Color Enhancement in Multispectral Image Using the Karhunen-Loeve Transform

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We propose a new method for the color enhancement of multispectral image in the visible wavelength region. The purpose of the proposed method is to explore the weak features contained in a specific wavelength by discounting the major color distribution. Such examination will be valuable in visual inspection applications, for example, a medical examination using color image to find a small spectral change of an abnormal part. In this method, Karhunen-Loeve (KL) transform is applied to multispectral data, and specific wavelength components of only high-order KL coefficients are amplified while low-order coefficients are not changed to retain the major color distribution. In the experiment, this method was applied to multispectral images: a printed test image and a human skin image of a bruised arm were captured by a 16-band multispectral camera. The resultant images were compared with the images obtained by saturation enhancement and that obtained by applying the proposed method to the 3-band image. The method successfully visualized the features, which are almost invisible in natural color images, with less change in background color than saturation enhancement.

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Key words: color enhancement, multispectral image, KL transform, color reproduction, human skin image

1. Introduction

Multispectral imaging techniques have recently been developed¹,² for the purpose of natural color reproduction, in which high fidelity color reproduction becomes possible even if the illumination environment is changed. Moreover, information invisible in visible light spectra can be captured in a multispectral image, and the visualization method of such information is required to make use of digital imaging in visual inspection applications.

Visualization methods for multispectral image have been studied in the field of remote sensing. To provide distinction between specific objects, different feature components are mapped into different primary colors and displayed as a pseudo-color image.³ When such a visualization method is applied to a medical image, such as in dermatology, an indistinct lesioned part can be distinguished from normal parts when these parts are mapped into different colors. However, in diagnosis with color images, the normal skin color and the color change from normal are important information to evaluate the kind of lesion and its degree. For example, when the skin color is reddish, it is an indication that blood volume in the surface of the skin is increasing. The purpose of this paper is to provide a visualization method which enhances the color changes of the lesioned part from normal parts while keeping the color of the normal part unchanged. Since a multispectral image carries wavelength dependent information, it is valuable to visualize the spectral features. Thus we propose a technique for the multispectral image visualization with the enhancement of features contained in every wavelength band.

There have been proposed several methods for color enhancement, for example, saturation enhancement, histogram equalization in color space, and color laplacian,⁴-⁷ that enhance the color difference from a specific color. Color enhancement methods make it easy to distinguish a part with a small color change, in which the difference from white or the average color is often emphasized. If we apply a color enhancement method to a medical image such as human skin, however, not only the color of the lesioned part but also the normal part is emphasized since normal skin has small color variations in an image. Enhancement of normal color variation is undesirable in the observation. In this case, conventional methods enhance the colors of both the lesioned and normal parts, so that the lesioned part may be concealed by changes color in the normal part. For the skin color analysis, an image synthesis method based on pigments has been proposed,⁸,⁹ in which the amount of a specific pigment is varied without changing other pigment components. In contrast to the pigment-based method for color synthesis introduced in ref. 8, the proposed method aims at the visualization of indistinctive spectral features involved in a multispectral image, such as ambiguous skin lesions.

In the method proposed in this paper, the color feature, that is the deviation from the normal color variation, of a specific wavelength region, is enhanced with preserving the direction of color difference. For this purpose, the normal color variation is represented by Karhunen-Loeve (KL) vectors of the spectral data, and defined as a reference color variation. Then a certain wavelength component of the component deviated from the reference color variation is enhanced. The method will be useful for exploring hidden features of multispectral image, by visualizing various...
enhanced image with specifying different wavelength regions.

2. Method

2.1 Color image enhancement

First, we briefly review conventional color image enhancement methods in 3-dimensional color space. Saturation enhancement is often used for color images. In this method, an RGB image is converted to the color space involving the saturation component, such as LHS (luminance, hue, and saturation) color space. L, H, and S are defined as

\[
L = 0.3R + 0.59G + 0.11B
\]

\[
H = \theta + \cos^{-1}\left(\frac{N}{\sqrt{6(r-1/3)^2 + (g-1/3)^2 + (b-1/3)^2}}\right)
\]

\[
S = 1 - 3 \min(r, g, b),
\]

where

\[
r = \frac{R}{R+G+B}, \quad g = \frac{G}{R+G+B}, \quad b = \frac{B}{R+G+B}
\]

\[
N = 2r - g - b, \quad \theta = 0^\circ \quad (r, g \geq b)
\]

\[
N = 2g - b - r, \quad \theta = 120^\circ \quad (g, b \geq r)
\]

\[
N = 2b - r - g, \quad \theta = 240^\circ \quad (b, r \geq g)
\]

(2)

and \(\min(\bullet)\) is an operator for the minimum value. The enhanced saturation component is given by multiplying a factor larger than 1 to the saturation components, then enhanced color image is obtained by inverse transformation to RGB values.

Color laplacian method was also proposed where the enhancement processing is described as follows,

\[
\begin{pmatrix}
R' \\
G' \\
B'
\end{pmatrix} = \begin{pmatrix}
R \\
G \\
B
\end{pmatrix} + (1-k) \begin{pmatrix}
-2 & 1 & 1 \\
1 & -2 & 1 \\
1 & 1 & -2
\end{pmatrix} \begin{pmatrix}
R \\
G \\
B
\end{pmatrix}
\]

(3)

where \((R, G, B)^T\) and \((R', G', B')^T\) are the pixel values of original and enhanced images, respectively, and \(k\) is a magnification factor. Let us examine eq. (3) in detail to prepare for the explanation of the proposed method. The last term, which means enhancing saturation component, can be rewritten as

\[
\begin{pmatrix}
R' \\
G' \\
B'
\end{pmatrix} = \begin{pmatrix}
R \\
G \\
B
\end{pmatrix} + (1-k) \begin{pmatrix}
1 & 1 & 1 \\
1 & 1 & 1 \\
1 & 1 & 1
\end{pmatrix} - 3 \begin{pmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1
\end{pmatrix} \begin{pmatrix}
R \\
G \\
B
\end{pmatrix}
\]

\[
= f + (1-k)3(Af - f)
\]

\[
= f + k'(w - f),
\]

where

\[
w = Af
\]

\[
k' = 3(1 - k).
\]

In eq. (4), \(w\) indicates the achromatic (white) component of \(f\), and only the chromatic component is enhanced. In other words, the achromatic component of \(f\) is considered as a reference color, and the difference from the reference color is magnified [Fig. 1(a)]. Since the reference color is determined for each pixel as \(R + G + B\), only the saturation

![Fig. 1. The schemes of enhancement processing: (a) saturation enhancement, (b) enhancing difference from average color, and (c) enhancing specified wavelength in the color difference from major color distribution in multispectral image.](image-url)