ASSIGNMENT 5

15663 Computational Photograpy Fall 2023
DUE: November 20, 2023

1 Photometric stereo (100 points)

Uncalibrated photometric stereo (20 points) Reshape A_e and N_e into single-channel and three-channel images with the same width and height as the original image, and visualize the results.

The visualization of the per-pixel albedoes A_e and the normals N_e:

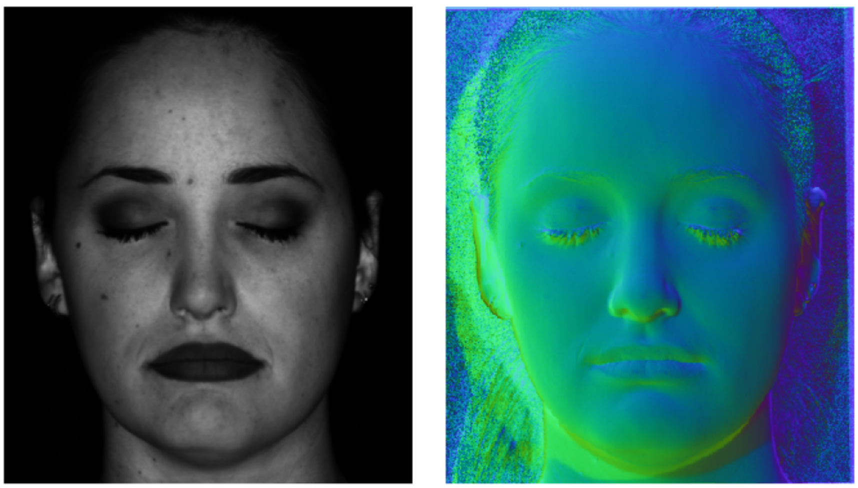

Figure 1: Uncalibrated photometric stereo results. Left: estimated albedo ($\times 10$), right: normals.

These estimates are not unique. Let Q be an invertible 3×3 matrix. Then, the matrices $L_Q = Q \cdot L_e$ and $B_Q = Q^{-T} \cdot B_e$ approximates $I = L_Q^T \cdot B_Q$ exactly as well as the original estimates L_e and B_e.

Select any non-diagonal matrix Q, and visualize the albedo A_Q and normals N_Q.

The invertible matrix Q used here is:

$$Q = \begin{bmatrix} 0.14315949 & 0.98048881 & 0.44061668 \\ 0.92047805 & 0.85780635 & 0.28470519 \\ 0.7154838 & 0.45099537 & 0.7966821 \end{bmatrix}$$

The visualization of the per-pixel albedoes A_Q and the normals N_Q:

Figure 2: Uncalibrated photometric stereo results. Left: estimated albedo ($\times 10$), right: normals.

Enforcing integrability (45 points) The resulting x of solving the linear equation

$$\begin{bmatrix} A_1 & A_2 & A_3 & A_4 & A_5 & A_6 \end{bmatrix} x = 0$$

is:

$$x = \begin{bmatrix} 0.1561 & -0.5469 & -0.0795 & -0.7698 & -0.2317 & -0.1547 \end{bmatrix}^T$$

,

and the matrix Δ is then

$$\Delta = \begin{bmatrix} -x(3) & x(6) & 1 \\ x(2) & -x(5) & 0 \\ -x(1) & x(4) & 0 \end{bmatrix} = \begin{bmatrix} 0.0795 & -0.1547 & 1 \\ -0.5469 & 0.2317 & 0 \\ -0.1561 & -0.7698 & 0 \end{bmatrix}$$

The resulting albedo, normals and depth:

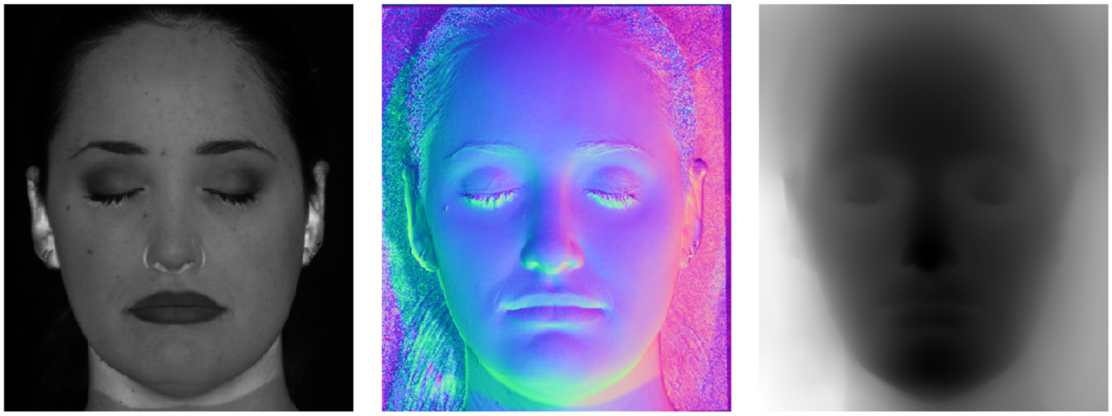

Figure 3: Uncalibrated photometric stereo results, after enforcing integrability. From left to right: albedo ($\times 10$), normals, and depth (normalized to $[0, 1]$)

Normal integration (15 points) Visualize the final surface you reconstructed as both a depth image and a 3D surface.

The reconstructed depth image:

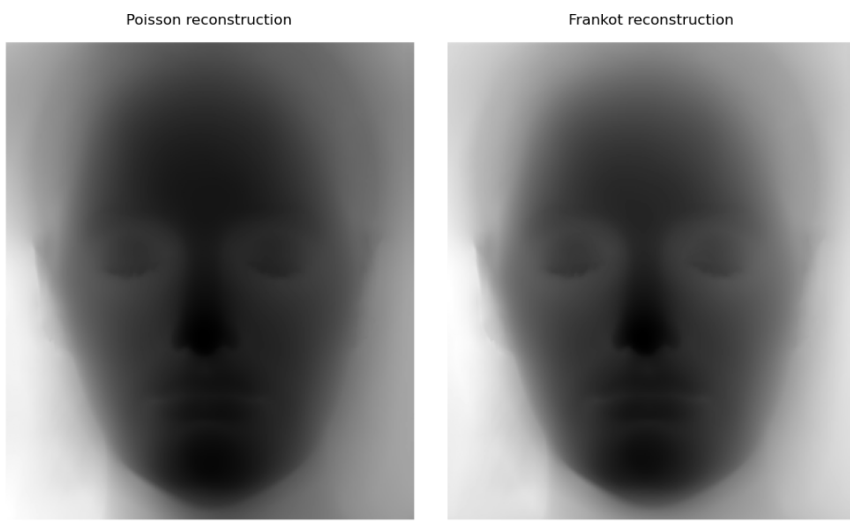

Figure 4: Uncalibrated photometric stereo result. Left: depth image computed using Poisson reconstruction, right: depth image computed using Frankot reconstruction.

The reconstructed 3D surface:

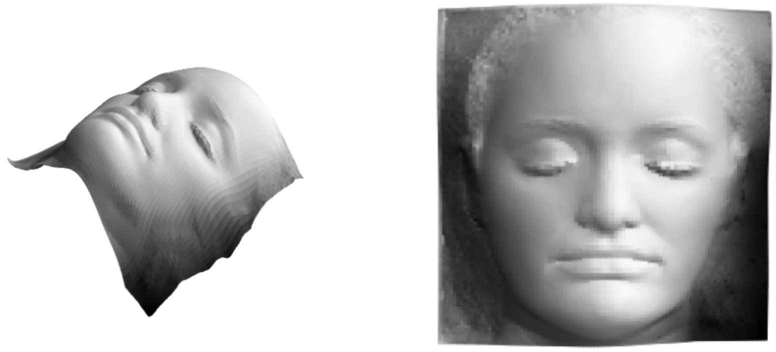

Figure 5: Uncalibrated photometric stereo results. Two views of the recovered face shape.

To remove the distortion, we experimented with GBR transformations G for different μ, υ, λ.

Experiments with μ, where $\upsilon = 0.0$ and $\lambda = 1.0$:

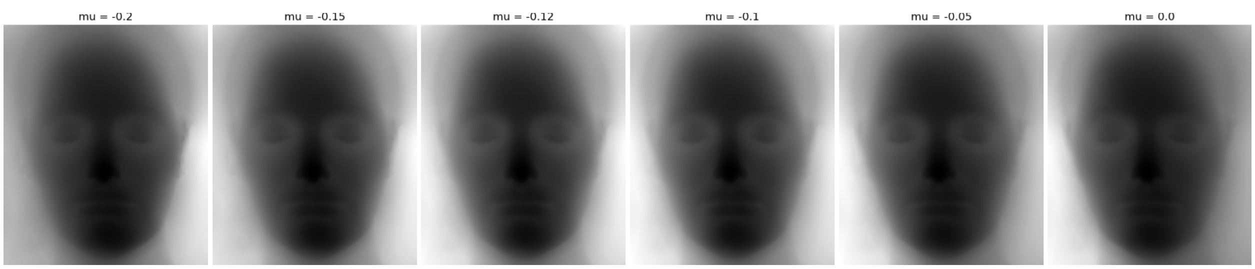

Figure 6: Experiments with different values of μ

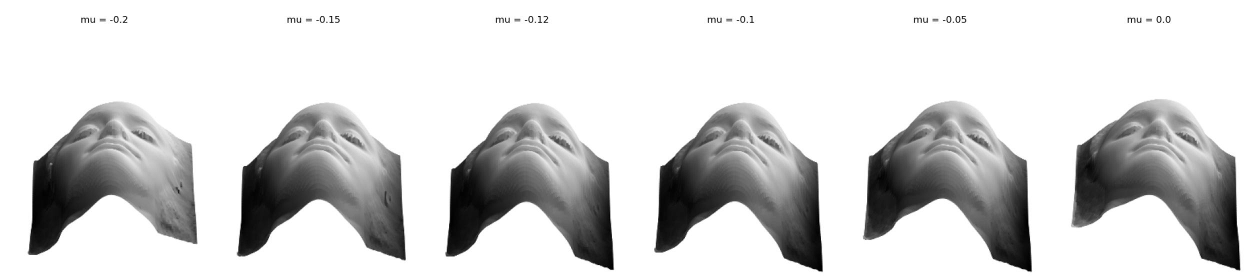

Figure 7: Experiments with different values of μ

It can be seen from the images corresponding to $\mu = -0.15$ and $\mu = -0.12$ appear to have the best undistorted shape. We chose $\mu = -0.12$.

Experiments with different values of υ, where $\mu = -0.12$ and $\lambda = 1.0$:

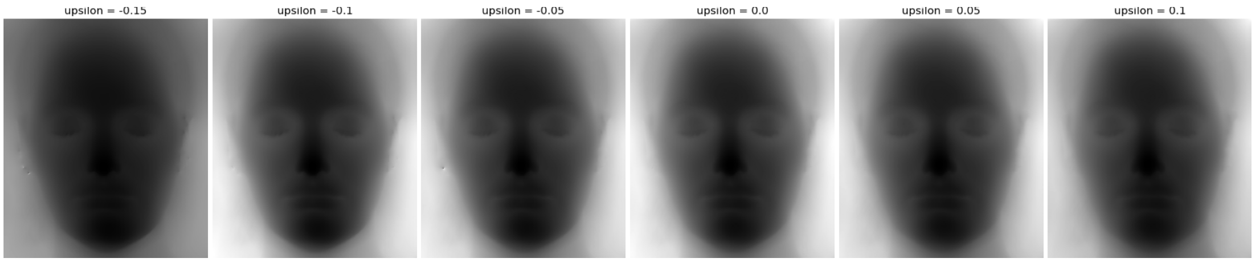

Figure 8: Experiments with different values of υ

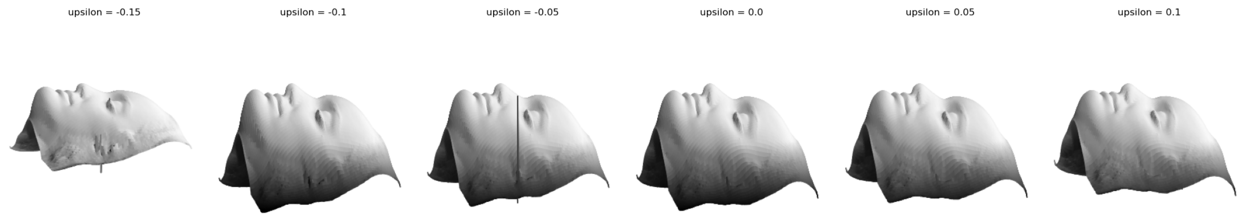

Figure 9: Experiments with different values o υ

We got the best results when υ is approximately $0.0 - 0.1$. We chose $\upsilon = 0.05$.

Finally, we experimented with different values of λ, where $\mu = -0.12$ and $\upsilon = 0.05$:

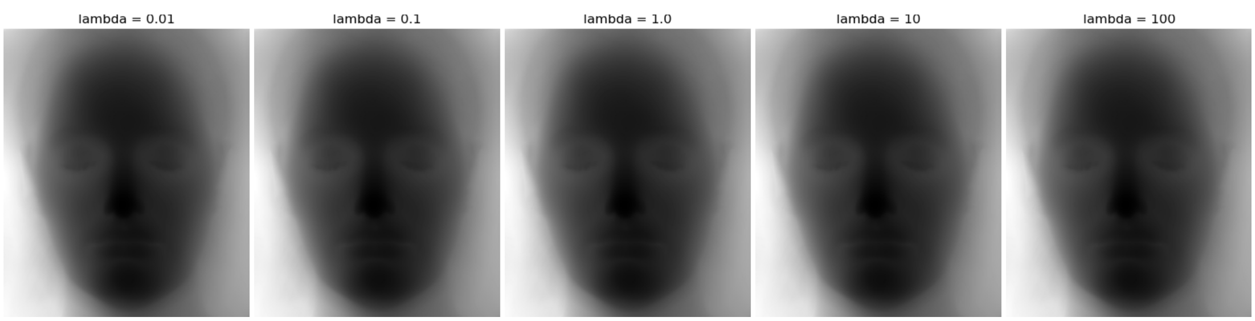

Figure 10: Experiments with different values of λ

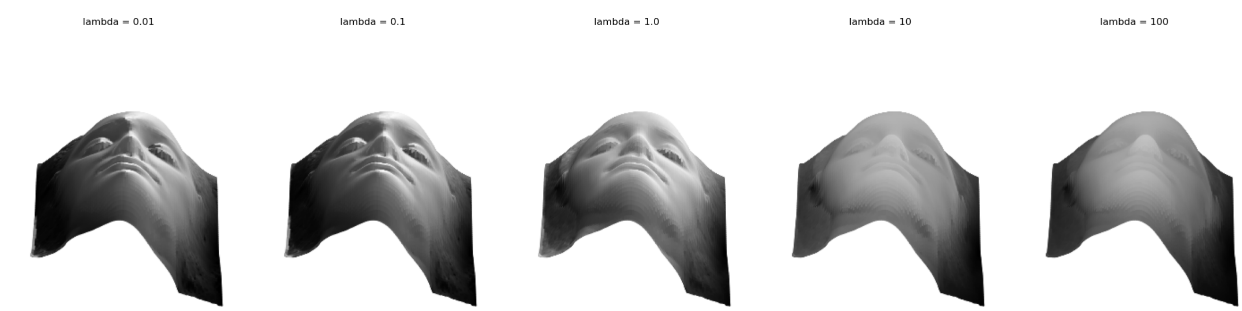

Figure 11: Experiments with different values of λ

We simply chose $\lambda = 1.0$.

The parameters we ended up using are $\mu = -0.12$, $\upsilon = 0.05$ and $\lambda = 1.0$. The blur kernel has $\sigma = 16$. The corresponding albedoes, normals and 3D surfaces are:

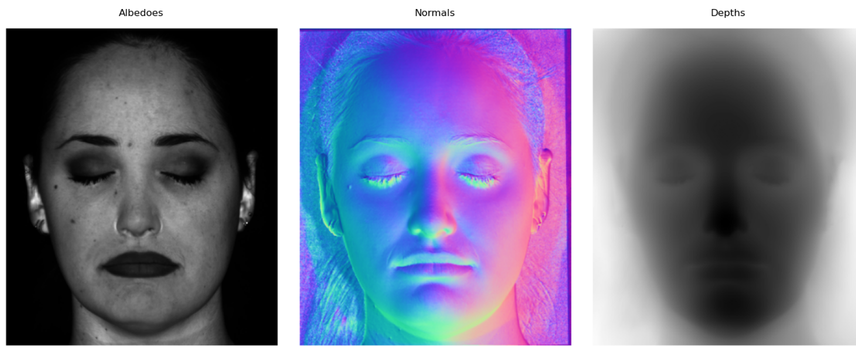

Figure 12: Caption

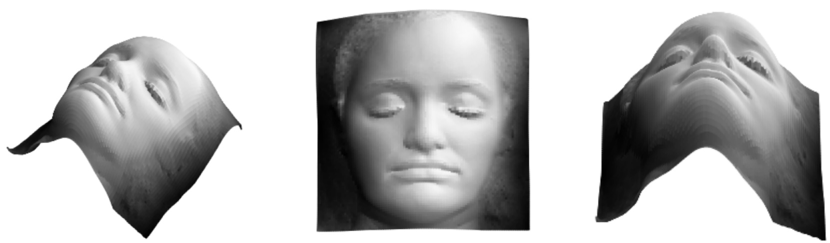

Figure 13: Caption

Calibrated photometric stereo (15 points) Load the groundtruth light matrix L and solve the linear system $I = L^T \cdot B$ to recover per-pixel albedoes and normals. Visualize the recovered albedoes, normals, and surface. How do these results compare to the results of the uncalibrated case?

The visualization of the recovered albedo, normals, and surface:

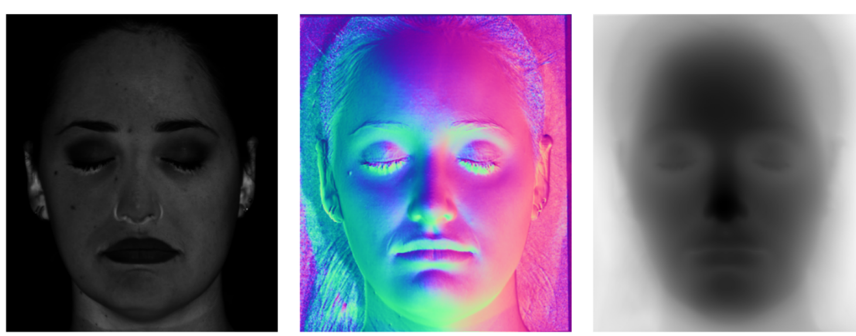

Figure 14: Calibrated photometric stereo results. From left to right: estimated albedo, normals and depth.

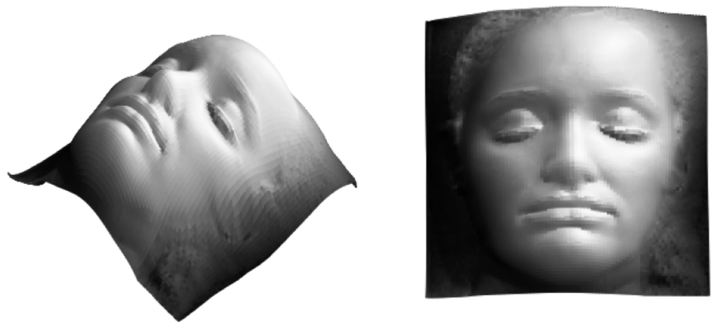

Figure 15: Calibrated photometric stereo results. Two views of the recovered face shape.

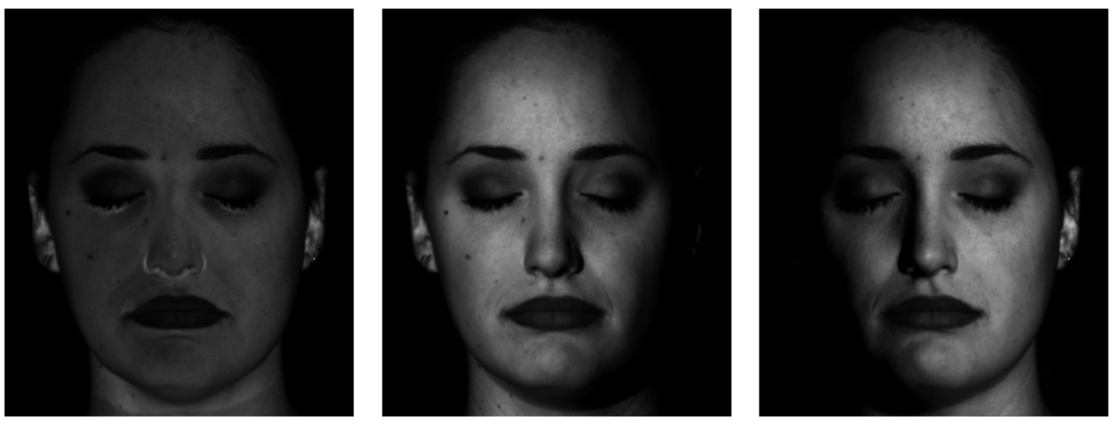

Figure 16: Rendering under new lighting conditions

The calibrated photometric stereo results are shaper and preserve more details (e.g. the hair), and the albedo is smoother, without much lighting change.

2 Capture and reconstruct your own shapes (100 points)

We selected three objects, two of them approximately satisfy the assumptions of photometric stereo, and the other one partially violates the assumptions by having some glossy parts. We first experimented with a toilet paper roll, which has a relatively simple shape. The G we used has $\mu = 0.08$, $\upsilon = 0.0$ and $\lambda = 1.0$. The blur kernel has $\sigma = 1$.

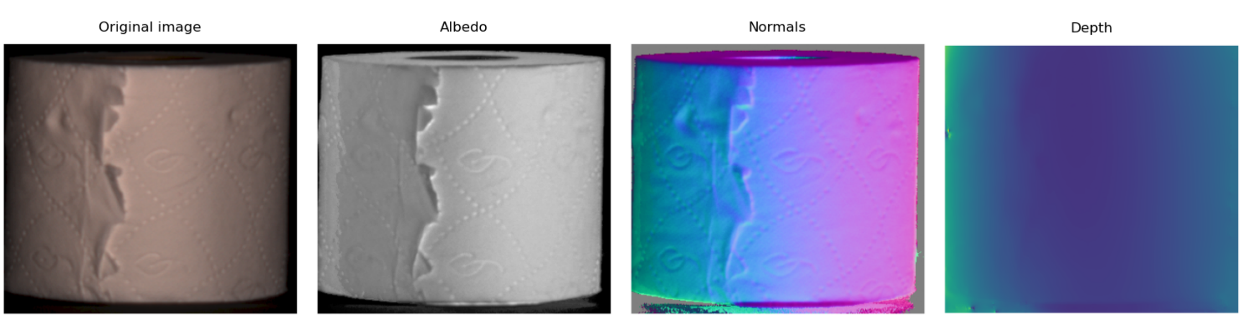

Figure 17: Uncalibrated photometric stereo results

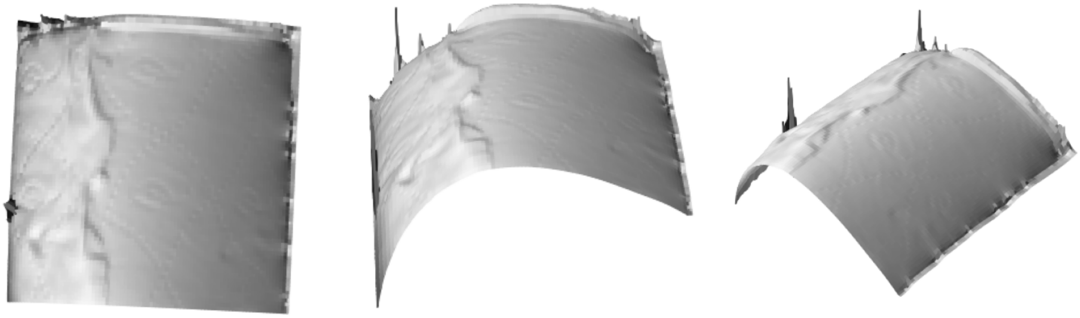

Figure 18: 3D surface reconstruction

Figure 19: Rendering under new lighting directions. Left: the albedo, middle and right: the rendering results.

Then we experimented with a paper cup holder which has a more complicated shape. The G we used has $\mu = 0.1$, $\upsilon = 0.24$ and $\lambda = 1.7$. The blur kernel has $\sigma = 1$.

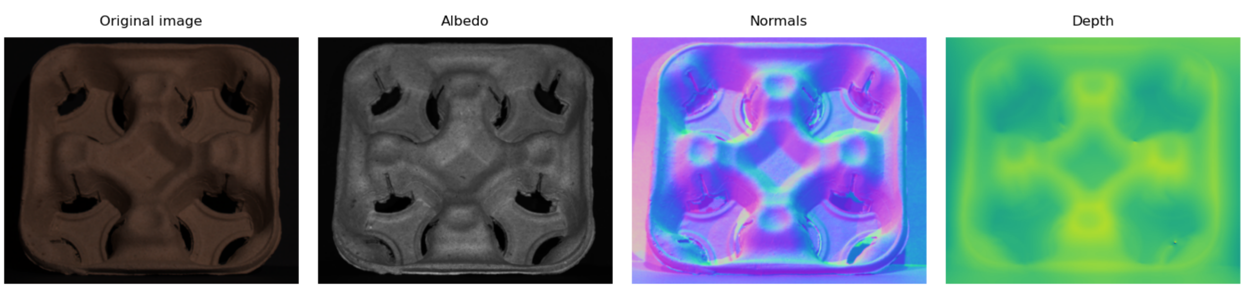

Figure 20: Uncalibrated photometric stereo results

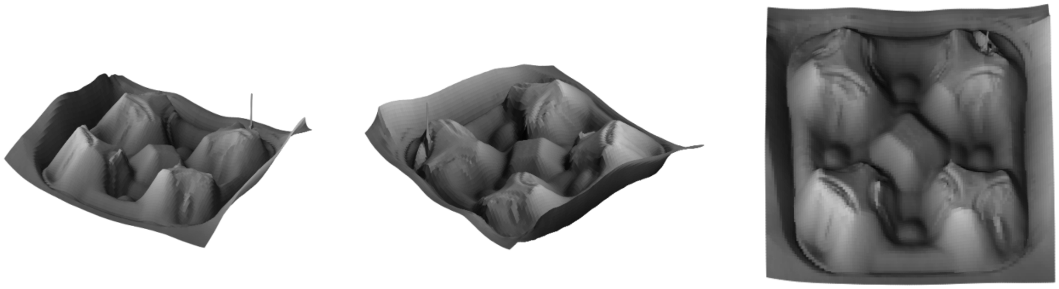

Figure 21: 3D surface reconstruction

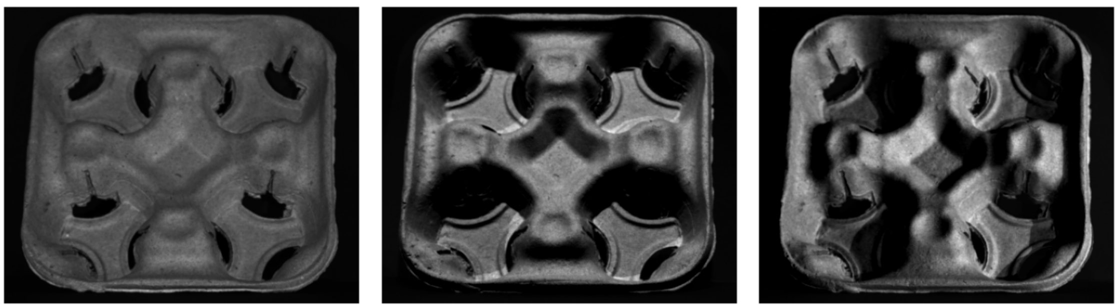

Figure 22: Rendering under new lighting directions. Left: the albedo, middle and right: the rendering results.

Lastly, we experimented with a plush toy whose eyes are glossy. Because the assumptions of photometric stereo were violated, the reconstruction failed in this case. The G we used has $\mu = 0.1$, $\upsilon = 0.0$ and $\lambda = 10.0$. The blur kernel has $\sigma = 1$.

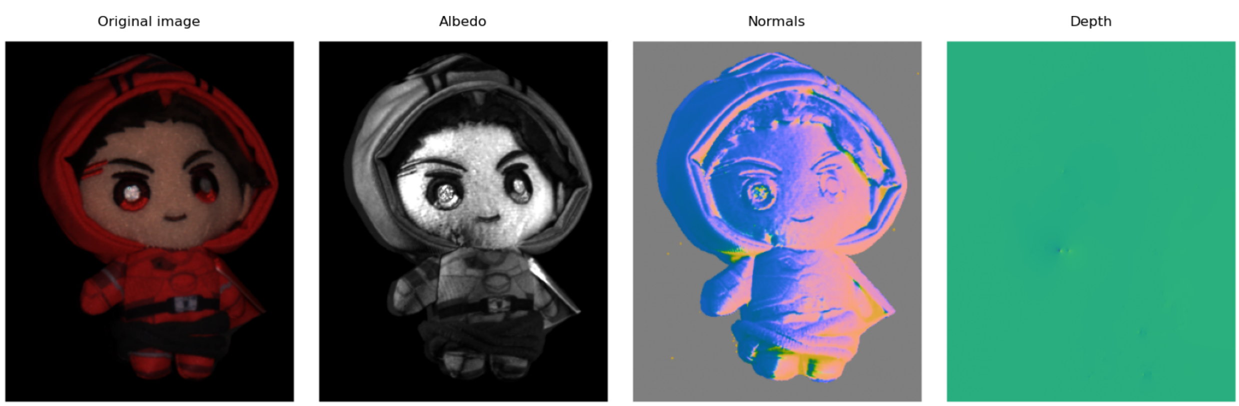

Figure 23: Uncalibrated photometric stereo results

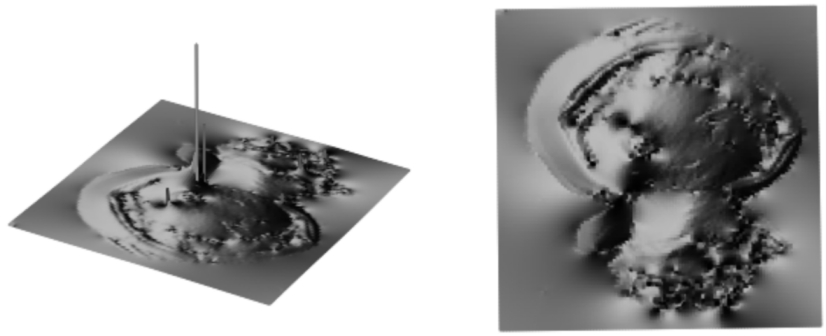

Figure 24: 3D surface reconstruction

Figure 25: Rendering under new lighting directions. Left: the albedo, middle and right: the rendering results.