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Realistic image display based on high-fidelity and wide-gamut color reproduction

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ABSTRACT

Technologies for realistic image display based on high-fidelity and wide-gamut color reproduction are presented. The system can be implemented with multiprimary color displays or laser projection displays, along with spectrum-based image acquisition and encoding. For improved material perception, techniques for gloss and high-luminance texture reproduction are also investigated.

1. INTRODUCTION

For realistic image display, the reproduction of high-fidelity color is one of the essential factors. For this purpose, there are various issues such as the display of wide-gamut colors, the characterization of imaging devices, the capture and encoding of wide-gamut color signals, and the adaptation to illumination environment. The realistic reproductions of gloss and high-luminance texture are also important factors for reproducing realism.

In this paper, the technologies for high-fidelity color reproduction is introduced, especially the system that breakthrough the limitation of conventional RGB-based systems [1]. The system, called "Natural Vision (NV)," deals with the color signal in spectral domain, so that high-fidelity and wide-gamut image display becomes possible. In NV system, multiprimary color displays were developed for wider color gamut, and real-time video system comprising of 6-band camera and multiprimary color display were experimentally implemented. As another wide-gamut display device, the color reproduction by a laser projection display is also investigated. The characterization of laser display was carried out and the reproduced color was evaluated both numerically and visually. Laser displays are also promising display devices for realistic image reproduction.

The reproduction of color is usually evaluated for the light diffusely reflected from object surface, but specular reflection is also a vital key for the perception of realism. Although wider dynamic range is expected for image capture and display devices, it will take time for high-dynamic range (HDR) display devices to become commonly available. Thus the compression of dynamic range of images that contain high-luminance glosses is needed. We tested some tone-mapping techniques for HDR imaging in the image reproduction of gold metallic materials, and subjective evaluation was performed [2]. The possibility of applying the laser projection displays for HDR display is presented as well.

2. REALISTIC IMAGE DISPLAY SYSTEM BY SPECTRUM- BASED COLOR REPRODUCTION

In the conventional color imaging systems, the color reproduced on the monitor does not represent the original color of the object. It is caused by the discrepancy between the spectral characteristics of cameras and human vision, the inaccurate correction of illumination color, and the limitation of color gamut of imaging devices. Conventional color imaging systems often aim at the reproduction of preferable color and the color fidelity has not been much paid attention. For high-fidelity color reproduction, it is necessary to consider designs of image input devices and color encoding schemes, in addition to the color reproducibility of display devices. In image input, two approaches can be considered; 1) to make the spectral sensitivity of the camera equivalent to human vision, and 2) to exploit spectrum-based color reproduction. In the former case, though wide-gamut color signal can be obtained, the fidelity is significantly decreased when the difference of illumination environment is corrected, namely, white balance adjustment. In 2), the spectral attributes of objects, which are independent of input devices and illumination light, are acquired by using spectral imaging technique such as multispectral camera. Using spectral information, it is possible to reproduce high-fidelity and wide-gamut colors even in the different illumination environment. The color signal is encoded in wide-gamut color space, and both RGB-based and multiprimary displays can be employed in the NV system.

Still-image and real-time video multispectral systems were experimentally implemented and experiments were carried out for exploring applications of high-fidelity and wide gamut imaging system in the fields of teleconference, surgery video, digital pathology, dermatology, textile, industrial design, visual content production, digital archive of artworks, and high-fidelity color printing [1].

3. WIDE-GAMUT COLOR DISPLAYS FOR NATURAL COLOR REPRODUCTION

3.1 Multiprimary color displays

The colors of natural scene distribute wider than the color gamut of conventional RGB standard, such as sRGB. The use of more than three primary colors is effective for covering the gamut of natural colors. Multiprimary color projection display was demonstrated in 1999 with using two modified RGB projectors [1]. It was shown that more than 99% of the natural colors could be covered by 6-primary color display [Figure 1]. After that, various developments on multiprimary color displays have been reported.

The 6-primary projection displays developed for NV system were employed for the experiments explained above. We collected wide-gamut video contents using 6-band camera, such as human models with deep-color clothes, textiles, flowers, butterflies, flame reaction colors, blue ocean, as well as surgery operations. Then it has been confirmed that vivid colors are reproduced with high naturalness. Conventional color display systems sometimes enhance the color saturation and high chroma colors are reproduced, but it often loses naturalness and reality. High-fidelity color reproduction of original color is important for natural color and highly realistic displays.

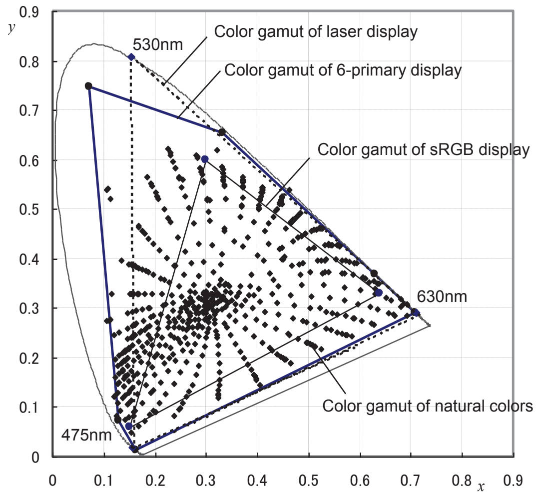


Fig. 1 Color gamut of sRGB, 6-primary and laser displays and the gamut of natural colors

3.2 Color reproduction in laser projection display

Another approach for wide-gamut display is to use purer RGB primaries, such as LED or laser light. Wide gamut color reproduction in laser projection display was also investigated in this research [3]. Figure 1 also shows an example of the color gamut of a laser display.

For the high-fidelity color reproduction, the characterization of a laser projection display was evaluated in this work. Using the spectral color measurement, the tristimulus values of RGB primaries and the tone reproduction curve were obtained. Then a matrix and a lookup table for color conversion were derived.

In the experiment, a mobile laser display (Microvision SHOWWX+™ Laser Pico Projector) and an LCD (NEC 2690WUXi) were used. As a result of the color reproducibility evaluation using 24 color patches of GretagMacbeth ColorChecker, the average color differences (CIELAB ΔE) were 2.84 in the LCD, and 3.01 in the laser display. From this result, it can be said that the color reproduction characteristics were successfully modeled and faithful accuracy was obtained.

It should be also considered that the influence of observer metamerism become more significant in the color reproduction by laser lights. It is known that the spectral sensitivity of human vision depends on individual observers and the size of color stimuli. It leads the disagreement of perceived colors between different media, even if the colors measured by colorimeters agree with each other. Such disagreement also appears between an observer and a color camera as well as different observers. It is a main reason why the color difference between the reproduced images by LCD and laser display can be observed in the photograph shown in fig.2. The color difference is not apparent in the case of direct observation. Since the primary colors are monochromatic in laser display, the influence of observer metamerism is relatively larger than other type displays.

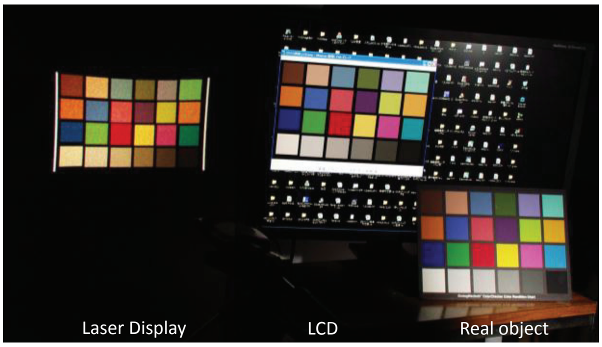


Fig. 2 Comparison of reproduced colors of LCD and laser display with real color chart. The color difference between laser display and others is not apparent in the case of direct visual observation.

4. REPRODUCTION GLOSS AND TEXTURE

4.1 Tone mapping for dynamic range compression

The reproduction of gloss and texture on object surfaces is also important for highly realistic image display, but physically accurate reproduction is usually impossible since the luminance of gloss is usually very high. The appearance of metallic gloss depends on the material and surrounding environment, and is influential to the perception of the realism of material surface. In this study, HDR images were obtained by 6-band camera system with synthesizing images captured with different exposure times, so that the high-luminance glosses are correctly captured. Figure 3 shows the color and luminance distribution of gold luster obtained in this experiment. It is observed that the gold object has high-luminance gloss (about 10 times higher luminance than the white). In the following experiment, tone mapping (TM) operations were adapted to compress the dynamic range of the image, and the reproduced images were visually evaluated [2].

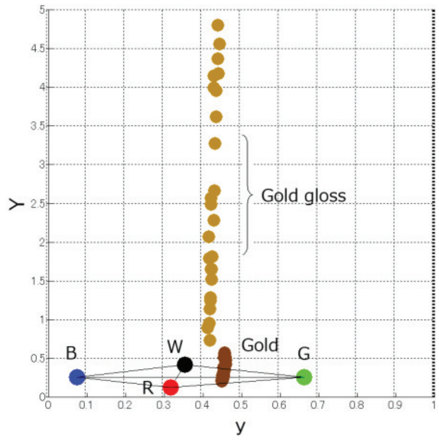
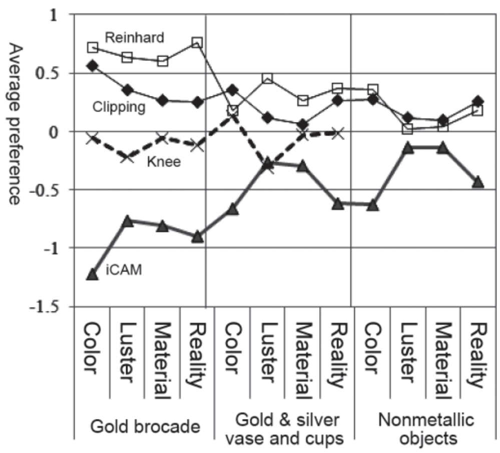


Fig. 3 Color distribution of gold metallic surface in y-Y plane.

(a)



(b)

Fig. 4 Visual evaluation of reproduced color, gloss, reality and material perception.

(a) Experimental setup for comparison of image on LCD and real objects, (b) experimental result.

In the first experiment, the images reproduced from 6-band camera system were compared with those from conventional RGB system, and it was confirmed that the high-fidelity color reproduction significantly contributes the perceived realism of the reproduced images.

In the next experiment, different TM techniques (Clipping, Knee Reinhard, iCAM) were compared through subjective evaluation. Figure 4 shows the results of this experiment. In the case of fine texture of golden fabric, the scores of subjective evaluation strongly depended on the method of TM; when the luminance was compressed to express the shiny gold tone considering the local average of luminance (Reinhard), the appearance of golden fabric texture was significantly improved. Another TM technique (iCAM) that based on the color appearance model changed the color of objects with no gloss, and was not suitable for high-fidelity color reproduction. A new TM technique suitable for gloss and high-luminance texture reproductions is one of the important issues for future investigation.

4.2 High dynamic range display with multiple projectors

The alternative approach to improve the reproducibility of gloss and brilliant texture is to implement HDR display. In the past, there have been reported dual modulation technique enabled excellent HDR display, while the color calibration is still difficult. In this work, the application of laser projection displays to high-luminance gloss reproduction is experimentally investigated.

In the projection displays such as LCD or DLP (Digital Light Processing), even though high contrast has been achieved up to now, the black level is not completely black. Thus it is difficult to realize HDR display by overlaying multiple projections. In contrast, if the input gray level is zero in laser scanning display, the reproduced intensity of black is less than the measurable level. Exploiting this feature of a laser display, we constructed an experimental system for better gloss and high-luminance texture reproductions as shown in figure 5 (a). In figure 5 (a), projector 1 displays whole image (b), whereas projector 2 only shows high-luminance glosses (c). The area of the image displayed by projector 2 is about 1/10 of the whole area, and the luminance is 10 times larger. Therefore high-luminance glosses can be reproduced by this system. Although it is difficult to see the difference from the conventional photograph in figure 5 (d) (e), it can be visually confirmed that the glossiness is well reproduced in (e). In many cases this method works well, since the region that contains high-luminance glosses does not occupy large area in an image. However, the arrangement of projectors depends on the image content, and for practical system it is required to implement modified scanning mechanism.

5. SUMMARY

High-fidelity and wide-gamut color reproduction is a crucial factor for realistic image display as well as the reproduction of glosses and high-luminance textures. It is indispensable to consider the whole imaging system, the devices for high-fidelity image capture, wide-gamut color encoding, and image editing, along with high-quality display systems. The spectrum-based system is promising because of its excellent color reproducibility and high functionality. The improvement of gloss and texture reproduction is one of the vital issues in the future.

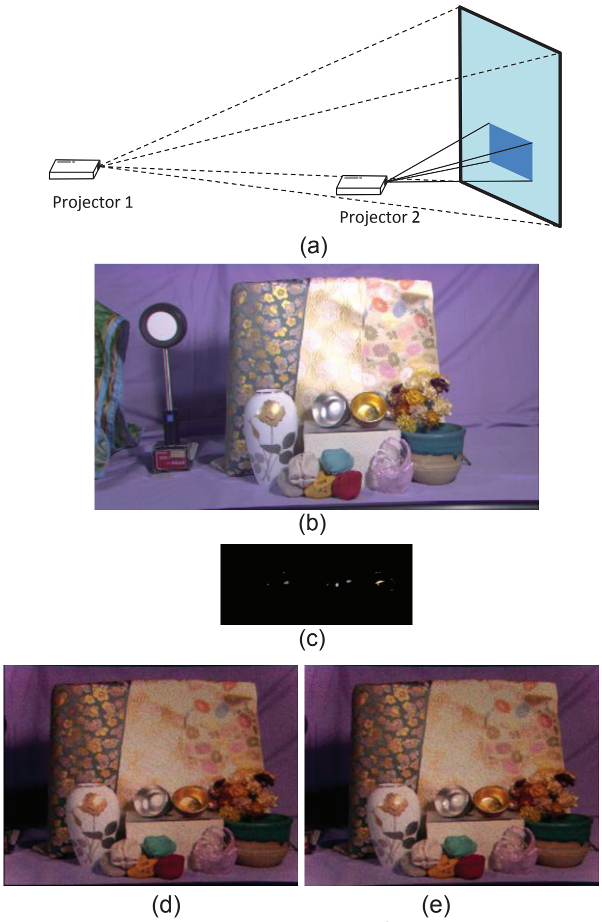


Fig. 5 Multiple projection display for high-luminance gloss reproduction

(a) Optical system, (b) image for projector 1, (c) image for projector 2, (d) reproduced image without projector 2, (e) reproduced image with projectors 1 and 2. The high-luminance gloss appearances of gold and silver cups at the center are improved.

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