Elimination of Highlights using RGB Color Distribution and Image Position

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Abstract

We propose two algorithms for performing highlight elimination from color images. The first algorithm is based on analyzing the spatial distribution of a surface's color in RGB space, and the second algorithm uses mostly image space information. For the second algorithm we assume the imaged surface to be a cylinder; the first algorithm is able to eliminate highlights from images of surfaces of arbitrary shape. Advance knowledge of the intensity or direction of the illumination, or the surface's diffuse or specular reflectances is not required.

Introduction

Highlights on surfaces with specular reflectivity are an obstacle to achieving satisfactory results for many image processing tasks, and for a certain class of problems, highlights render exact solutions impossible. In stereo vision, for example, errors due to highlights occur because the positions of highlights on photographs of a surface differ in the left and right images, resulting in quite large errors of computed disparities in highlight areas. It is therefore desirable to eliminate highlights from images before further image processing is performed.

In the past, several methods for estimating the set of parameters of reflection models based on color measurements have been reported.[1,2] These methods may be used for eliminating highlights as well, but in general their purpose differs from the goal of highlight elimination. In this paper, we first analyze the highlight problem by examining synthetic images that were generated by simulating the imaging process based on Phong's reflection model and then we derive two efficient and effective algorithms for performing highlight elimination from color images.

The first algorithm is based on analyzing the spatial distribution of a surface's color in RGB space, without paying attention to image space information. The second algorithm, by contrast, uses mostly image space information such as the position of highlights and the relative positions of surface parts. For this algorithm we assume the imaged surface to be a cylinder (or a sphere), whereas the first algorithm is able to eliminate highlights from images of arbitrarily shaped surfaces. Advance knowledge of the intensity or direction of the illumination, or the surface's diffuse or specular reflectances is not required for either algorithm. The effectiveness of both algorithms is demonstrated for both synthetic and real images.

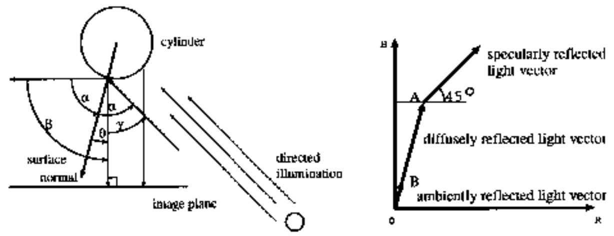
Highlight Elimination Based on Color Distribution in RGB Space

In this section the algorithm based on analyzing the color distribution in RGB space is developed.

Assumptions and Reflection Model

We make the following **Assumptions**:

1. As test object we assume a cylindrical surface whose major axis is orthogonal to the optical axis of the camera.
2. The illumination consists of two kinds of light rays: (a) a field of parallel light rays of a given direction (directed illumination), and (b) a field of light rays of random directions (ambient illumination). Directed illumination is assumed to be white, and ambient illumination may be of any color, but usually it would be white or colored but with very low saturation.
3. The direction of the directed light ray field is assumed to be in the range $-90° < \gamma < +90°$ (see Figure 1a).
4. The reflective properties of the cylindrical surface are approximated by Phong's reflection model.
5. The viewpoint is at infinity in a plane orthogonal to the major axis of the cylinder (i.e. orthogonal projection onto an imaging plane parallel to the cylinder's major axis). The restriction to a cylindrical surface is actually not required for this method since it works exclusively in RGB space, but the development of the algorithm is simplified by this restriction.



(a) Imaging geometry *(b) Vector sum in RGB space*

Figure 1.

When using Phong's model, the light reflected from the cylindrical surface and its environment is the sum of a term for an ambiently reflected light portion, a term for a diffusely reflected light portion, and a term which models the specularly reflected portion of light.[3,4] Denoting the total reflected light by a vector $\vec{I}_0 = [r,g,b]^T$, the diffuse reflectances (the body color) by a vector $\vec{\rho} = [\rho_r, \rho_g, \rho_b]^T$, the specular reflectance by a vector $\vec{\rho}_s = [\rho_{sr}, \rho_{sg}, \rho_{sb}]^T$, and using the geometric variables shown in Figure 1(a), the total reflected light can be expressed as

$$\vec{I}_0 = \vec{\rho} \cdot \left|\vec{I}_a\right| + \frac{\vec{\rho} \cdot D(\alpha) + \vec{\rho}_s \cdot S(n,\beta)}{2} \cdot \left|\vec{I}\right| \qquad (1)$$

where

$$D(\alpha) = \begin{cases} \cos(\alpha), & if \ |\alpha| < 90° \\ 0, & if \ |\alpha| \geq 90° \end{cases} \qquad (2)$$

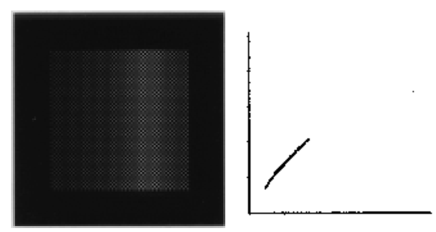
and

$$S(n,\beta) = \begin{cases} \cos^n(\beta), |\beta| < 90° \ \ AND \ \ |\alpha| < 90° \\ 0, \quad |\beta| \geq 90° \ \ OR \ \ |\alpha| \geq 90° \end{cases} \qquad (3)$$

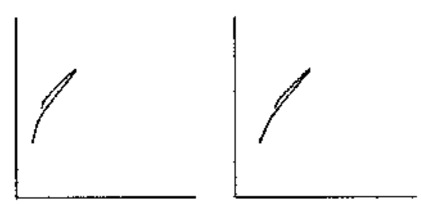
($|\vec{I}_a|$): intensity of ambient illumination; $|\vec{I}|$: intensity of directed illumination; *n:* a variable that correlates with the inverse of the surface's roughness; (α and β: angles as given in Figure l(a).

Analysis of the Color Distribution in RGB Color Space

An example of orthogonal projections of the color distribution of the light reflected from the cylindrical surface onto the RG-, RB-, and GB-planes of RGB color space are shown in Figure 2. The form of this spatial distribution results from the additive combination of the three terms in the Phong reflection model, as is illustrated by the sum of projected vectors in Figure 1b. If we assume the ambient illumination to be white and the ambient reflectances to coincide with the diffuse reflectances, the direction of the ambiently reflected light vector coincides with the direction of the diffusely reflected light vector. Because we assume the specular reflectances as $\rho_{sr} = \rho_{sg} = \rho_{sb} = \rho_s$ and the directed illumination as white, the direction of the specularly reflected light vector is given by 45° on all three projection planes. For any given pixel's color, we denote the point where the specularly reflected light vector begins as point A, and the point where the diffusely reflected light vector begins as point B in RGB space (Figure 1b). Eliminating highlights (i.e., the specularly reflected light portion) from a cylindrical surface is equivalent determining point A in RGB space. Point A may be found as the intersection of the straight line along the direction the diffusely reflected light vector and the line along the specularly reflected light vector. These two straight lines may be determined from their projections onto the RG-, RB-, and GB-planes.



(a) Highlight on surface (γ = 45o) (b) RG plane



(c) RB plane *(d) GB plane*

Figure 2. Surface and projections of RGB space

The direction of the line along the specularly reflected light vector is given *a priori* as 45° on each projection plane, and the line passes through the pixel's color point in RGB space (called *specularity line).*

The line along the diffusely reflected light vector passes through the origin of the RGB coordinate system and forms one of the boundaries to the projected spatial distribution, as is shown in Figure 3. Thus an iterative search procedure for determining the line's direction may be used, as illustrated in Figure 3. A *search line* is initialized along one of the coordinate axes and is rotated around the coordinate origin until the point distribution's boundary (called *boundary line*) is reached.

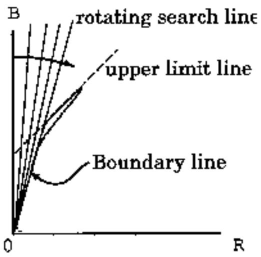


Figure 3. Search for the distribution's boundary.

The criterion for deciding at which rotation step the boundary has been reached is based on computing the integral over the projected point distribution along the search line, as it is rotated. When the integral value shows significant increase, the boundary line is reached *(boundary line criterion).*

For deciding to which coordinate axis the search line should be initialized, the following method is effective: First, the *upper limit line* to the spatial distribution's projection is determined. It has the same direction as the specularly reflected light vector's projection (i.e., 45°) and is the top boundary of the spatial distribution. The search line is initialized to the coordinate axis that is intersected by the upper limit line *(initial search line criterion).*

Highlight Elimination Algorithm using Only RGB Space Information

Highlight Elimination Algorithm I

1. Compute the following steps (a) - (c) for all three projections of the color point distribution onto the RG-plane, RB-plane, and GB plane:
   a. For a sample image, compute the projection the RGB spatial point distribution onto the selected projection plane.
   b. Initialize the search line to the coordinate axis indicated by the initial search line criterion.
   c. Determine the boundary line through iterative search that rotates the search line around the coordinate origin until the boundary line criterion is satisfied.

2. Execute the following steps (a) - (d) for each pixel of the cylindrical surface's image.
   a. Select the next pixel and determine the pixel's RGB-value.
   b. If $R = G = B = 0$. then go to step (2).
   c. Execute the following steps (i) - (iii) for each projection plane (RG, RB, GB)
      i. Project the pixel's color point onto the selected plane.
      ii. Determine the specularity line through the projected color point (45° dir.)
      iii. Determine the intersection A between specu larity line and boundary line.
   d. Compute the average of the two R-values, the two G-values, and the two B-values found in step (2-c-iii) for the coordinates of color point A. Save the averages of the R, G, B values as the highlight-deleted color of the selected pixel.

3. Exit.

Highlight Elimination Based on Geometric Relations in Image Space

In this section we develop a method for highlight elimination which relies on the estimation of positional information in image space.

This method is more constrained than the first one in the sense that it explicitly uses the shape of the surface. On the other hand, the assumption of white illumination is relaxed to allow both the ambient and the directed light illuminating the scene to be colored. In order to accommodate these changes, the form of Phong's equations has to be altered. It is convenient to define the following equivalences:

$$\vec{I}_0 = [r, g, b]^T, \vec{\rho} = [\rho_r, \rho_g, \rho_b]^T, \vec{\rho}_s = [\rho_{sr}, \rho_{sg}, \rho_{sb}]^T.$$

We also define the operator '*' by the equivalence $[a1, a2, a3]^T * [b1, b2, b3]^T = [a1 \cdot b1, a2 \cdot b2, a3 \cdot b3]^T$ and express Phong's reflection model as

$$\vec{I}_0 = \vec{\rho} * \vec{I}_a + \frac{\vec{\rho} \cdot D(\alpha) + \vec{\rho}_s \cdot S(n,\beta)}{2} * \left|\vec{I}\right| \tag{4}$$

where $D(\alpha)$ and $S(n,\beta)$ are given by Equation (2) and (3), and the geometric variables are shown Figure 1a. The following two relations involving the angles can be derived:

$$2 \cdot \alpha = \beta + \gamma \tag{5}$$

$$\alpha = \theta + \gamma \tag{6}$$

This method needs the following information which must be extracted from the image of the cylindrical surface (using the a priori knowledge that the colored image region is indeed the cylindrical surface's region): (1) the cylinder's diameter (width of the colored region), (2) the location of the cylinder's major axis, (3) the length of the minimal RGB vector of any pixel on the surface ($\vec{I}_{0min}$), and (4) the length of the maximal RGB vector of any pixel on the surface ($\vec{I}_{0max}$ highlight position).

This information is used to determine the first and second terms of Equation (4). The first term $\vec{\rho} * \vec{I}_a$ can be found when the terms of Equations (2) and (3) are equal to zero. This is the case for pixels on either the right or left edge of the cylinder's region. In this case Phong's equation (4) is reduced to

$$\vec{I}_{0min} = \vec{\rho} * \vec{I}_a \tag{7}$$

Next, we determine the second term of Equation (4). First, angle γ is determined from the location of the highlight on the cylindrical surface. Assuming the brightest highlight locations to be at the brightest pixels, the imaging geometry of Figure 4 holds, giving the relation:

$$\gamma = 2 \cdot \alpha = 2 \cdot (-\theta) \tag{8}$$

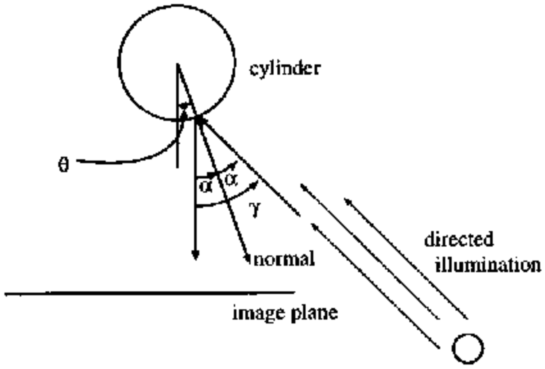


Figure 4. The imaging geometry for the highlight's brightest location.

Since the location of the highlight's brightest point occurs at angle θ in Figure 4, θ must be computed using the cylinder's diameter and the brightest highlight point. From Equation (8) the direction of the directed illumination can then be computed as angle γ. Next, in order to determine the second term in Phong's equation, we need the third term to equal zero. By Equation (3), this happens when $\beta \geq 90°$. Therefore, we need to determine the point(s) on the surface for which $\beta \geq 90°$ and then express that location by angle $\alpha_{(\beta \geq 90°)}$ using γ and Equation (5). After having found $\alpha_{(\beta \geq 90°)}$ Phong's equation is reduced to

$$\vec{I}_{(\beta=90°)} = \vec{I}_{0\,\min} + \frac{\vec{\rho} * \vec{I}}{2} \cdot \cos\left(\alpha_{(\beta \geq 90°)}\right) \quad (9)$$

$\vec{I}_{(\beta=90°)}$ and $\vec{I}_{0min}$ can be measured from the image, and the cos-term can be computed because $\alpha_{(\beta \geq 90°)}$ is already known. Therefore, the coefficient of $\cos(\alpha)$ ($\vec{I}_{0diff}$) is given as

$$\vec{I}_{diff} = \frac{\vec{\rho} * \vec{I}}{2} = \frac{\vec{I}_{(\beta=90°)} - \vec{I}_{0\,\min}}{\cos\left(\alpha_{(\rho \geq 90°)}\right)} \quad (10)$$

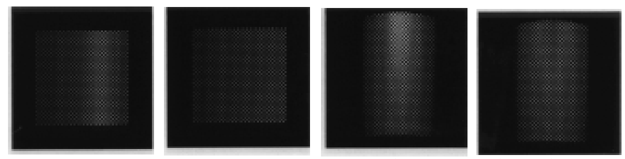
Since the ambiently reflected light portion $\vec{I}_{0min} = \rho * \vec{I}_a$ and the coefficient I_{diff} of the diffusely reflected light portion are known, it becomes possible to compute the combined ambiently and diffusely reflected light portion (i.e. excluding the specular portion):

$$\vec{I}_{in} = \vec{I}_{0\,\min} + \vec{I}_{diff} * \cos(\alpha) \quad (11)$$

The variable in this equation is the angle α (the angle between light source direction and surface normal at a given surface point). Highlight elimination is based on Equation (11).

Experimental Results

Both algorithms were tested on both ideal and real images. The ideal images were generated computationaly by using Equations (1) - (3), and an example is shown in Figure 5. The real images are photographs of a cylindrical surface with both diffuse and specular reflection properties; these images were taken in a darkroom experimental set-up. In both cases, both algorithms were able to eliminate the highlights on the cylindrical surfaces satisfactorily.



(a) Ideal image: original *(b) Ideal image: deleted highlight* *(c) Real image: original* *(d) Real image: deleted highlight*

Figure 5. Result of highlight elimination

Conclusion

We presented two algorithms for performing highlight elimination from color images based on Phong's reflection model. The first algorithm utilizes properties of the spatial distribution of a surface's color in RGB space, and the second algorithm uses mostly image space information. For this algorithm we assume the imaged surface to be a cylinder (or a sphere), whereas as the first algorithm is able to eliminate highlights from images of surfaces of arbitrary shape. Advance knowledge of the intensity or direction of the illumination, or the surface's diffuse or specular reflectances is not required for either algorithm. Both algorithms perform well on both synthetic and real images.

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References

1. C. L. Novak and S. Shafer, A method for estimating scene parameters from color histograms, *Proc. of CVPR*, pp. 153-158, Seattle (1994).
2. J. Nishitsuji and S. Tominaga, A method for estimating the parameters of a reflection model, *Technical Report of the Institute of Electronic, Information and Communication Engineers*, Tokyo, PRU95-207, pp. 69-74 (1996). (in Japanese).
3. Bui-Tong, Phong, Illumination for computer-generated pictures, *Communications of the ACM*, **18** (6), pp. 311-317 (1975).
4. J. D. Foley and A. van Dam, Fundamentals of interactive computer graphics, Addison-Wesley Publishing Company (1984).