Spring 2020 - CS 477/577 - Introduction to Computer Vision

Assignment Six

Due: 11:59pm (*) Thursday, March 05.

(*) Due to spring break is **extra** grace until 08:00 AM on March 16, as we will not grade assignments before then. Once grading, no more assignments will be accepted.

Weight: Approximately 5 points

This assignment must be done individually

General instructions

You can use any language you like for this assignment, but unless you feel strongly about it, you might consider continuing with Matlab.

You need to create a PDF document that tells the story of the assignment, copying into it output, code snippets, and images that are displayed when the program runs. Even if the question does not remind you to put the resulting image into the PDF, if it is flagged with ($), you should do so. I should not need to run the program to verify that you attempted the question. See

http://kobus.ca/teaching/assignment-instructions.pdf

for more details about doing a good write-up. While it takes work, it is well worth getting better and more efficient at this.

Learning goals

- Further experience with solving problems using linear least squares
- Understand shape cues from shading by implementing photometric stereo
- Further understand the role of light in images and solving vision problems (grads)
- Better understand the simplification of the BRDF to three angles (optional)

Assignment specification

This assignment has five parts, **one** of which is required for undergrads, a **second** which is required for graduate students only. There are three optional problems. The third one is relatively easy, and the last two are duplicates from the previous homework.

Part A

The following seven files (also in D2L/Content/Data)

http://kobus.ca/teaching/cs477/data/4-1.tiff
http://kobus.ca/teaching/cs477/data/4-2.tiff
http://kobus.ca/teaching/cs477/data/4-3.tiff
http://kobus.ca/teaching/cs477/data/4-4.tiff
http://kobus.ca/teaching/cs477/data/4-5.tiff
http://kobus.ca/teaching/cs477/data/4-6.tiff
http://kobus.ca/teaching/cs477/data/4-7.tiff

are seven images taken of a Lambertian surface with the light at seven different directions. Those directions are listed in order in this file (also in D2L/Content/Data):

http://kobus.ca/teaching/cs477/data/light_directions.txt

We are assuming that the lights are far enough away that only their directions, as provided in the file, matter. To further clarify, the rows of the matrices are **directions in space** (not points in space)

You can assume that the projection is orthographic, with the z axis being normal to the image plane. You may recall that this means that the point (x,y,z) is simply projected to (x,y,0). If we ignore issues of rotation and units, this is like an aerial photograph where the points are far enough away that the relief does not matter.

As we have learned, images are typically indexed by row (increases in the direction that you normally think of as negative Y), and column, (increases in the direction that you normally think of as positive X). Because we have orthographic projection, the camera is far away, and having the origin in the top left corner instead of the center of the image is fine. Use this convention for this assignment. If you use a different one, such as using X as the horizontal axis, you will get a different solution that is more difficult to interpret.

Now the meat:

1. Use photometric stereo to compute the surface normals at each point of the image. Notice that the surface has different albedo in the four quadrants. The normals that you compute must be independent of this. Demonstrate that you have good values for the normals by creating an image of the surface as if it had uniform albedo, and though it was illuminated by a light in the direction of the camera (i.e., in direction (0, 0, 1). You can assume that the albedo/light combination is such that a surface that is perpendicular to the camera direction (i.e., the normal is in the direction (0, 0, 1)) has pixel value (250, 250, 250). Let's call this the canonical view. Put this image into your writeup together with a nice readable explanation of how you got produced it. Do not forget an informative caption for the image **($)**.

2. Now compute a depth map of the surface, and make a 3D plot the surface *z=f(x,y)*. Do this by integrating the partial derivatives along a path. Use the origin described above as the reference "sea-level" point with z=0. Put this plot into your writeup together with a nice readable explanation of how you produced it. **($)**.

3. Next, explain how your surface explains the **minima** and **maxima** of the canonical view image you created based on uniform albedo (part A1) **($)**.

4. Finally, **check your process** by using your depth map to calculate the normals at every point, and use those normals to re-create the canonical view image. This is very similar to doing it the first time (modular code opportunity) except the normals come from part A2.

If you are an undergraduate student, and you have done all the questions until here, then congratulations, you are done! However, if you are looking for alternatives, or extra problems, feel free to keep reading.

Part B (required for grad students only).

The following three files (also in D2L/Content/Data)

http://kobus.ca/teaching/cs477/data/color_photometric_stereo_1.tiff
http://kobus.ca/teaching/cs477/data/color_light_colors_1.txt
http://kobus.ca/teaching/cs477/data/color_light_directions_1.txt

as well as the following three alternatives (also in D2L/Content/Data)

http://kobus.ca/teaching/cs477/data/color_photometric_stereo_2.tiff
http://kobus.ca/teaching/cs477/data/color_light_colors_2.txt
http://kobus.ca/teaching/cs477/data/color_light_directions_2.txt

contain a color image, a matrix of light directions (one per row), and a matrix of light RGB (again, one per row). These lights were used to make an image of a surface (the color image). The setup is much like classic photometric stereo (e.g., Part A), except that **1)** the lights are colored and we know their RGB, and **2)** all lights were on at the same time. You can further assume that the albedo in each channel is unity—i.e., the surface is pure white. Finally, you can assume that the red components of each of the three lights only has non-negligible response in the red channel and similarly for green and blue.

Your mission, should you choose to accept it, is to recover the surfaces for each triplet and plot them (**$**). Dealing with points that are in the shadow of any light is tricky, and so I have chosen data where you do not need you to do this. In both cases there is either little or no shadowing, or it does not affect the result too much (at least in my implementation). As you might guess from the image, the second surface is the same one that I used to create the data for Part A.

I recommend thinking through the problem as best you can **before** consulting the hint below.

Hint. You might find it easiest to convert the lighting situation to an equivalent one consisting of three lights that are entirely red, green, and blue, respectively. However, it needs to be clear that the new representation is equivalent with respect to the recorded image color. This will demonstrate that you understand the linearity of light aggregation and enable you to cast the problem into a more conventional photometric stereo one.

Part C (optional, modest extra credit is possible)

Consulting Figure 1, derive an expression for g as a function of $\varphi_i - \varphi_o$ (and ϑ_i and ϑ_o) and vice versa.

Hint. If you provide some justification, you can assume that $\varphi_o = 0$.

Hint. As discussed in class, this kind of problem is often best approached using vector representation. In particular, you could try thinking about the two rays as unit vectors and relating g *to their dot product.*

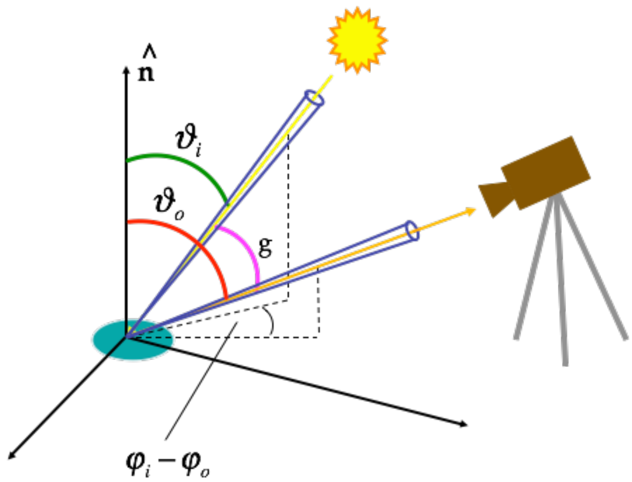

Figure 1. The BRDF figure from the notes.

Part D (optional, modest extra credit is possible)

If you did not have time to do optional part D in HW05, it can count as optional questions for this assignment **provided that** you have not already studied any posted solution for this question (or any of your colleagues' solutions).

Also, if you **did** to part HW05 part D using the geometric approach, you could extend it by using the matrix approach, making use of whatever infrastructure you have from before.

Part E (optional, modest extra credit is possible)

If you did not have time to do optional part E from the previous homework, it can count as optional questions for this assignment **provided that** you have not already studied any posted solution for this question (or any of your colleagues' solutions).

What to Hand In

As usual, the main deliverable will be PDF document that tells the story of your assignment as described above. Ideally the grader can focus on that document, simply checking that the code exists, and seems up to the task of producing the figures and results in the document. So, you need hand in your code as well.