Natural Vision Image Data File Format for Spectral-based Color Reproduction

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Abstract

Natural Vision Image Data File Format has been developed in order to realize spectral-based color reproduction. This paper introduces the profile format of Natural Vision Image Data File Format. It is based on ICC Profile Format. New Profiles, Tags and Tag Types, therefore, have been developed to cover the lacks of ICC Profile Format for spectral-based color reproduction. The design concepts of Natural Vision System are introduced with respect to the requirements. Input Profiles and Display Profiles are expanded in order to provide spectral characteristics to color reproduction system. ColorSpace Conversion Profiles is expanded in order to provide rendering illuminant and CMFs to Color Reproduction Intent Management System. Relationships between the expanded Profiles and image processing are also descried.

Introduction

Spectral-based color reproduction system has more flexibility and reliability rather than colorimetric-based one from the viewpoint of colorimetry. The establishment of CIE Technical Committee 8-07 multispectral imaging symbolizes the importance of spectral-based color reproduction.

Ohsawa has summarized the concept of spectral-based color reproduction system.[1] The basic architecture of Natural Vision Image Data File Format also has been introduced as the solution of spectral-based color reproduction system. This paper introduces the details of the profile component. Relationship between the profile format and image processing is also explained.

Design Concepts of Natural Vision System

The following three requirements are established for the design of Natural Vision system:

1) To handle spectral data - (R-1)
2) To be acceptable arbitrary illuminants - (R-2)
3) To be acceptable arbitrary Color Matching Functions (CMFs) - (R-3)
4) To be compatible with current system - (R-4)

Color reproduction system that realizes the above requirements has the following benefits:

a) R-1 overcomes the problems of metameric matching.
b) R-2 makes possible illumination exchanges.
c) R-3 makes possible optimizations for individual CMFs.
d) R-4 gives flexibility to Natural Vision System.

Based on the above idea, Natural Vision system is designed as shown in Fig.1. To satisfy R-1, capturing system has to provide spectral reflectance or radiance of the object. Color Reproduction Intent Management System (CRI management system) is in charge of determining color reproduction target. To satisfy R-2 and R-3, CRI Management System has to be acceptable arbitrary illuminants (i.e. $\mathbf{E}_{target}$) and CMFs (i.e. $\mathbf{c}_{target}$) given by ColorSpace Conversion Profiles. In other words, color reproduction target (i.e. $\mathbf{S}_{estimated,target}$ or $\mathbf{C}_{estimated,target}$) has to be able to define with the arbitrary illuminants and CMFs. The number of dimension of stimulus value $\mathbf{C}^*$ should be arbitrary.[2-4] To satisfy R-4, the profile format is based on ICC profile format,[5] AVI or BMP is used as the image format, and WAV format is used as the audio format in Natural Vision Image Data File Format.[1] Figure 2 illustrates the details of the capturing system. It consists of multi-band camera, spectral estimation module and colorimetric estimation module. Input Profiles has to provide spectral characteristics of multi-band camera. The multi-band structure** is useful to heighten the accuracy of the spectral estimation.[5] Figure 3 illustrates the details of the CRI management system. It consists of spectral targeting module, colorimetric targeting module. The spectral targeting module is able to accept arbitrary illuminations (i.e. $\mathbf{E}_{target}$). The colorimetric targeting module is also able to accept arbitrary CMFs (i.e. $\mathbf{c}_{target}$).

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* The term "stimulus value" corresponds generalized (i.e. multi-dimensional) XYZ. Tristimulus value is a part of the stimulus value, where the number of dimension is three.

** The term "multi-band" means that the number of bands is arbitrary. Three-band camera (i.e. RGB camera) is included to the multi-band camera. It does not restrict that the number of the bands is over three.

ColorSpace Conversion Profiles is expanded with respect to illuminations and CMFs as mentioned later. Figure 4 illustrates the details of the display system. It consists of spectral prediction module, colorimetric prediction module and multi-primary display. The spectral prediction module should find out the display signal that controls the multi-primary display to present the color reproduction target $\mathbf{S}_{estimated,target}$ or $\mathbf{S}_{estimated}$ on the display screen. The colorimetric prediction module also should find out the display signal that controls the multi-primary display to present the color reproduction target $\mathbf{C}_{estimated,target}$ or $\mathbf{C}_{estimated}$ on the display screen. Display Profiles has to provide spectral characteristic of the multi-primary display. Natural Vision Image Data File Format supports the above functions for still image system and motion picture system.[1]

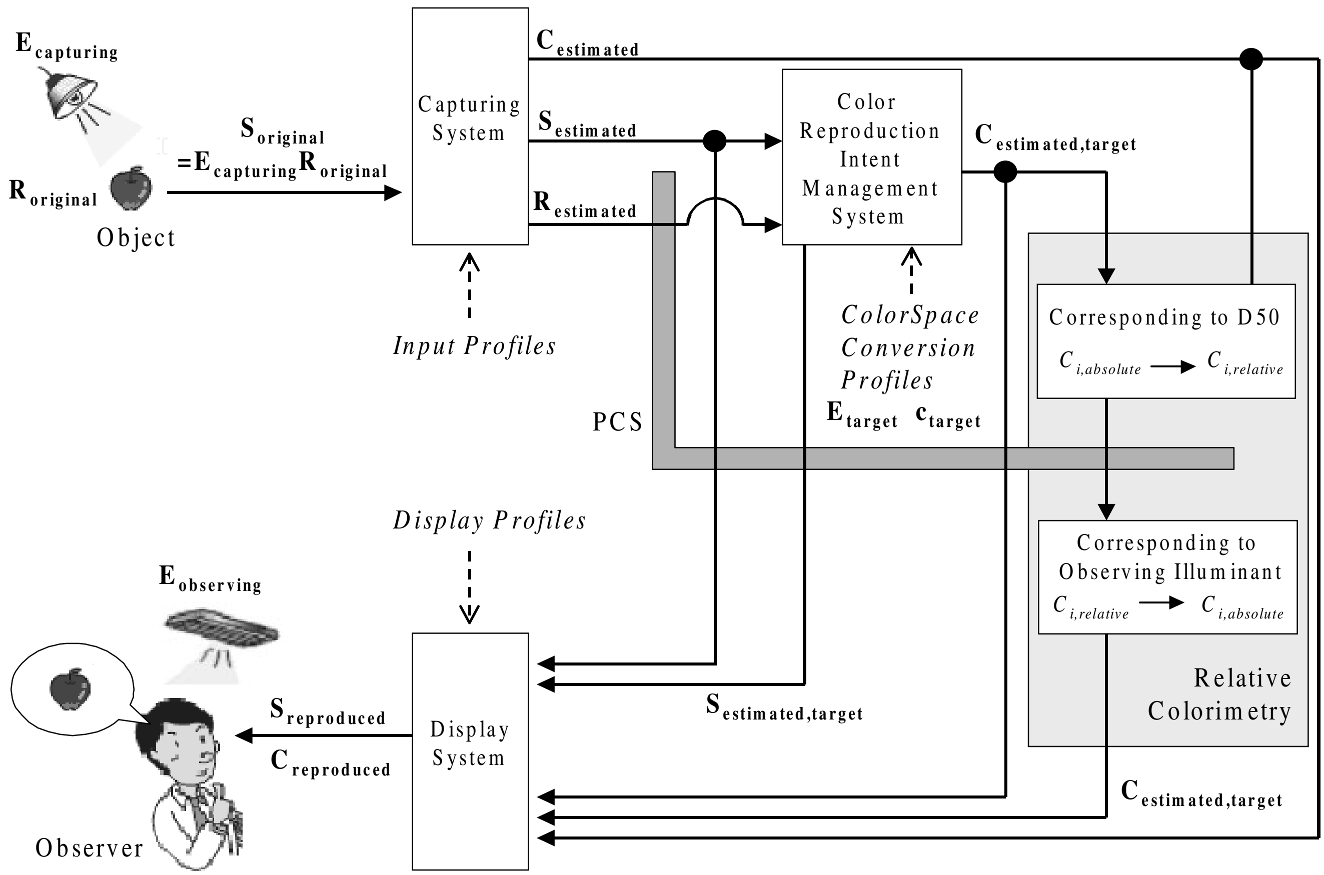

Figure 1. Functional diagram of Natural Vision System.

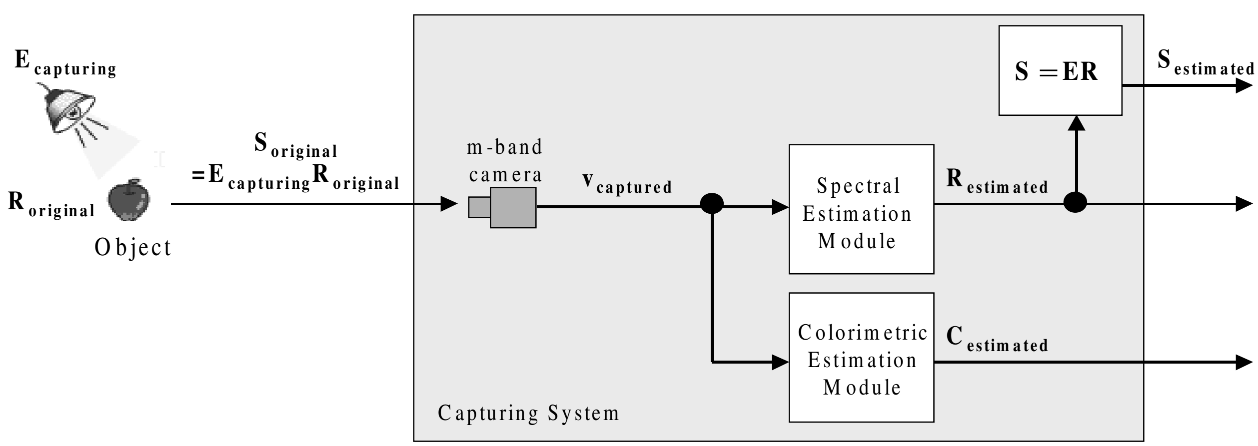

Figure 2. Functional diagram of Capturing System.

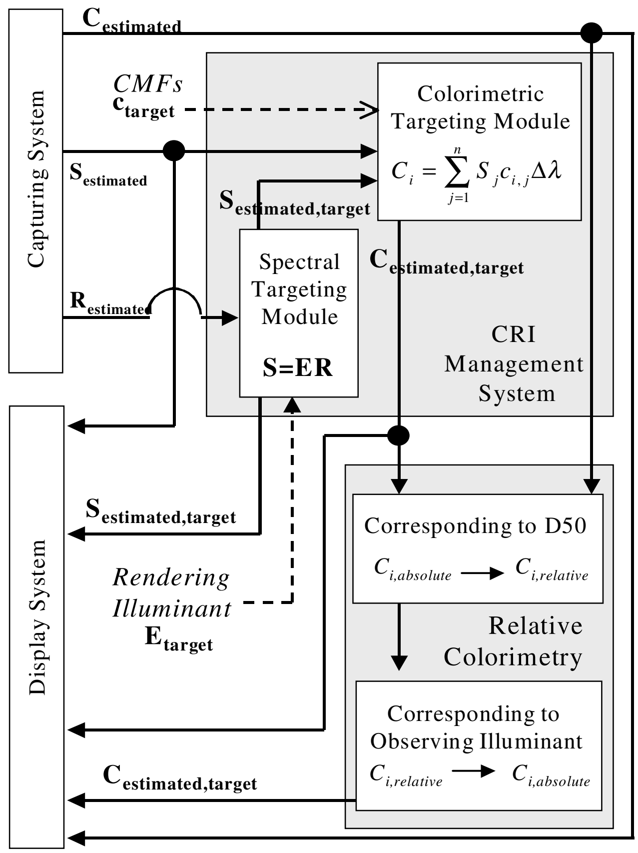

Figure 3. Functional diagram of Color Reproduction Intent Management System.

Profile Format of Natural Vision Image Data File Format

The framework of ICC Profile Format[5] as shown in Fig. 5 (a) is utilized for the profile format of Natural Vision Image Data File Format because of compatibility to the current colorimetric-based system. By comparing Fig.5 (b) with Fig.2, Fig.3 and Fig.4, the lacks of ICC Profile Format are summarized as follows:

i) The matrix-based profile does not support multi-dimensional devices.
ii) Display Profile has no multi-dimensional type.
iii) Profile Connection Space (PCS) does not support spectral format.
iv) PCS does not support arbitrary illuminants and CMFs.

As shown in Fig.6, N-Component Spectrum-Based Input Profiles and N-Component Spectral Matrix-Based Input Profiles are introduced to provide $\mathbf{S}_{estimated}$. N-Component Matrix-Based Input Profiles is introduced to provide $\mathbf{C}_{estimated}$. N-Component Spectrum-Based Display Profiles and N-Component Matrix-Based Display Profiles are introduced to provide $\mathbf{v}_{estimated,target,predicted}$. Spectrum-Based Profile is introduced to provide rendering illuminant $\mathbf{E}_{target}$ and CMFs $\mathbf{c}_{target}$. Nineteen Tags and five Tag Types are newly introduced to support the expansion of Profiles. In the latest version, Output Profile is outside the scope of the expansion. So far, Natural Vision does not ensure the performance of Output Profile including the rendering intents.

Image Processing with the Profile Format of Natural Vision Image Data File Format

Three types of mathematical model converts digital count of input device to the color reproduction target $\mathbf{C}_{estimated,target}$ or $\mathbf{S}_{estimated,target}$. The first one is given as follows:

$$\mathbf{C}_{estimated,target} = \mathbf{cE}_{target}\mathbf{kMv} \quad (1)$$

where $\mathbf{c}$ is CMFs, $\mathbf{E}_{targeti}$ is spectral radiance of rendering illuminate, $\mathbf{k}$ is coefficient of sensitivity level correction, $\mathbf{M}$ is spectral reflectance estimation matrix, $\mathbf{v}$ is luminance-linearized digital count of input device. N-Component Spectrum-Based Input Profile and ColorSpace Conversion Profile support Eq.1 with Tags as listed in Table 1. The second one is given as follows:

$$\mathbf{C}_{estimated,target} = \mathbf{kUv} \quad (2)$$

where $\mathbf{U}$ is relative stimulus value. N-Component Matrix-Based Input Profile supports Eq.2 with Tags as listed in Table 2. The third one is given as follows:

$$\mathbf{S}_{estimated,target} = \mathbf{kAv} \quad (3)$$

where $\mathbf{A}$ is the matrix converting digital count of input device to spectral radiance $\mathbf{S}$. N-Component Spectral Matrix-Based Input Profile supports Eq.3 with Tags as listed in Table 3.

The following mathematical model converts spectral radiance $\mathbf{S}_{estimated,target}$ to the digital count of display device $\mathbf{v}_{estimated,target,predicted}$:

$$\mathbf{v}_{estimated,\ target,\ predicted} = f_s\left(\mathbf{p}_0, \mathbf{p}_p, \mathbf{c}_{target}, \mathbf{S}_{estimated,\ target}\right) \quad (4)$$

where $\mathbf{p}_p$ is spectral radiance of display primary, $\mathbf{p}_o$ is spectral radiance of bias component of display primary. $f_s()$is an arbitrary function.[10] N-Component Spectram-Based Display Profiles supports Eq.4 with Tags as listed in Table4. The following mathematical model converts the color reproduction target $\mathbf{C}_{estimated,target}$ to the digital count of display device $\mathbf{v}_{estimated,target,predicted}$:

$$\mathbf{v}_{estimated,\ target,\ predicted} = f_c\left(\mathbf{q}_o, \mathbf{q}_q, \mathbf{C}_{estimated,\ target}\right) \quad (5)$$

where $\mathbf{q}_q$ is stimulus value of display primary, $\mathbf{q}_o$ is stimulus value of bias component of display primary. $f_c()$ is an arbitrary function.[11,12] N-Component Matrix-Based Display Profiles supports Eq.5 with Tags as listed in Table 5. These mathematical models are executed in display system and CRI management system as illustrated in Fig.6.

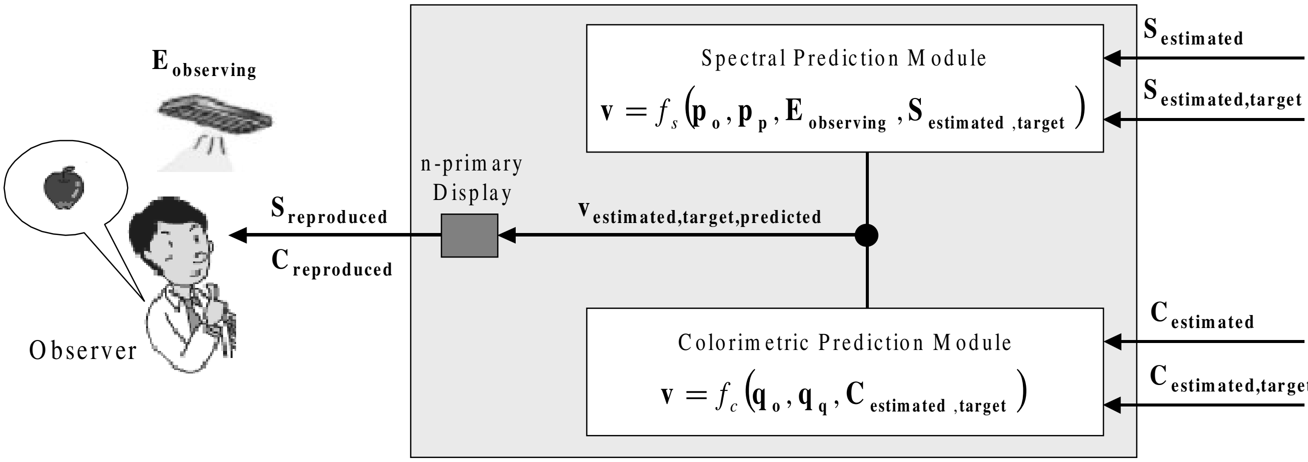

Figure 4. Functional diagram of Display system

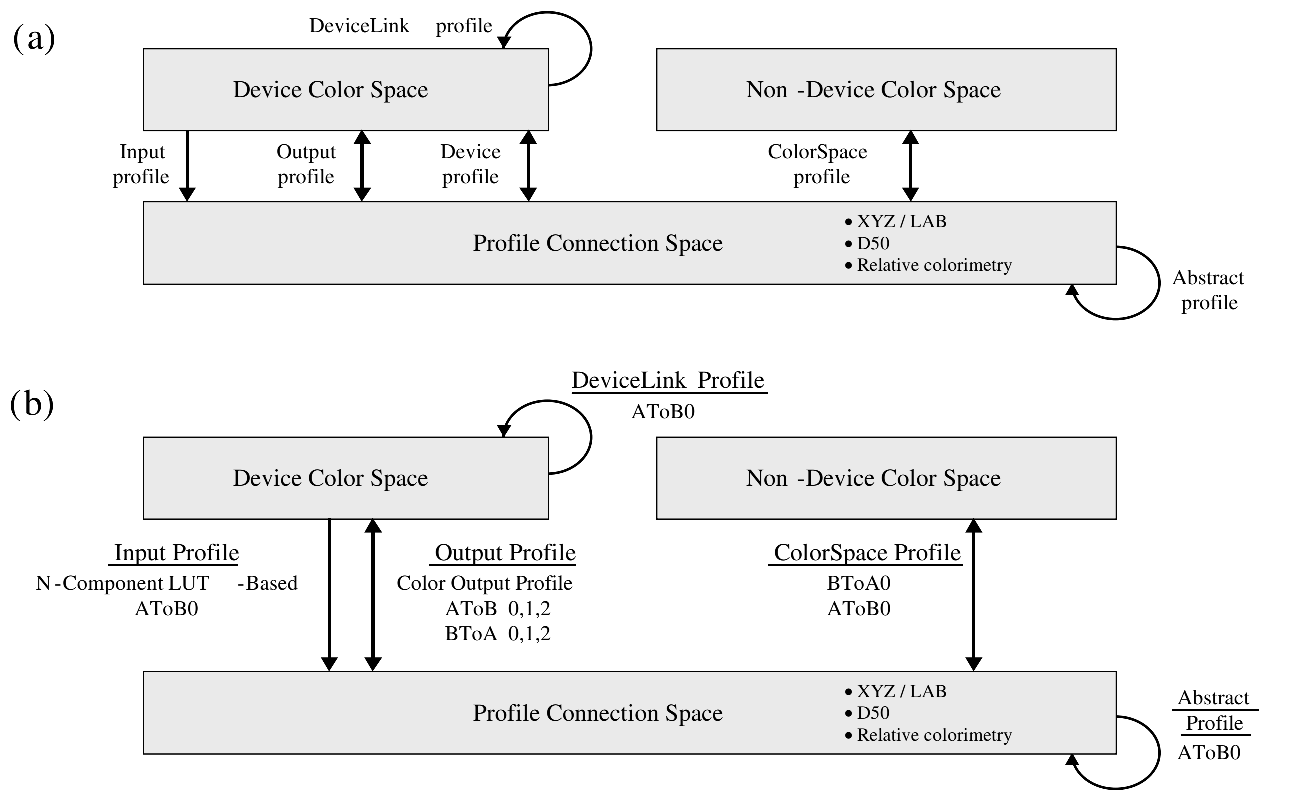

Figure 5. Functional diagram of ICC Profile Format: (a) The role of all profiles, (b) The list of profiles that support multi-band structure.

- (1) Input Profile
  - Monochrome Input Profiles
    - grayTRCTag
  - Three-Component Matrix-based Input Profiles
    - redMatrixColumn Tag • greenMatrixColumn Tag • blueMatrixColumn Tag
    - redTRCTag • greenTRCTag • blueTRCTag
  - N-Component LUT -Based Input Profiles
    - AtoB0Tag
  - N-Component Matrix -Based Input Profiles
    - D2CMatrixTag • TRCTag • MbiasTag
  - N-Component Spectral Matrix -Based Input Profiles
    - D2RMatrixTag or D2SMatrixTag • TRCTag • MbiasTag
  - N-Component Spectrum -Based Input Profiles
    - SpectralSensitivityTag • InputIlluminationSpectrumTag • TRCTag • MbiasTag
- (2) Display Profile
  - Monochrome Display Profiles
    - grayTRCTag
  - Three-component Matrix -based Display Profiles
    - redMatrixColumn Tag • greenMatrixColumn Tag • blueMatrixColumn Tag • BkMatrixColumn Tag
    - redTRCTag • greenTRCTag • blueTRCTag
  - N-Component LUT -Based Display Profiles
    - AtoB0Tag • BtoA0Tag
  - N-Component Matrix -Based Display Profiles
    - D2CMatrixTag • TRCTag • MbiasTag • CMFTag
  - N-Component Spectrum -Based Display Profiles
    - MultiPrimarySpectrumTag • MbiasSpectrumTag • TRCTag
    - ObservingIllumination SpectrumTag
- (3) ColorSpace Conversion Profile
  - N-Component LUT -Based Profiles
  - Spectrum -Based Profile
    - RenderingIlluminationSpectrumTag • CMFTag

Figure 6. The Profiles supported by Natural Vision Image

Table 1. The list of Tags of N-Component Spectrum-Based Input Profiles.

Tag Name	General Description
profileDescriptionTag	Structure containing invariant and localizable versions of the profile name for input device
SpectralSensitivityTag	Spectral Sensitivity of P-channel input device
MsensitivityLevelCoefficientTag	Coefficient of Sensitivity Level Correction
InputIlluminationSpectrumTag	Spectra of Q-Input illuminations
TRCTag	N- Component tone reproduction curves
MbiasTag	N- bias digital counts
mediaWhitePointTag	Media XYZ white point
CopyrightTag	7 bit ASCII profile copyright information

Table 2. The list of Tags of N-Component Matrix-Based Input Profiles.

Tag Name	General Description
ProfileDescriptionTag	Structure containing invariant and localizable versions of the profile name for input device
D2CmatrixTag	N-Component XYZ relative tristimulus values
MsensitivityLevelCoefficientTag	Coefficient of Sensitivity Level Correction
TRCTag	N-Component tone reproduction curves
MbiasTag	N-Component bias digital counts
MediaWhitePointTag	Media XYZ white point
copyrightTag	7 bit ASCII profile copyright information

Table 3. The list of Tags of N-Component Spcetral Matrix-Based Input Profiles.

Tag Name	General Description
profileDescriptionTag	Structure containing invariant and localizable versions of the profile name for input device
D2RmatrixTag or D2SmatrixTag	Matrix coefficients converting Device to Spectral reflectance or Spectrum
MsensitivityLevelCoefficientTag	Coefficient of Sensitivity Level Correction
TRCTag	N-Component tone reproduction curves
MbiasTag	N-Component bias digital counts
mediaWhitePointTag	Media XYZ white point
copyrightTag	7 bit ASCII profile copyright information

Table 4. The list of Tags of N-Component Spectrum-Based Display Profiles.

Tag Name	General Description
profileDescriptionTag	Structure containing invariant and localizable versions of the profile name for display device
MultiPrimarySpectrumTag	Spectra of M-primaries of display device
MbiasSectrumTag	bias spectrum
TRCTag	M-channel tone reproduction curves
ObservingIlluminationSpectrumTag	Spectrum of Observing illumination
mediaWhitePointTag	Media XYZ white point
copyrightTag	7 bit ASCII profile copyright information

Table 5. The list of Tags of N-Component Matrix-Based Display Profiles.

Tag Name	General Description
ProfileDescriptionTag	Structure containing invariant and localizable versions of the profile name for input device
D2CmatrixTag	N-Component XYZ relative tristimulus values
TRCTag	N-Component tone reproduction curves
MbiasXYZTag	Stimulus values of bias
MediaWhitePointTag	Media XYZ white point
copyrightTag	7 bit ASCII profile copyright information

Conclusions

Natural Vision Image Data File Format was introduced especially in terms of the profile formats. The framework of ICC Profile Format was utilized to design the profile format of Natural Vision Image Data Profile Format. Relationship between the Profiles and image processing was described.

References

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Biography

Hideto Motomura received his M.S. degree in Image science and technology from Chiba University, Japan, in 1990. In the same year, he joined Matsushita Research Institute Tokyo Inc. in Kawasaki, Kanagawa. From 1997 to 1999, he was Visiting Scientist of Center for Imaging Science, Rochester Institute of Technology. He is Staff Researcher of Advanced Technology Research Laboratory, Matsushita Electric Industrial Co., Ltd. Since 2001 he has been on loan to Telecommunication Advancement Organization of Japan as Researcher of Akasaka Natural Vision Research Center. He is a member of CIE TC8-03, gamut mapping.