Appearance reproduction and multi-spectral imaging

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Abstract: With the recent progress of broad-band network, accurate appearance reproduction across the various environments is required for objects in various applications such as e-commerce, designing process, and tele-medicine. Multi-spectral imaging techniques are expected to perform the cross-environment color reproduction for objects. However, color is just one attribute for appearance of the objects. Other attributes such as glossiness, graininess and translucency should be also considered for practical cross-environment appearance reproduction. In this review, a frame-work for appearance reproduction is introduced with relating the computer graphics, computer vision, and image processing techniques. The importance of the multi-spectral imaging technique is also recognized again on this frame-work. The case studies are introduced based on the examples we have performed in our practical applications.

Key words: color imaging, computer graphics, computer vision, multi-spectral imaging

INTRODUCTION

We feel that the distance in the world became smaller with the development of airplane and aviation service. As this distance in the world, we feel and recognize that watches in the world run faster with the development of the computer network and information technology. In the manufacturing industry, the cycle of the product development becomes shorter based on the support by information technology. Since consumer's preference for product is variable in this age of information technology, the cycle of the product development is also accelerated to reflect this variable preference of the consumers. In this short cycle, color and appearance of products are expected to be controlled and designed effectively, since color and appearance are one of the important points to reflect the impression for the product.

In the process of product development, the color and appearance are often evaluated by directly observing the trial pieces. The shape of products can be evaluated by making the mock up or showing the computer graphics image. However, it is difficult to evaluate the color and appearance without making a trial piece, since they are dependent on the viewing devices, environmental illuminant. It is said that the evaluation of color and appearance become bottle neck in the cycle of the development. Therefore, it is required to predict the color and appearance, and reproduce them on the display appropriately. In the case of corroborated development between the distant places, accurate appearance reproduction is required across the various environments in the computer network.

For the accurate color reproduction across the various illuminant, a multi-spectral imaging[1-11] has been developed to perform this cross-environment color reproduction for objects. The reflectance spectra of the object are acquired in this imaging system for calculating the colorimetrical values under arbitrary illuminants. The multi-spectral imaging was usually performed by using five or more color filters for multi-band imaging. It is typically used that the rotating filters are mounted in front of the monochrome type of CCD camera. However, color is just one attribute for appearance of the objects. Other attributes such as glossiness, graininess and translucency should be also considered for practical cross-environment appearance reproduction.

In this review, a frame-work for appearance reproduction is introduced with relating the computer graphics, computer vision, and image processing techniques. The importance of the multi-spectral imaging technique is also recognized again on this frame-work. The case studies are introduced based on the examples we have performed in our practical applications. Although, the frame-work is introduced based on the application for product development, this frame-work can be applied to the other applications such as the electric commerce, tele-medicine.

In the next three sections, appearance reproduction is related to the computer graphics, computer vision, and computer network respectively. The case studies are introduces based on the our previous research for 3D color proof system, image-based skin analysis and synthesis system, device independent gloss reproduction system.

APPEARANCE REPRODUCION AND COMPUTER GRAPHICS

This section introduces the relation between the appearance reproduction and computer graphics techniques. Figure 1 shows a flow of the evaluation for color and appearance of the trial pieces, which is simplified to show the concept clear. The real trial piece is produced by processing the materials. For example, trial piece for beverage can is mainly produced by metal sheet and ink, and metal sheet is processed to make the 3D shape, the ink is printed on the sheet to make the appearance of the can. The produced trial piece is evaluated by human observer under some illuminant. The result of the evaluation is fed back to the processing, and the real trial piece is improved based on this evaluation. For example, the ink is often re-prepared and replaced into another ink in the beverage can. It is clear that huge effort and time are required for this iterative improvement, and this become bottle neck in the cycle of the product development.

Recent progress of computer graphics techniques is remarkable. By using the computer graphics techniques, an image of the trial piece can be reproduced on the display as digital trial piece based on the process in the computer as is shown in Figure 2. It is called “modeling” to make the 3D shape and giving the property of reflection on the surface, and “rendering” to make the image by casting the optical rays into the 3D shape and gathering the rays into the virtual camera in the computer. The process of rendering needs a long time by ray tracing to obtain the realistic image of the product. Therefore, it was difficult to show the image of the product in real-time under different viewing angle and illuminant. However, with recent remarkable progress of the graphic processing unit on the graphic board, real-time rendering can be possible for the various type of appearance of the products by this hardware. Therefore, it is expected to use the computer graphics in the cycle of product development to evaluate the color and appearance. Moreover, the process of graphic hardware become programmable since 2003, and the more complicated reproduction of appearance become possible year by year.

The color in the computer graphics was R, G and B and α for a long time. The attribute α defines the transmittance of the surface. However, these four attributes were not enough to reproduce the change of color by illuminates and inter-reflection. Recently, necessity of spectral rendering is recognized[12,13], and studied actively. With the progress of programmable graphics hardware, the spectral rendering will be practically used in the real-time rendering. With the progress of spectral-rendering, the multi-spectral imaging technique is expected to play important role for capturing the spectral information of basis pieces such as BRDF and textures for computer graphics[14].

APPEARANCE REPRODUCION AND COMPUTER VISION

Although the techniques of realistic reproduction are very substantial these days by the progress of computer graphics, there are many products which will take a huge time to model the 3D shape or will be impossible to simulate the process in the computer. For example, this difficulty can be understood in the development of cosmetics or cosmetic advertisement for individual person, In the cosmetic industry, recently, the digital model of human face is expected to be used to evaluate the cosmetics on the face. However, it is not practical to make the realistic digital human face by using the huge modelling time. Actually, it is impossible to make the realistic digital human face for individual person at cosmetic advertisement to advice the appropriate cosmetics.

Image based modelling is studied for the objects that will be difficult to make the 3D shape from pieces. The 3D shape and reflectance properties are estimated from the images which are taken by changing the view points and positions of illuminant. The realistic image under arbitrary view points and arbitrary illuminants can be synthesized from the estimated 3D shape and reflectance properties. These techniques are traditionally called computer vision technologies, which recover the scene from the images.

The inverse rendering in Figure 3 indicates the process to extract the reflectance property and 3D shape which are not influenced by illuminates and viewing angle from the taken images. By extracting these unique properties of the object, it is possible to predict the image under various conditions. The inverse modelling indicates the process to decompose the reflectance property or 3D shape into the material or elements. This make possible to predict the change of appearance by changing the material property. By using the computer graphics and computer vision technologies based on the characteristic of object, it is possible to synthesize the image as digital trial piece under various process and environment.

At the inverse rendering and inverse modelling, it is necessary to consider the real process of rendering and modelling. It is clear that this real process should be physics-based process. The multi-spectral imaging technique will be the key technique for this physics-based process, since the spectral information such as spectral reflectance can be handled in the multi-spectral imaging technique.

APPEARANCE REPRODUCION AND COMPUTER NETWORK

In the recent process of the product development, it is required to evaluate the products through the computer network to save the time to move between the distant places. For example, accurate digital color proof is expected to used in printing industry. The conventional color proof has been widely used to evaluate and refer the color reproduction in printing, which gives the guarantee to the customers for the quality of print based on the colorimetric color reproduction. In recent years, accurate digital color proof instead of conventional proof has been required to reduce the cost of transportation and saving the time by using the computer network.

This evaluation of the products through the computer network is compulsory requirement for the e-commerce and tele-medicine. For this purpose, as is shown in Figure 4, the change of environmental illuminants and viewing devices are much more important since it influence to the observers sensation. Therefore, it is necessary to consider this change to reproduce the color and appearance appropriately.

The spectral imaging is a key technology for the accurate reproduction under various environmental illuminants. The gloss is also one of the important attribute of the appearance. The perceived gloss will be changed with the change of viewing devices. The effective compression of high dynamic range of luminance is necessary for appropriate reproduction of the gloss on the products.

CASE STUDIES

3D COLOR PROOF SYSTEM[15] (APPEARANCE AND COMPUTER GRAPHICS)

There are many kinds of 3D prints such as beverage cans, PET bottles, snack packages, and so on in our life. In the field of B to B e-commerce system on designing and marketing of products, it is required to display the measured or simulated images of the 3D prints. Figure 5 show the software to evaluate appearance of the beverage cans. This system made by DIC Corporation in the collaboration with our laboratory. However, these images tend to be higher dynamic range than the luminance range of usual monitor, because the 3D prints are made of smooth materials such as papers, plastics, and metals that have sharp and strong specular reflection. Therefore, the images of 3D prints cannot be displayed without certain image processing for dynamic range compression.

Accurate reproduction of contrast gloss and that of color and shading are trade-off in tone mapping. For the accurate reproduction of contrast gloss, it is required to decrease luminance in non-highlight area. The resultant tone mapped images tend to be unsatisfactorily dark except highlight area. On the contrary, it is required to clip luminance in highlight area into the maximum monitor luminance for the accurate reproduction of color and shading. The resultant tone mapped images tend to have less contrast gloss than real objects.

As is shown in Figure 6, we proposed to map luminance of diffuse reflection and specular reflection in different ways. In Figure 6, the luminance on the virtual CCD on the camera is calculated in the computer by using the computer graphics techniques. The rendered luminance image is shown by pseudocolor scale in Figure 6, since the rendered image can not be displayed in the conventional imaging system. This is because that the rendered image is expected to be high dynamic range, and the luminance image has higher dynamic range than the luminance range of usual monitor. In the proposed tone mapping[15], the luminance images for diffuse and specular reflection are separately calculated. It is easy to separate diffuse and specular reflections in rendered luminance images, since the BRDF used in the rendering process is formulated as a sum of both reflections. Rendering using BRDF formula of diffuse (specular) reflection gives images of diffuse (specular) reflection. In the proposed tone mapping, only the specular reflection is mapped to the target dynamic range by controlling the slope of specular reflection component as is shown in Figure 6.

Figure 7 shows the effectiveness of the proposed method. The conventional results for (1)non-linear compression (3) linear compression show that color of diffuse components can not be reproduced in these method. The conventional results for (2) clipping show the accurate color reproduction of diffuse components, however, the relative magnitude of glossiness is not preserved compared to the real object. The result of proposed method shows the accurate color reproduction of diffuse components and preservation of the relative magnitude of glossiness.

IMAGE-BASED SKIN COLOR ANALYSIS AND SYNTHESIS[16] (APPEARANCE AND COMPUTER VISION)

The reproduction of human skin color may be considered as the most important function of various imaging systems. With the recent progress of various imaging systems, such as mobile phones with CCD cameras, cosmetic advisory systems, and telemedicine systems, the reproduction of skin color has become increasingly important for image communication, cosmetic recommendations, medical diagnosis, and so on. We proposed an E-cosmetic function for digital images, based on physics and physiologically-based image processing. In this method, the scattering in the skin is modelled in a simple linear form in the optical density domain, and inverse optical scattering is performed by a simple inverse matrix operation. Figure 8 shows the schematic of flow in the proposed image-based skin color and texture analysis/synthesis. The original image is separated into the images of surface and body reflection based on polarized illumination, and the body reflection image is analyzed by independent component analysis with the shading removal to obtain the melanin, hemoglobin, and shading components. These processes are written as follows.

We define $\boldsymbol{v}_{sp}$ as the color vector taken by the P-polarized illumination and S-polarized filter in front of the camera at the current pixel, and $\boldsymbol{v}_{ss}$ is the vector taken by the P-polarized illumination and P-polarized filter. The diffuse reflectance components $\boldsymbol{v}_d$ are calculated as $\boldsymbol{v}_d = 2\boldsymbol{v}_{ps}$ and the secular reflectance components $\boldsymbol{v}_{sp}$ are calculated as $\boldsymbol{v}_{sp} = 2(\boldsymbol{v}_{pp} - \boldsymbol{v}_{ps})$. The diffuse reflection is transformed into the density space as $\boldsymbol{v}_d^{\log} = -\log(\boldsymbol{v}_d)$. The diffuse component in the density space is separated into the component vector of the melanin, hemoglobin and shading components as follows,

$$\boldsymbol{c} = B^{-1}\boldsymbol{v}_d^{\log} \tag{1}$$

where $B = [\boldsymbol{b}_M \quad \boldsymbol{b}_H \quad \boldsymbol{1}]$ and $\boldsymbol{b}_M$, $\boldsymbol{b}_H$ are the basis vectors for melanin and hemoglobin, respectively, in the density space, and $\boldsymbol{1}$ is the vector for shading.

Physiologically based image processing could be applied to the components to control the physiologically meaningful change of skin. The processed components are synthesized to obtain the image using E-cosmetic. Figure 9 show the increase or decrease of the component homogeneously. Realistic change can be achieved by this method. Computer graphics technique can not be archived to this realistic change. This result shows the effectiveness of the image-based approach using computer vision technique.

DEVICE INDEPENDENT GLOSS REPRODUCTION[17]
(APPEARANCE AND COMPUTER NETWROK)

It is important to reproduce equally perceptible images across different displays in the Internet shopping system. To solve the difference of color appearance between two displays, many studies have been done on the device independent color reproduction. However, a little has been studied on a device independent reproduction of glossiness of the object.

In the e-commerce system, the gloss reproduction is also important for customer. We developed the gloss reproduction system based on a perception of the human vision by using the various images of glossiness and luminance of display. Figure 10 show the images used to model the glossiness which is the function of luminance of display and parameters of BRDF on the object surface. The approach is based on the technique proposed by Ferwerda et al.[17] where glossiness is modelled under various diffuse reflectance of the object. Psychophysical scaling technique was introduced to clarify the relationship between the attribute of human gloss perception and the physical properties of the glossiness of the object in their paper.

Our developed model for glossiness is as follows.

$$G = 54.7\sqrt{A_s} + 4.1\times 10^2\sqrt{n} + 5.4\sqrt{I} - 76.3 \qquad (R^2 = 0.803) \tag{2}$$

where G is the glossiness value obtained by the subjective evaluation to the images shown in Figure 10, I is the simulated luminance of display in those images. As the parameters for BRDF, A_s is the power of specular components, n is an index that simulate the degree of imperfection of a surface in the Phong reflection model[19]. It is noted that the simulated luminance I is introduced into our glossiness model.

The developed glossiness model is used for matching the gloss on different devices. As is written above, the model is written by parameter for BRDF on the surface and the luminance of the display. The luminance of the display may be pre-defined in color management system such as sRGB or ICC profile, or estimated by simple subjective evaluation on the display. Figure 11 shows an example of the isogloss curve, which is obtained based on the gloss model. By using this isogloss curve, glossiness of the object can be preserved in changing the luminance of the display.

Figure 12(a), (b) shows the images on high luminance display and low luminance display, respectively. The same data is displayed on each device, although the appearance of gloss looks different. Figure 12(c) shows the image compensated along the isogloss contour by keeping the luminance in Figure 12(b).

By using images along the contour, we can produce images with same glossiness on different displays.

CONCLUSIONS

The basic points and the frame-work for the reproduction of color and appearance were introduced with relating the computer graphics, computer vision, and image processing techniques. The role and importance and of multi-spectral imaging is recognized in this frame-work. In the computer graphics, multi-spectral imaging will be used to acquire and process the basic pieces such and BRDF and texture for spectral rendering. In the computer vision, multi-spectral imaging will be used to acquire and process the image to be used for physics based inverse rendering and modelling. In the computer network, multi-spectral imaging is the key technique to reproduce the color across the various environmental illuminant. Parts of this frame-work have already practiced in various industries. I just summarized those into a frame-work. The case studies were also introduces based on the our previous research for 3D color proof system, image-based skin analysis and synthesis system, device independent gloss reproduction system. These case studies showed the effectiveness of the frame-work to understand the reproduction of color and appearance in the product development.

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Figure Captions

FIG. 1. A flow of the evaluation for color and appearance of the trial pieces

FIG. 2. Appearance reproduction and computer graphics

FIG. 3. Appearance reproduction and computer vision

FIG. 4. Appearance reproduction and computer network

FIG. 5: Software to evaluate appearance of the products
(with DIC Corporation.)

FIG. 6: Rendering high dynamic range image and proposed tone mapping

FIG. 7. Resultant image by conventional and proposed range compression methods.

FIG. 8. Image based skin color analysis and synthesis
(with Kao Corporation.)

FIG. 9. Skin color synthesis with the change of pigmentation

FIG. 10. Images used to make the gloss model

FIG. 11. Iso-gloss contours

FIG. 12. Device independent gloss reproduction based on the iso-gloss contours

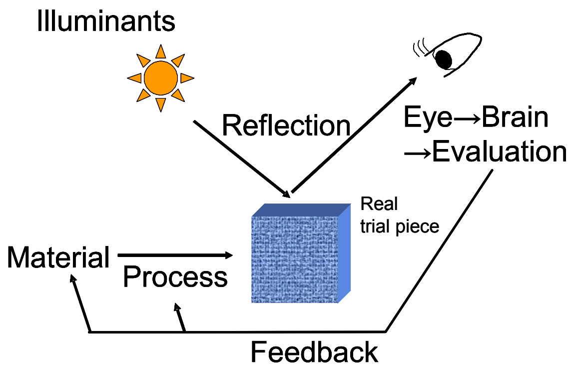

FIG. 1. A flow of the evaluation for color and appearance of the trial pieces

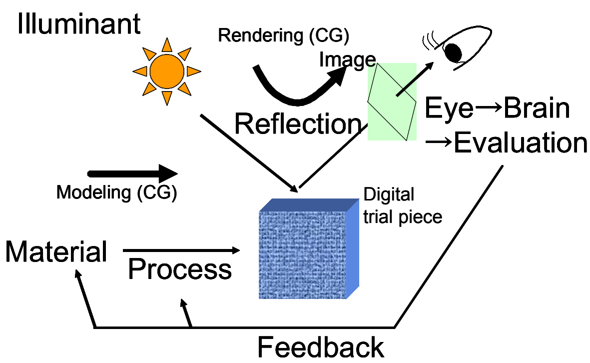

FIG. 2. Appearance reproduction and computer graphics

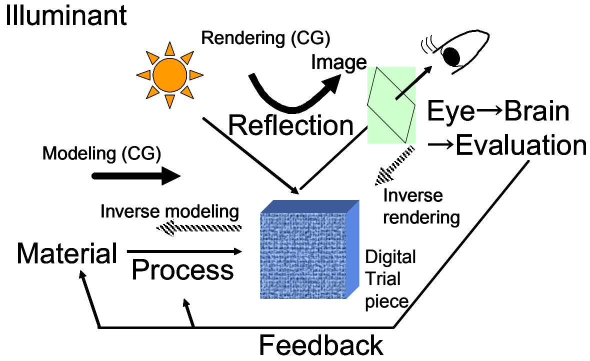

FIG. 3. Appearance reproduction and computer vision

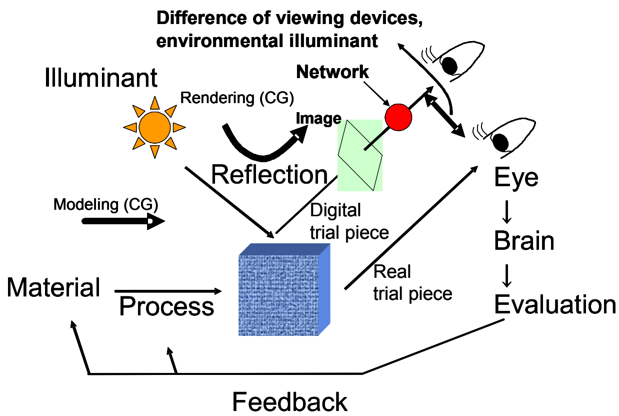

FIG. 4. Appearance reproduction and computer network

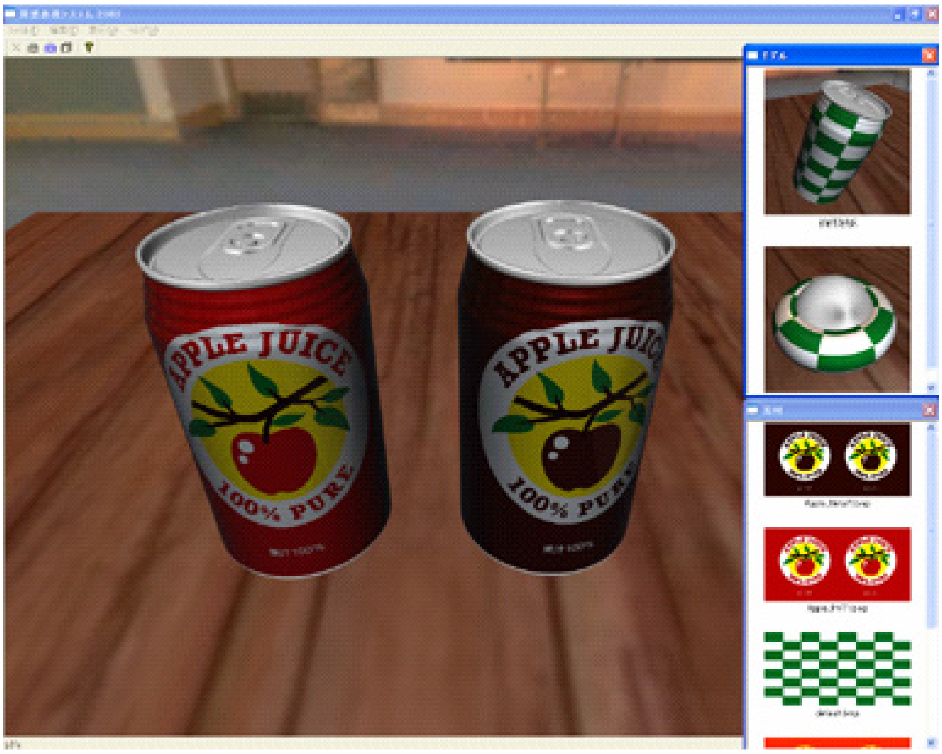

FIG. 5: Software to evaluate appearance of the products (with DIC Corporation.)

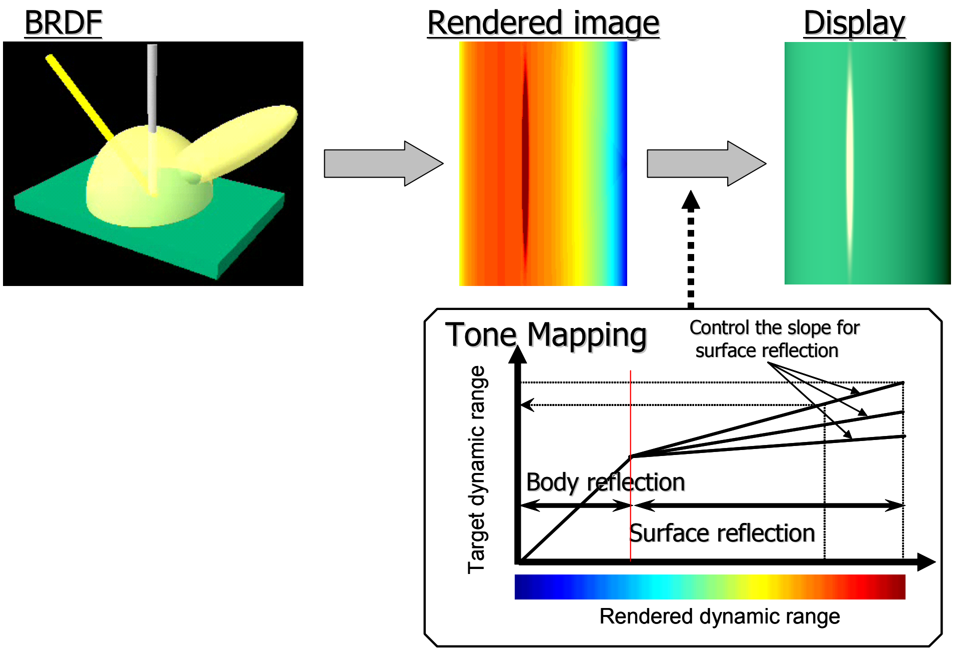

FIG. 6: Rendering high dynamic range image and proposed tone mapping

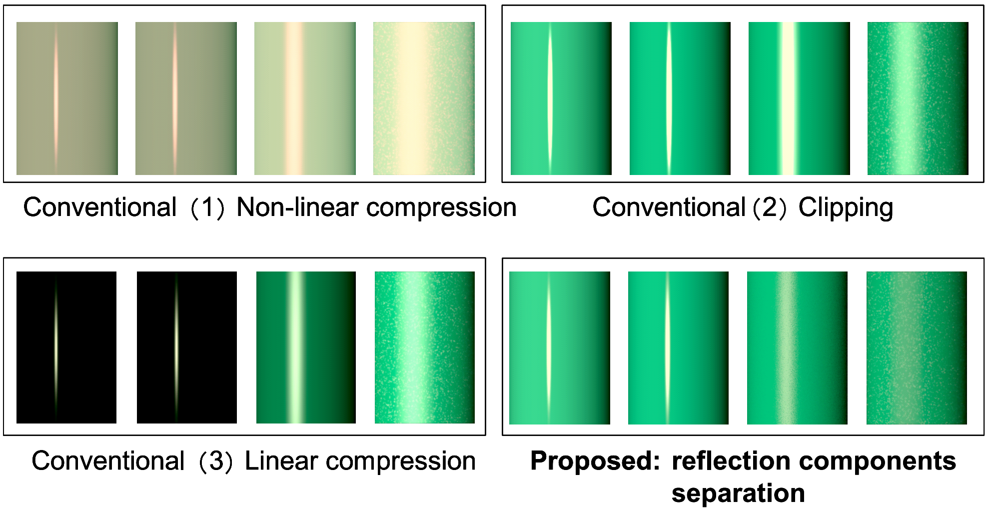

FIG. 7. Resultant image by conventional and proposed range compression methods.

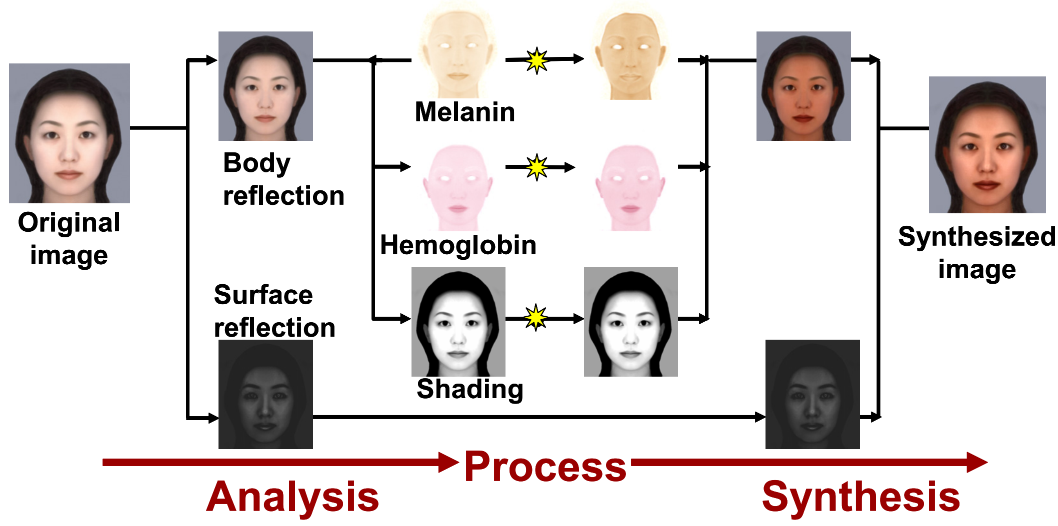

FIG. 8. Image based skin color analysis and synthesis
(with Kao Corporation.)

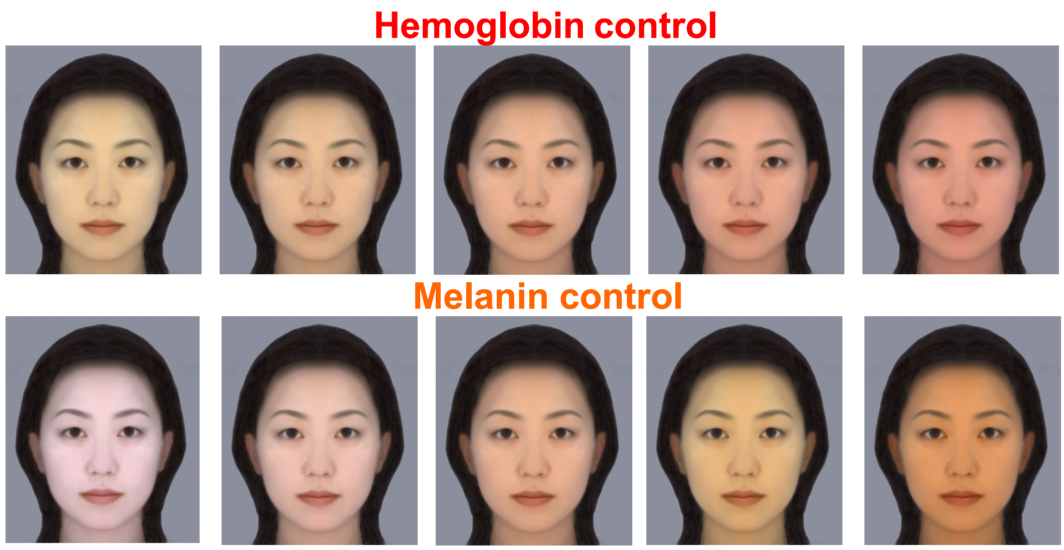

FIG. 9. Skin color synthesis with the change of pigmentation.

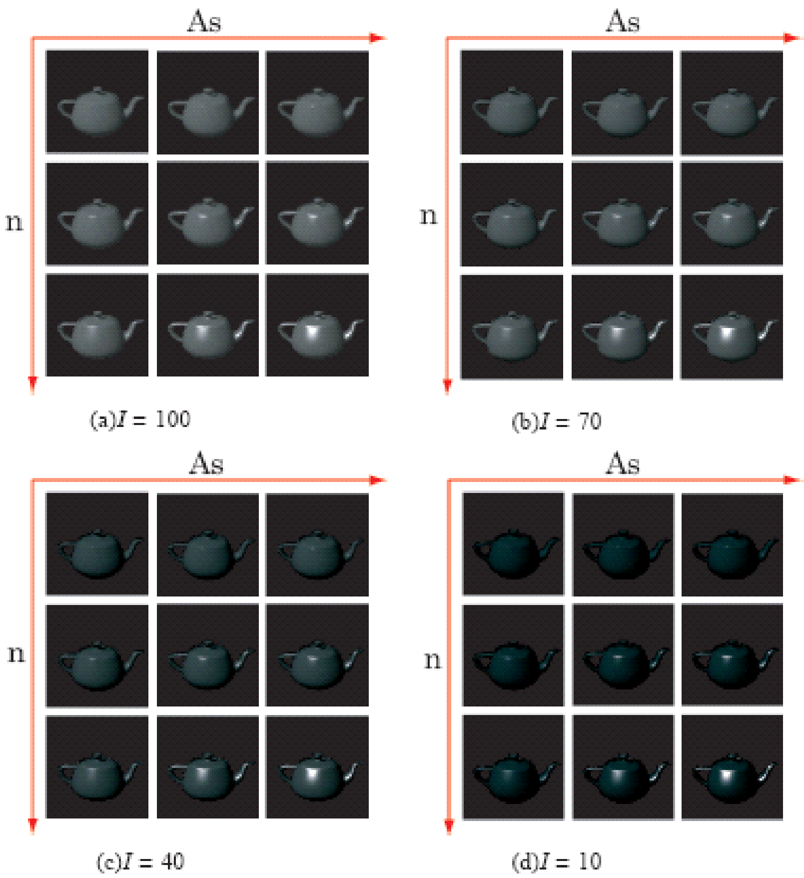

FIG. 10. Images used to make the gloss model

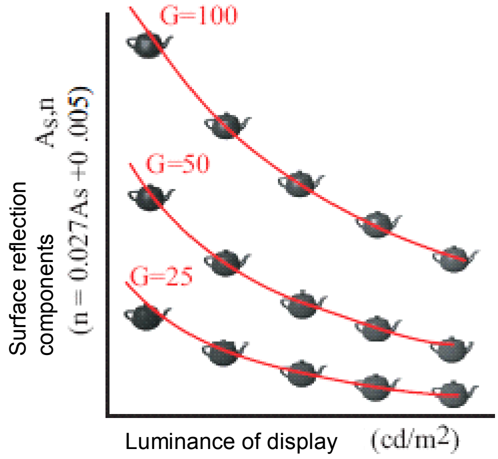

FIG. 11. Iso-gloss contours

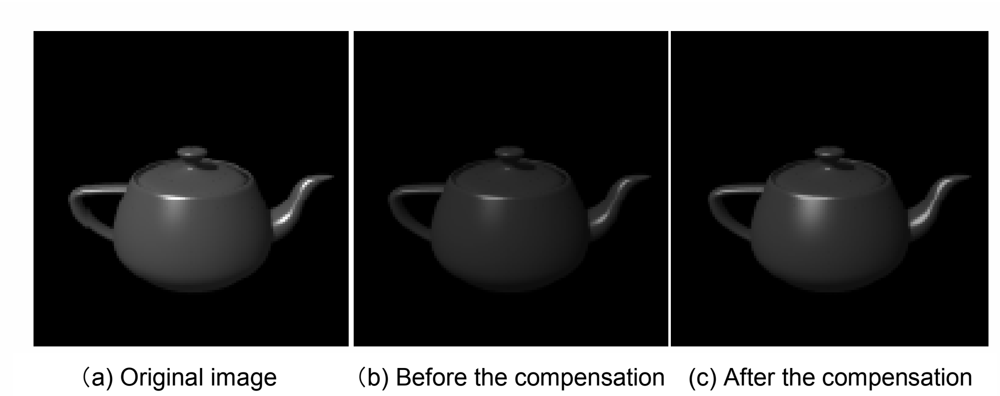

FIG. 12. Device independent gloss reproduction based on the iso-gloss contours