Recovery of Reflectance Properties for Merging Multiple 3D Scans

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Abstract

We present a method to merge multiple scans of a 3D object, which exhibit color variation in the overlapped regions. Our method attempts to recover the reflectance properties of the object from the color image of each view. Then we use the recovered reflectance properties to produce a more consistent color blending in the overlapped regions. The recovered reflectance properties can also be used to apply different lighting to the acquired 3D model. Our method differs from previous works by allowing the object colors to vary across the surfaces and by allowing each scan to have a different light source position.

1. Introduction

In computer graphics, the accuracy of the 3D models plays an important role in the quality of the final rendering. Since the manual process of constructing those 3D models is time consuming and requires artistic skills, using 3D scanning devices to automatically acquire the 3D models of interesting objects has become a popular approach. Many 3D scanning devices today are capable of acquiring the 3D shapes of objects as well as their surface colors [6][2]. Usually, multiple scans are taken from various viewing directions, and then those individual scans are merged and registered to each other to produce a complete 3D model [4].

Here we face a problem: what should we do if the colors of the overlapped regions do not agree with each other? A straightforward solution is to take a weighted average of the observed colors. However, the observed colors represent the reflected radiance of the surface. For example, the specular highlights could appear in different places when the viewpoint or the light source position changes. Furthermore, the observed color could vary due to noises or other errors in the scanning devices (see [6], Section 4.2). So, a more sensible approach would be to factor out the view-dependent lighting effects and recover the underlying material colors. Ideally, the recovered material colors from different viewing angles would agree with each other in the overlapped regions. If not, taking the average of those recovered material colors still makes more sense than simply taking the average of the observed colors.

Figure 1: An example data set that contains 3D scans from 8 different viewing angles.

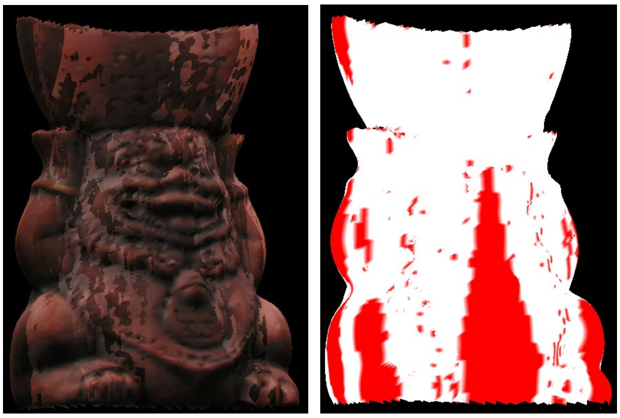

Figure 2: (Left) The 8 scans in Figure 1 are registered to each other geometrically but no processing is done in their colors. (Right) The regions where multiple scans overlap are displayed in white.

So, the problem we are facing is actually how to model and recover the reflectance properties of the observed objects. Our reflectance modeling method differs from previous methods due to the limitations of the acquisition process, which has the following characteristics:

1. 3D scans and color images are acquired from only a few viewing angles. For example, Figures 1 and 2 show an input data set that contains 3D scans from 8 different angles.
2. The object surfaces are not limited to Lambertian surfaces. Therefore, the specular highlights may appear in different places when the view changes.
3. The object surfaces contain heterogeneous colors. In other words, the material color may vary across the surface.
4. The light source may be moved to a different position at each scan.

The 3D scanning device we use in this work is the Portable 3D Scanner built by the Industrial Technology Research Institute in Taiwan. However the above listed characteristics apply not only to our system, but to many other similar systems as well.

In the next section, we discuss the related work and explain why they cannot be applied to our system.

2. Related Work

The reflectance modeling problem is a topic that has obtained great attention in computer graphics. For example, Ward introduced a simple reflectance model and a novel reflectometry device to measure the reflectance of real surfaces [9]. Ward's method requires a sample patch to be taken from the object surface, thus is not applicable to the 3D scanning process in general.

More recently, Sato and Ikeuchi used color images that were taken from hundreds of viewing angles to obtain the reflectance model of an object [8]. For each surface sample, they constructed a response curve of the radiance versus various viewing angles. Using the response curves, they were able to separate the specular and diffuse components of the reflected colors. However their method cannot be applied to our 3D scanning system, which acquires images from much fewer angles. (See item 1 of the characteristics of the acquisition process listed in Section 1)

Boivin et al. [1], Yu et al. [10] and Nishino et al. [7] proposed methods to recover the reflectance models from just a sparse set of images. In fact, Boivin's method requires only a single image. In order to obtain enough information of the reflected radiance under different viewing directions, both Yu's and Boivin's works assume a surface sample shares the same reflectance properties with nearby surface or a cluster of other surface samples. In a sense, forming clusters of surface samples that share the same reflectance properties makes up for the deficits of using fewer images. However, forming clusters of samples from nearby surfaces becomes difficult when the object surfaces contain heterogeneous colors. (See item 3 of the characteristics of the acquisition process listed in Section 1.) In the work by Nishino et al., they handle the heterogeneous surface colors by decomposing the input images into a diffuse component (which they call the global texture) and a specular component. For each surface point, the diffuse component may be obtained by taking the minimal pixel value from multiple observations, because they assume the light source is fixed. In our work, however, each input image may be taken with a different light source position. (See item 4 of the characteristics of the acquisition process listed in Section 1.)

Merging multiple 3D scans and their color images is a common problem in image-based modeling and rendering, which has been discussed in [3][5][6]. A common technique is to adjust the weights for blending the pixels near the edges to ensure smooth transition between the boundary of two different views.

3. Recovery of Reflectance Properties

Our method of merging multiple 3D scans relies mainly on the recovery of reflectance properties of each individual scan. The reflectance model we use is the Phong illumination model:

$$I = Ka + Kd*(N \cdot L) + Ks*(N \cdot H)^n$$

where I is the reflected intensity, N is the surface normal, L is the lighting direction, H is the half vector between the viewing direction and the lighting direction, and (Ka, Kd, Ks, n) are the ambient, diffuse and specular reflectance parameters to be recovered.

Similar to [10], we assume that the specular parameters Ks and n are uniform within the surface of each scan. To avoid

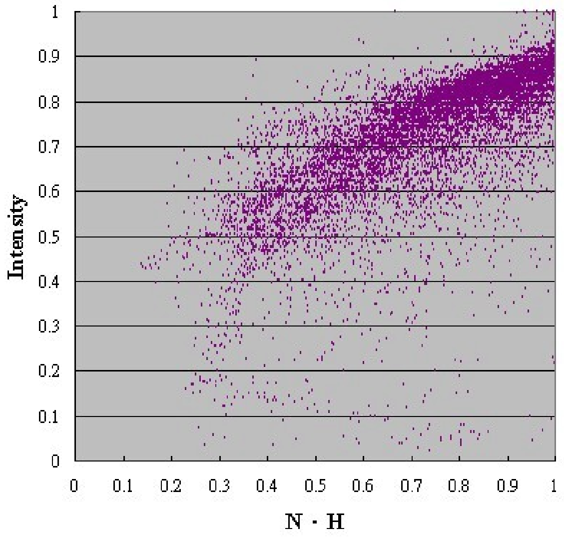

Figure 3: For each sample point, its reflected intensity versus (N · H) is plotted. Note that some points are scattered in the lower region because of the varying surface colors.

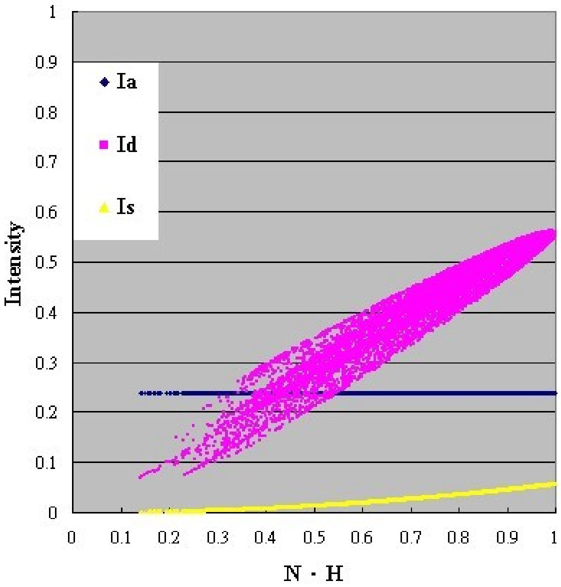

Figure 4: The above plot shows the ambient (Ia), the diffuse (Id), and the specular (Is) components of the recovered reflectance model that approximate the data in Figure 3. Note that the diffuse (Id) component is spread out since N · L may still vary under the same N · H

solving a nonlinear optimization problem, we assume n to be fixed at first in order to find the appropriate Kd and Ks. Then we simply make multiple guesses of n and use the one that produces the minimal error.

In our work, we assume that the camera and light source positions for each scan are already known. From the geometric data of the 3D scans, we can also obtain the position and surface normal for each sample point. Using those information, we can create a plot of reflected intensity versus the computed N · H value. Figure 3 shows such a plot from a model that is shown in Figure 5. We use (N · H) instead of (N · L) to denote the viewing angle because we are more interested in the specular component than the diffuse component.

Our reflectance modeling method can be summarized as the following steps:

1. The user manually selects a rectangular region which contains a specular highlight and its surrounding area. The main purpose of this step is to recover the light source position. Therefore, this step may be skipped if the light source position is already known. Note that although we allow object surfaces to contain various colors, the user is asked to select a region that contains surface colors as uniform as possible.
2. Each pixel from the manually selected region thus provides a sample point of the Phong model. We then use a least square method to fit a Phong model to all the sample points of the region. This produces the (Ka, Kd, Ks, n) parameters.
3. We then obtain the ambient component of each pixel by adjusting it intensity according to the ratio of :

$$Ka / (Ka + Kd^*(N \cdot L) + Ks^*(N \cdot H)^n)$$

Figure 4 shows the results of the recovered reflectance model, where the ambient, the diffuse, and the specular components are separated.

4. Handling Color Variation

Since we have recovered the parameters of the reflectance model, the next step is to obtain the underlying material colors so that we can merge the colors from all 3D scans. In our method, we use the ambient component to represent the material color since it does not depend on the lighting direction.

How do we adjust the colors of an image so that the colors contain only the ambient components? We might rush to the approach of adjusting the intensity of each pixel to the same level as the recovered ambient intensity. However, that approach fails to account for the variance in the surface colors. In our method, we adjust the intensity of each pixel to:

$$I * Ka / (Ka + Kd^*(N \cdot L) + Ks^*(N \cdot H)^n)$$

where I is the intensity of the pixel, and (Ka, Kd, Ks, n) are the recovered reflectance parameters. Note that in the above equation, the parameters (Ka, Kd, Ks, n) remain the same for all pixels while the pixel intensity I could vary. Therefore, $Ka + Kd^*(N \cdot L) + Ks^*(N \cdot H)^n$ is different from the pixel intensity I.

5. Merging Multiple 3D Scans

After we recover the reflectance parameters of the Phong model, we can start reconciling the differences between different 3D scans. Ideally, the ambient component of each individual scan would agree with each other at the overlapped regions. However that is rarely the case in practice. Since we have now decomposed the color images into the ambient, diffuse, and specular components, we simply average the ambient components for the overlapped regions. We also compute a consensus parameter set (Ka, Kd, Ks and n) from all 3D scans and apply them to all surfaces.

6. Results

We apply our method to a woman model which is acquired using the Portable 3D Scanner from the Industrial Technology Research Institute in Taiwan. The model consists of 8 scans. One of those 8 scans is shown in Figure 5.

In Figures 3 and 4, we have demonstrated how we estimate the parameters (Ka, Kd, Ks, n) from a single scan. Using the process that we describe in Section 4, we obtain the ambient component which is shown in Figure 6. By applying the same procedure to the other scans, we obtain the ambient components of all other scans as well.

Figure 7 and Figure 8 are the results when all 8 scans of the model are merged. In Figure 7, our reflectance modeling method is not used. The colors in the overlapped regions are simply blended with the original colors. In contrast, Figure 8 shows a much improved result when our reflectance modeling method is used. In Figure 8, we blend the ambient colors in the overlapped regions and illuminate the model under a new lighting condition.

7. Limitations and Future Work

The most important limitations of our current methods are:

1. The camera positions must be given.
2. It assumes a single light source at each input image. This is particularly important if we want to recover the light source position from specular highlights.
3. Although the object may contain spatially varying colors, we assume that the object is made of the same material.

In the future, we hope to address those limitations. We also hope to investigate the possibility of using reflectance models other than the Phong illumination model.

8. Acknowledgement

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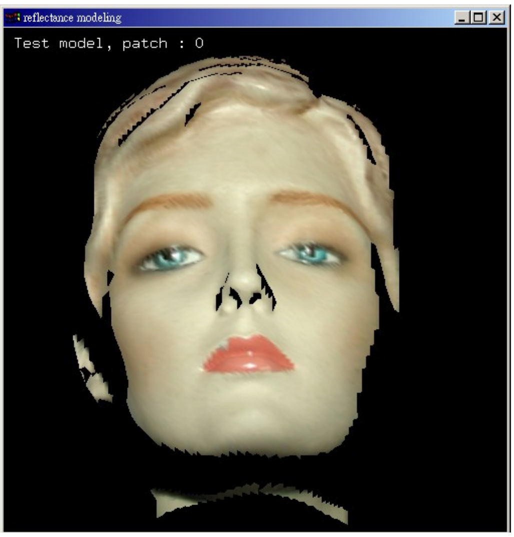
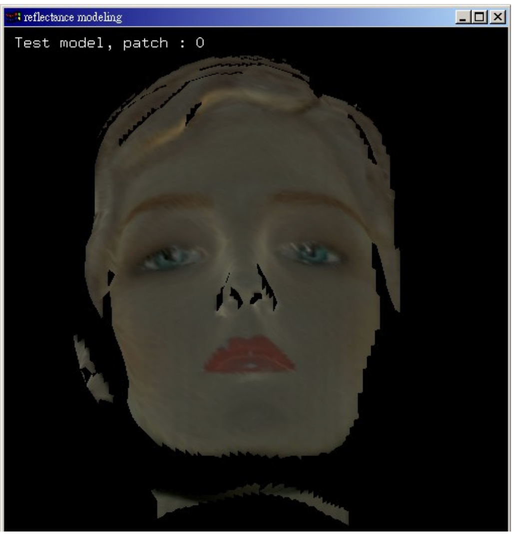


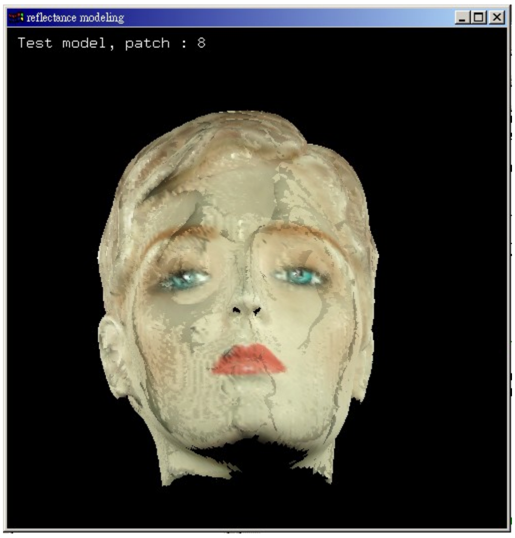
Test model, patch : 0

Figure 5: The woman model that is used in our experiment. The above shows one of the 8 scans.



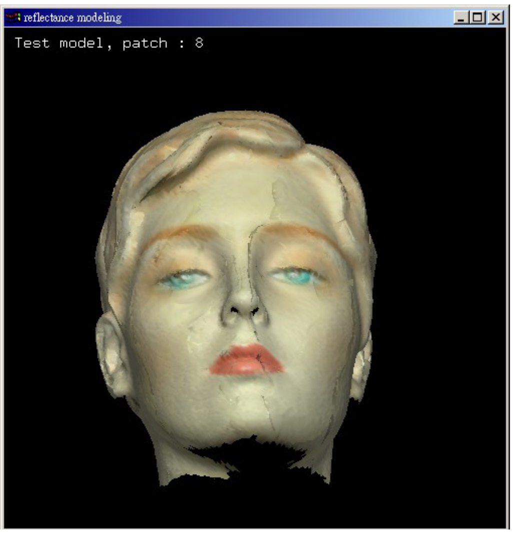
Test model, patch : 0

Figure 6: The above shows the recovered ambient component after applying our method to the data in Figure 5.



Test model, patch : 8

Figure 7: The observed colors of the original images are blended in the overlapped regions. The color differences from different scans cause serious artifacts.



Test model, patch : 8

Figure 8: This is result of applying our reflectance modeling method. We blend the recovered ambient colors in the overlapped regions, and then illuminate the model under a new lighting condition.