CSC320H1, Winter 2019
Assignment 1

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Part 2. Bonus component: Efficient implementation

In this section, I would like to explain my implementation of the triangulation matting method that beat the reference solution's by a significant amount. Initially, the nested for loops were employed to implement the triangulation matting technique. However, this algorithm is highly-inefficient and offers significantly higher timings in comparison with the reference implementation. Hence, in order to improve the efficiency, the idea came to mind is to reduce the use of for loops and do all the computations in matrix form instead of pixel by pixel. Thus, I adopted the formulas mentioned in **Theorem 3** and **Theorem 4** in the paper, Blue Screen Matting by Alvy Ray Smith and James F. Blinn, which are

$$\alpha_0 = \frac{(R_{f_1} - R_{f_2})(R_{k_1} - R_{k_2}) + (G_{f_1} - G_{f_2})(G_{k_1} - G_{k_2}) + (B_{f_1} - B_{f_2})(B_{k_1} - B_{k_2})}{(R_{f_1} - R_{f_2})^2 + (R_{f_1} - R_{f_2})^2 + (R_{f_1} - R_{f_2})^2}$$

$$c_0 = c_{f_1} - (1 - \alpha_0)c_{k_1} = c_{f_2} - (1 - \alpha_0)c_{k_2}$$

, where f_1 and f_2 represent the composite images and k_1 and k_2 represent the background images. Then, all computations can be done in matrix form by using **numpy** package, which significantly enhance the efficiency without compromising the correctness. Taking *flowers-backA.jpg*, *flowers-backB.jpg*, *flowers-compA.jpg*, and *flowers-compB.jpg* in the **tiny** folder as four input images, the timings of my implementation and the reference solution are shown below. (NOTE: Timings may vary for each time execution.)

```
Triangulation matting...
----------------------------------
Timings
----------------------------------
Reading:    0.032927 seconds
Processing: 0.0552271 seconds
Writing:    0.0999482 seconds
```

Figure 1: Timings of My Implementation

```
Triangulation matting...
----------------------------------
Timings
----------------------------------
Reading:    0.00884294 seconds
Processing: 15.6452 seconds
Writing:    0.135612 seconds
```

Figure 2: Timings of Reference Solution

Part 3. Experimental evaluation & report

In this section, several experiments are conducted in order to test the limits of the triangulation matting method. Each experiment along with its specific conditions, results generated by my implementation and analysis is shown below.

1. **Experiment 1 – Simple Case**

   - ***Foreground Object:*** Eye drops bottle
   - ***Backgrounds:*** Cardstock in blue, Cardstock in yellow
   - ***Procedures to capture the images:***
     - Set up the camera at a fixed position
     - Lock the focus and the exposure of the camera
     - Turn off the flash light of the camera to make sure the use of the natural light
     - Take a picture of one background, then take a picture of the background with the object
     - Change the background, then take picture of the new background with the object and the picture of the new background in order
   - ***Camera Settings:***
     - Camera settings remain the same for four input images
     - Device: iPhone camera
     - Focal length: 4.25
     - F number: 1.8
     - Exposure program: 2
     - Exposure time: 1/35
   - ***Four Input Images:***

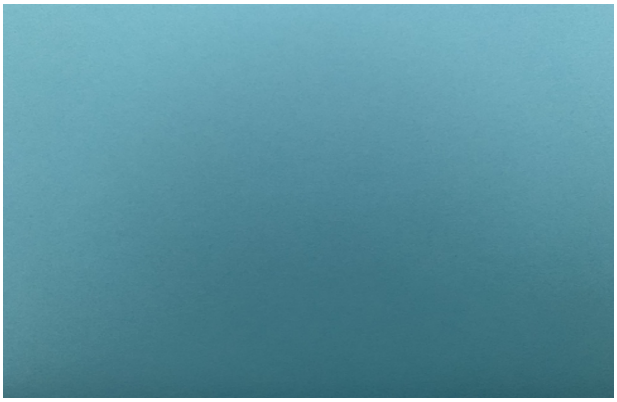

Figure 3: backA

Figure 4: compA

Figure 5: backB

Figure 6: compB

- ***Alpha and Color Images:***

Figure 7: Alpha Image

Figure 8: Color Image

- ***Composite Results:***

Figure 9: backIn

Figure 10: Composite Result

- ***Analysis:*** This experiment is designed to produce decent outputs to test whether my implementation can work successfully. Every condition is set as ideal and simple as possible. Based on the Alpha and Color Images (**Figure 7** and **Figure 8**), the triangulation matting method works quite well in this case. As you can see in the Alpha Image, most of the background area are nice in black except some area around the bottle. This is because of the shadow around the bottle. The shadow increases the difference in RGB values when subtracting background RGB values from composite RGB values for pixels around the bottle, which results in low but non-zero alpha for those pixels. Moreover, the bottle cap seems narrower than it should be. This is due to the property of reflection of the bottle cap. The side parts of the bottle cap reflects the color of the background. Hence, those pixels have zero or near-zero alpha. By compositing the foreground object onto **Figure 9**, the shadow and reflection issue can be seen clearly in **Figure 10**. In conclusion, the triangulation matting method works fine in this case but it can not deal with the foreground object's reflection property and its shadow.

2. **Experiment 2 – Similar Color With Backgrounds and Foreground Object**

   - ***Foreground Object:*** Wristband
   - ***Backgrounds:*** Cardstock in pink, Cardstock in other pink, Cardstock in blue
   - ***Procedures to capture the images:***
     - Set up the camera at a fixed position
     - Lock the focus and the exposure of the camera
     - Turn off the flash light of the camera to make sure the use of the natural light
     - Take a picture of one background, then take a picture of the background with the object
     - Change the background, then take picture of the new background with the object and the picture of the new background in order
     - Take a picture of another new background, then take a picture of this background with the object
   - ***Camera Settings:***
     - Camera settings remain the same for four input images
     - Device: iPhone camera
     - Focal length: 4.25
     - F number: 1.8
     - Exposure program: 2
     - Exposure time: 1/24
   - ***Six Input Images:***
     NOTE: Two more input images for results comparison.

Figure 11: backA

Figure 12: compA

Figure 13: backB

Figure 14: compB

Figure 15: backC

Figure 16: compC

- ***Alpha and Color Images:***
  - **Case 1: Use Figure 11, 12, 13, 14 as Input Images**

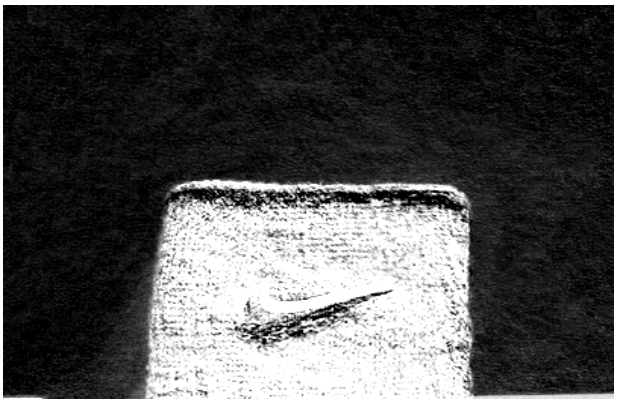

Figure 17: Alpha Image

Figure 18: Color Image

– **Case 2: Use Figure 11, 12, 15, 16 as Input Images**

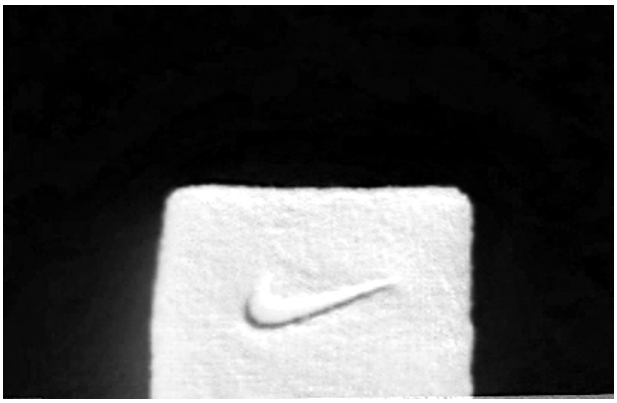

Figure 19: Alpha Image

Figure 20: Color Image

- ***Analysis:*** The purpose of this experiment is to test whether having similar color for the foreground object and the backgrounds is going to have any effect on the results of the triangulation matting method. Based on the outputs, **Case 2** generates better results than **Case 1**. If the foreground object has similar color with both backgrounds, then there are some pixels of foreground object have zero or near-zero alpha. Thus, those pixels cause the dark points within foreground object in **Figure 17** and **Figure 18**. In addition, the pink in the background in **Figure 18** is due to color difference in backgrounds between **Figure 13** and **Figure 14** and the color difference is carried to the foreground image. Hence, if both backgrounds have similar color with the foreground object, then this would fail the triangulation matting method.

3. **Experiment 3 – Distinct Light Levels**

- ***Foreground Object:*** Eye drops bottle

- ***Backgrounds:*** Cardstock in black, Cardstock in blue
- ***Procedures to capture the images:***
  - Set up the camera at a fixed position
  - Lock the focus and the exposure of the camera
  - Turn on the flash light of the camera to get **Figure 21** and **Figure 22** while use natural light for taking **Figure 23** and **Figure 24**
  - Take a picture of one background, then take a picture of the background with the object
  - Change the background, then take picture of the new background with the object and the picture of the new background in order
- ***Camera Settings:***
  - Device: iPhone camera
  - For **Figure 21** and **Figure 22**: Focal length: 4.25, F number: 1.8, Exposure program: 2, Exposure time: 1/48
  - For **Figure 23** and **Figure 24**: Focal length: 4.25, F number: 1.8, Exposure program: 2, Exposure time: 1/15
- ***Four Input Images:***

Figure 21: backA

Figure 22: compA

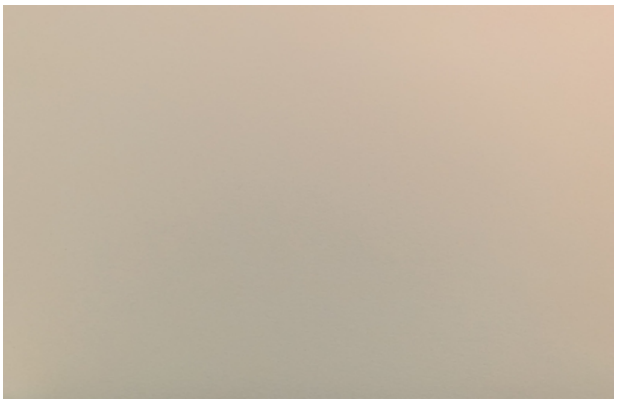

Figure 23: backB

Figure 24: compB

- ***Alpha and Color Images:***

Figure 25: Alpha Image

Figure 26: Color Image

- ***Analysis:*** This experiment aims to test the effect of light levels on the triangulation matting method. In this experiment, **Figure 21, 22** are taken with flash light while **Figure 23, 24** uses the natural light. Even though the results do not look good, they are expected and reasonable. Due to the use of flash light, the color of the foreground object in **Figure 22** is distorted and not consistent with the color of the foreground object in **Figure 24**. Therefore, the Color Image incorrectly reflect the color of the foreground object. Also, there is a noise part (white area) around the bottle in Alpha Image and Color Image. It is due to RGB value difference (color difference) between **Figure 21** and **Figure 22** in that area. Hence, different light level would affect the results of the triangulation matting method.

4. **Experiment 4 – Different Materials in Backgrounds**

- ***Foreground Object:*** Bio true solution bottle
- ***Backgrounds:*** MacBook Lid, Cardstock in green

- ***Procedures to capture the images:***
  - Set up the camera at a fixed position
  - Lock the focus and the exposure of the camera
  - Turn off the flash light of the camera to make sure the use of the natural light
  - Take a picture of one background, then take a picture of the background with the object
  - Change the background, then take picture of the new background with the object and the picture of the new background in order
- ***Camera Settings:***
  - Camera settings remain the same for four input images
  - Device: iPhone camera
  - Focal length: 4.25
  - F number: 1.8
  - Exposure program: 2
  - Exposure time: 1/60
- ***Four Input Images:***

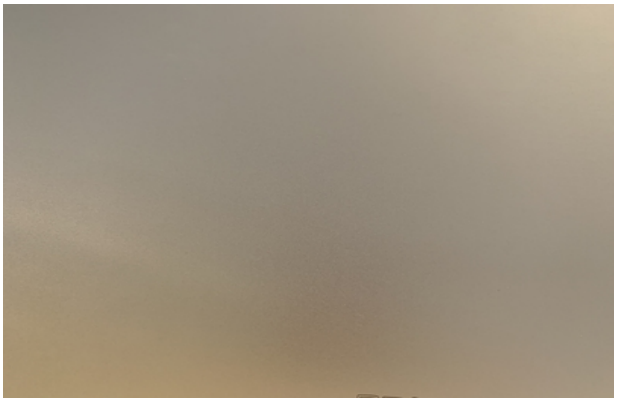

Figure 27: backA

Figure 28: compA

Figure 29: backB

Figure 30: compB

- ***Alpha and Color Images:***

Figure 31: Alpha Image

Figure 32: Color Image

- ***Analysis:*** This experiment is designed to test the effect of different materials of the background on the results of the triangulation matting method. In this experiment, keep other conditions unchanged and employ two backgrounds with distinct materials, one is metal (MacBook Lid) and the other one is paper (Cardstock). Based on the Alpha and Color Images, the results are pretty decent. Although there are some noises in the Alpha Image, it is within the tolerance of error since the photos are taken manually and there could be some color difference in the backgrounds between composite and background images. Consequently, the background materials would not affect the results of the triangulation matting technique.

5. **Experiment 5 – Color Difference in Backgrounds**

- ***Foreground Object:*** Contact lenses box
- ***Backgrounds:*** Table mat, Cardstock in green

- ***Procedures to capture the images:***
  - Set up the camera at a fixed position
  - Unlock the focus and the exposure of the camera
  - Turn off the flash light of the camera to make sure the use of the natural light
  - Take a picture of one background, then take a picture of the background with the object
  - Change the background, then take picture of the new background with the object and the picture of the new background in order
- ***Camera Settings:***
  - Camera settings remain the same for four input images
  - Device: iPhone camera
  - Focal length: 4.25
  - F number: 1.8
  - Exposure program: 2
  - Exposure time: 1/60
- ***Four Input Images:***

Figure 33: backA

Figure 34: compA

Figure 35: backB

Figure 36: compB

- ***Alpha and Color Images:***

Figure 37: Alpha Image

Figure 38: Color Image

- ***Analysis:*** This experiment aims to test the effect of the color difference in backgrounds between composite and background images on the triangulation matting method. In this experiment, the focus and exposure of the camera is unlocked, which causes **Figure 33** and **Figure 35** are slightly lighter than **Figure 34** and **Figure 36**. This issue leads to color difference in backgrounds, which implies to have larger difference when subtract background RGB values from composite RGB values and causes non-zero alphas. Thus, in Alpha and Color Images, the background pattern and color difference are carried to the foreground image. Also, the edges of the box are blur, which is due to position difference of the box between **Figure 34** and **Figure 36**. Therefore, it is obvious that triangulation matting method is not able to deal with the position difference of the foreground object and the color difference in backgrounds.

6. **Experiment 6 – Dark Environment**

- ***Foreground Object:*** Contact lenses retail package

- ***Backgrounds:*** Cardstock in purple, Cardstock in green
- ***Procedures to capture the images:***
  - Set up the camera at a fixed position
  - Lock the focus and the exposure of the camera
  - Turn off the flash light of the camera to make sure the use of the natural light in a dark environment
  - Take a picture of one background, then take a picture of the background with the object
  - Change the background, then take picture of the new background with the object and the picture of the new background in order
- ***Camera Settings:***
  - Camera settings remain the same for four input images
  - Device: iPhone camera
  - Focal length: 4.25
  - F number: 1.8
  - Exposure program: 2
  - Exposure time: 1/4
- ***Four Input Images:***

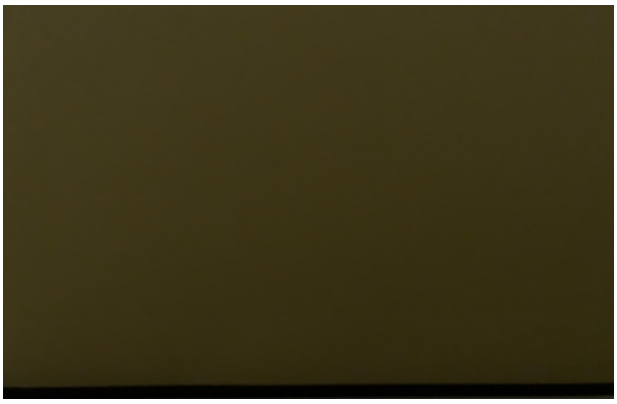

Figure 39: backA

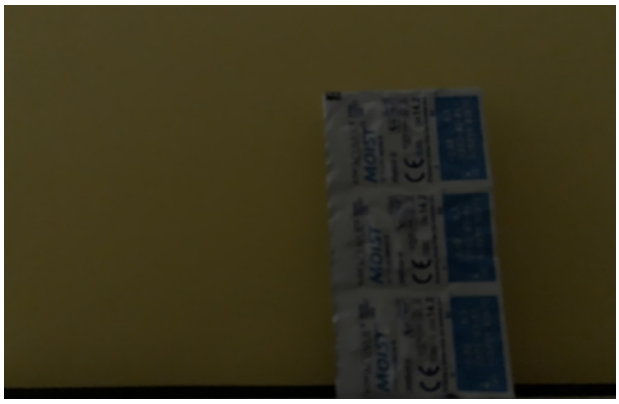

Figure 40: compA

Figure 41: backB

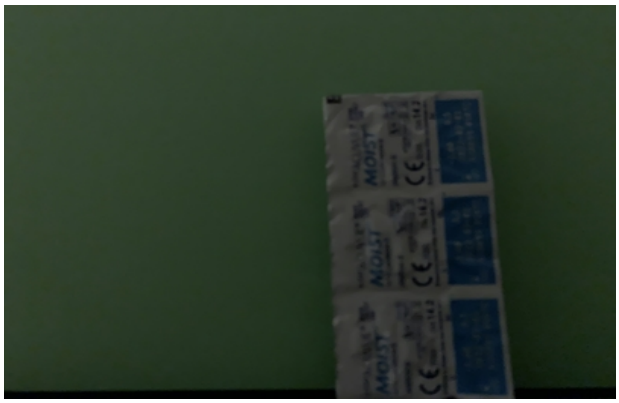

Figure 42: compB

- ***Alpha and Color Images:***

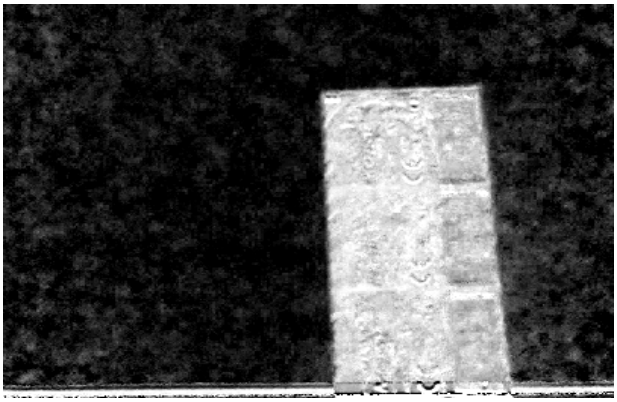

Figure 43: Alpha Image

Figure 44: Color Image

- ***Analysis:*** This experiment is designed to test the performance of the triangulation matting method on the input images taken in a dark environment (lower light level). Based on the condition of the input images given, the outputs are decent. Since the foreground object are not clear in the composite images, therefore it is reasonable for the blur of the object in Color Image. In addition, the white parts in the Alpha Image are due to color difference in backgrounds between composite and background images at those area. This issue is accepted since there might be error as the photos are manually taken. In conclusion, as long as there are color contrast (relatively larger non-zero values when doing subtraction between RGB values of composite and background images), this technique would do its job but the condition of the foreground image based on the condition of the input images.

7. **Experiment 7 – Screenshots to test Complex Backgrounds**

- ***Foreground Object:*** Poll Everywhere App Icon

- ***Backgrounds:*** Multi-color Wallpapers with some app icons
- ***Procedures to capture the images:***
  - Take four screenshots of the phone desktop
- ***Camera Settings:***
  - No camera settings for this case
- ***Four Input Images:***

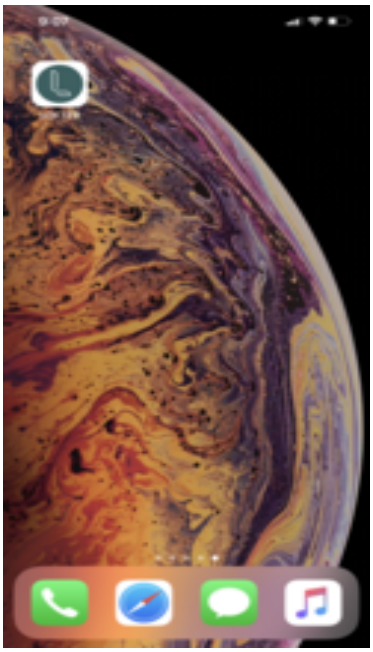

Figure 45: backA

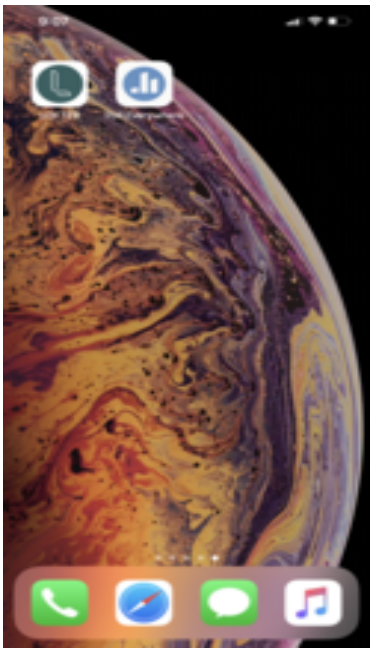

Figure 46: compA

Figure 47: backB

Figure 48: compB

- ***Alpha and Color Images:***

Figure 49: Alpha Image

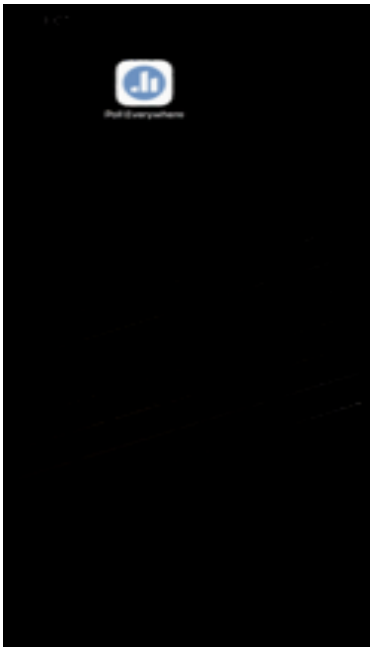

Figure 50: Color Image

- ***Analysis:*** This experiment aims to test whether the triangulation matting method can perform

on complex backgrounds successfully. I tried to take several sets of photos with complex backgrounds, however, this process is done manually and there always exists some experimental errors. Thus, the triangulation matting method could not produce good results. Then, I conducted this experiment. Based on the Alpha and Color Images, the triangulation matting technique works successfully. Consequently, this proves that the triangulation matting technique can deal with complex backgrounds.

Based on the experiments above, I would like to make an analysis of the limits of the triangulation matting method. First, list the strengths of the triangulation matting method below.

- This technique can deal with different materials for both backgrounds and foreground objects.
- This technique can apply on the input images taken in lower light level environment as long as all input images are taken under the same light level. However, the condition of the results depends on the conditions of the input images.
- This technique can deal with complex backgrounds (e.g. background with multi-color and/or patterns).

Then, show the weaknesses of the triangulation matting method below.

- This technique can not deal with foreground object's shadow. It treats the shadow as part of the object.
- This technique can not deal with the property of reflection of the foreground object. When the background color is reflected by parts of the object, those parts may not be extracted successfully from the background.
- This technique can not perform successfully on the case that both backgrounds have similar color with the foreground object.
- This technique is going to generate poor results if the light level change between input images (as shown in Experiment 3).
- This technique can not deal with the position difference of the foreground object between two composite images.
- This technique can not deal with the color difference in backgrounds between composite and background images.

Part 4. Written question

In this section, I would explain the reason why the alpha matte on the left side of the vase has low but non-zero intensities. The non-zero alpha implies that there is a foreground "object" to the left of the vase and that "object" is not totally transparent. In this case, the "object" is the shadow. In the composite images, the shadow of the foreground object exists on the left side of the vase. However, on the background images, not only the foreground object is removed but also its shadow is removed as well. Therefore, the pixels in the shadow area have non-zero and larger difference in RGB values by subtracting RGB values of the background images from the RGB values of the composite images. Then, those pixels on the left side of

the vase has non-zero alpha. Due to the direction of the light, there is no shadow of the foreground object on the right side of the vase. Therefore, RGB values on the right side of the vase between composite and background images are quite similar or the same. Thus, the alpha matte on the right side of the vase has zero or near-zero intensities.