Assignment 5: Photometric Stereo and Structure from Motion

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I. Lighting a Scene

Fig. (1-4) show the result of lighting the Stanford Bunny using the Lambertian model.

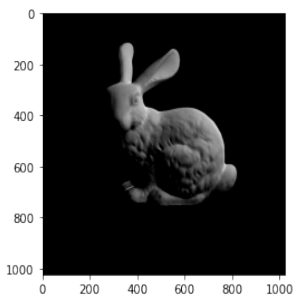

Fig. 1. Lighting the Stanford Bunny using Lambertian model (View point 1)

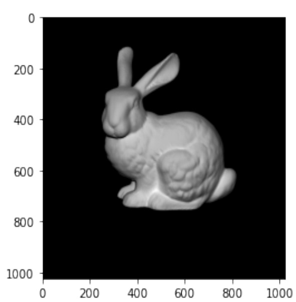

Fig. 2. Lighting the Stanford Bunny using Lambertian model (View point 2)

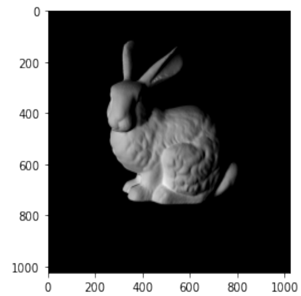

Fig. 3. Lighting the Stanford Bunny using Lambertian model (View point 3)

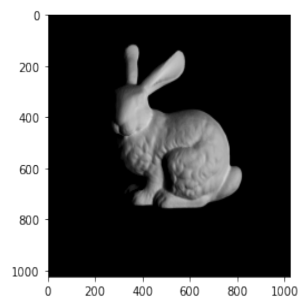

Fig. 4. Lighting the Stanford Bunny using Lambertian model (View point 4)

II. Photometric Stereo

A. Using provided data

Fig (5-8) show depth map (using Frankot-Chellappa algorithm), directions of surface normals of the Buddha and Scholar idols.

B. Imperfections in Photometric Stereo

Fig. 9 shows the difference between actual view and generated view under a certain lighting direction.

Explain (in 2–3 sentences) why there is a significant difference between the two images to the lower-left of the scholar's face.

Because our framework of modeling Lambertian doesn't account of occlusion, whereas we can observe shadows due to occlusion. This was clearly shown in the teddy bear example in the class.

Provide an explanation (in 2–3 sentences) why the body of the scholar is (on average) darker in the original image than in the reconstruction. (There are a few potential explanations to this question.)

This could be because the surface is not purely Lambertian.

C. Lambertian Objects in Blender

D. Non-Lambertian Objects in Blender

Explain (2-3 sentences) why the albedo and normals change. Is there a linear solution to finding the correct normals?

Since the surface is not purely Lambertian, the system of linear equations $I = Lb$ do not hold true. As a consequence, it doesn't preserve the property "*Looks equally bright when viewed from any direction.*" of Lambertian surfaces. Making the surface a little metallic, loses the said property. It also disrupts the assumption of "*isotropy (BRDF doesn't change the surface is rotated about the normal)*". This implies the albedos and normals change.

Find a research paper (I recommend using Google Scholar) that attempts "non-lambertian Photometric

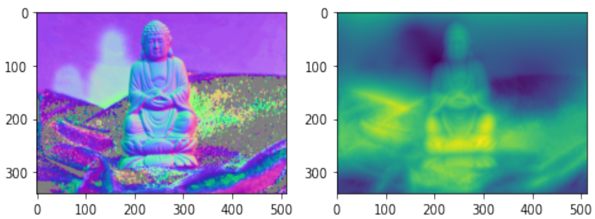

Fig. 5. Left - Depth map of the Buddha idol, Right - Surface normals of the Buddha idol

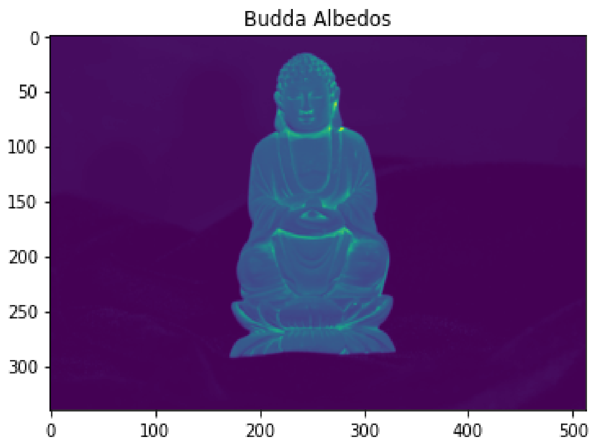

Fig. 6. Albedo plot of the Buddha idol

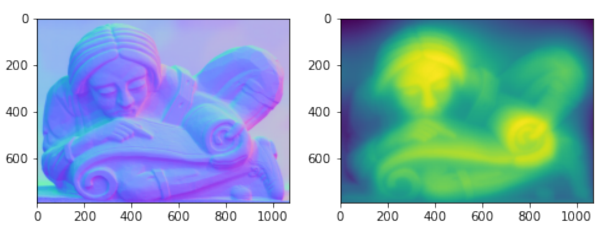

Fig. 7. Left - Depth map of the Scholar idol, Right - Surface normals of the Scholar idol

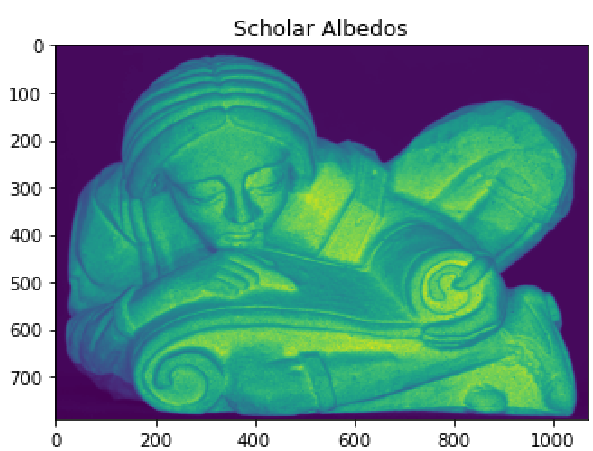

Fig. 8. Albedo plot of the Scholar idol

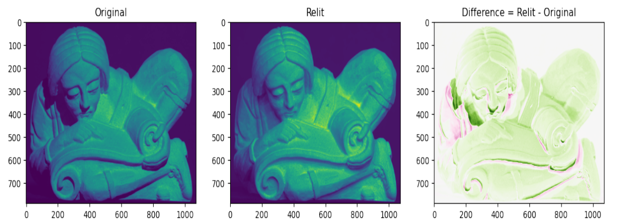

Fig. 9. Difference between actual and generated view of the Scholar idol

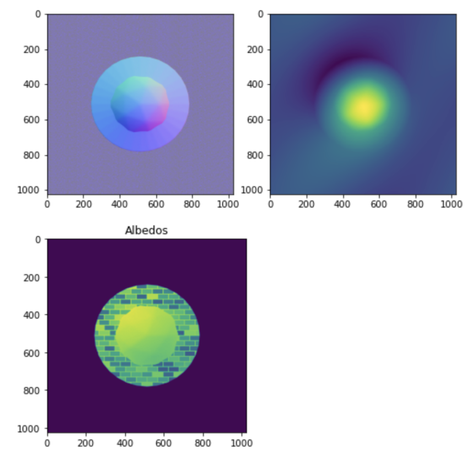

Fig. 10. Depth, surface normals, and albedos of a Lambertian surface

Stereo": trying to recover material properties for a non-lamberitan object, like the one shown above. Include a citation of the paper and (in 3–5 sentences) explain how it works and how the approach differs from the lambertian photometric stereo we studied in class.

Schlüns K. in [1] initially developed a photometric stereo approach for Lambertian surfaces but extended it to non-Lambertian surfaces as well. They extend the reflection model by adding an additive composition of diffuse and glossy reflection. This is a 2-stage process. The first stage was a refined highlight separation process yielding good results for synthetic objects. In the second stage an ordinary PMS method for Lambertian surfaces was used.

III. Structure from Motion

A. Implementation

See Fig. 12 for results of Affine Structure from Motion.

B. Followup Question

See Fig. (13-16) showing different perspectives of the 3D points on the object shown in the Fig. 12.

What is the relationship between the Affine matrix you have computed and the 3x4 camera projection matrix? Pick one of the input images above. Using the affine transformation matrix you computed for that image, what is the 3x4 camera projection matrix for this image? Include it in your writeup.

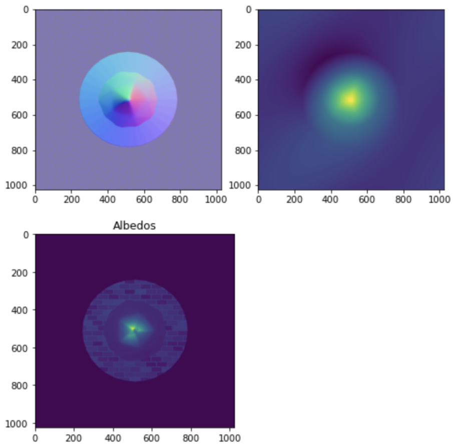

Fig. 11. Depth, surface normals, and albedos of a Non-Lambertian surface

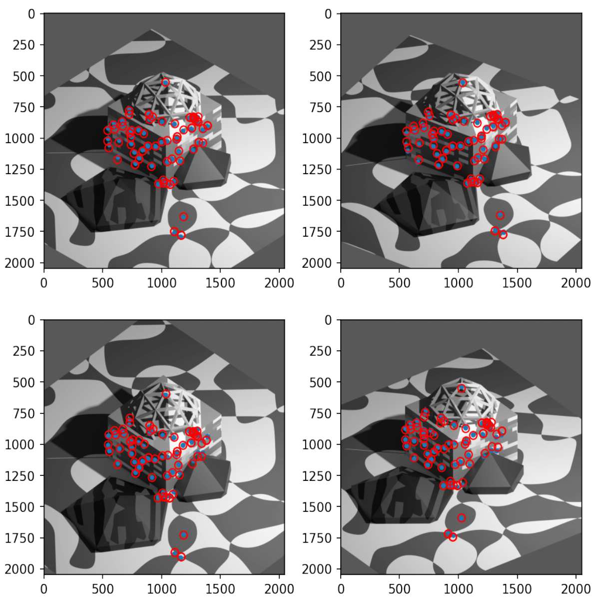

Fig. 12. Reprojected points using Affine Structure from Motion

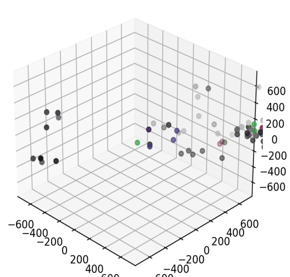

Fig. 13. Points of the object in 3D space (Perspective #1)

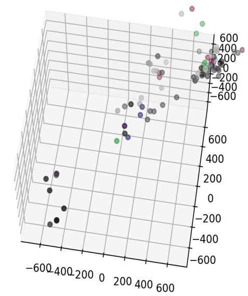

Fig. 14. Points of the object in 3D space (Perspective #2)

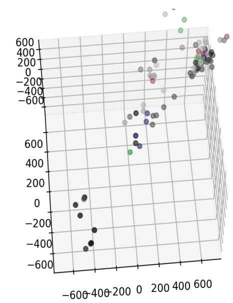

Fig. 15. Points of the object in 3D space (Perspective #3)

The Affine transformation matrix for the reprojected points in top-left image is

$$A = \begin{bmatrix} -1.1677 & -0.0827 & 0.0579 \\ -0.9094 & -0.2975 & -0.1276 \end{bmatrix} \quad b = \begin{bmatrix} 991.5897 \\ 1058.5256 \end{bmatrix}$$

The projection matrix is given by combining A and b.

$$P = \begin{bmatrix} \mathbf{A} & \mathbf{b} \\ \mathbf{0} & 1 \end{bmatrix} = \begin{bmatrix} -1.1677 & -0.0827 & 0.0579 & 991.5897 \\ -0.9094 & -0.2975 & -0.1276 & 1058.5256 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

I have provided you with the function correct_affine_ambiguity so that the Affine projective matrices produced by our algorithm satisfy certain properties. What are these properties? You may refer to the code itself or the course notes in your answer. It may help you to print the matrices before and after the correction is applied.

To eliminate the affine ambiguity, we're imposing the constraint of orthography (image axes are perpendicular and of unit length). The affine ambiguity is caused by the fact that the decomposition of $D = MS$ is not unique. The affine projective matrices satisfy the following properties for each image i:

$$\mathbf{\tilde{a}_{i1}^T C C^T \tilde{a}_{i1}^T = 1}, \quad \mathbf{\tilde{a}_{i2}^T C C^T \tilde{a}_{i2}^T = 1}, \quad \mathbf{\tilde{a}_{i1}^T C C^T \tilde{a}_{i2}^T = 0}$$

where $\mathbf{\tilde{A}_i} = \begin{bmatrix} \mathbf{\tilde{a}_{i1}^T} \\ \mathbf{\tilde{a}_{i2}^T} \end{bmatrix}$

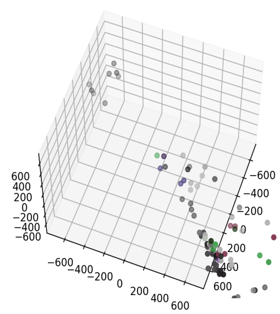

Fig. 16. Points of the object in 3D space (Perspective #4)

References

[1] Schlüns K. (1993) Photometric stereo for non-lambertian surfaces using color information. In: Chetverikov D., Kropatsch W.G. (eds) Computer Analysis of Images and Patterns. CAIP 1993. Lecture Notes in Computer Science, vol 719. Springer, Berlin, Heidelberg. https://doi.org/10.1007/3-540-57233-3_58