UNIVERSITY OF AMSTERDAM

Assignment 1 Report

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Computer Vision 1

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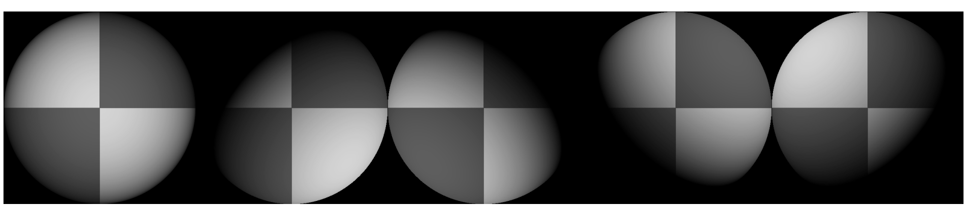
Photometric Stereo

The description of this assignment is divided in four different parts, each one representing a separate step in the photometric process.

$\mathcal{V}$ matrix calculation

The $\mathcal{V}$ matrix defines the lighting proprieties of the input image under different conditions. Figure 1 shows the given images.



(a) front (b) bottom right (c) bottom left (d) top right (e) top left

Figure 1: Images given in the assignment with indication of the light position

Each row of $\mathcal{V}$ defines the light position of one image with respect to a Cartesian coordinate system with the center of the x, y and z axis at the center of the image. The resulting matrix is

$$\mathcal{V} = \begin{bmatrix} 0 & 0 & 1 \\ -1 & 1 & 1 \\ 1 & 1 & 1 \\ -1 & -1 & 1 \\ 1 & -1 & 1 \end{bmatrix}$$

notice that the z coordinate is always 1 and not 0, as it would create a shade passing through the center of the sphere in that case. $\mathcal{V}$ is normalized afterwards, and multiplied by a scaling factor.

Changing the value of such factor alters the final albedo of the image, as it changes the distance of the light sources, increasing or decreasing the reflectance of the result. Examples of this phenomena can be seen in Figure 2 located in the next section.

Surface gradient and Albedo calculation

For each pixel coordinate of the input image, we calculated the values for the *Albedo*, p and q, where p and q are the derivative w.r.t. x and y of $f(x, y)$ respectively.

In order to output the results we first had to calculate the vector field g by solving the equation $\mathcal{I} * \mathcal{V} * g = \mathcal{I} * i$, where $\mathcal{I}$ is a diagonal matrix used in order to account for points in shadowed regions in multiple light circumstances. The value for g is then

$$g = (\mathcal{I} * \mathcal{V})^{+} * i^2$$

with the value for g we can proceed to calculate the rest

$$Albedo = \|g\|$$

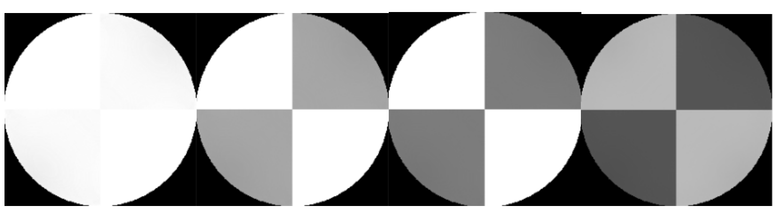
$$Normal = \frac{g}{\|g\|}$$

Normal is a 3-dimensional matrix, so p and q are calculated as

$$p = Normal[:, :, 1]/Normal[:, :, 3]$$

$$q = Normal[:, :, 2]/Normal[:, :, 3]$$

Figure 2 shows the resulting Albedo from the given images.



(a) scale:100 (b) scale:150 (c) scale:200 (d) scale:300

Figure 2: The Albedo recovered using different scale factors.

Integrability check

Having computed the values of the p and q matrices, we can calculate the second derivatives with a numerical approximation method and check the magnitude of the error of the approximations. The calculations are done by using the neighbor approximation method, where each second derivative is calculated as

$$\frac{\partial q}{\partial x} = \frac{q[x+1] - q[x-1]}{2}$$

$$\frac{\partial p}{\partial y} = \frac{p[y+1] - q[y-1]}{2}$$

When the calculations are done for the elements lying in the border (without both neighbors) we set the derivative to 0. Having calculated the second derivatives, an integrability check can be done by plotting the squared differences of the derivatives, as shown in Figure 3. We can see that the error lies only on the border, where the shape ends, indicating correct calculations that have errors only when the function is at its limit. Also, the errors are mirrored taking the center of the sphere as the mirroring point.

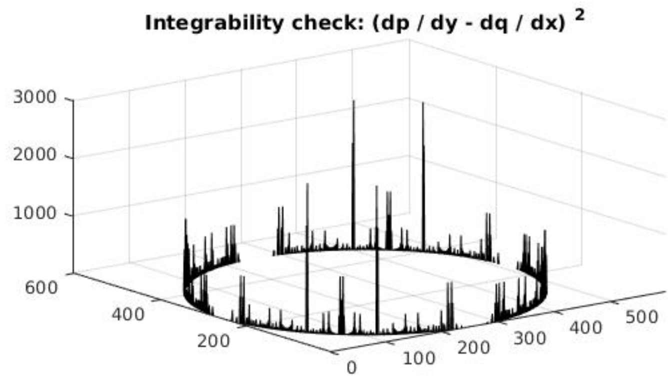


Figure 3: Integrability Check

Height map construction

Before reconstructing the height map of the object in the image, we have to recover its surface normals. The surface normals were obtained by the following equations:

$$\frac{\partial f}{\partial x} = \frac{a(x,y)}{c(x,y)} \qquad \frac{\partial f}{\partial y} = \frac{b(x,y)}{c(x,y)}$$

Given the unit normal vector at point (x,y) is (a(x,y), b(x,y), c(x,y))

The value of f(x,y) was then recovered by integrating the surface normals, such that f(x,y) = f(x,y-1) + p(x,y), and result in the height map in Figure 5.

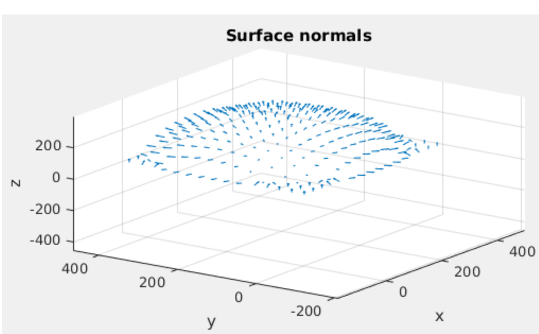


Figure 4: Surface Normals

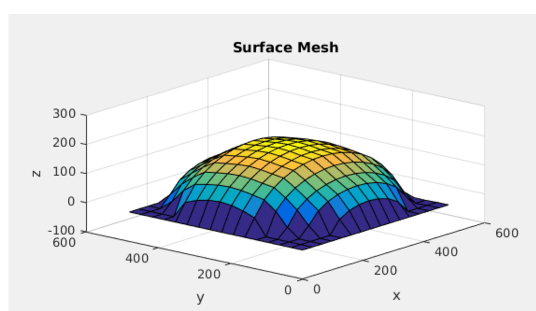


Figure 5: Recovered height map

Color Spaces

No particular techniques are discussed in this section, the image has been treated as a 3-dimensional matrix, where each matrix layer represents a color channel. When converting the input RGB image using four different methods, a 4-dimensional matrix is used, one layer per grayscale encoding. The results of the conversions can be seen in the following images.

Figure 6: Original image

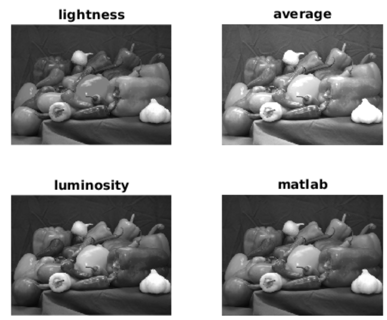


Figure 7: Grayscale using different methods

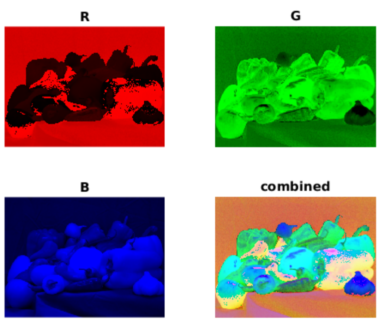


Figure 8: HSV color space

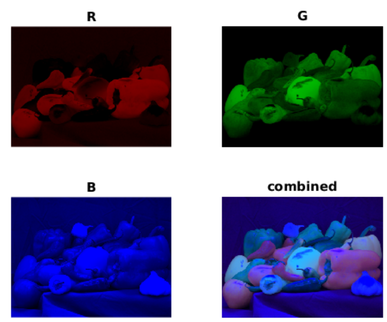


Figure 9: Opponent color space

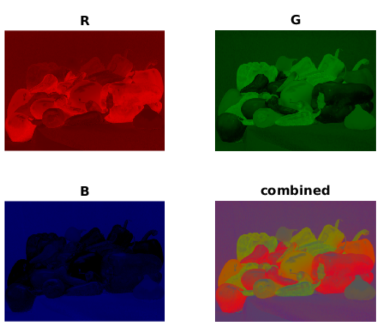


Figure 10: Normalized RGB color space

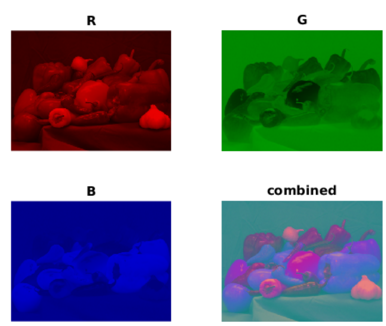


Figure 11: YCBCR color space