Natural Vision: Visual Telecommunication based on Multispectral Technology

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ABSTRACT

For high-fidelity visual telecommunication with natural color, “natural vision” system is under development. In the natural vision system, color information is handled as multispectral data, beyond the conventional trichromatic RGB imaging systems. The multispectral data with illumination spectrum are employed for image capture, transmission, storage, and display, so that the natural color of the object is reproduced, as well as the gloss, texture, and other key-factors for the image reality. This paper presents the principle, methods, devices, and possible applications of the natural vision.

INTRODUCTION

The visual telecommunications using color image are currently very important in various fields, such as electronic commerce, medicine and healthcare, culture, education, and so on. Along with the progress of information technology, our life and society are intensifying dependence to information accumulated or interchanged through network. The information resources will be employed to enrich our life, but if the quality of information would be low, our life would be affected. It is thus quite important to assure the quality of information, i.e., to exactly reproduce the original information. The reproduction of reality is accordingly one of key issues for the visual telecommunications in information society. High-resolution imaging systems such as HDTV, SHD, are the significant technologies in this respect. Conventional color television and other color imaging systems, however, do not reproduce the same color as the original, due to the following reasons;

- Conventional system is not designed for natural color reproduction.
- Spectral sensitivity of the camera is not equivalent to the human vision.
- The input and output colors are device-specific.
- The illumination conditions are sometimes different between the image capture and observation environments, and are not correctly compensated.
- Color gamut of a display device is not large enough.

In spite of the great progress of color management technology, with device independent colors, it is still difficult to reach the complete solution against above problems, since most color imaging systems are essentially based on RGB three-primary colors.

In the digital archiving of art works, etc., high-quality color information is needed and multispectral imaging has been applied. Multispectral imaging technique for telemedicine has been also developed [1]. However, there is still not a common specification for exchanging multispectral information, and the platform for the visual telecommunication with high-fidelity color is expected.

In the image display step, even though the device calibration works well to display the given chromaticity, some of the colors, especially pure colors cannot be displayed by the conventional displays, such as CRT and LCD. This is because the range of reproducible color, called color gamut, is limited within the color triangle of the display device, and not enough for reproducing the natural objects. Even though gamut mapping techniques reduce the impression of color difference, the reconstructed color is no more same as the original.

Under these backgrounds, the "Natural Vision" project, which is targeting the super-reality color reproduction, was started in the Telecommunication Advancement Organization (TAO), from 1999 by the investment from the Ministry of Posts and Telecommunications. The purposes of the natural vision project are;

- Development of color imaging and display systems based on the multispectral information, so as to break through the limitation of conventional RGB-based systems. For example, precise color reproduction, illumination difference compensation, and expanded gamut reproduction.
- To enable the interchange of the natural color image by a common data format suitable for describing the spectrum of illumination environment, the spectral characteristics of the image input device, etc., as well as the captured multispectral image.
- To explore the utilization of the quantitative information obtained by the natural image data, and realize high-fidelity image reproduction with natural color, textures, gloss, and so on.

In this article, we introduce the principle, technology, and possible applications of natural vision.

PRINCIPLE OF NATURAL VISION

Multispectral Image Capture for Natural Color Reproduction

The general models of color image communication are shown in Fig.1. In (a), the observer can see the color image as if he/she were at the site where the image was captured. However, if the illumination environments of

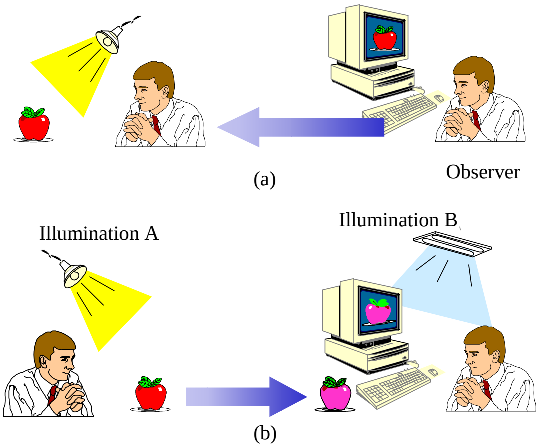

Fig.1 The concept of color reproduction
(a) Reproducing the color as if the observer were at the site. Reproducing color as if the object is placed at the front of the observer

the image capture and display sites are different, the color reproduction shown in (b) is needed. Namely, the color of an object should be reproduced as if the object were placed under the observation illumination. In the following the color reproduction principle is presented.

If the the illumination lights of the image capture and display sites are same, or in the situation shown in fig.1 (a), the essential condition to exactly determine chromaticity from captured data is called Luther condition. That is, the spectral sensitivity of human vision must be able to be expressed by the linear combination of the spectral sensitivities of the camera. Conventional color cameras that have R, G, and B channels do not usually satisfy this condition, and therefore, some objects that give same color signal can be perceived as different colors by a human observer. In consequence, we need a camera that has a same spectral sensitivity as human vision for exact color reproduction.

When the illumination environments of image capture and observation are different, it is necessary to find the spectral reflectance at the good accuracy. For this purpose, multispectral image capture is required as well as the spectral measurement of illumination spectrum. The multispectral imaging devices have been developed and the example is introduced in the next chapter.

Once we have multispectral image and illumination spectrum of image capturing environment, the color image is reproduced through the steps shown in fig.2. After the correction of camera characteristics such as gamma curve and dark current, the spectral reflectance of the object is estimated for each pixel of the captured image, using the illumination spectrum. Then, for given illumination spectrum of observation environment, the chromaticity is calculated [1].

Multiprimary Color Display for Expended Gamut Representation

At the display step, the calibration of display device is necessary, using the profile of each device, so that any

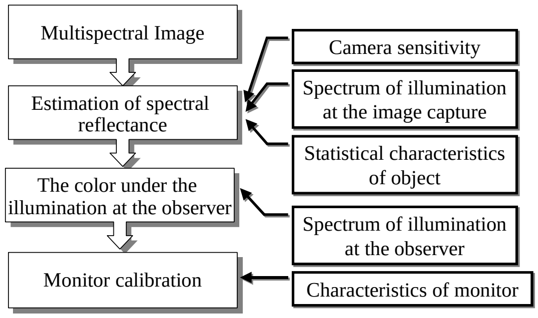

Fig.2 The color reproduction method with illumination difference correction

given color is correctly reproduced.

Even if the tristimulus values are accurately acquired and the display device calibration is performed, some of the colors cannot be reproduced by the conventional display devices, because the color gamut of displays such as CRTs and LCDs (liquid crystal displays), does not cover all the existent colors.

Attempts to enlarge the color gamut have been made by increasing the saturation of primary colors [3], but the gamut is still limited within a triangle, or hexahedron in three-dimensional color space. On the other hand, four through seven primary colors are used in hardcopy materials. The multiprimary color approach, i.e., using more than three primary colors, can be also applied to the softcopy display devices for larger color gamut [4]. The color gamut then becomes a polygon as shown in fig.3, where its vertices correspond the color coordinates of the primaries. Two examples of the optical systems for projection displays are presented in fig.4.

Consider a color pixel composed of M subpixels, where M is the number of primary colors, and narrow-band light is reproduced through each subpixel. Then the total spectral intensity reproduced by a color pixel is the sum of narrow-band light spectra from M subpixels. Accordingly, the color is reproduced as the additive mixture of primary colors. The color gamut becomes a polygon in a color plane and a polyhedron in three-dimensional color space, where its vertices are chromaticity coordinates of primary colors.

To display natural color, the image data of chromaticity, such as CIE 1931 XYZ chromaticity coordinates are given, and the signal to be applied to the LCD pixels is calculated. The color signal in multiprimary space is obtained by matrix inversion in consideration of dynamic range of display device. Since M-dimensional vector is computed from three-dimensional chromaticity, the conversion involves the degree of freedom, which is originated from metamerism. Therefore, we need to find a solution of the inversion under the constraint that the signal range is limited. It is possible to implement the color conversion by look-up-table (LUT), but the LUT size becomes very large. A method with small-size LUT to switch several color conversion matrices has been developed. In the method, the 3-D color space is divided into subspaces, and LUT is used to distinguish which

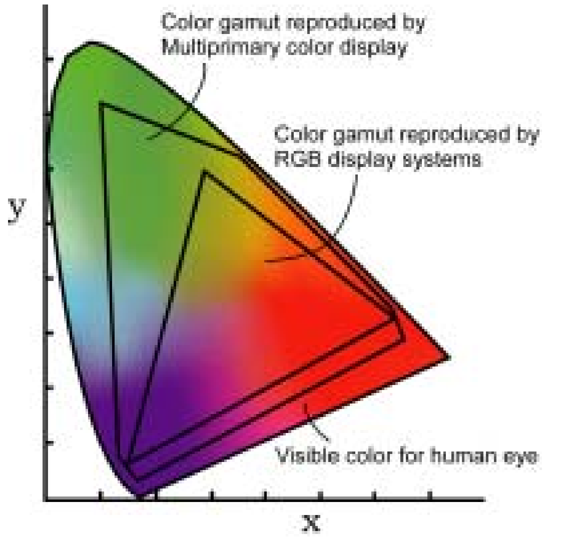

Fig.3 The concept of gamut expansion by multiprimary-color display

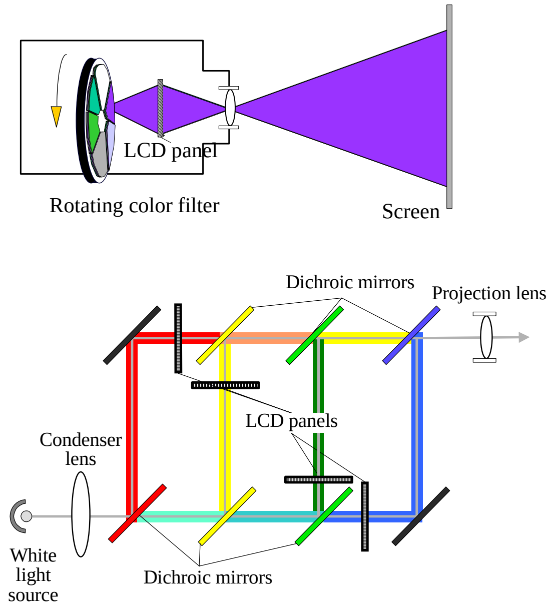

Fig.4 The examples of optical systems for multiprimary color projection display

Fig.5 A photograph of multispectral camera with rotating interference filters.

Fig.6 Six-primary 2x2 multi-projection display system with about 2300x2000 resolution

subspace the chromaticity data belongs, then a 3x6 matrix is used for the color data in each subspace. By this method, color conversion considering the dynamic range of the display device is realized at high-speed [4].

TECHNOLOGIES FOR NATURAL VISION

Multispectral image capture

There have been several proposals and implementations of multispectral cameras, using narrow-band interference filters, dichroic mirrors, etc. Fig.5 shows a 16-band multispectral camera, which captures 1k x 1k resolution images, used in natural vision project. Interference filters are attached on a rotating tablet as shown in fig.5. Using this multispectral camera, color reproduction with high-accuracy, as well as illumination difference correction, are possible.

The number of bands, however, is expected to be reduced from the aspect of reducing device complexity and data amount, and increasing sensitivity. If the characteristics about the spectral reflectance of the object class, it is possible to accurately estimate the spectral reflectance from the images of fewer bands [5]. From the principal component analysis of the spectral reflectance data, it has been shown that the reflectance of human skin, mucous membrane, paintings, and natural scene can be well described by small number of basis functions. Therefore, the spectral reflectance of the object can be estimated by Wiener Estimation technique using the correlation matrix of the object class.

Commercial digital still cameras are very convenient and its use to color reproduction is wished. However, color fidelity is not guaranteed by commercial digital still cameras, because the spectral sensitivity is different from that of human vision, and as well, image processing is usually applied for the preferable (not natural) color reproduction. To apply a digital still camera for natural color reproduction, the color reproduction system have been realized by modifying the internal processing of the camera and applying the calibration method that uses the color chart [6]. Nevertheless, note that there is a limit in color reproduction accuracy realized by 3-band camera.

For the color reproduction in motion picture, there is a difficulty in using multispectral camera with rotating tablet, because colored artifacts appear due to the motion blur. A simple method has been developed for the simultaneous capture of all bands; a six-band multispectral camera using two commercial RGB cameras [4].

Multispectral image coding

The image coding is a essential issue to interchange the color image with securing color accuracy. The image format for the multispectral image is developed so that the image of arbitrary number of bands can be represented with the information such as illumination spectrum [4]. Image compression and coding methods that assure color accuracy are also under development mainly for the image transmission.

Multispectral image analysis

Once a color image is acquired as quantitative information, which corresponds to the substantial property of the object, the image data can be employed for the analysis of target object. In the medical applications, the color or spectral reflectance of skin or mucous membrane contains the condition of disease, and can be utilized for the support of diagnosis.

Multiprimary color display

For the wide-gamut display, a projection-type display with six-primary colors of 1365*1024 pixels is constructed using two conventional liquid crystal projectors. For the one of two projectors, color filters that transmit longer wavelength of each primary color is inserted in optical path of RGB lights, and color filters that only transmit shorter wavelength is inserted in the other projector. The images projected by these two projectors are overlapped on the screen, and color image is reconstructed by six-primary colors. The image distortion due to the parallax of two projectors is compensated by the image processing in which the distortion parameters are measured by capturing test patterns. The hexagon in fig.3 is the color gamut obtained by the prototype six-primary projection display. The gamut becomes much larger than conventional color display in particular in pure red and purple region, and covers most of the reflection objects existing in natural world [7]. High-resolution version is also constructed, as shown in Fig.6, which is a 2x2 multi-projection six-primary display system equipped by the natural vision project.

Acquisition and display of glosses and shades

For the reproduction of reality, glosses, shades and 3-D effects are also important factors as well as the natural color. If we move the viewpoint, the appearance of gloss and shades changes, so that motion picture display and interactive reproduction are effective for the reality representation. To represent the reality as if the object were actually observed, a method is proposed for the interactive reproduction of specular and diffuse components of the image using spectral information. In the method, a sequence of multispectral images is captured with rotating the object, and the specular and diffuse components are separated using the illumination spectrum. Then we can regenerate the image of arbitrary viewpoint with correct reproduction of glosses and shades, and in addition, we can simulate the image as if the object is illuminated by different type of illuminant (ex. a point or a line source, diffuse illumination, etc.).

APPLICATIONS

It is anticipated that high-reality color reproduction technologies will be applied in many applications such as

- Exchange visual information for merchandise procurement, collaboration in product design, etc.
- Telemedicine in dermatology, endoscopy and pathology, etc.
- Multimedia education, such as instructional materials and encyclopedia, which vividly introduce natural subjects.
- Natural vision theater; to exhibit art works, natural scenes, or important heritages of the world.

CONCLUSION

In the natural vision project, a color image is treated as multispectral information beyond the limitation of conventional trichromatic (RGB) imaging systems. Multispectral image data are transmitted or stored with additional information such as the illumination spectra and input device characteristics, so that high fidelity reproduction of reality, including the colors, glosses, textures, shades, and 3-D effects becomes possible. The motion picture system with high-fidelity color reproduction is also the subject. It is expected that the standardization of natural vision be promoted as groundwork for the next-generation picture display, transmission and digital broadcasting.

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