CS543/ECE549 Assignment 3

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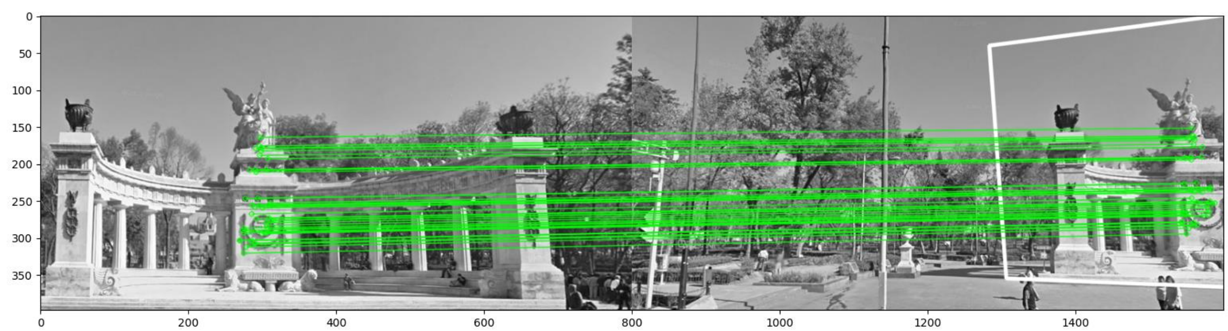
Part 1: Homography estimation

A: Describe your solution, including any interesting parameters or implementation choices for feature extraction, putative matching, RANSAC, etc.

I employ the SIFT descriptor to compute the spatial dissimilarity between two descriptors within each image. Following the calculation of distances, I employ a threshold to eliminate matches with distances exceeding 15,000. When it comes to computing the homography translation matrix and performing the RANSAC loop, I use the `` `findHomography` `` function from the OpenCV (cv2) library and set the inlier threshold to 1.0.

B: For the image pair provided, report the number of homography inliers and the average residual for the inliers. Also, display the locations of inlier matches in both images.

The number of homography inliers is 42.
The average residual for inliers is 470.48.

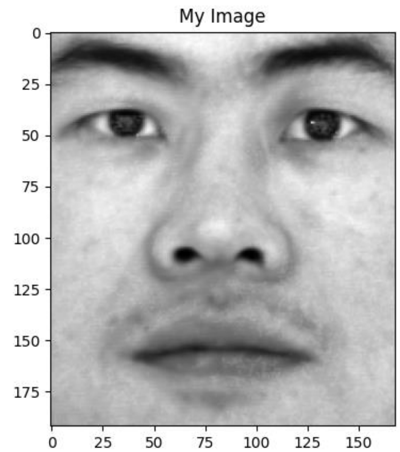


C: Display the final result of your stitching.

Part 2: Shape from shading

A: Estimate the albedo and surface normals

1) Insert the albedo image of your test image here:
   file name: 'yaleB02'



2) What implementation choices did you make? How did it affect the quality and speed of your solution?
   In accordance with the assignment guidelines, I have implemented three functions: `preprocess`, `photometric_stereo`, and `get_surface`.
   a) In the `preprocess` function, I subtract the ambient image from each input image and then scale the resulting values to a range from 0 to 1.
   b) In the `photometric_stereo` function, I employ np.linalg.norm and np.linalg.lstsq to determine the albedo image and surface normals.
   c) In the `get_surface` function, I calculate the cumulative partial derivatives in both the horizontal and vertical directions, albeit following distinct paths to compute the height map.

   The preprocessing step has a positive impact on the quality of the solution by effectively removing ambient lighting and ensuring consistent pixel values. The normalization and the use of least squares in the photometric stereo process are beneficial for both quality and speed since they adhere to standard practices in photometric stereo. It's worth noting that while averaging can yield good results, it may come at the cost of slower processing, whereas the random path integration method introduces robustness to the solution.
3) What are some artifacts and/or limitations of your implementation, and what are possible reasons for them?
   Artifacts:
   a) **Noise Sensitivity:** Photometric stereo can be sensitive to noise in the input images. Small variations in pixel values or measurement errors can lead to noisy albedo and surface normals.
   b) **Ambiguity in Light Direction:** If the light directions are not accurately estimated or are highly correlated, it can lead to ambiguity in the surface normal solution.

c) **Shadow and Specular Highlights:** Photometric stereo struggles with surfaces that exhibit significant shadows and specular highlights, as these can distort intensity values.

Limitations:

a) **Lack of Texture:** Photometric stereo works best on textured surfaces where shading provides valuable information about the surface orientation. It may not perform well on flat, textureless regions.

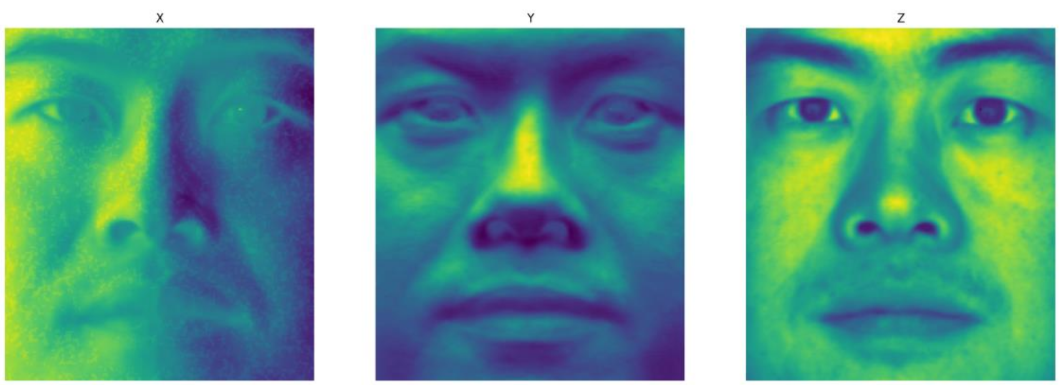
b) **Complex Surfaces:** Highly curved or complex surfaces can challenge photometric stereo methods, especially if the surface exhibits self-shadowing or inter-reflections.

c) **Computational Cost:** Depending on the algorithm and integration method used, photometric stereo can be computationally expensive, especially for high-resolution images.

d) **Smoothness Assumption:** Photometric stereo typically assumes that the surface is smooth. If the surface exhibits fine details or discontinuities, it can lead to inaccuracies in the height map.

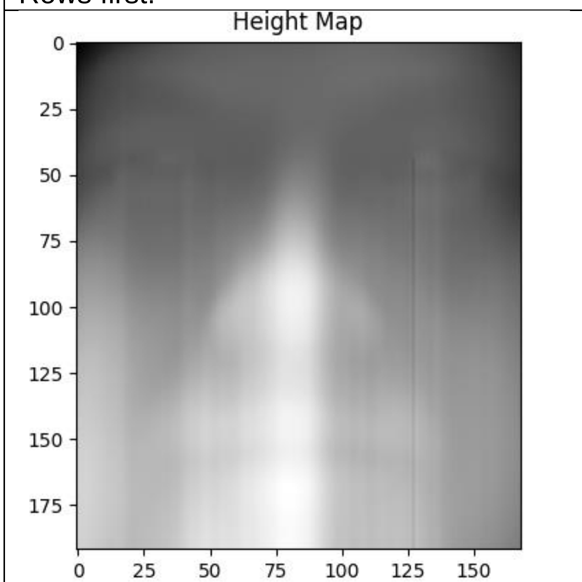
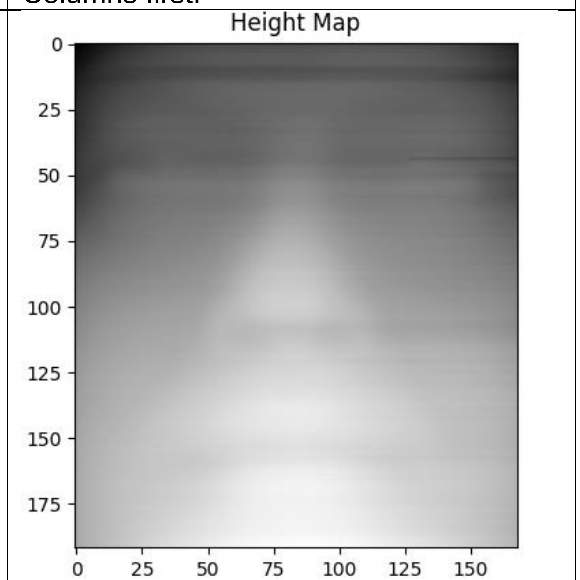
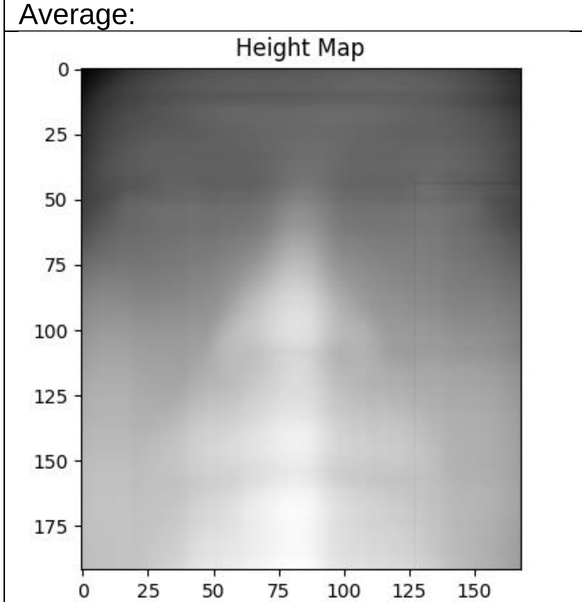
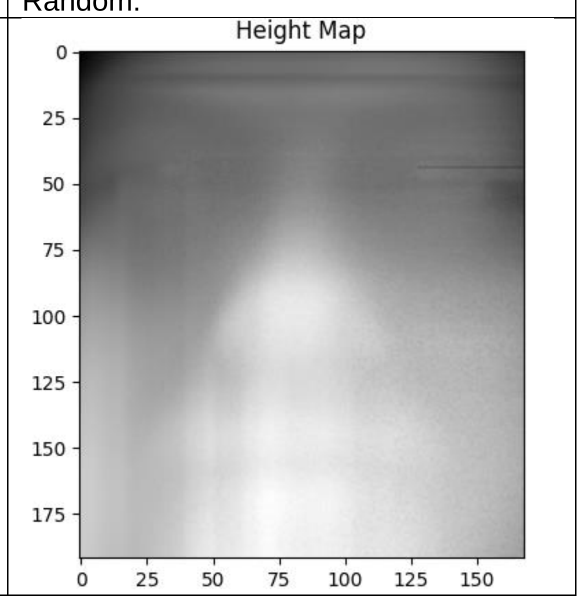
e) **Number of Images:** The quality of the results can depend on the number of input images. Too few images may lead to inaccurate solutions.

4) Display the surface normal estimation images below:



B: Compute Height Map

5) For every subject, display the surface height map by integration. Select one subject, list height map images computed using different integration method and from different views; for other subjects, only from different views, using the method that you think performs best. When inserting results images into your report, you should resize/compress them appropriately to keep the file size manageable -- but make sure that the correctness and quality of your output can be clearly and easily judged.

Rows first:	Columns first:
	
Average:	Random:
	

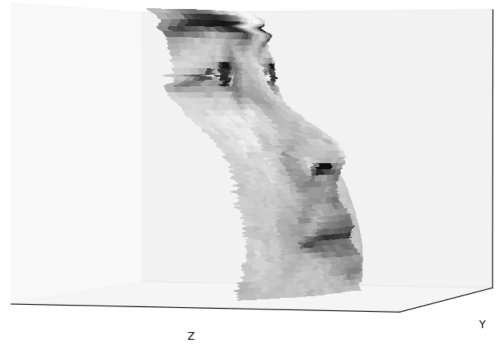
6) Which integration method produces the best result and why?
   The random path integration method has proven to be the most effective. By integrating along multiple random paths and averaging the results, the robustness of the surface reconstruction is enhanced. This approach is beneficial because each randomly chosen path can capture distinct information about the surface, and the averaging process serves to mitigate the influence of noise, outliers, or inaccuracies in the surface normals.
7) Compare the average execution time (only on your selected subject, “average” here means you should repeat the execution for several times to reduce random error) with each integration method, and analyze the cause of what you’ve observed:

Integration method	Execution time
random	19.318 s
average	1000, 881 ns
row	507, 116 ns
column	129, 699 ns

   The random path method consumes the most time due to its necessity to randomly select ten distinct paths (as set by default in the code) for each pixel in the derivative function matrix. Consequently, it demands a longer execution time. On the other hand, the average method, combining both the row and column methods, takes twice as long as the single row or column method.

C: Violation of the assumptions

8) Discuss how the Yale Face data violate the assumptions of the shape-from-shading method covered in the slides.
   a) **Non-Lambertian Surfaces:** SFS assumes that the surface has Lambertian reflectance, which means that the surface reflects light uniformly in all directions. Real faces, especially when captured under different lighting conditions, may not have purely Lambertian reflectance.
   b) **Textured Skin:** The dataset contains face images with textured skin, which can introduce additional complexities in the SFS process. SFS often works best on smooth, textureless surfaces.
9) Choose one subject and attempt to select a subset of all viewpoints that better match the assumptions of the method. Show your results for that subset.



10) Discuss whether you were able to get any improvement over a reconstruction computed from all the viewpoints.
    Applying Smoothing: Given the presence of noise in the height map generated using the random path method, we can enhance the quality of the reconstruction by applying smoothing to the surface normals or height maps, either before or after the random path integration.

Part 3: Extra Credit

Post any extra credit for parts 1 or 2 here.Don't forget to include references, an explanation, and outputs to receive credit. Refer to the assignment for suggested outputs.