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1 Background and Literature Review

1.1 Survey of methods for changing and matching skin colour in Photoshop

The are a wide range of online video tutorials available for adjusting human skin tone in individual images using Photoshop. The purposes of these videos include giving the subject of an image the appearance of a tan, matching the skin tone of the subject to a desired skin tone on another individual, or matching the skin tone of a subject's face to the rest of the subject's body, which is often a slightly different colour [4] [3] [2]. We surveyed a range of these videos and summarize the techniques of the most relevant videos with reasonably realistic results. See Appendix A for a more detailed description of three of these Photoshop processes.

Summary of Photoshop techniques

Levels and curves are frequently used for small brightness adjustments [1] [2] [3]. For large brightness adjustments, one technique was found (see Appendix A.1), where the skin area is brightened in a conversion to black and white, and then the luminosity blend mode is used to place the colour back into the image. Sometimes highlights and shadows are adjusted separately; curves or the "blend if" function (which blends in an effect only if the original pixel is above a certain threshold of brightness) can be used to achieve this effect [4].

There are many different methods to match colour, and the colour can be adjusted separately from the brightness or simultaneously - often one would affect the other [2] [3]. Methods for matching colour include matching the ratios of cyan, magenta and yellow by making adjustments with the selective colour tool, or using curves or levels on individual colour channels. Adjustments are made either by eye or to numerically match a target color [5] [2] [3]. Often to reduce the vividness of the colour adjustments the saturation must be slightly decreased [1] [2].

After all other effects are applied, the opacity of the overall effect is often reduced from 100% for a more natural appearance [1] [2].

Limitations of Photoshop techniques

These Photoshop techniques are generally meant to be tailored to each specific image that a human is adjusting. There are many junctures where the specific numerical amount of an adjustment often have to be judged by eye. While Photoshop has a method for automating processes using actions, the processes are meant for increasing ease of use by artists who can make additional adjustments and are familiar with the tool, rather than in commercial applications where the process is entirely automated [6].

Another limitation is that Photoshop operates at a higher level of abstraction than image processing software making use of libraries such as OpenCV. Image processing code has much more control over processes that can be applied to images, and the regions on the image that processes are applied to.

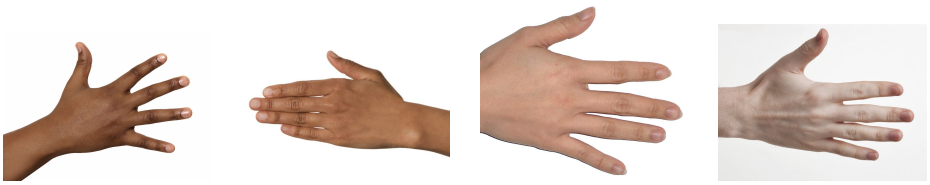
Finally, some Photoshop effects may be proprietary and are of course limited to the platforms that Photoshop supports, while a program developed with a platform such as OpenCV can be made open source and adapted to uses on a variety of different platforms.

2 Methods

To accomplish the objective of recolouring the skin tone of a hand to a target colour, we wrote algorithms in C++ in Eclipse on OS X using OpenCV libraries. Eclipse is used to compile each iteration of the algorithm into a debug-mode executable program named Recolor. For ease of testing, as the algorithm is modified, we add more functionality to the Recolor program and retain the ability to use previous versions of the algorithm. We use a custom Python script to run new versions of Recolor from the terminal to test it. All of the relevant code and its versions are hosted on a git repository at https://github.com/tiantianhan/recolor

Recolor takes as input a hand image, a mask instructing it where to find the average skin colour of the hand, and a desired target skin colour. (Other flags and inputs are also used for testing purposes, see the Github repository readme file for a full description of the usage.) Recolor then outputs the processed image where the skin tone is adjusted to the target colour.

We iterated from simple to more complex algorithms, at each step testing the algorithm and evaluating the results. We tested progressive iterations on a set of hand images with varying skin tones. The images are are shown in Figure 1.



(a) (b) (c) (d)

Figure 1: Different hand images used for testing

For each test, we called the Recolor program to transform the image of one hand to have the skin tone of the hand in another image, then visually compared the processed image to the image of the target hand. We performed the process on all possible combinations of our test images, paying particular attention to the extreme cases, such as transforming from Figure 1a to Figure 1d and vice versa, as well as cases that start with a hand with mid-tone skin such as in Figure 1b (as this is the most likely use case for applications that change the image of a model's hand to match a range of skin tones). We

evaluated the resulting images subjectively, based on whether the processed hand looks believably like a hand naturally of that skin tone, and noted any flaws that we then attempted to correct with the next iteration of the algorithm.

In the following subsections we summarize the results of each algorithm and our evaluation of the results.

2.1 Simple brightness addition / subtraction

Algorithm

To begin, we performed a simple addition of a value to each of the rgb channels of the hand, such that the average colour of the hand in the processed image is equal to the average colour of the hand in the target image. The algorithm is shown in Equation 1.

$$r' = r + \delta_r \tag{1}$$

Where

$$\delta_r = \bar{r_t} - \bar{r}$$

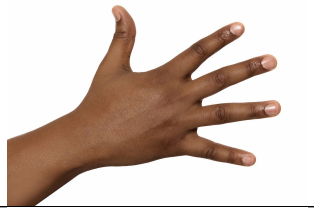
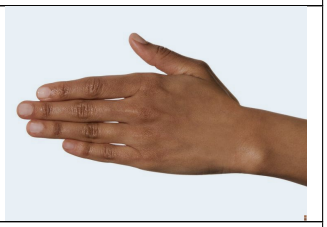
With the same equation applying for the g and b channels.

Results

The complete results are shown in Table 7 in Appendix B, and a portion is shown here for convenience.

Portion of test results of simple addition / subtraction brightening function from Table 7 in Appendix B

No.	Original	Target	Result

7.2			
7.4			
7.5			
7.6			

Evaluation

Images of darker skin tones and smaller changes from the original skin tone to the target colour to begin with (Row 7.4) tend to have better results than images with large changes (Rows 7.2, 7.6). In the case of changes towards brighter colours, this is because large changes force bright points in the original image to be truncated at white, and also causes dark regions on the image, such as shadows and grooves, to become significantly brighter and less close to true black, giving the image a "high-key" appearance (Row 7.2 and 7.5).

In addition, we noted that at this stage the transformation from a dark coloured hand to a very pale hand, or even from a mid-toned hand to a pale

hand and vice versa is especially unconvincing. (Row 7.6, also see 7.3 and 7.10)

2.2 Proportional adjustment relative to average color

Algorithm

To correct for the effect of the bright spots in the image being over bright and the high-key appearance resulting from all the shadows being brightened, we used an algorithm that maps the black and white points of the image to the same value, and adjusts the colours in between to match the target average colour. The algorithm is shown in Equation 2.

$$r' = \begin{cases} \left(\frac{\bar{r}_t}{\bar{r}}\right) r, & \text{for } r \leq \bar{r} \\ 255 - \left(\frac{255 - \bar{r}_t}{255 - \bar{r}}\right)(255 - r), & \text{for } r > \bar{r} \end{cases} \tag{2}$$

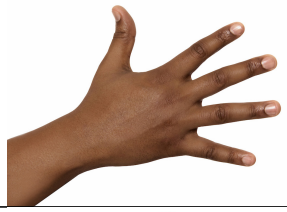
With the same equation applying for the g and b channels.

Results

The complete results are shown in Table 8 in Appendix C, and a portion is shown here for convenience.

Portion of test results of adjusting proportionally based on distance of color to the average from Table 8 in the Appendix C

No.	Original	Target	Results
8.2			

8.4			
8.5			
8.6			

Evaluation

This method improved the appearance of cases with over-bright spots or "high-key" appearance issues, as Figure 2 shows:

(a) Simple addition algorithm (Equation 1)result

(b) Proportional adjustment algorithm (Equation 2) result

Figure 2: Comparison of algorithms 1 and 2 results for transforming a dark hand (Figure 1a) to a light hand (Figure 1c).

We noted however, that this method noticeably does not correct for, and even exacerbates slightly relative to the simple addition algorithm the dark spots at the joints and creases of a hand of darker skin tone when it is transformed to a lighter skin tone (Row 8.5). Other results are similar to the results of the simple addition algorithm.

2.3 Proportional adjustment with dark spot correction

Algorithm

We attempted to correct the dark spot issue by significantly reducing the absolute difference between dark pixels and the average colour, ensuring that the dark spots would instead have colours close to the average. We perform this correction on the output of the proportional adjustment algorithm.

$$r'' = \begin{cases} \bar{r'} - \dfrac{(\bar{r'} - r')}{\alpha}, & \text{for } r' < \bar{r'} \\ r', & \text{for } r' \geq \bar{r'} \end{cases} \tag{3}$$

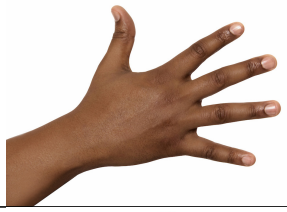
Where α is a constant, $\alpha > 1$. The same equation applies for the g and b channels.

Results

See Tables in Appendix D, E and F for complete results for a range of values for α. A portion of the results for $\alpha = 3$ is reproduced here for convenience.

Test results of proportional adjusting with correction for dark spots, alpha = 3 from Table 11 in the Appendix F

No.	Original	Target	Results
11.1			

11.4			
11.5			
11.6			

Evaluation

As shown in Figure 3, the dark spots and creases noted in Section 2.2 are reduced.

(a) Proportional adjustment algorithm (Equation 2)result

(b) Proportional adjustment algorithm with correction (Equation 3) result

Figure 3: Comparison of algorithms 2 and 3 results for transforming a mid-toned hand (Figure 1b) to a light hand (Figure 1c).

However, we have noted that even for the more lower strength effect where $\alpha = 3$, this process brings back the problem where true black is eliminated from the image, making the image appear to be without shadows (See Row 11.1 and 11.5).

Also, it should be noted that for completeness, we performed this algorithm on all possible combinations of hand images, even though it was intended for cases where the original image is of a skin tone darker than the target image.

Interestingly, in a couple of cases of transformation from lighter skin tone to darker skin tone, the hand takes on a darker colour around joints in a similar manner to how a hand of dark skin tone is naturally coloured, though the algorithm was not intended for this purpose (See Row 11.4 as well as 11.7, 11.8). This is not always the case, however. Row 11.10 does not seem to exhibit this effect, possibly due to the different lighting of the hand in the image.

2.4 Next iteration

We could try to bring back darker shadows and detail to the transformed image by making the previous correction algorithm apply for a narrower range of colour, distinguishing between shadow and dark spots and creases of the hand.

We should also apply a different algorithm for hands transforming from lighter skin tones to darker skin tones, possibly adding the characteristic darker regions on a hand of darker skin tone instead of removing it.

We could also try different test images, particularly for the lightest coloured hand case (Figure 1d), since the results for a darker or mid-toned hand (Figure 1a, 1b) transforming into it are less realistic than for other colours, and it is possible that the particular lighting of Figure 1d is affecting its calculated average colour and therefore the results.

References

[1] J. Shaver. (2014) How to change a person's skin color from dark to light in photoshop. [Online]. Available: http://www.designpanoply.com/blog/how-to-change-a-persons-skin-color-from-dark-to-light-in-photoshop

[2] Phlearn. (2014) How to match skin tones in photoshop. [Online]. Available: https://www.youtube.com/watch?v=5-DE49Muc0g

[3] PiXimperfect. (2017) How to match skin tone in photoshop cc 2017. [Online]. Available: https://www.youtube.com/watch?v=zEeknlHydfE

[4] Phlearn. (2016) How to get a tan in photoshop. [Online]. Available: https://www.youtube.com/watch?v=Har8CSjei2k

[5] M. Woloszynowicz. (2014) How to accurately match skin tones using selective color in photoshop. [Online]. Available: https://www.youtube.com/watch?v=IOYFhumpmv8

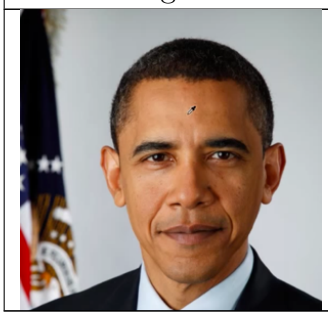
[6] ——. (2014) How to easily correct colors and match tones in photoshop. [Online]. Available: http://www.vibrantshot.com/how-to-easily-correct-colors-and-match-tones-in-photoshop/

A Photoshop techniques for changing skin-tone from select online video tutorials

A.1 Changing skin colour from dark to light [1]

Effect

Table 4: Screen captures from Photoshop tutorial for changing skin colour from dark to light.

Original	Result
	

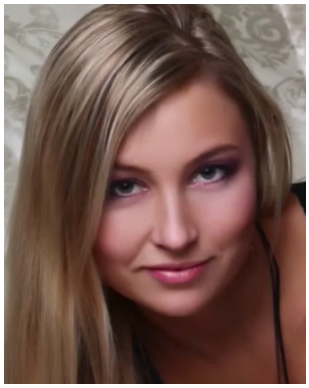
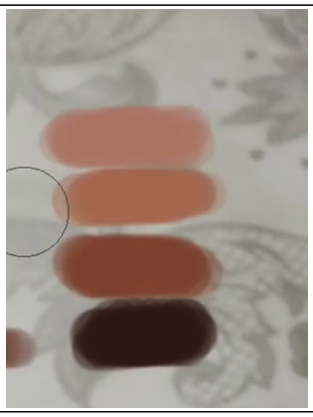
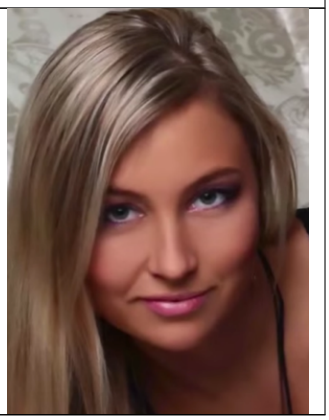
Summary of the process

- Levels adjustment layer - Make gamma value adjustment, adjusting midtones, and adjust the white point for overall brightening effect
- Curves adjustment layer - Reduce highlights resulting from brightening with a custom curve dipping at the highlights
- HSV adjustment layer - Reduce saturation, correcting the oversaturation caused by brightening the image
- Further brightening: obtain greyscale image; boost reds and yellows in the greyscale conversion, brightening the skin area, then use greyscale image to inform the original images luminosity; set this effect to a reduced opacity for a more natural appearance
- Adjust colours by eye with a colour balance layer

A.2 Matching the skintones of face and body [2]

Effect

Table 5: Screen captures from Photoshop tutorial for matching the skintones of face and body.

Original	Target	Result
		

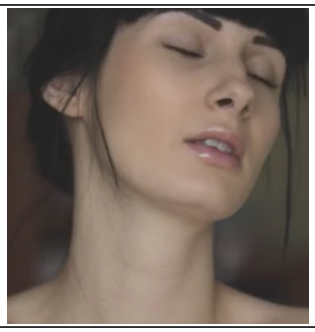
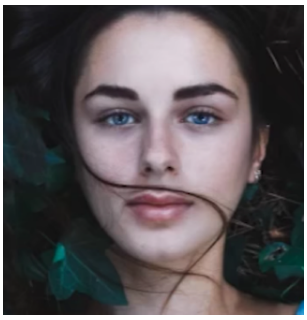
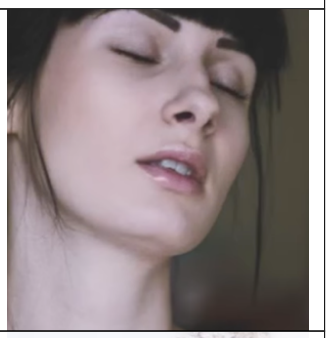
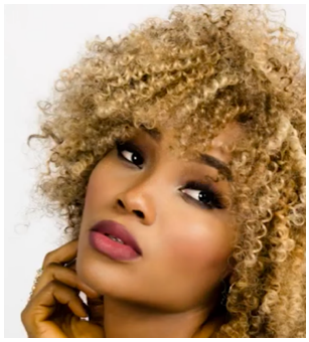
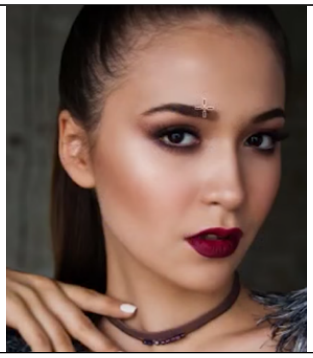
Summary of the process

- Sample a range of colours from face and body (the area with the desired colour) and determine by eye if face should become warmer or cooler, or lighter or darker
- Simultaneously adjust brightness and colour with levels adjustment for each colour channel, adjusting the output and input white and black points
  - For darker and warmer colours, add yellow and magenta to the image highlights while simultaneously dimming the image by lowering the output white points
- Reduce saturation to counteract oversaturation caused by colour adjustment
- Reduce opacity of effect for more natural appearance

A.3 Matching the skintones of portraits of different people [3]

Effect

Table 6: Screen captures from Photoshop tutorial for matching the skintones of portraits of different people.

No.	Original	Target	Result
6.1			
6.2			

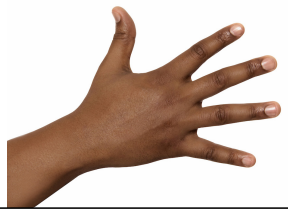
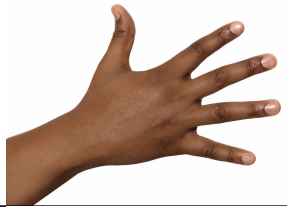
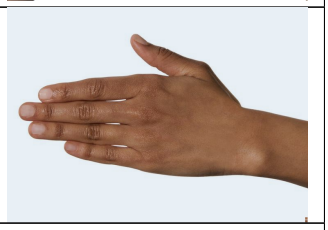
Summary of the process

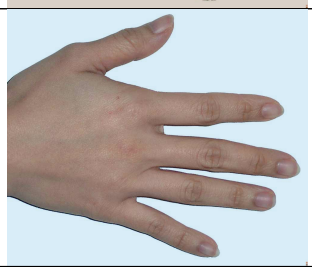
- For both the target and original image, select an area on face with even skin tone and calculate the average colour. It is important to select the same areas on both images for the effect to work - if the cheek is selected for one person, the cheek should be selected for other person as well
- Using the curves adjustment layer, adjust the curves for each channel, manipulating the point of the original colour and the target colour such that the output of the original color is equal to the target colour
- Make some additional adjustments to the curve to change brightness and contrast

- Sometimes the colour curves will have to be further adjusted by eye; sometimes, different areas of the skin must be adjusted separately what works for the face may not work for the body areas

B Complete results for simple brightening

Table 7: Test results of simple addition / subtraction brightening function.

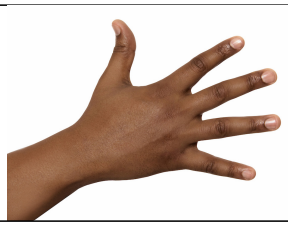
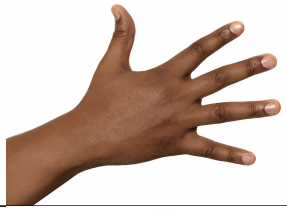
No.	Original	Target	Results
7.1			
7.2			
7.3			
7.4			
7.5			

7.6			
7.7			
7.8			
7.9			
7.10			
7.11			

7.12			

C Complete results for proportional brightness adjustment

Table 8: Test results of brightening proportionally based on distance of color to the average.

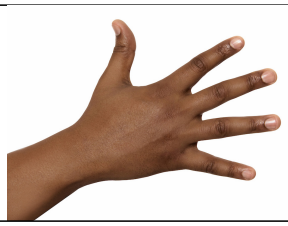
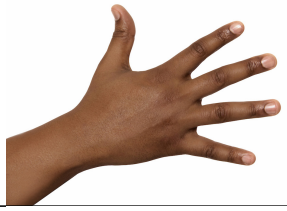
No.	Original	Target	Results
8.1			
8.2			
8.3			
8.4			
8.5			

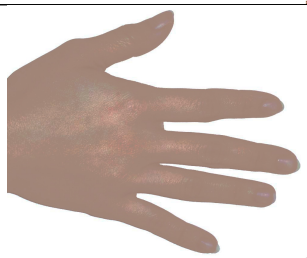
8.6			
8.7			
8.8			
8.9			
8.10			
8.11			

8.12			

D Complete results for proportional adjustment with darkspot correction, $\alpha = 10$

Table 9: Test results of proportional adjusting with correction for dark spots, $\alpha = 10$

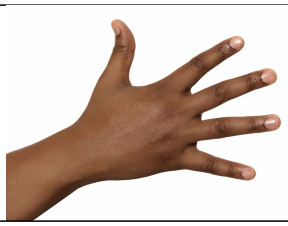
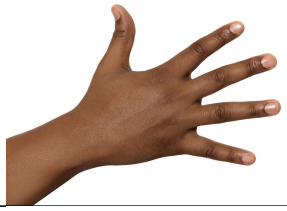
No.	Original	Target	Results
9.1			
9.2			
9.3			
9.4			
9.5			

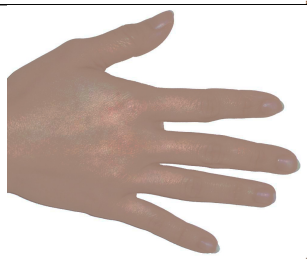
9.6			
9.7			
9.8			
9.9			
9.10			
9.11			

9.12			

E Complete results for proportional adjustment with darkspot correction, $\alpha = 5$

Table 10: Test results of proportional adjusting with correction for dark spots, $\alpha = 5$

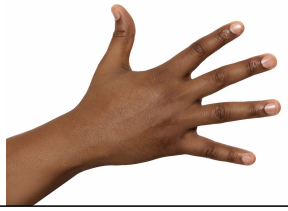
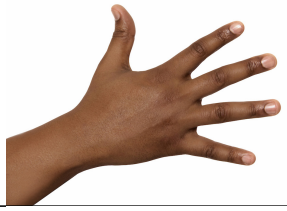
No.	Original	Target	Results
10.1			
10.2			
10.3			
10.4			
10.5			

10.6			
10.7			
10.8			
10.9			
10.10			
10.11			

10.12			

F Complete results for proportional adjustment with darkspot correction, $\alpha = 3$

Table 11: Test results of proportional adjusting with correction for dark spots, $\alpha = 3$

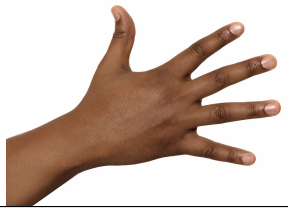
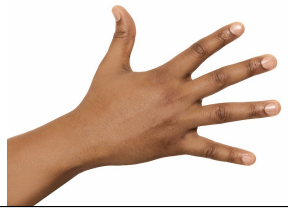
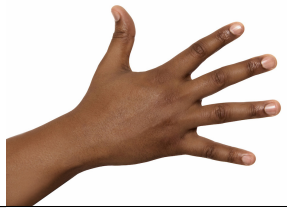
No.	Original	Target	Results
11.1			
11.2			
11.3			
11.4			
11.5			

11.6			
11.7			
11.8			
11.9			
11.10			
11.11			

11.12			

G Complete results for proportional adjustment with darkspot correction, $\alpha = 1.1$, calculating target average color with 5th percentile bright pixels

Table 12

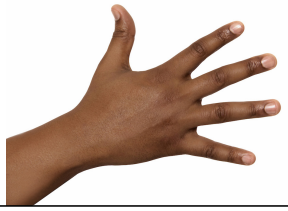
No.	Original	Target	Result
12.1			
12.2			
12.3			
12.4			
12.5			

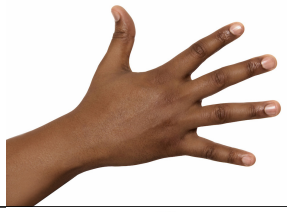
12.6			
12.7			
12.8			
12.9			
12.10			
12.11			

12.12			

H Complete results for proportional adjustment with darkspot correction, $\alpha = 1.1$, calculating target average color with 10th percentile bright pixels

Table 13

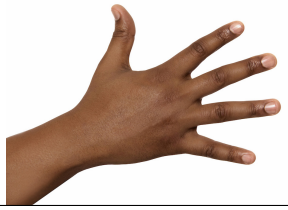
No.	Original	Target	Result
13.1			
13.2			
13.3			

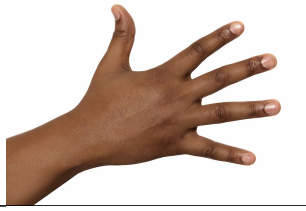
13.4			
13.5			
13.6			
13.7			
13.8			
13.9			

13.10			
13.11			
13.12			

I Complete results for proportional adjustment with darkspot correction, $\alpha = 1.1$, calculating target average color with 25th percentile bright pixels

Table 14

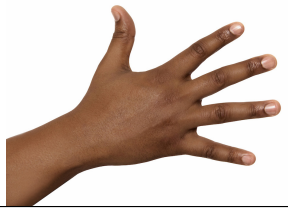
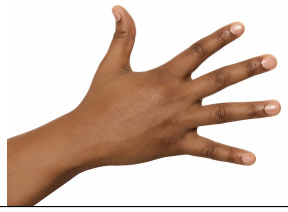
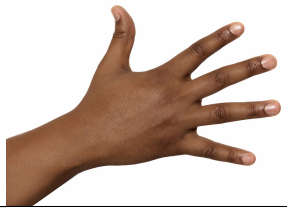
No.	Original	Target	Result
14.1			

14.2			
14.3			
14.4			
14.5			
14.6			
14.7			

14.8			
14.9			
14.10			
14.11			
14.12			

J Complete results for proportional adjustment with darkspot correction, $\alpha = 1.1$, calculating target average color with 100th percentile bright pixels

Table 15

No.	Original	Target	Result
15.1			
15.2			
15.3			
15.4			
15.5			

15.6			
15.7			
15.8			
15.9			
15.10			
15.11			

15.12