Image-Based Control of Skin Translucency

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Abstract

This paper proposes a method for skin translucency control of facial images. This is one of the important tasks in the reproduction of posters, TV commercials, movies, and so on. As the first step of processing, we extracted the component maps of melanin, hemoglobin and shading from skin color images by using our conventional method. The extracted shading component is controlled to change the translucency of the skin by simple kernel operations for the component. The efficiency for the change of translucency is confirmed by using the images of numerical and optical skin phantoms. The method is also applied into the real skin color image with the consideration of each component, and realistic change of skin translucency was observed from the resultant images synthesized by the proposed method.

OCIS codes: 100.2960, 100.2980, 110.7050, 100.3010

1. Introduction

Controlling the skin appearance is one of the important tasks in the reproduction of human images in posters, TV commercials, movies and other media. Skin appearance is mainly caused by the color, texture and translucency of the skin, and people are very sensitive to any change of the skin appearance in photographs and other reproduced images. The appearance of human skin is often controlled manually by an experienced operator in a time-consuming process. Therefore, to accelerate the reproduction process, a tool that can help to control the skin appearance would be useful in the fields of imaging. We have already proposed techniques to control the color and texture based on the extracted components of melanin, hemoglobin and shading from skin color image[1-3]. The spatial distributions of melanin and hemoglobin in human skin are separated by independent component analysis of skin color image[1]. The analysis is based on the skin color model with assumptions; (1) spatial variation of color in the skin is caused by two pigments; melanin and hemoglobin, (2) their quantities are mutually independent spatially, (3) the linearity holds among the quantities and observed color signals in the optical density domain. By these assumptions, skin color is distributed approximately on 2-dimentional plane under the homogeneous shading area, and melanin and hemoglobin component can be found by independent component analysis. Based on this 2-dimentional plane under the homogeneous shading area, the shading component for the large area of the face is also easily separated in the optical density domain by projecting the observed color on to the 2-dimentional plane of melanin and hemoglobin[2]. The results of these separations agreed well with the physiological knowledge[2]. In controlling the color and texture, we have changed spatial distributions of melanin and hemoglobin components[1-3]. The shading components are not examined in our previous papers.

Skin translucency is related to the subsurface scattering of light in the skin layers. It is not practical to control the degree of the scattering in the microscopic level of photon migration. A simple macroscopic method is expected to be developed to control the translucency of skin image.

In this paper, we propose a method for skin translucency control by simple kernel operations for the extracted component from skin color image, especially for the component of shading. The kernel is designed from the optical point spread functions for both original and target skins. The optical point spread function for original skin is measured by digital camera with focusing the light into a point on the skin. The validity for the change of translucency is confirmed by using the images of numerical and optical phantoms for homogeneous turbid media. The method is practically applied into the real skin color image; the kernel operation is only applied into hemoglobin and shading components based on the structure of skin layers.

In reproducing the skin translucency, the model based approach has recently experienced great progress for interactive rendering[4-8] with the calculation of the subsurface scattering. Jensen et al.[4] proposed a practical BSSRDF (Bi-directional Scattering Surface Reflectance Distribution Function) model based on the diffusion approximation of multiple scattering. Jensen and Buhler[5] decoupled the computation of irradiance from the evaluation of the diffusion approximation to speed up the rendering process. Based on this decoupling, the local response due to subsurface scattering can be stored as kernels for an irradiance map[6-8]. Our method to control the translucency is the same process as this kernel-based process on an irradiance map, although our technique is an image-based approach. Goesele et al.[9] illuminated individual surface points by a scanning laser projector, and the object's impulse response is recorded with a high-dynamic-range video camera to capture the translucent object. This technique can also be considered as an image-based approach, although tremendous measurements are impractical for human skin. No practical image-based model has been proposed yet for skin. This paper proposes a practical image-based method for skin translucency control.

The technique of skin components separation is briefly introduced in the next section. In the section 2, we propose a technique of the image-based translucency control for homogeneous turbid media, and the effectiveness of proposed technique is verified by both computer simulation and experiments using the optical phantom. In the section 3, the proposed technique is practically applied into real skin color image. In the section 4, conclusion and discussion are described for the proposed image-based translucency control.

2. SKIN COMPONENTS SEPARATION

For the control of skin translucency, it is necessary to extract the shading components from color images as is written in the next section. We used the technique proposed by Tsumura et al. [1,2] to separate two images with different polarizing filters into specular, shading, melanin and hemoglobin components, as shown in Figure 1. Since the original process by Tsumura et al. [1,2] was unstable for obtaining well-separated components, we improved their technique by introducing an interactive operation for finding the basis vector of the components.

We define $\boldsymbol{v}_{ps}$ as the color vector taken by the P-polarized illumination and S-polarized filter in front of the camera at the current pixel, and $\boldsymbol{v}_{pp}$ 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 specular reflectance components $\boldsymbol{v}_{specular}$ are calculated as $\boldsymbol{v}_{specular} = 2(\boldsymbol{v}_{pp} - \boldsymbol{v}_{ps})$. 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,

$$\boldsymbol{c} = B^{-1}\boldsymbol{v}_d^{\log} \qquad (1)$$

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. The basis vectors for melanin and hemoglobin components, $\boldsymbol{b}_M$, $\boldsymbol{b}_H$, are extracted by using the independent components analysis[1,2].

Since our original method occasionally fails to extract the components in our imaging system, we modified the technique by introducing the two-step interactive process. From the pattern of the texture of the components, it is easy to evaluate the separated map of components, whether they are well separated or not. The first step of the interactive technique iterates the independent component analysis by changing the region of the analysis, and then the separation is evaluated by the user. The iteration will finish if the separation is evaluated as generally valid. The second step of the interactive technique is performed interactively to adjust the basis vectors, $\boldsymbol{b}_M$, $\boldsymbol{b}_H$, to adequately separate the melanin, hemoglobin and shading components. The adjustment is performed using the graphical user interface to move the basis vector in two-dimensional space,

and the resultant separations are visualized in real time.

3. IMAGE-BASED TRANSLUCENCY CONTROL FOR SHADING IMAGE

In this section, we propose a technique of the image-based translucency control for homogeneous turbid media. In the homogeneous turbid media, the taken image can be directly thought as a shading component by normalizing the color into white. The shading component is used to control the translucency of skin appearance in the proposed technique. Since the local response due to subsurface scattering can be represented as kernels for an irradiance map[5-7], the shading component image $Sh(x,y)$ in each color channel can be expressed by the irradiance $L(x,y)$ and kernel $K(x,y;x',y')$ in each color channel as follows.

$$Sh(x,y) = \iint L(x',y')K(x,y;x',y')dx'dy' \quad (2)$$

In this paper, the kernel is assumed shift-invariant in the image and is expressed by the point spread function (PSF) as $PSF(x,y) = K(x,y;x',y')$. As shown in Figure 2, the shading component is simply calculated by convolution between the irradiance and PSF as follows.

$$Sh(x,y) = \iint L(x',y')PSF(x-x',y-y')dx'dy' \quad (3)$$

Based on the above insight, it is easily understood that the irradiance can be estimated by deconvolving the PSF (if it is known) or blindly deconvolving for the shading component. The estimated irradiance can be convolved by another PSF to get the synthesized appearance of the skin translucency. Exactly speaking, the kernel is not homogeneous in the turbid media with non flat shape of surface, since the local response will be deformed by the shape of the surface. Therefore, it is necessary to evaluate validity for using the shift-invariant kernel instead of the shift-variant kernel. In the following paragraphs, cpmputer simulation is performed to confirm this validity.

Figure 3(a) shows the optical phantoms prepared by changing the scattering coefficients of the medium. The particles of the foundation used in cosmetic material are induced into the silicon to change the scattering coefficient. The foundation is composed from iron oxide red, iron oxide yellow, and iron oxide black, and

empirically obtained the skin like phantoms about color and translucency. The induced foundation is 0.5%, 0.2%, 0.15%, 0.1% and 0.05% from left to right in Figure 5. There are lined cuts at each phantom to imitate wrinkles on the skin. The shapes of the cuts are the same for all phantoms, since the cuts are modeled after the same mold. Figure 4 shows the imaging geometry for taking the image of the phantoms. The sample is illuminated from 45 degrees and the image is taken from 0 degrees. The polarized filters are used to remove the specular reflection. Figure 3(b) shows the image taken of the phantoms, and the change of translucency can be seen with the change of the amount of induced foundation. The PSFs are also measured by using the similar method of Jensen et al.[3]. Figure 3(d) shows PSFs in the logarithmic space, which is measured for each phantom.

Figure 5 shows the result of deconvolution of the image for the 0.5% phantom. We cannot feel the translucency from the resultant image, and the contrast by cuts is well reconstructed as if it is a plastic. We apply the other PSFs of the phantoms to this deconvolved image from the 0.5% phantom. Figure 3(c) shows the resultant synthesis for the 0.2%, 0.15%, 0.1% and 0.05% PSFs. Comparing Figures 3(b) and (c), we can see that our image-based translucency control works very well in these samples.

Numerical skin phantoms are developed in the computer, and the phantoms are assumed to be illuminated from angle of 45 degree, and the image taken by virtual camera is calculated by photon mapping technique[9]. Figure 6(a) shows the images of numerical phantoms prepared by changing the scattering coefficients of the medium. The lined cuts are set at each phantom to imitate wrinkles on the skin. The shapes of the cuts are the same for all numerical phantoms. The sample is illuminated from 45 degrees and the image is taken from 0 degrees by virtual camera. The specular reflection was not included in the image. In the Figure 6(a), the change of translucency can be seen with the change of the a scattering coefficients of the medium. The PSFs are also simulated by using the photon mapping technique. Figure 6(b) shows the synthsized images from the left side of image in Figure 6(c) to others. It can be seen the realstic change of translucency. Figure 7 show the cross section of the luminance profile in the Figure 6. It is clearly seen that shift-invariant kernel is sufficient to simulate the change of translucency.

4. IMAGE-BASED TRANSLUCENCY CONTROL FOR SKIN IMAGE

The proposed method is practically applied into the real skin color image; the kernel operation is only applied into hemoglobin and shading components based on the structure of skin layers. Melanin component is not blurred compared to hemoglobin and shading components, since the epidermis layer is thin upper layer on the dermis layer. We applied this control to real skin images. The shading components are separated from the real skin images by using the method of Tsumura et al.[1,2]. The blind deconvolution is applied to the shading components since the PSF is not known in the skin image. Then another PSF is applied to the deconvolved image to get the synthesized appearance of the increased translucency. Figures 8 and 9 show the results of the images for skin pattern and facial pattern: (a) original image, (b) deconvolved image for shading components, (c) convolved image for the shading component, (d) convolved image for all RGB components in the color image. It is seen that the translucency of skin is controlled by our proposed method. On the other hand, the convolved images for the color image show that conventional blurring cannot control the translucency of the skin.

A set of psychophysical experiments were performed to subjectively evaluate the translucency by changing the melanin, hemoglobin, and shading components for the four skin images shown in Fig. 10. Figure 11 shows the example of changing the components. The original images are set on the middle of the figures. The observers were asked to rate the value of translucency compared with the original image.

In synthesizing the images the subjective experiment, it was also necessary to consider the human sensitivity to the change of amount for each component, since unobserved physiologically plausible changes will not mean anything to changes of the skin appearance. For this purpose, we normalized each amount for each component by using the degree of human sensitivity to each component. The degree of human sensitivity is alternatively obtained by using the reciprocal of the just noticeable difference (JND)[3].

Figure 12 shows the results of the experiments. The horizontal axis indicates the increase or decrease of the each component. The vertical axis indicates the observer rating value for skin translucency. It is seen that change of melanin and optical scattering influence into the observed translucency.

5. CONCLUSION AND DISCUSSION

The shading component is extracted from the color image by using the method by Tsumura et al. The shading component was controlled to change the translucency of the skin by a simple convolution process. The resultant images showed the effectiveness of the proposed method to control the skin translucency realistically.

Optical phantoms were also made to show the effectiveness of the proposed method. The refractive index, absorption and scattering coefficients and anisotropy factor were not measured for the optical phantoms in this paper. The change of these coefficients and factor is related to the change of point spread function for the optical phantoms. It is necessary for our future works to measure these coefficients and factor for optical phantoms for the repeatability of the experiments and for further precise control of skin translucency.

The proposed method is based on the assumption that kernel for optical scattering is shift-invariant and is expressed by the point spread function. We evaluated the validity for the lined cuts for optical and simulated phantom, also for the grained skin image. However, the face is not a flat plane, and the 3-dimensional facial shape is projected on 2-dimensional image. The point spread function will deform with the change of surface normal on the 3-dimensional face. In the Fig. 8, we did not consider this change. This will be our future work with the acquisition of the 3-dimensional shape of the face.

In this paper, we subjectively evaluated the effect to the translucency by changing the melanin, hemoglobin, and shading components as shown in Fig. 12. It is noted that decreasing the melanin component also increase the translucency for human observer. The change of hemoglobin is not effected into the translucency for human observer. The specular reflection is not changed in this paper. It will be our future work to change the specular reflection for the evaluation of skin appearance.

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Figure Captions

Figure 1 Separation of two images with different polarizing filters into specular, shading, melanin, and hemoglobin components based on our previous method.

Figure 2 Estimation of irradiance by deconvolving the point spread function (PSF) of the medium. The new shading component is simply calculated by convolution between the estimated irradiance and another PSF.

Figure 3 The physical validity of the proposed control of translucency. (a) optical skin phantoms prepared by changing the scattering coefficients of the medium. The particles of foundation used in cosmetic material are induced into the silicon to change the scattering coefficient. The induced foundation is 0.05%, 0.2%, 0.15%, 0.1%, 0.5% from left to right, (b) Images of the phantoms. The change of translucency can be seen with the change of the amount of induced foundation, (c) The resultant syntheses for 0.2%, 0.15%, 0.1%, 0.05% PSFs for a real image of 0.5% density. (d) PSF for each phantom

Figure 4 Imaging system to take the image of the phantoms.

Figure 5 The result of deconvolution for the image of the 0.5% phantom by using the PSF measurement.

Figure 6 Numerical validity of the proposed control of translucency. (a) numerical skin phantoms prepared by changing the scattering coefficients of the medium. (b) The resultant syntheses from rendered image of high scattering medium and its PSF into synthesized images by using their own simulated PSF. (c) The difference image between images in Figure 6(a) and Figure 6(b).

Figure 7 Cross section of the luminance profile in the Figure 3. Original image with high scattering is changed into the synthesized images to compare the rendered images.

Figure 8 The effect of the proposed method in skin pattern image: (a) original image, (b) deconvolved image for shading components, (c) convolved image for the shading component, (d) convolved image for all RGB components in the color image

Figure 9 The effect of the proposed method in facial .image: （a） original image, (b) deconvolved image for shading components, (c) convolved image for the shading component, (d) convolved image for all RGB components in the color image

Figure 10 Four skin images used in the subjective experiment for skin translucency

Figure 11 Example of changing the components of the skin. The original images are set on the middle of the figures.

Figure 12 Results of the subjective experiments. The horizontal axis indicates the increase or decrease of the each component. The vertical axis indicates the observer rating value for increase of skin translucency.

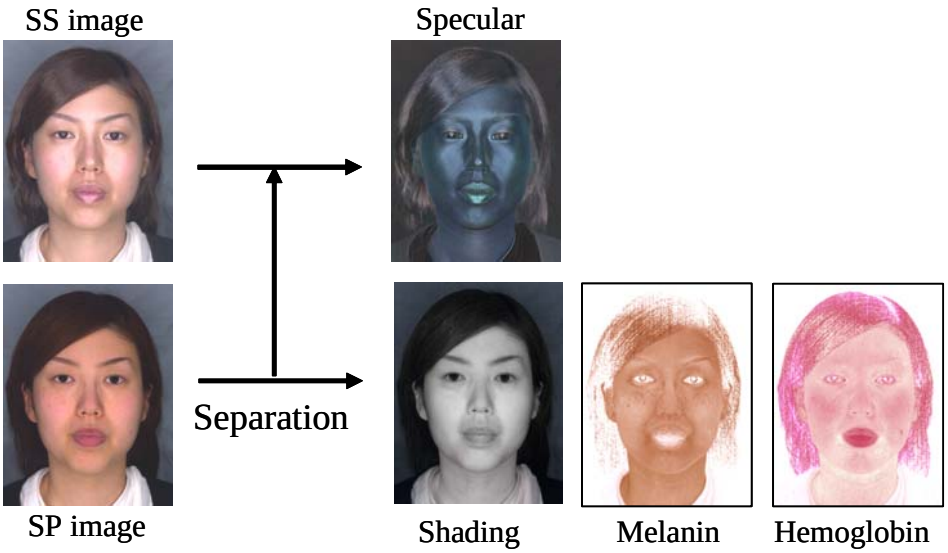

Fig. 1. Separation of two images with different polarizing filters into specular, shading, melanin, and hemoglobin components based on our previous method.

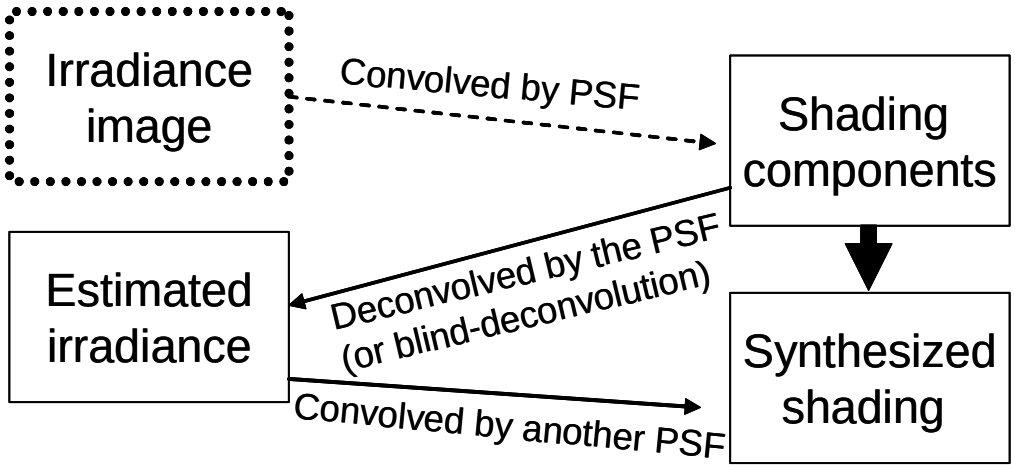

Fig. 2. Estimation of irradiance by deconvolving the point spread function (PSF) of the medium. The new shading component is simply calculated by convolution between the estimated irradiance and another PSF.

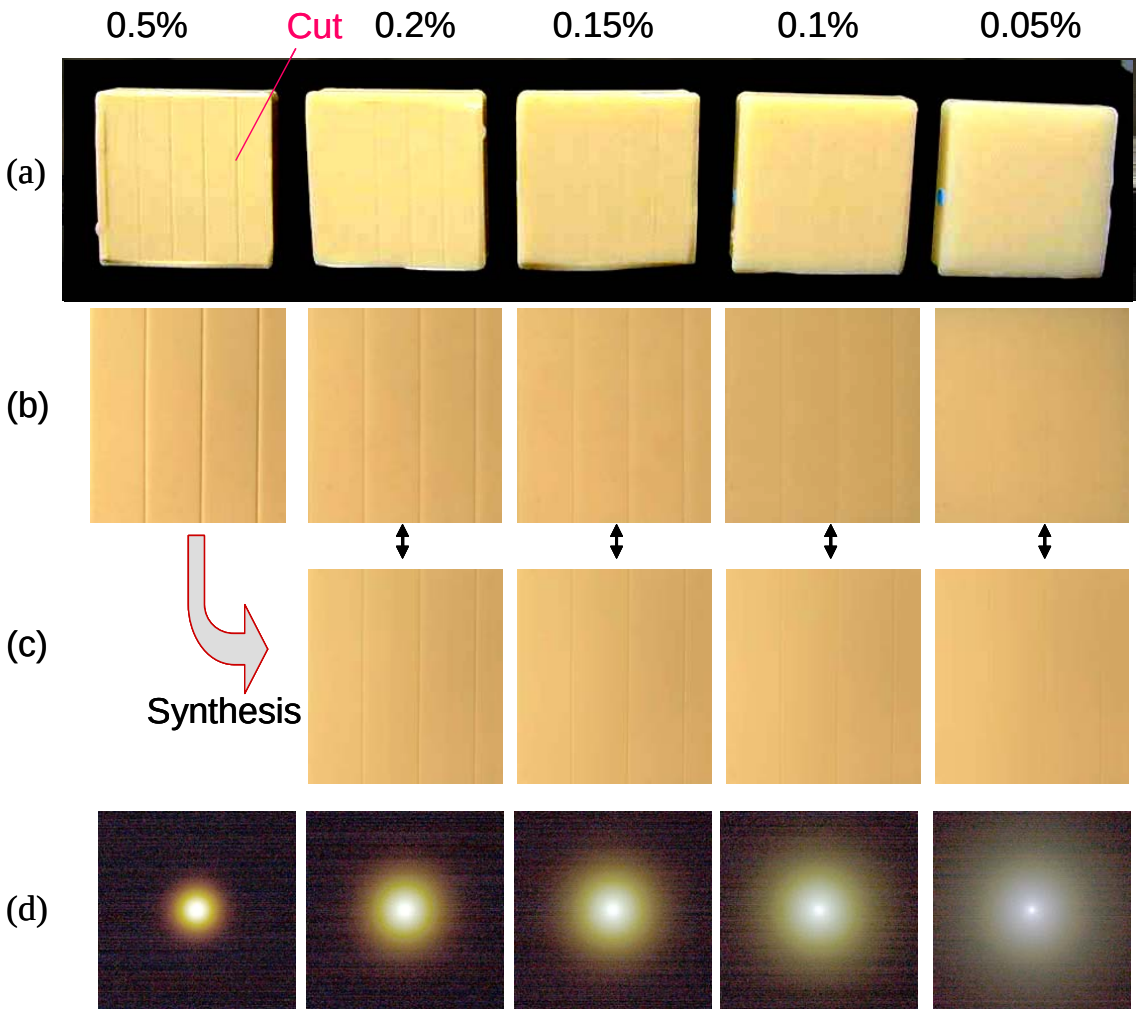

Fig. 3. The physical validity of the proposed control of translucency. (a) optical skin phantoms prepared by changing the scattering coefficients of the medium. The particles of foundation used in cosmetic material are induced into the silicon to change the scattering coefficient. The induced foundation is 0.05%, 0.2%, 0.15%, 0.1%, 0.5% from left to right, (b) Images of the phantoms. The change of translucency can be seen with the change of the amount of induced foundation, (c) The resultant syntheses for 0.2%, 0.15%, 0.1%, 0.05% PSFs for a real image of 0.5% density. (d) PSF for each phantom.

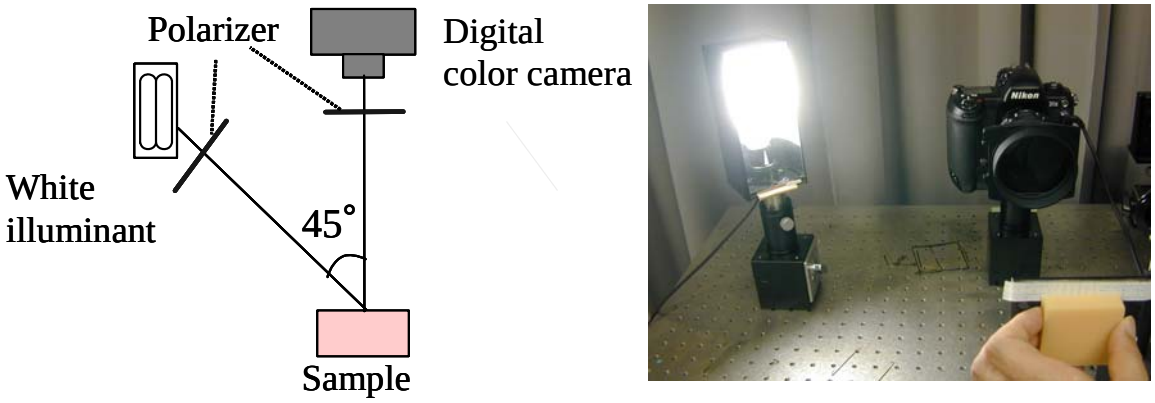

Fig. 4. Imaging system to take the image of the phantoms.

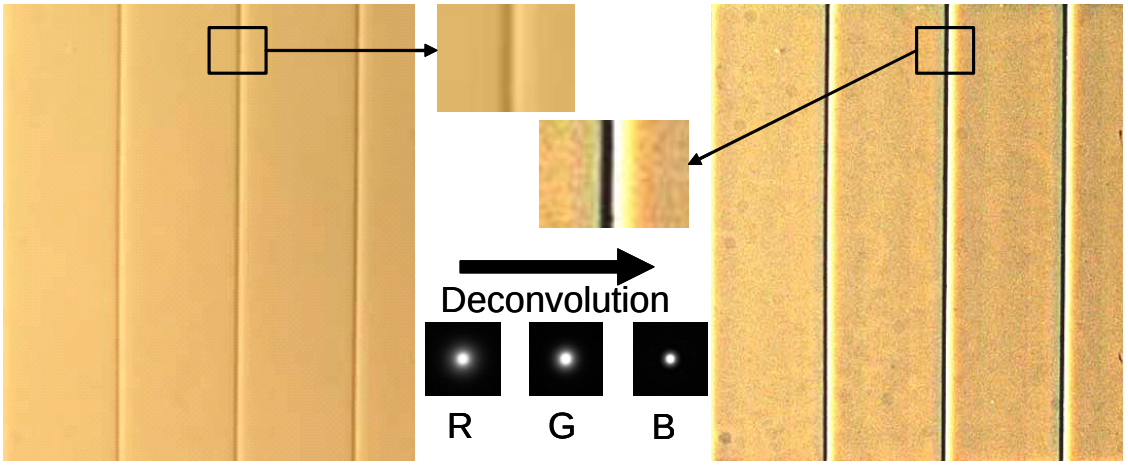

Fig. 5. The result of deconvolution for the image of the 0.5% phantom by using the PSF measurement.

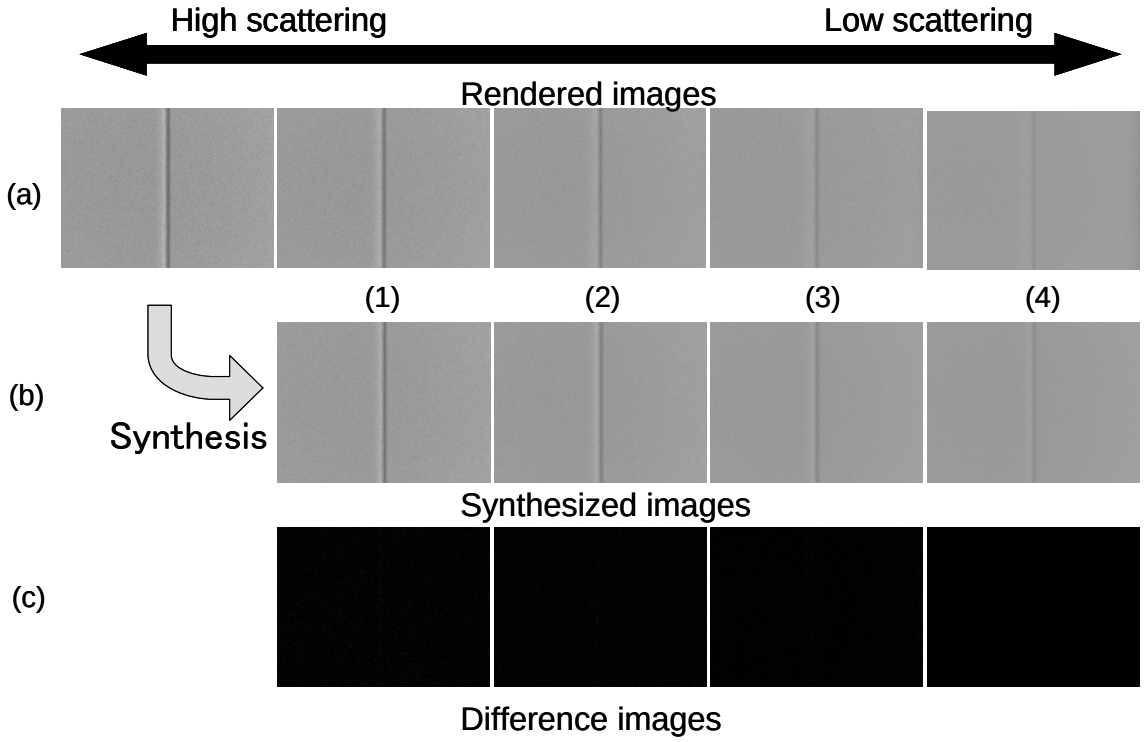

Fig. 6. The numerical validity of the proposed control of translucency. (a) numerical skin phantoms prepared by changing the scattering coefficients of the medium. (b) The resultant syntheses from rendered image of high scattering medium and its PSF into synthesized images by using their own simulated PSF. (c) The difference image between images in Figure 6(a) and Figure 6(b).

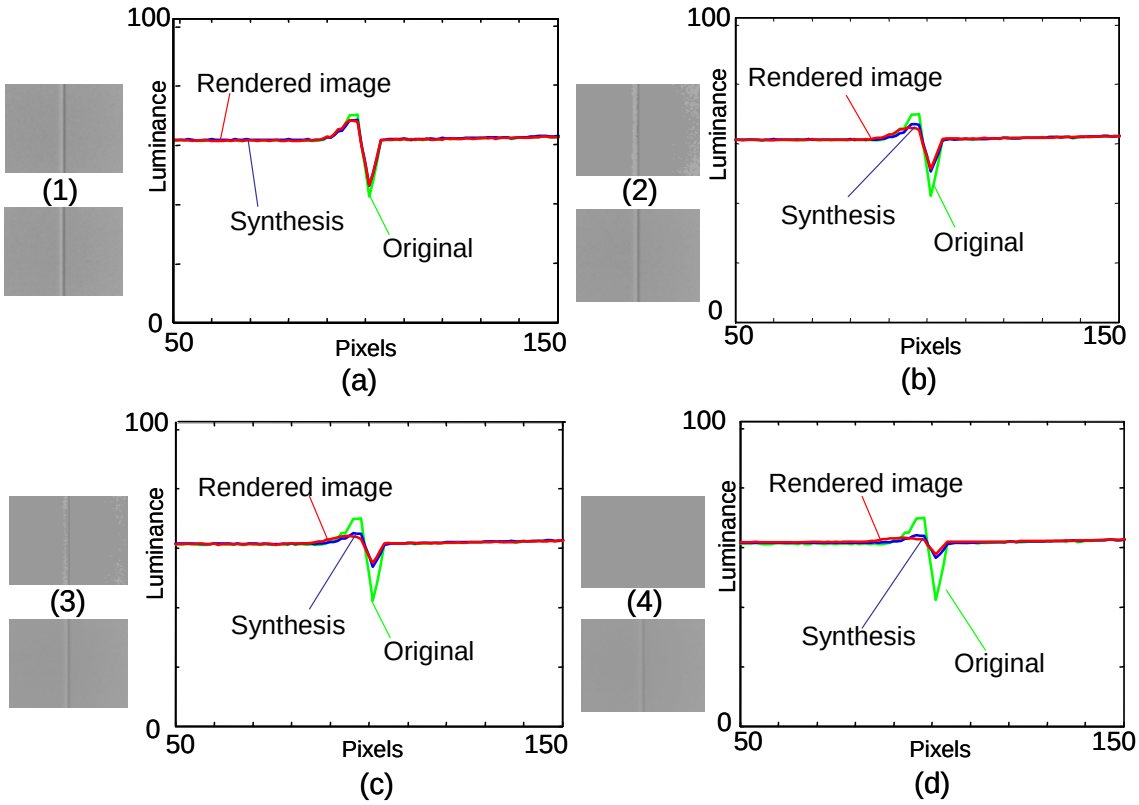

Fig. 7. Cross section of the luminance profile in the Figure 3. Original image with high scattering is changed into the synthesized images to compare the rendered images.

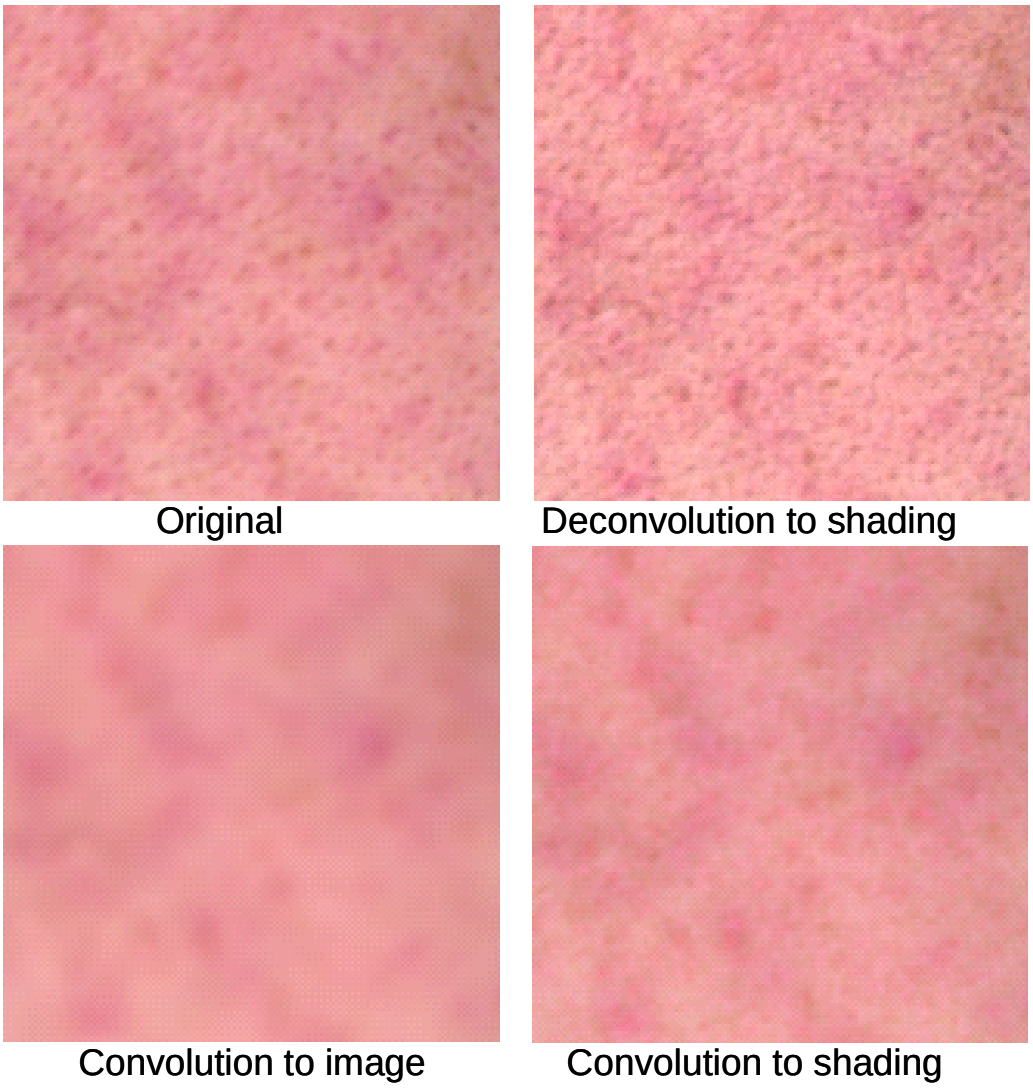

Fig. 8 The effect of the proposed method in skin pattern image: (a) original image, (b) deconvolved image for shading components, (c) convolved image for the shading component, (d) convolved image for all RGB components in the color image

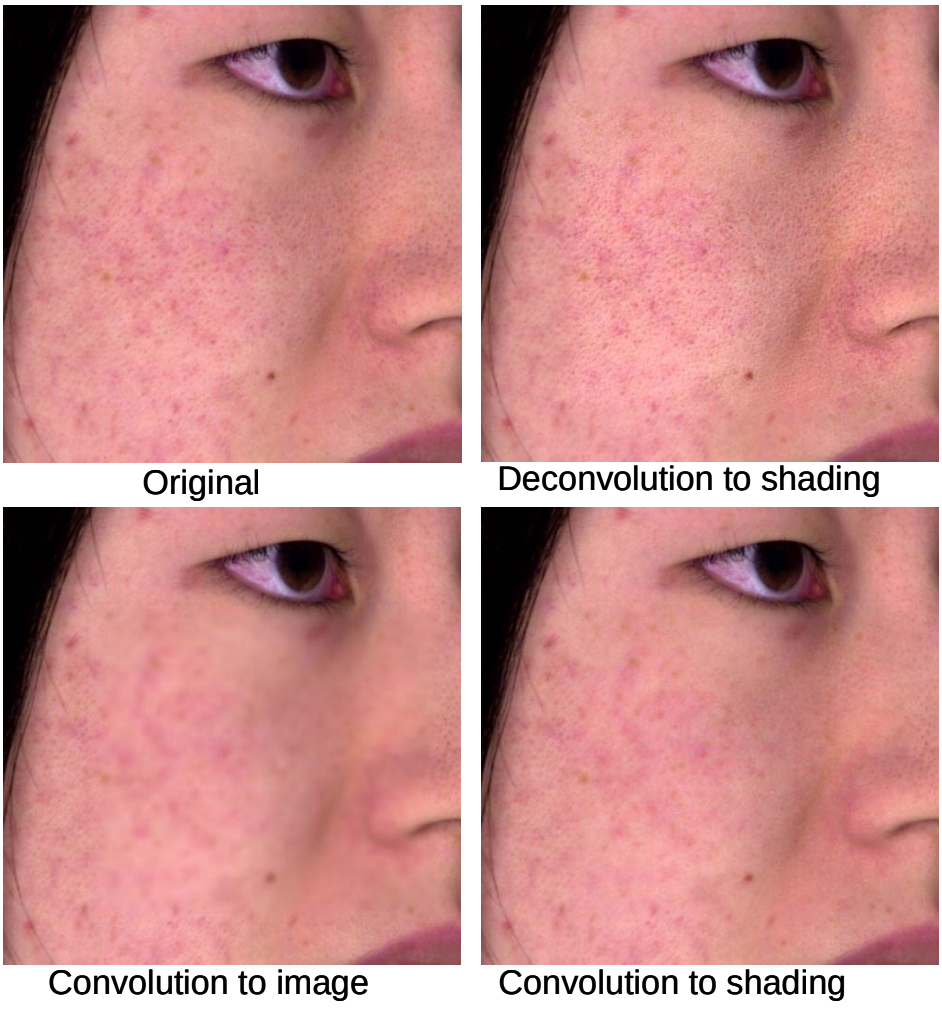

Fig. 9　The effect of the proposed method in facial .image: （a） original image, (b) deconvolved image for shading components, (c) convolved image for the shading component, (d) convolved image for all RGB components in the color image

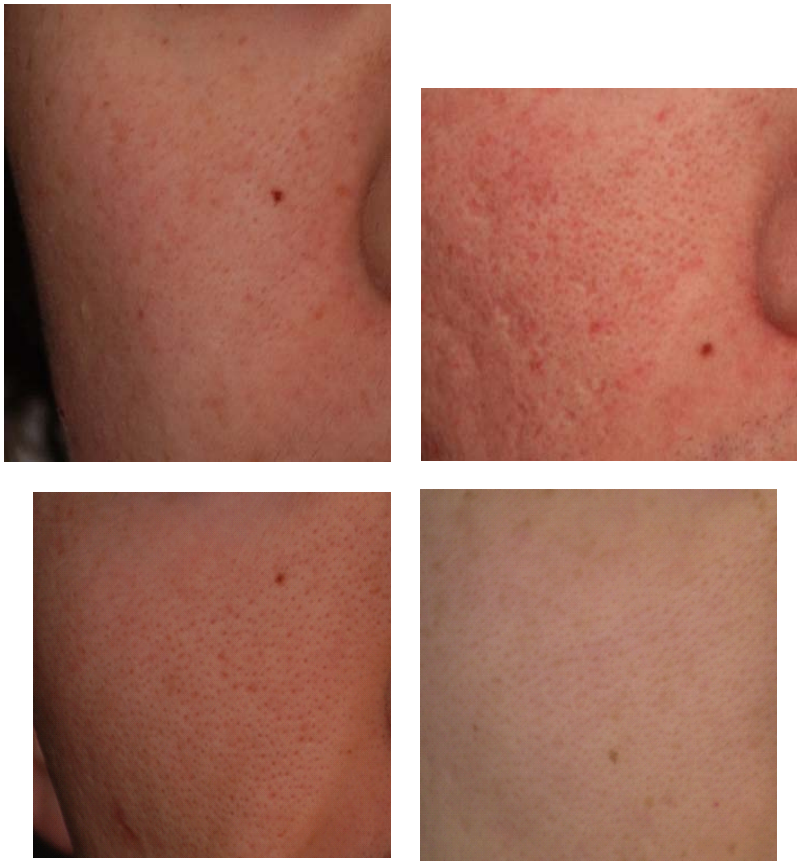

Fig.10 Four skin images used in the subjective experiment for skin translucency

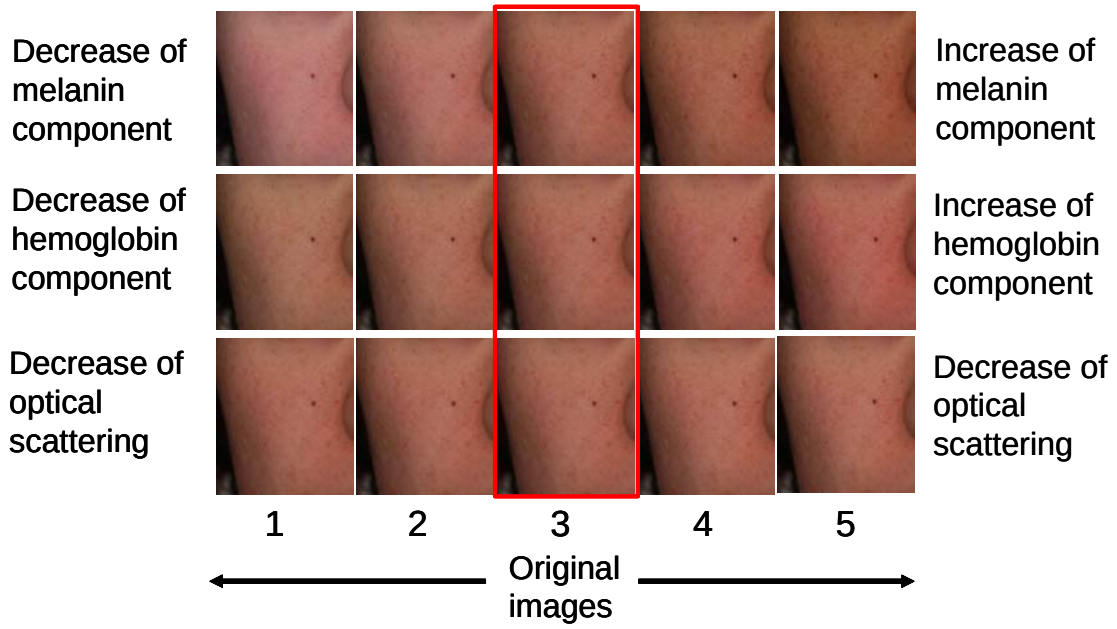

Fig.11 Example of changing the components of the skin. The original images are set on the middle of the figures.

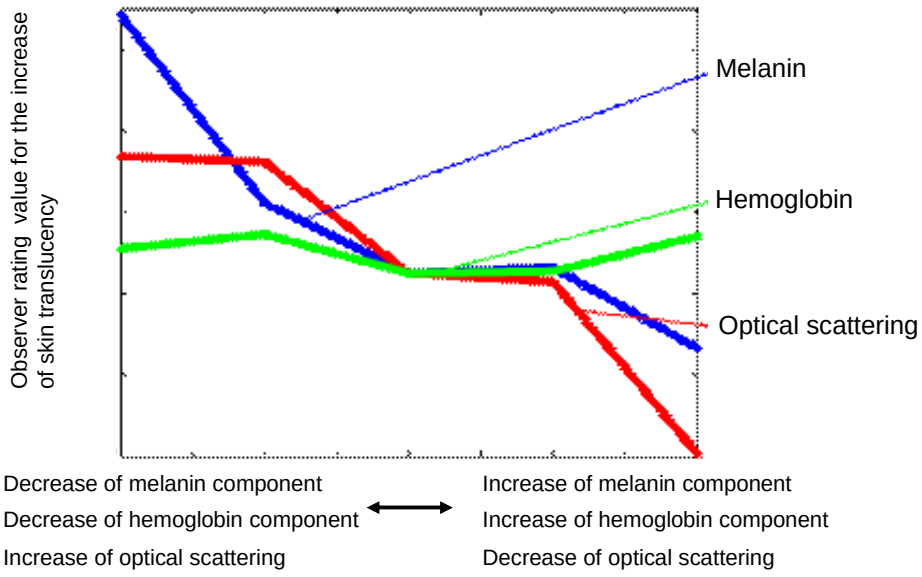

Fig.12 Results of the subjective experiments. The horizontal axis indicates the increase or decrease of the each component. The vertical axis indicates the observer rating value for increase of skin translucency.