Frequency Analysis and Synthesis of Skin Color Textures

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Abstract

This paper describes a method for the analysis and synthesis of human skin with color texture. The approach is based on the spatial frequency analysis of skin images. First, the observed color image is transformed into the frequency domain. Then, color texture patterns are separated on the spatial frequency. The original image is decomposed into four image components of (1) base color component, (2) regular surface texture component, (3) internal texture component and (4) local texture component. Moreover realistic images of the human skin under different conditions are synthesized by a linear combination of the four components. The color texture is particularly noticeable in the case of human palms. The reliability of the proposed method is shown in an experiment for palm images.

Introduction

Human skin provides often the key to solving many problems in color imaging, computer vision, and computer graphics. In color imaging, human skin color is a performance index for image acquisition and color reproduction of human images. In computer vision, the skin color is useful for detecting some parts of the human body such as faces and hands from the color image of a natural scene. In computer graphics, the detailed description of human skin is essential for realistic image rendering of various natural objects including human bodies.

There were some works on color analysis of human skin.[1-4] For instance, Tsumura et al. showed the relationship between skin color reproduction and pigmentation inside the skin by a spectral analysis technique.[1-2] Jones et al. created a skin probability map in the RGB color space from a large skin image database.[3] However, these works were limited to color analysis of human skin without texture. It should be noted that various texture patterns often appear on the skin surface. For instance, Figure 1 shows the color image of a person's palm, which includes clear texture patterns of palm-wrinkles and palm-prints.

There were a few works on image analysis and synthesis of skin texture.[5-7] Ishii et al. proposed a model for generating skin surface textures for computer graphics.[5] Nahas et al. presented a texture mapping technique for facial images.[7] All these works did not discuss color texture but just simple texture pattern.

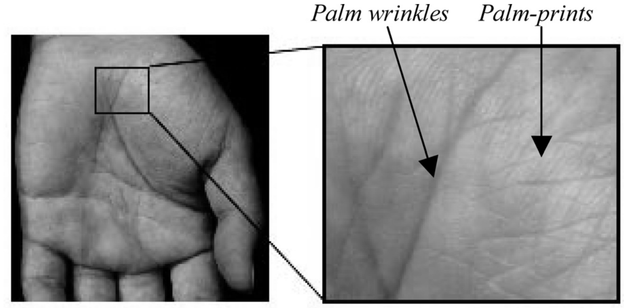


Figure 1. Color image of a person's palm.

In this paper, we propose a new method for the analysis and synthesis of human skin with color texture patterns. The approach is especially based on the spatial frequency analysis of the color image of a person's palm. First, the observed image is transformed into the frequency domain in order to separate the original image into four components of color texture patterns. The component images are (1) base color component, (2) regular surface texture component, (3) internal texture component and (4) local texture component. Moreover realistic images of the human palms under different conditions are synthesized by a linear combination of the four components.

Features of Skin Color Textures

In this study, we classify the color textures of human skin into the following three groups.

The first group has the texture of regular fine patterns on the skin surface, that we call the regular surface texture. This class includes palm-prints and regular tile patterns on the other parts of human skin. The palm-prints consist of a set of regular fine lines like fingerprints.

The second group is the texture caused by pigments inside the skin, that we call the internal texture. The main pigments in human skin are melanin and hemoglobin. Spots by blood appear on the skin surface, the color of which is caused by hemoglobin in blood. This group includes the blood spots and freckles.

The third group is the texture without periodic pattern, that we call the local texture. This includes wrinkles and moles. The wrinkles mean an uneven surface with grooves and the moles mean color change by pigments. Note that these objects do not appear periodically.

Figure 1 shows the observed image of a person's palm that includes the above color texture. Note that the palm-prints of fine regular lines are clearly distinguished from the wrinkles localized with bold lines. Moreover the blood spots appear clearly on the palm when the hand is lowered as shown in the left of Figure 1.

Model for Skin Color Image

The uniform color of a human skin without texture is called the base color. The skin color image can be modeled as a linear combination of the basis color component and three texture components. The image components are (1) base color component, (2) regular surface texture component, (3) internal texture component and (4) local texture component. The base color component consists of fixed color coordinates over the image. This model is expressed as three sets of matrix equation.

$$\begin{aligned} \mathbf{O}_\mathrm{r} &= C_\mathrm{r} \cdot \mathbf{E} + \mathbf{S}_\mathrm{r} + \mathbf{I}_\mathrm{r} + \mathbf{L}_\mathrm{r} \\ \mathbf{O}_\mathrm{g} &= C_\mathrm{g} \cdot \mathbf{E} + \mathbf{S}_\mathrm{g} + \mathbf{I}_\mathrm{g} + \mathbf{L}_\mathrm{g} \\ \mathbf{O}_\mathrm{b} &= C_\mathrm{b} \cdot \mathbf{E} + \mathbf{S}_\mathrm{b} + \mathbf{I}_\mathrm{b} + \mathbf{L}_\mathrm{b} \end{aligned} \qquad (1)$$

where each matrix represents a squared image component with *n*-by-*n* pixels, and the subscripts r, g, and b denote the red, green and blue components. The set of matrices (O_r, O_g, O_b) in the left hand side in (1) represent the original image observed by a digital camera. The first term in the right hand side represents the base color component. The vector (C_r, C_g, C_b) means the base color vector and all elements of the constant matrix **E** are 1. The three sets of matrices (S_r, S_g, S_b), (I_r, I_g, I_b) and (L_r, L_g, L_b) represent the regular surface texture component, the internal texture component, and the local texture component, respectively.

In the following section of frequency analysis, a skin color image is decomposed into these four image components, and the characteristics of each component are investigated in terms of spatial spectrum. In the process of image synthesis, the extracted component images are synthesized for creating a variety of skin color images by different component enhancements.

Frequency Analysis of Skin Color Textures

We have created an image database of skin color images. This database consists of three sets of the measured images for three portions of human skin, which are 10 persons' palms, 5 persons' arms and the backsides of 10 persons' hands. These objects were photographed in the same illumination and viewing conditions, and the observed images were normalized into the image resolution of 64 pixel/cm and the image size of 128-by-128 pixels.

We have developed the GUI tool as a tool for analyzing the image components in frequency domain. Figure 2 shows the window page of this tool, where the original image is displayed in the upper left, and the two-dimensional power spectra by the Fast Fourier Transform (FFT) are displayed on R (upper right), G (lower left) and B (lower right) component. Filtering operation in the spatial frequency domain can be performed easily using this tool. A user sets the numerical values of the cut-out frequencies for band-eliminated filtering to the open spaces of the window. The band-limited spectra are inversely transformed into spatial domain and the filtered color image is displayed immediately in the original image window. This procedure suggests that the component images of skin color textures depend on spatial frequency.

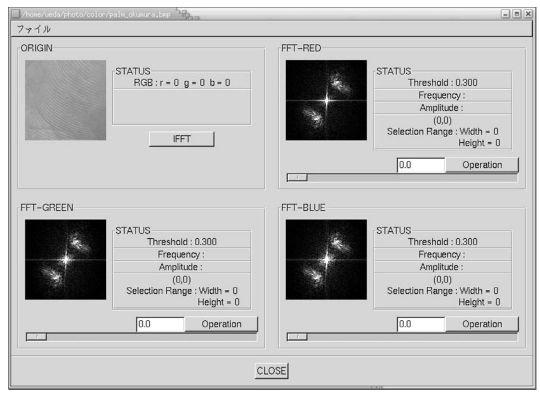


Figure 2. Image-processing tool for analyzing image components on 2D power spectrum.

Table 1 shows the frequency ranges of texture components in different parts of the human body. In the case of palm, the frequency ranges for blood spots and palm-prints are separable at the threshold value of 25 cycles. Although the ranges include individual difference, the threshold value for classification is almost fixed around 25. This result suggests that a palm image is decomposed into image components.

Table 1. Frequency Ranges of Texture Components

Part of the human body	Frequency range of texture component [cycles]			
	Internal texture component		Regular surface texture component	
	Min	Max	Min	Max
Palm	1	24	25	55
Arm	1	18	19	49
Back of hand	1	18	19	53

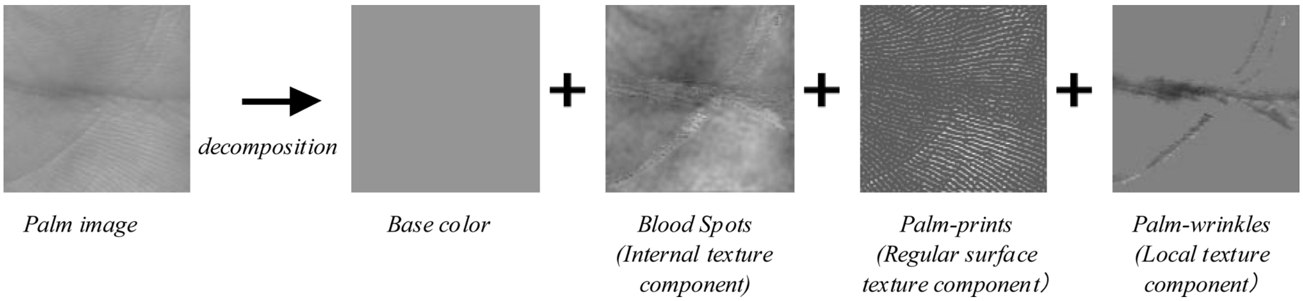
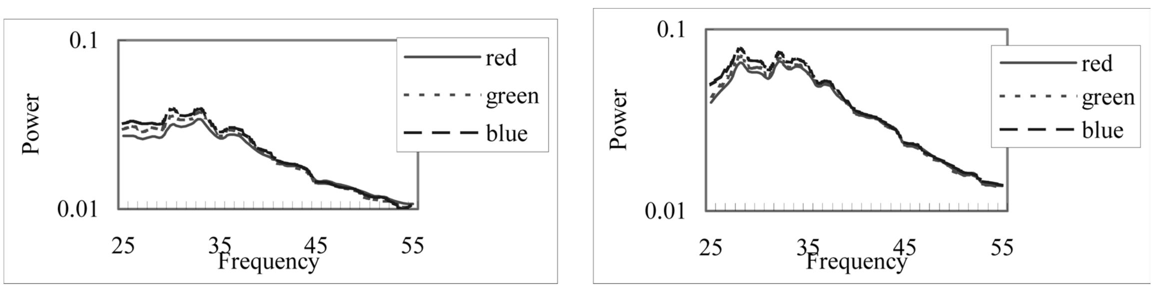


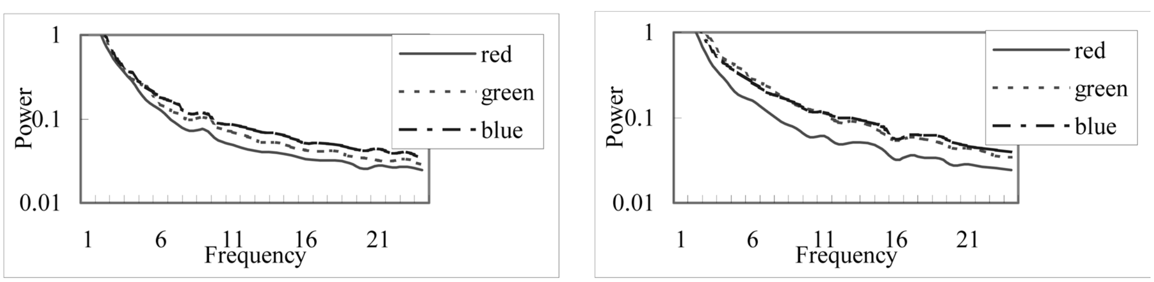
Figure 3. Image decomposition into four components.



(a) vague palm-prints

(b) clear palm-prints

Figure 4. Power spectrum of the palm prints



(a) vague blood spots

(b) clear blood spots

Figure 5. Power spectrum of the blood spots

Figure 3 represents a typical image decomposition of a palm image. First, the DC component with 0 cycles corresponds to the base color component. Second, the frequency range of less than 25 cycles corresponds to the blood spot component. Third, the frequency range between 25 and 55 cycles corresponds to the palm-print component. Fourth, the frequency higher than 55 is neglected as noise component. Fifth, the local texture has no periodicity and so is independent on frequency. Therefore this component was extracted by subtracting one part of skin image without the local texture from another part with the local texture.

Figures 4 and 5 demonstrate the power spectra of palm-prints and blood spots, respectively. The clearness of palm-prints depends on individual person. For instance, Figure 4 shows the difference between the clear palm-print of one person and the vague palm-print of another. We have found that the clear palm-print image has higher intensity values than the vague image in the range of 25-55 cycles. Figure 4 depicts three curves of RGB primaries. We see no color variation on the power spectral curves.

On the other hand, it is noted in Figure 5 that the blood spot texture has color variation on the power spectra. Comparison between the clear and vague spots suggests two features: (1) green and blue power spectra are higher than red power spectrum in any case, and (2) the power spectral intensities for green and blue increase as the clearness of the spots increases, while the red intensity is constant. These findings are very useful for synthesizing skin color images.

Synthesis of Skin Color Image

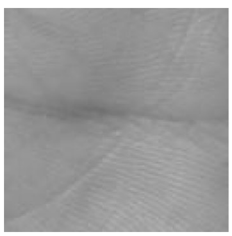
Realistic images of skin color textures under various conditions are synthesized on the basis of a linear combination of the four image components. A variety of skin images can be created by enhancing the components and exchanging the components with different person's components. The image synthesis can be described as the following equations.

$$\begin{aligned} C_{\mathrm{r}}' \cdot \mathbf{E} + \alpha \cdot \mathbf{S}_{\mathrm{r}} + \beta_r \cdot \mathbf{I}_{\mathrm{r}} + \gamma \cdot \mathbf{L}_{\mathrm{r}} &= \mathbf{M}_{\mathrm{r}} \\ C_{\mathrm{g}}' \cdot \mathbf{E} + \alpha \cdot \mathbf{S}_{\mathrm{g}} + \beta_g \cdot \mathbf{I}_{\mathrm{g}} + \gamma \cdot \mathbf{L}_{\mathrm{g}} &= \mathbf{M}_{\mathrm{r}} \\ C_{\mathrm{b}}' \cdot \mathbf{E} + \alpha \cdot \mathbf{S}_{\mathrm{b}} + \beta_b \cdot \mathbf{I}_{\mathrm{b}} + \gamma \cdot \mathbf{L}_{\mathrm{b}} &= \mathbf{M}_{\mathrm{r}} \end{aligned} \quad (2)$$

where a set of matrices ($\mathbf{M}_r$, $\mathbf{M}_g$, $\mathbf{M}_b$) denotes the RGB primaries of the synthesized image. The vector (C_r', C_g', C_b') is the base color vector for rendering a skin image. Change in the base color (C_r', C_g', C_b') can realize color change in lighting and color change in racial skin difference or even in individual skin difference. The scalar α is a weighting coefficient for enhancing the regular surface texture component. If α is set larger than one, the intensity of palm-prints is enhanced. The vector (β_r, β_g, β_b) is a weight for enhancing RGB primaries of the internal texture component. The blood spots are enhanced by increasing both values of green and blue, that is, setting β_g and β_b to larger than one and β_r to one. The scalar γ is a weighting coefficient for enhancing the local texture component. The intensity of palm wrinkles is enhanced with γ larger than one.

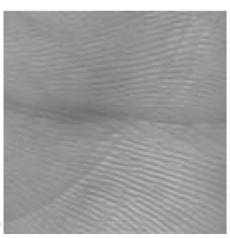
Figure 6 demonstrates a series of the synthesized images with different enhancements for the four image components. Figure 6 (b) represents the image with the base color brighter than the original. Figure 6 (c) represents the resulting image of palm-print enhancement with $\alpha = 2$. Figure 6 (d) represents the blood-spot enhanced image with (β_r, β_g, β_b) = (1, 1.5, 1.2). Figure 6 (e) represents the wrinkle enhanced image with $\gamma = 2$.

Figures 7 and 8 show the synthesized images for other parts of the human body, arm and back of hand. Figure 7 (b) and Figure 8 (b) represent the resulting images of fine wrinkles enhancement with $\alpha = 2$. The fine wrinkle is regular surface texture component. Figure 7 (c) and Figure 8 (c) represent the blood-spot enhanced images with (β_r, β_g, β_b) = (1, 2, 1.7).

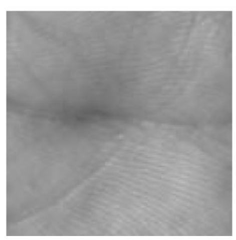


(a) Original image

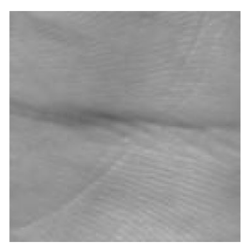
(b) Blighter base color



(c) Enhanced palm-prints



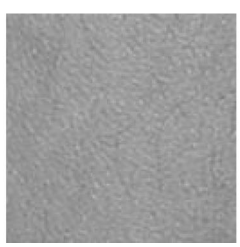
(d) Enhanced blood spots



(e) Enhanced wrinkles

Figure 6. Palm images synthesized with four different conditions.

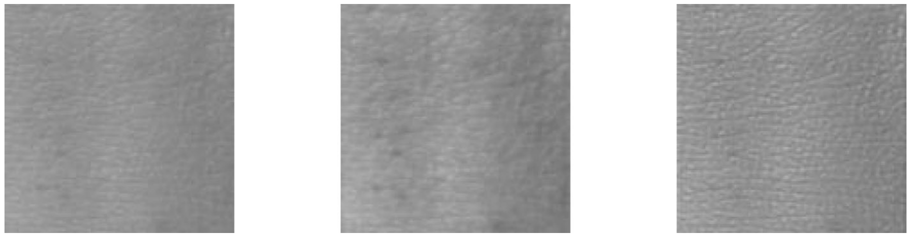
(a) Original arm image



(b) Enhanced fine wrinkles

(c) Enhanced blood spots

Figure 7. Synthesized and enhanced arm images.



(a) Original image of back of hand *(b) Enhanced fine wrinkles* *(c) Enhanced blood spots*

Figure 8. Synthesized and enhanced image of back of hand.

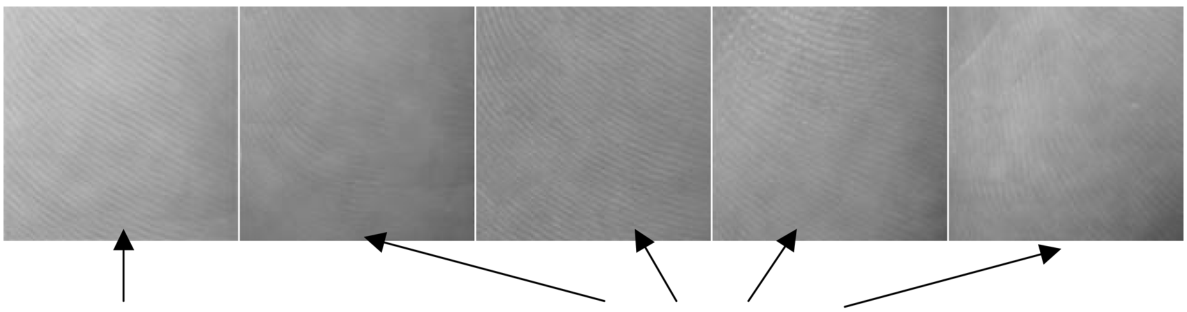


Figure 9. Palm images used in a visual experiment.

Visual Experiment

In order to confirm the validity of the synthesized skin images, a visual experiment was conducted using 13 subjects. First, we created a skin color image without wrinkles for a small portion on person's palm as the following way. The three components of base color, regular surface texture and internal texture were extracted from three different persons. These three component images with individual person's features were then combined artificially into a single skin color image.

Second, we measured the real skin image of the same portion on the palm for four different persons. Figure 9 shows a set of the synthesized image and the four real images. These images were presented to the subjects on a color display system. The subjects were asked to answer which image was a synthesized image, not real. Only one subject could show the correct answer. Such experimental results suggest the validity of the proposed method based on the frequency analysis and the reliability of the image rendering algorithms.

Conclusion

This paper has described a method for the analysis and synthesis of human skin color images with texture patterns. The method was based on the power spectral analysis in a frequency domain. We modeled the skin color image in a linear combination of the four components of (1) base color, (2) surface texture, (3) internal texture, and local texture. These texture components range in different frequency bands. Therefore the original skin images are separated into the components according to the corresponding frequency ranges. In image rendering, a skin color image is synthesized by a linear combination of the four image components. A variety of color images for human skin can be created by controlling the texture component. A visual experiment using synthesized palm images showed the reliability of the proposed method.

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Biography

Motonori Doi received his B.E. degree in Control Engineering from Osaka University in 1993. He received his M.E. and Ph.D. degrees in Information Science from Nara Institute of Science and Technology in 1995 and 1998 respectively. He was a research associate in Graduate School of Information Science at Nara Institute of Science and Technology during 1998-2001. Since 2001, he has been a lecturer in the Department of Telecommunication and Computer Networks at Osaka Electro-Communication University.