Extracting Reflection Components of Glossy Woven Fabrics with High Dynamic Range Image

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Abstract This paper describes a method of estimating the color vectors of the body and the interface reflection component of glossy woven fabrics based on the color histogram analysis of a local region. We choose the homogenous colored polyester satin as objective glossy fabrics. We fix woven fabrics on the surface of a side of cylinder and acquire images, which consist of both regions with highlights and with no highlights, with different amount of exposure. We then generate a high dynamic range image from a set of acquired images of multiple exposure time. In the local region, the body reflection is constant but the interface reflection varies with the microscopic roughness. Therefore, the distribution of the color cluster of the local region is linear. We estimate the color vectors based on the linearity of the color cluster distribution of a local region. We separate the body and the interface reflection component from the original image of the objective polyester satin by means of the estimated color vectors.

1 Introduction

Recent advances in 3D visualization from research on computer graphics and computer vision have stimulated vigorous research on the digital recording of precious cultural assets and heritages for preservation, archiving and production of media content. Cultural assets include many costumes made of variety fabrics. Fabrics have unique characteristics owing to the materials, for example deformation, luster and feel. It is important in computer graphics and computer vision to reproduce realistically those qualities.

Generally, it is well known that reflected light contains the body reflection component and the interface reflection component [1,2]. The dichromatic reflection models have been used to create realistic images in computer graphics and remove the highlights from the image in machine vision. There are three type of the dichromatic reflection model: Type1 is the standard dichromatic reflection model for the inhomogeneous materials, Type2 is the extended dichromatic reflection model for cloth, Type3 is the extended dichromatic reflection model for metals [7]. The interface reflection color of inhomogeneous materials, such as plastics, is equal to the illumination color. In this case, a color histogram consists of two linear-distributed clusters which represent the feature of object color and highlights. The methods were proposed to estimate the color vectors of the body reflection component and the interface reflection component based on the feature of color histogram [3,4,5]. On the other hand, the interface reflection color of glossy fabrics is different from the illumination color [6,7]. The study has not adequately done for estimating the body and the interface reflection color of glossy fabrics from the image analysis.

In this paper, we propose a method of estimating the color vectors of the body and the interface reflection component based on a linearity of a color histogram of a local region. We use a cylinder to fix fabrics for obtaining the both of highlights part and object color part in the fabrics area. We acquire a set of images of multiple exposure time and generate a high dynamic range image [8]. We estimate the color vectors based on the linearity of a color histogram of a local regions. We then separate the reflection components from the original image based on the estimated color vectors.

2 Dichromatic Reflection Model

The reflected light from objects is the sum of the body reflection component and the interface reflection component, called dichromatic reflection model.

2.1 Standard Dichromatic Reflection Model

In case of inhomogeneous dielectric materials, such as plastic, the interface reflection color is equal to the illumination color. It is called standard dichromatic reflection model and described as follows [1]:

$$L(\theta,\lambda) = m_i(\theta)E(\lambda) + m_b(\theta)S_b(\lambda)E(\lambda)$$

where λ is over visible wavelength, θ is an angle parameter related to incident angle and viewing direction, $E(\lambda)$ is the spectrum distribution of the light source, $S_b(\lambda)$ is the spectral reflectivity of the body reflection component, $m_i(\theta)$ and $m_b(\theta)$, each of which is scaled according to the geometric reflection properties of the body and the interface reflection.

2.2 Extended Dichromatic Reflection Model

Glossy fabrics, such as silk, wool, satin and velour, have the interface reflection color which is different from the illumination color. The reflection is represented as extended dichromatic reflection model [7] and described as follows:

$$L(\theta,\lambda) = m_i(\theta)S_i(\lambda)E(\lambda) + m_b(\theta)S_b(\lambda)E(\lambda)$$

where $S_i(\lambda)$ is the spectral reflectivity of the interface reflection component.

2.3 Dichromatic Reflection Model in RGB color space

In the RGB color space, the body reflection component $S_b(\lambda)E(\lambda)$ describes as the color vector of the body reflection component $\mathbf{C_b}$, the interface reflection component $E(\lambda)$ or $S_i(\lambda)E(\lambda)$ describes as the color vector of the interface reflection component $\mathbf{C_i}$. Observed color vector $\mathbf{C}(x)$ which locates at x is described as follows:

$$\mathbf{C}(x) = m_i(x)\mathbf{C_i} + m_b(x)\mathbf{C_b}$$

where $m_i(x)$ and $m_i(x)$, each of which is scaled according to the geometric reflection properties of the body and the interface reflection. $\mathbf{C_i}$ is equal to the illumination color vector in the standard dichromatic reflection, but $\mathbf{C_i}$ is different from the illumination color vector in the extended dichromatic reflection. $\mathbf{C_b}$ and $\mathbf{C_i}$ define a hyper plane called dichromatic plane in the RGB color space. All color pixels of the object region distribute on this hyper plane.

3 Characteristics of the Color Histogram

3.1 Histogram Characteristics of Inhomogeneous Dielectric Materials

If an object is an inhomogeneous dielectric material and has a smooth convex surface, the color cluster forms a skewed L or a skewed T shaped linear distribution. Figure 1 shows an image of a green cup and a color histogram of a strip region of the image on the dichromatic plane. The color vectors are estimated based on line extraction using PCA or Hough transform [3].

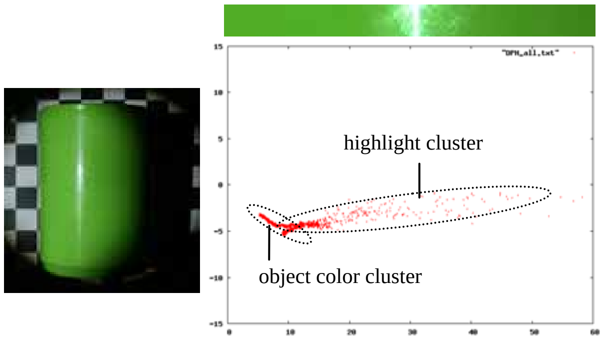


Fig. 1: Image of a green plastic cup and color histogram of a strip region

3.2 Histogram Characteristics of Glossy Woven Fabrics

The color cluster of glossy woven fabrics forms a planar cluster on the dichromatic plane. But its distribution is wider than that of inhomogeneous dielectric materials.

Figure 2 shows an image of cyan polyester satin fixed on the surface of a cylinder where the direction of the weft of the polyester satin is corresponding in the direction of the center axis of the cylinder and a color histogram of a strip region of the image on dichromatic plane. Figure 3 shows an image of cyan polyester satin fixed on the surface of a cylinder where the direction of the warp of the polyester satin is corresponding in the direction of the center axis of the cylinder and a color histogram of a strip region of the image on dichromatic plane. Figure 4 shows a color histogram of a local region of Figure 2.

As shown in Figure 2, when the direction of the weft of the polyester satin is corresponding in the direction of the center axis of the cylinder, we can observe strong highlights at the specific region. As shown in Figure3, when the direction of the warp of the polyester satin is corresponding in the direction of the center axis of the cylinder, we can see the highlights over the whole fabrics surface. This is caused by the anisotropic reflection characteristic of woven fabrics by the shape of the string and the weaving structure. Figure 5 shows a schematic view of the woven fabrics section fixed to the cylinder. As shown in Figure 5 left, the warp curves along the surface of the cylinder when the direction of the weft accords with the direction of the center axis of the cylinder. Therefore, the surface of the woven fabrics is similar to smooth surface. Therefore the highest interface reflection occurs at the same position of inhomogeneous dielectric materials. On the contrary, when the direction of the warp accords with the direction of the center axis of the cylinder, as shown in Figure 5 right, the sections of the strings line up along the surface of cylinder. The interface reflection is caused not due to the surface normal of the cylinder but due to the surface normal of the strings.

As shown in Figure 2 and 3, the color cluster is distributed widely on the dichromatic plane. Conventional methods based on line detection are unsuitable for such a color histogram.

As shown in Figure 4, the color cluster of a local region is distributed linearly when the direction of weft of woven fabrics is collinear to the direction of a center axis of the cylinder. Woven fabrics have a microscopic roughness on the surface due to the shape of the string and the weaving structure. We assume that the body reflection is constant in the local region. The interface reflection of different size, which varies with the distribution of microfacets of the surface, is added to the constant body reflection component, therefore the distribution of the color histogram of a local region become linear. Over the cylinder surface, the size of body reflection component changes according to the geometry of the surface of the cylinder. The color cluster of the entire glossy woven

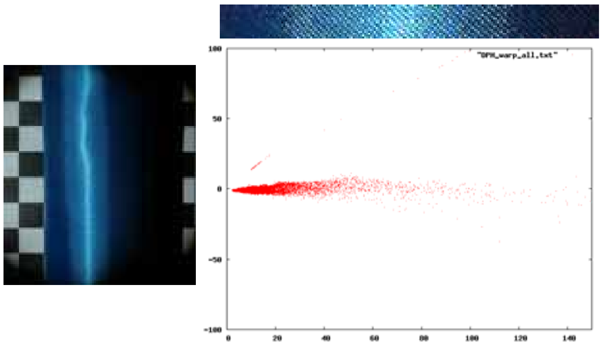


Fig. 2: Image of cyan polyester satin and color histogram of a strip region (Weft direction is collinear to the cylinder center axis)

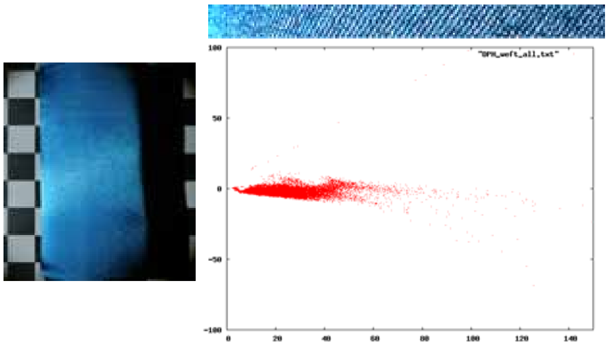


Fig. 3: Image of cyan polyester satin and color histogram of a strip region (Warp direction is collinear to the cylinder center axis)

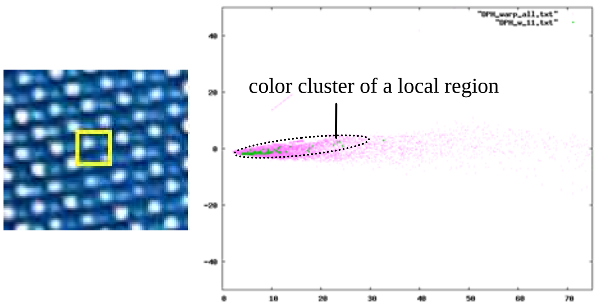


Fig. 4: Color histogram of a local region

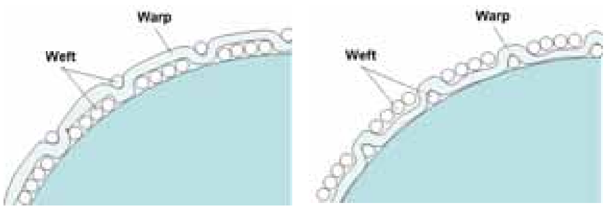


Fig. 5: Schematic view of the woven fabrics section fixed to the cylinder

fabrics over the cylinder surface widely is distributed on the dichromatic plane.

4 Proposed Method

We assume that the distribution of the color histogram of a local region indicates the direction of the interface reflection color vector. We estimate the interface reflection color vector from color histograms of local regions over the selected woven fabrics area. Next, we determine the body reflection color vector from the distribution of the color cluster of extracted pixels which only have the body reflection component. The steps of the proposed method are shown as follows.

① Detection of the dichromatic plane

Dichromatic plane is determined by PCA of the selected strip woven fabrics area. The average of pixel value $\mathbf{C}_{avg}$ and the variance-covariance matrix $\mathbf{S}$ defines as follows:

$$\mathbf{C}_{avg} = \frac{1}{N}\sum \mathbf{C}(x)$$

$$\mathbf{S} = \frac{1}{N}\sum (\mathbf{C}(x) - \mathbf{C}_{avg})(\mathbf{C}(x) - \mathbf{C}_{avg})^T$$

where N is the number of pixels. The eigenvalue λ_1, λ_2, λ_3 ($\lambda_1 \geqq \lambda_2 \geqq \lambda_3$) and the eigenvector $\boldsymbol{v}_1$, $\boldsymbol{v}_2$, $\boldsymbol{v}_3$ are obtained from eigenvalue decomposition. We can verify from $\lambda_1 + \lambda_2 \geqq \lambda_3$ that the color cluster spread in the two dimensions which is defined by the eigenvector $\boldsymbol{v}_1$ and $\boldsymbol{v}_2$. This means that the eigenvector $\boldsymbol{v}_1$ and $\boldsymbol{v}_2$ is the axis of the dichromatic plane. All pixels in the selected woven fabrics area are projected to this dichromatic plane by following equation using the conversion matrix [$\boldsymbol{v}_1$, $\boldsymbol{v}_2$].

$$\begin{bmatrix} c_1 \\ c_2 \end{bmatrix} = [\mathbf{v}_1, \mathbf{v}_2]^T \mathbf{C}(x)$$

② Estimation of the color vector of interface reflection component

The color cluster distribution of a local region indicates the direction of the interface reflection color vector. We calculate the first eigenvector $\boldsymbol{u}_{1\_i}$, where the center pixel of a local region locates at i on the horizontal axis, by PCA of a local region over the strip woven fabrics region. The color vector of the interface reflection component is obtained from the average of the first eigenvectors $\boldsymbol{u}_{1\_i}$.

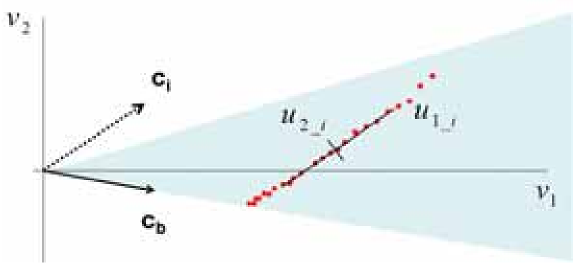


Fig. 6: Linearity of the color histogram of a local region

③ Estimation of the color vector of body reflection component

Next, we extract the pixels which only have body reflection component. There are pixels with highlight and no highlights in a local region because of the weaving structure. We calculate the value of the weighted filter defines as follows:

$$G = \sum_l \sum_k \omega_{k,l}(y_{k,l} - y_{avg})$$

where k, l show the location of weighted filter, $y_{k,\,l}$ is the intensity at (k, l), y_{avg} is the average of the intensity of near-field region and $\omega_{k,\,l}$ is the weighted value at (k, l). The value G means how bright the pixel is compared with the near-field region. We get the pixels which have little interface reflection component to extract the subthreshold pixels from the strip region.

Extracted pixels are projected to the dichromatic plane and carried out PCA. The first eigenvector $\boldsymbol{w}_1$ indicates the color vector of the body reflection component.

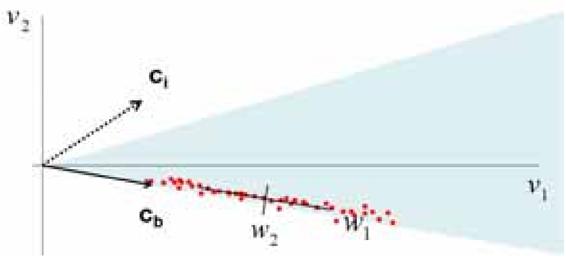


Fig. 7: Body reflection color vector in the distribution area

5 Experiments

5.1 Experimental Environment

The experiments were conducted using the polyester satin as glossy woven fabrics, Xenon ramp and a CCD camera: EOS Kiss Digital X. We winded the objective polyester satin onto the surface of a cylinder which has a diameter of 52 mm where the direction of the weft accords the direction of the center axis of the cylinder and placed on a table covered with a black paper. The xenon lamp was placed about 50 cm away from the object. The angle between the illumination and the normal line of a table was about 30°. The camera was placed 38 cm away just above the object. We captured the images by setting ISO-100 and f/8.0 and changing the shatter speed 1/5, 1/10, 1/20, 1/40. We then generated a high dynamic range image from a set of images of multiple exposure time.

5.2 Experimental Result

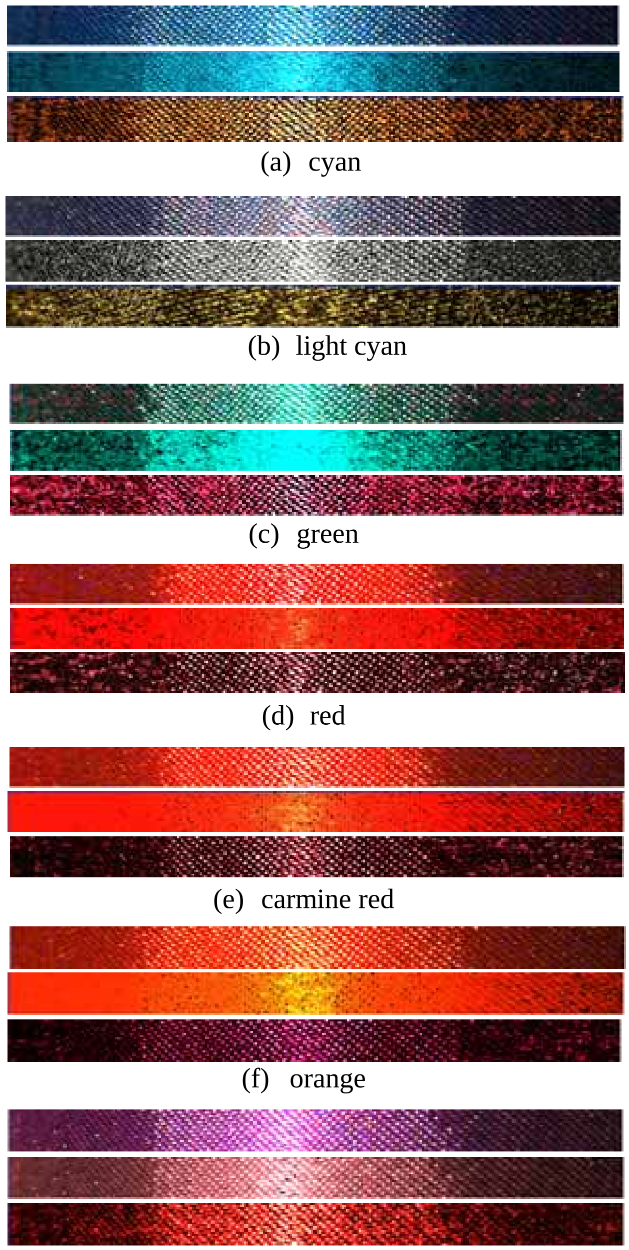
We applied our approach to 7 color polyester satin. The strip region had the height of 50 pixels and the width of 600 pixels. The size of local region was 11×11 pixels. Table 1 shows the result of the estimated color vectors of the body and the interface reflection component. Figure 8 shows the results of separating the reflection components based on the estimated color vectors. The body reflection components are divided from the highlights region on cyan, green, red, carmine red and orange. But the separation is not enough on light cyan and purple. The body reflection component color is a little different from the original image on cyan, light cyan and purple to the eye. This is caused by the insufficient extraction of the pixels which only hold the body reflection components.

6 Conclusion

We proposed the novel method of color vector estimation for glossy woven fabrics by using the linearity of the color histograms of local regions. A high dynamic range image was generated from a set of images of the multiple exposure time, which consist of object color and highlights parts on the cylindrical surface to take the camera responsibility into

Table 1: Result of estimated color vectors

	$\mathbf{C}_i$ = [R, G, B]	$\mathbf{C}_b$ = [R, G, B]
Cyan	0.923, 0.365, 0.126	0.049, 0.624, 0.780
Light cyan	0.787, 0.583, 0.200	0.584, 0.560, 0.547
Green	0.973, 0.110, 0.205	0.001, 0.776, 0.631
Red	0.944, 0.221, 0.244	0.999, 0.048, 0.022
Carmine red	0.969, 0.154, 0.194	0.997, 0.072, 0.027
Orange	0.981, 0.032, 0.192	0.989, 0.143, 0.015
Purple	0.992, 0.098, 0.075	0.842, 0.366, 0.397



(a) cyan

(b) light cyan

(c) green

(d) red

(e) carmine red

(f) orange

(g) purple

Fig. 8: Result of separating reflection components (top: original HDR image, middle: image of the body reflection component, bottom: image of the interface reflection component)

consideration. We supposed that the color cluster of a local region was distributed linearly because the body reflection was constant and the interface reflection varied with the microfacet distribution of woven fabrics in local region. We estimated the color vectors based on the linearity of color histograms of local regions. We then separated the reflection components based on the estimated color vectors.

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