibility of noise in an image. It is based on a simulation of the human visual system applied to the image.

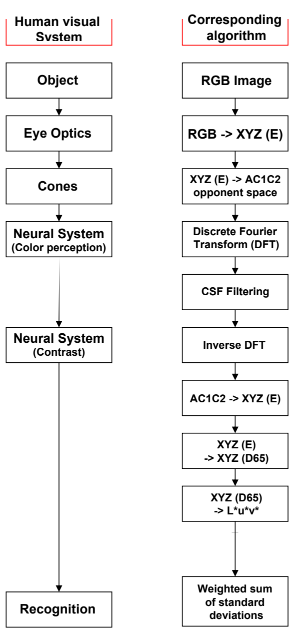

Figure 1: Simulation of the human visual system

In its calculation procedure, firstly csf is applied in spatial frequency domain of an opponent color space for uniform grey areas. After this "filtering" the standard deviation in these areas is determined for all three channels in the L*u*v* representation of the image. The weighted sum of the standard deviation describes the visibility of noise in the image.
The fact that the luminance curve of the contrast sensitivity function of the human eye which is part of the filtering had a maximum value of 3 lead to the assumption by some scientists that for images with extreme noise levels the amplification by a factor of 3 could lead to saturation problems during the filtering. This led to a different filtering in the IEEE P1858 project also known as cellphone image quality group (CPIQ). They use a CSF approach with all curves reaching a maximum value between 1 and 1.3. The result is a Lab image with weighted sums of the standard deviations in Lab space. In the CPIQ approach the b* channel has a negative weighting implying that noise in the b* channel leads to a less noisy image. This of course is not the case. The two approaches with their pros and cons lead to an attempt within the ISO group to revise the standard.

Revision concept

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].

The CPIQ approach is summarized in the paper by Donald Baxter and Andrew Murray [6].

Three aspects were criticized by the CPIQ experts namely:

1. The used contrast sensitivity function (CSF) had a luminance filtering curve with a maximum of 3 which in principle could lead to a noise clipping in filtered images. Even though it has never been an issue in real images it is a theoretical imperfection.

2. They wanted to add a filter for a simulation of the output system on which the image is displayed which has become more or less obsolete due to modern display technology.

3. The change of the CSF also required a change of the weighting factors especially since they wanted to use Lab instead of the currently used Luv space.

ISO technical committee 42, working group 18 took on the criticism and is working on a revision of the visual noise part of the standard.

The revision will incorporate 3 changes:

1. Change the CSF to avoid theoretical problems with potential clipping.

2. Move from CIELUV space for the evaluation space to the more commonly-used CIELAB space. In the previous editions, CIELUV space was used for better perceptual uniformity for small color differences. However, CIELAB space was selected which is known to have better uniformity for larger color differences. This is important in measuring larger noise possibly assumed for recent cameras with higher ISO sensitivity settings. Also, from practical point, calculation of noise at darker levels CIELAB space is much more stable than CIELUV space that involves division in its calculation.
3. Adjust the weighting factors to most closely match the human visual system. Also investigate both formulations of linear sum and square sum of standard deviation and choose one that represents visibility of noise better.

Adjustment of the contrast sensitivity function (csf)

The current idea regarding the contrast sensitivity function is pretty straight forward with normalizing the CSF to a max value of 1 for all three channels. To deal with the sensitivity differences between luminance and chrominance values the weighting factors for the standard deviations will be determined in a psychophysical experiment.
The formula regarding the contrast sensitivity functions are:

For the luminance csf

$$csf_{lum,old}(f) = \frac{(K + a \cdot f^{c}) \cdot e^{-bf}}{K} \qquad (1)$$

$$csf_{lum,new}(f) = \frac{a \cdot f^{c} \cdot e^{-bf}}{K} \qquad (2)$$

Table 1: values for luminance csf variables

Luminance variables	old	new
a	75	75
b	0,2	0,2
c	0,9	0,8
K	46	102,16

For the chrominance csf

$$csf_{chrom}(f) = \frac{a_1 \cdot e^{-b_1 f^{c_1}} + a_2 \cdot e^{-b_2 f^{c_2}} - S}{K} \qquad (3)$$

Table 2: values for chrominance csf variables

Chrominance variables	C_1	C_2
a_1	109,1413	7,0328
b_1	0,0004	0
c_1	3,4244	4,2582
a_2	93,5971	40,61
b_2	0,0037	0,1039
c_2	2,1677	1,6487
K	202,7384	40,691
S	0	7,0328

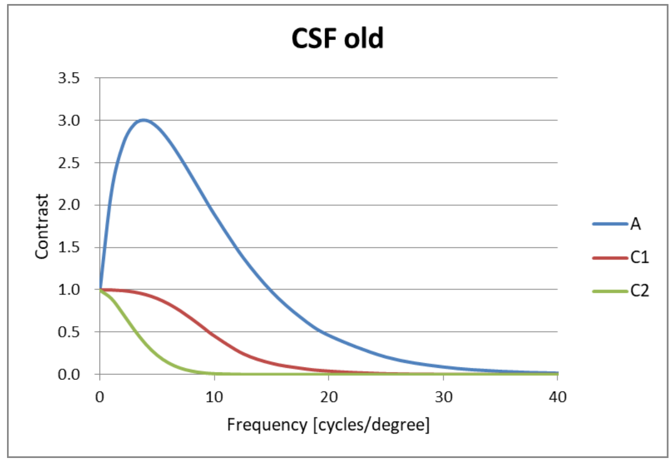

Figure 2: The csf curves of the current ISO 15739 standard

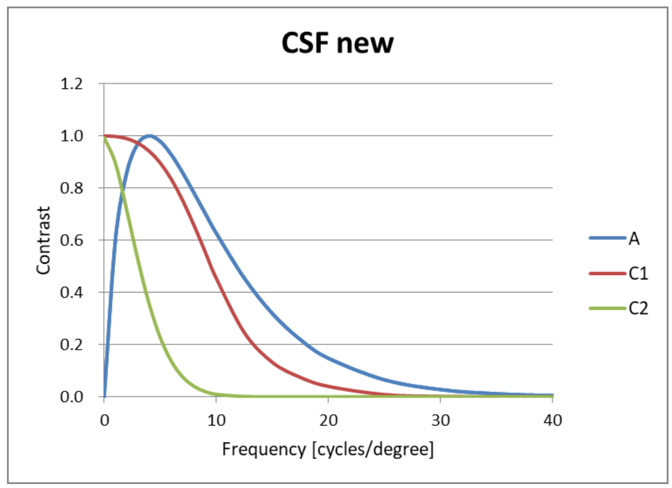

Figure 3: The csf curves of the future ISO 15739 standard

Weighting factors for the L*, a* and b*

ISO 15739 visual noise measurements are performed on uniform gray patches in an OECF [7] test chart captured with the camera under test. A single visual noise value is generated in the last step of the human visual simulation described in Figure 1. This value is generated as the weighted sum of the standard deviations (σ) in each of the three channels L*, a* and b*. To determine these weighting factors multiple psychophysical pilot studies have been performed.

For the first pilot study a MATLAB program was developed showing three patches to which noise was added. The patch in the center was preset as a reference and consisted of one of three background levels (L* at 25, 50, and 75) and 1 of 4 standard deviation levels (0, 2, 5, and 10). The patches left and right were adjusted to the same background level as the center patch. For the left patch noise in the a* channel was added by adjusting a slider underneath the patch. For the right patch the same was done with the b* channel.

The observers were asked to adjust the sliders to the same noise level perception as the L* noise in the center.
The monitor had been calibrated and profiled and the viewing distance had been adjusted to a distance where the observers were able to see every pixel. The viewing conditions for this first studies were not strictly controlled due to the given environment, but the recommended conditions of ISO 3664 were used as a guideline.

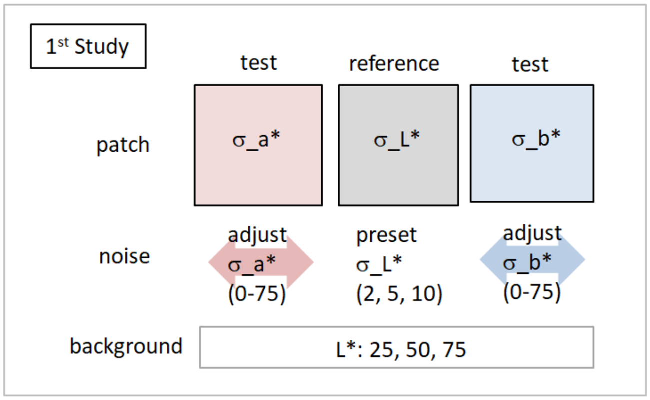

Figure 4: The principle setup for the first pilot study.

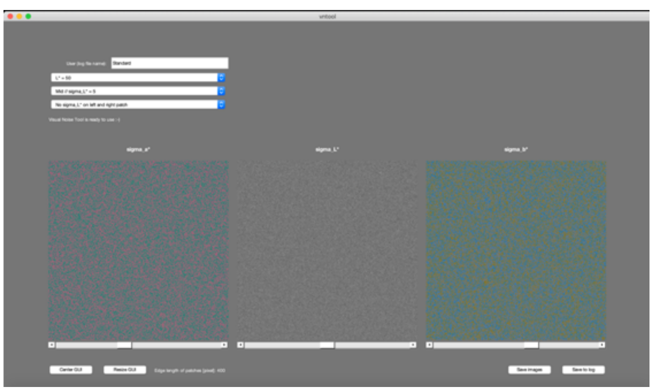

Figure 5: A Screenshot of the software for the first pilot study.

After evaluating the results, it turned out that due to the encoding of Lab images and the limited monitor gamut the noise generation in the a* and b* patch resulted in significant clipping suggesting that the weighting factors were found to be dependent on the level of luminance noise by its influence on perception.

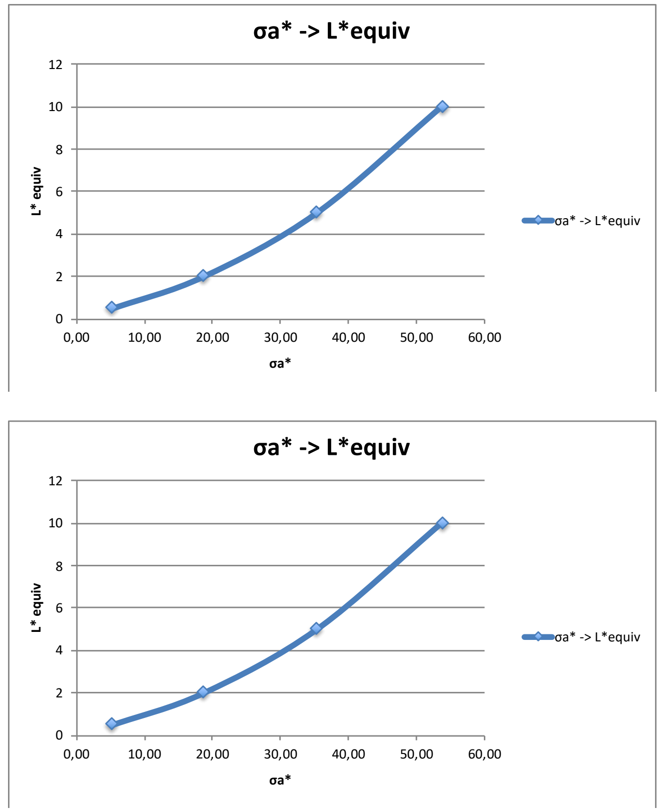

Figure 6: Clipping in the a and b* channels suggested that the weighting factor would depend on the amount of luminance noise.*

After this clipping problem had been discovered a second pilot study was initiated in which the noise on the left and right side was generated as a combination of luminance and chrominance noise (Figure 7)

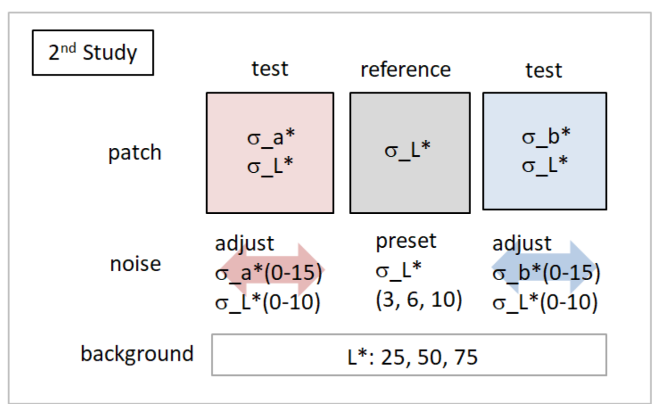

Figure 7: The principle setup for the second pilot study.

The σ_a*/σ_b* and σ_L* was applied onto the color noise patches in the ratio of 3:2 (3 times color noise and 2 times L* noise).

The second pilot study was performed by just a small number of people. It led to the recognition that applying uncorrelated noise to an image in Lab space results in different distributions in RGB space (sRGB serves as an example here).
In Figure 8, uncorrelated noise was applied to an sRGB image with a sigma value of 32. This resulted in a different sigma level for L*, a* and b* when transformed into Lab space. Taking the same L*, a* and b* sigma levels applied to an Lab image as uncorrelated noise and converting them back to sRGB it leads to different RGB sigma levels.

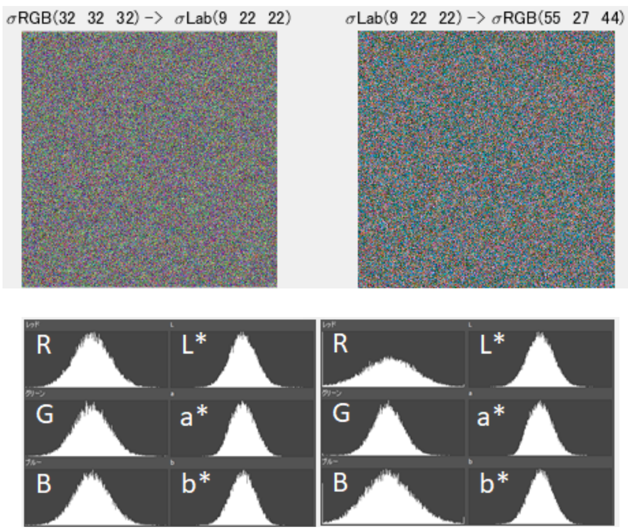

Figure 8: applying uncorrelated noise to an sRGB image results in different L a* and b* sigma levels (left). Applying those sigma levels to an Lab image as uncorrelated noise and converting them back to sRGB it leads to different sigma levels for the RGB channels (right).*

This shows that for judging the noise generated by digital cameras it is important to apply the noise in RGB camera space and then evaluate the Lab representation, since most of conventional cameras comprise RGB image sensors where noise is added.

This realization lead to a third and so far final pilot study where the noise was applied to patches in RGB space and then the Lab standard deviation was analyzed on those patches.
So, for the third pilot study the noise was applied in sRGB space at three different levels (σ 8, 16 and 32).

Table 3: applied standard deviations

(σR σG σB) ratio			
	(0.33 0.33 0.33)	(1 1 1)	
(1 0.33 0.33)	(0.33 1 0.33)	(0.33 0.33 1)	Normal
(0.33 1 1)	(1 0.33 1)	(1 1 0.33)	
(1 0 0)	(0 1 0)	(0 0 1)	Extreme
(0 1 1)	(1 0 1)	(1 1 0)	

These three different levels were then applied to the RGB gray patches with different attenuation factors for the three channels as described in Table 2. The normal case describes noise being applied to all three color channels at the same or different levels. The extreme case describes noise being applied to only one or two of the three channels which usually does not happen in real images. The background L* level used was 50.

In total these noise values resulted in 42 images used as reference patches. They were displayed to the participants of the study one by one. Aside of these reference images was a patch with a slider used to adjust the L* based noise of the patch. The participants were asked to adjust the slide so that the L* noise of the patch would match the noise level of the RGB reference patches. To ensure the correct visualization a color managed workflow was used as described in Figure 9.

Even though the study is still ongoing the data of 31 participants has already been evaluated. The data is showing good correlation between the results.

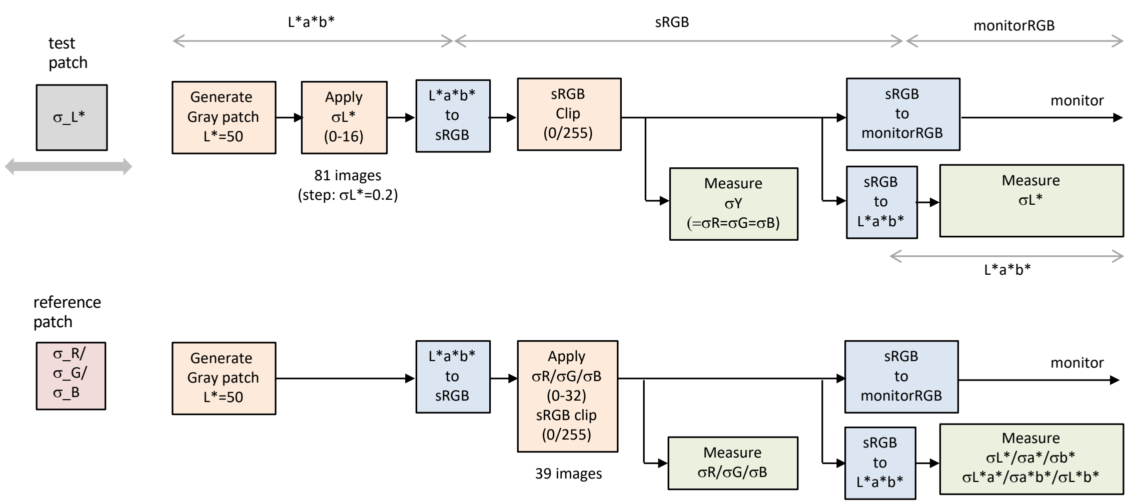

Figure 9: Representation of the noise application and color management workflow for the third pilot study.

The question that was raised is if the linear weighting formula (4) of the standard deviations or the squared formula (5) of the variances shows a better correlation with the acquired data.

$$\sigma L^*_{test} = \sigma L^*_{ref} + \omega_1\, \sigma a^*_{ref} + \omega_2\, \sigma b^*_{ref} \quad (4)$$

$$(\sigma L^*_{test})^2 = \sqrt{(\sigma L^*_{ref})^2 + (\omega_1\, \sigma a^*_{ref})^2 + (\omega_2\, \sigma b^*_{ref})^2} \quad (5)$$

The data analysis shows that the squared results using the variance produces the higher correlation and will therefore be selected. For the normal noise levels, it produced a correlation level of 0.997 and even for the extreme levels, the correlation was 0.995.

From the data the weighting factors ω_1 and ω_2 were determined as 0.180 and 0.152 resulting in a visual noise value VN:

$$VN = \sqrt{(\sigma_{L^*})^2 + (0.180\sigma_{a^*})^2 + (0.152\sigma_{b^*})^2} \quad (6)$$

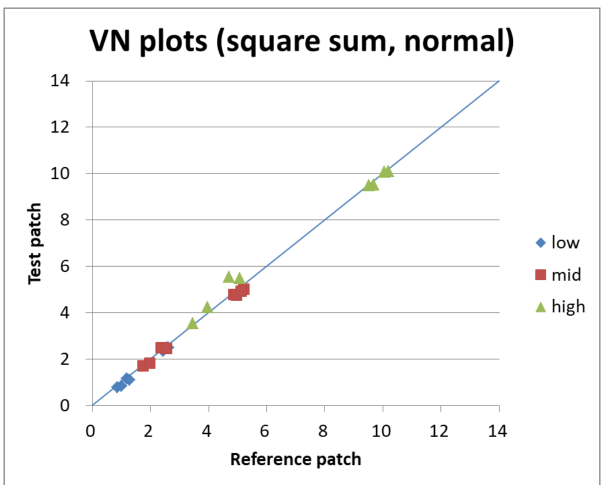

Figure 10: Visual noise plots for the normal noise cases.

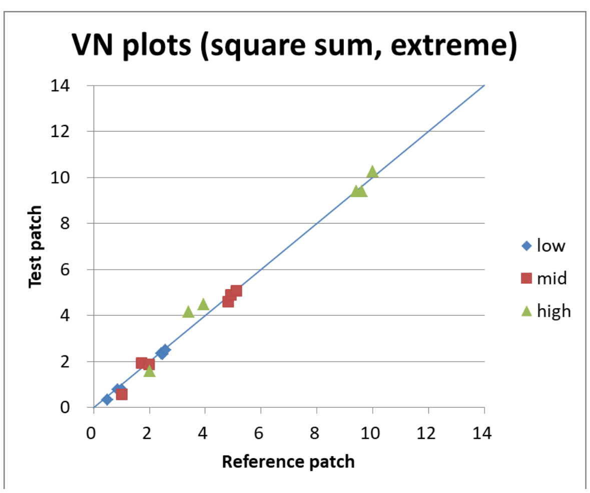

Figure 11: Visual noise plots for the extreme noise cases.

Conclusions

The contrast sensitivity functions for all three color channels will be updated normalizing the maximum of each channel to 1.

Three psychophysical pilot studies have been performed.

The square root of the weighted sum of the variances (squared standard deviations) shows the better correlation with the test data and will therefore be used for the visual noise.

To make sure that the determined formula works for the evaluation of cameras it has to be tested on images captured with real cameras. This test is part of the future work.

Acknowledgement

The authors would like to thank TC42/WG18 members for their cooperation for the psychophysical experiments.

References

[1] ISO 15739 Photography — Electronic still-picture imaging — Noise measurements

[2] X, Zhang, B.Wandell, "A Spatial extension of CIELAB for digital color image reproduction", J. Soc. Info. Display. 5. 10.1889/1.1985127, 1998.

[3] G. Johnson, M. Fairchild, "A Top Down Description of S-CIELAB and CIEDE2000", 2003.

[4] K. Aoyama, H. Enomoto, and Po-Chieh Hung, "An evaluation method for image noise of various output devices", Journal of the Society of Photographic Science and Technology of Japan, 57, 6, 1994, pp 392-398.

[5] J. Kleinmann, D. Wueller, "Investigation of two methods to quantify noise in digital images based on the perception of the human eye", Proceedings Volume 6494: Image Quality and System Performance IV, 2007

[6] D. Baxter, A, Murray, "Calibration and adaptation of ISO visual noise for I3A's Camera Phone Image Quality initiative", Proceedings Article, Electronic Imaging Conference 2012

[7] ISO 14524 Photography — Electronic still picture cameras — Methods for measuring opto-electronic conversion functions (OECFs)

Author Biography

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.

Akira Matsui studied mechano-informatics technology at the University of Tokyo, Japan. He is Senior Imaging Engineer at Sony Imaging Products and Solutions and has been developing signal processing algorithm and LSI for digital cameras for over the past 20 years. He is a Japanese delegate to TC42/WG18, and actively involved in standardization on photography.

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.*