Pretty Pictures: *RGB Accuracy*

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Abstract—In order to determine the color accuracy of images taken by a variety of cameras, we conducted a comparison between three smartphone cameras, a full color astronomy camera, and a monochrome camera. A full color image with the monochrome camera was created by stacking exposures captured with a red, green, and a blue filter. We analyzed and compared the red, green, and blue values at a particular location and color value for each image.

Keywords—RGB, stacking[c]

I. RGB Imaging and Stacking[a][c]

RGB, which stands for "red green blue," refers to the digital units for measuring color accuracy in photos. Every color in the visible spectrum can be assigned a red, green, and blue value--these can be combined in various proportions and are each represented by an integer value ranging from 0 to 256. RGB imaging, which we explored, is a technique in which three images taken through a red, green, and blue filter are stacked on top of each other to created a full color image.

Stacking, a technique used to improve the quality of photographs, reduces the blurriness caused by diffraction through a color lens. Several photos are taken at different focal lengths, and a final composite is created using only the sharpest parts of each image.[4] Typically, multiple exposures are taken with each colored filter applied, and the images are stacked together, resulting in an image with less noise. Together, RGB imaging and stacking are used to achieve a more accurate representation of the colors we see.

With modern technology, RGB imaging can be done in different ways. One method is to take several photos using a monochrome camera with red, green, and blue filters applied separately, and to use a software to stack them and create a full-color image.[3] Alternatively, one can also use more traditional digital filters, which are built within a software, to mimic the effect of physical filters. Either way, RGB stacking results in not only a full-color photo, but also one with reduced noise. In order to get the best results, photographers also utilize white balancing to render more realistic colors onto the image, taking into account the "color temperature" of a light source.[6] When done correctly, the color variation in the image due to the light source becomes minimal due to the optimal balance of color temperature.

II. Filters[a]

A. Color by Definition

First, it is worth mentioning how we perceive colors with our eyes. When surfaces of different objects are hit by light, they reflect some wavelengths while absorbing others on the spectrum.[2] The photoreceptors in the cones of our retina respond to that reflected light. Like RGB stacking, our cones respond to three colors: red, green, and blue, and the colors that we see are only the reflected spectrums off an object. [7]Therefore, we do not see any absorbed colors.

Take an apple for example. By definition, the apple is not "red," rather, it is reflecting the red spectrum, which is why it appears red. This becomes important as photographers stack red, green, and blue filters together to allow the human eye to work in order to see a "full-color" image.

B. Color Filters

The way that the red, green, and blue filters work is therefore quite contrary to how the word "filter" is perceived to mean. Filters of a certain color block some of the wavelengths of light that are not wanted for that color while allowing the desired wavelengths. Sunlight, for instance, contains all the wavelengths of color in its spectrum, which is why it appears white.[7] With the light being its only source of color, a color filter can only block or take away colors from that light, not add to it. Therefore, it is common to have a chromatic camera with a monochromatic image sensor that also employs mechanics such as color filters or a Bayer Filter to create the full-color effect.[1]

III. Stacking by Using Digital Software[a]

For stacking monochrome images taken through physical red, green, and blue filters, we used FireCapture to take the images and ImageJ to stack them. On FireCapture, the images needed to be taken with the correct exposure (with the right lighting) to produce the best results. It is crucial to keep the angles of photography and lighting as constant as possible to successfully stack the exposures. Otherwise, they could become variables in the stacking process and produce unwanted noise and incorrect RGB values.

In ImageJ, we stacked the monochrome photos and ran RGB analysis for each camera. We extracted the mean RGB values for the red, green, blue, white, and black squares for each photo, and compiled the data to be compared to the true RGB values for those colors.

IV. Objective and Experimental Plan[b]

The objective of our project was to compare the accuracy of a color image produced from the capabilities of modern color cameras and a monochrome camera using colored filters. Specifically, we used an iPhone 8 Plus, iPhone 5s, Samsung Galaxy S7, ZWO full color camera and a ZWO monochrome camera.[1] We hypothesized that calculated RGB values would be similar to the true values, and that the iPhone 8 Plus' color accuracy would be the best out of the three phone cameras.

We used each camera to capture the same image of a color palette containing multiple color squares, among which were red, green, blue, white and black. The palette was partially enclosed by a black box to prevent interference from any extraneous light sources. All room lights were shut off so illumination was solely provided by a Soft White 75 Watt bulb. The phone images were taken under the automatic setting available for each camera. The settings applied using the FireCapture application were the Jupiter filter with an exposure of 3, gain of 50, gamma value of 50 and an exposure time of a single frame. These were applied when using the ZWO Color camera and ZWO Monochrome camera. The three filtered images produced by covering the lens of the Monochrome camera with a red, green and blue filter were stacked using the ImageJ application. All of the images were then analyzed for their color accuracy based on the RGB values obtained using the ImageJ histogram function. The colored squares of the palette we chose to analyze were red, green, blue, white, and black.

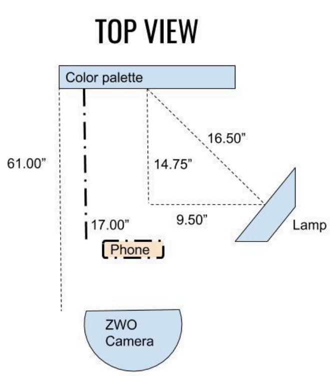

Figure 1

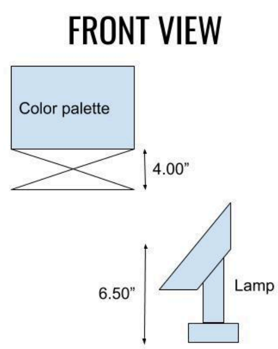

Figure 2

(not to scale)

Figure 3: The color palette used. We analyzed RGB values for the blue, green, and red squares in the third row, as well as the white and black squares in the fourth row.

To analyze RGB values under identical conditions for all five cameras, we arranged a setup in which a color palette was illuminated by one light source a distance of 15 inches away in order to keep constant lighting. We then gathered data on the RGB values of the red, green, blue, white, and black squares of the color palette for each image. (Figure 1 and 2)

V. Results and Analysis[b]

By calculating each camera's total deviation from its image's true RGB values, we were able to form a conclusion about the relative color accuracy of the five cameras. Among the three phone cameras, we predicted the Galaxy S7 to have the highest and the iPhone 5s to have the lowest RGB accuracy. After experimentation, however, our results showed that the iPhone 5s had the highest and the iPhone 8 Plus had the lowest RGB accuracy.

The sum of the individual deviations in color value can be used to represent each camera's ability to produce an accurately colored image. We use this value to analyze the relative color accuracy of the five cameras. The smaller the total deviation, the better the camera is at imaging the realistic color. With a total difference of 630, the photograph made by stacking the filtered images using the ZWO Monochrome camera was the most accurate. Next was the iPhone 5s with a total deviation of 710, followed by the ZWO color camera at 743, the Samsung Galaxy S7 at 771 and iPhone 8 Plus at 782.

The most surprising result was the quality of the iPhone 5s camera. While the aperture specifications suggest that the Galaxy S7 would produce the best quality photo, the iPhone 8 Plus to produce the second best, and the iPhone 5s to produce the poorest quality photo, the experimental results demonstrate otherwise. A smaller F-stop value equates to a larger aperture which allows more light to enter the camera. Allowing more light to reach the camera sensors would be advantageous in the experimental setting since only the small area covered by the lamp light was illuminated. Thus, we expected the Galaxy S7's F1.7 to outperform the iPhone 8 Plus at F1.8 and the iPhone 5s at F2.2. However, the iPhone 5s was the best and the iPhone 8 was the worst at capturing the true colors of the palette, as determined from our "total deviation" values.

The unexpected result of the camera ranking may be partially attributed to the short exposure time. Since the light was not very bright, a single frame may have been too short an interval to capture the amount of light needed to form an accurate color. This would validate color values that were below the target since the brightness of the light was lower. Also, a more accurate image could have been made if multiple shots taken by the same camera were stacked. Doing so would help reduce the noise that is more prevalent in a single exposure. Analyzing stacked images would have be more reliable since anomalies that might occur in a single image would be lessened. The inconsistency of light distribution on the color palette may have also affected the image quality. The lamp was angled at approximately 58° and was positioned such that the palette was not equally illuminated at all places. A smaller angle would have improved the lighting as the lamp would face more directly towards the palette.

In general, the red and green values appeared the strongest and were the closest to the actual values. The total deviation for the blue values was approximately double the total deviation for either the red or green values across all imaging techniques. Since the settings on FireCapture were made in reference to the red filter, the quality of the red filter image was highly accurate. This is shown by the R-value of 255 for the red square using the red filter and the R-value of 255 for the white square using the red filter. Moreover, the light source was a soft white hue, which displays light that is warmer in temperature. The composition of such light included more red and green, so these values were slightly enhanced by the light source. Similarly, the light had less blue light, so the blue values tended to be lower than expected and had greater deviations. Since white light was not used, it is possible that there was always some interference caused by the "colored" light reflecting off of the object into the camera. As a result, none of the color values reached absolute zero to produce the exact colors of red, green, blue or black.

Some of the largest individual discrepancies were apparent using the monochrome stacking technique. The blue values for the blue and white square were significantly below what was expected. An explanation for this lack of blue light may be a result of imaging with the blue filter at a low exposure. To reduce the number of independent variables in the experiment, each of the colored filter images were taken using the same exposure settings. However, these settings may not have been optimal for each colored filter. When analyzing the white square of the image taken with the blue filter, the average B-value was observed to be 104, below half of the expected value of 255. The darkness of the blue filter image translated to the composition of blue light in the final stacked image. Had the exposure been increased such that the brightness in the white square was represented more accurately in the blue filter image, the B-values in the stacked image would also have increased, producing a more accurate full-color picture. The variation of the red and green values were minimal in comparison, meaning the exposure used in the experiment was optimal for these color filters. This is verified by measuring the brightness of the white square for the red and green filter images, as the average values were 255 for both colored filters. The combination of these results still yielded the most accurate color image as a whole amongst the devices used in the experiment.

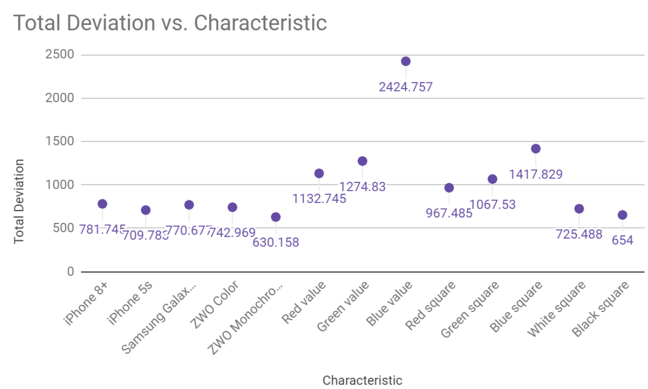

Figure 3: We compare the the total deviation between true and observed RGB values for each camera, the RGB values, and for individual squares. From the graph we observe that B-values were typically below expected values while R and G-values were more accurate. The discrepancies were mainly due to inadequate lighting and exposure time.

VI. Data Tables[b]

	Red square			Green square		
	R value	G value	B value	R value	G value	B value
iPhone 8+	246.069	32.792	59.566	95.71	175.038	78.967
iPhone 5s	253.017	26.682	75.166	67.888	165.792	84.168
Samsung Galaxy S7	232.407	45.245	86.948	82.608	165.616	80.765
ZWO Color	242.5	73.006	61.602	57.266	68.063	36.749
Stacked Image (ZWO Monochrome)	255	32.065	11.406	60.982	110.757	26.801
Expected values	255	0	0	0	128	0

	Blue square			White square		
	R value	G value	B value	R value	G value	B value
iPhone 8+	39.032	61.649	167.265	244.925	245.708	233.781
iPhone 5s	28.004	42.9	127.836	241.359	224.918	210.082
Samsung Galaxy S7	35.317	54.798	151.445	250.734	231.369	219.75
ZWO Color	18.572	14.917	22.979	254.981	224.317	155.745
Stacked Image (ZWO Monochrome)	22.255	23.164	24.254	255	254.878	103.965
Expected values	0	0	255	255	255	255

	Black square		
	R value	G value	B value
iPhone 8+	91.024	77.531	61.184
iPhone 5s	53.268	49.906	26.221
Samsung Galaxy S7	62.685	51.34	44.06
ZWO Color	20.776	15.023	10.643
Stacked Image (ZWO Monochrome)	25.35	21.376	7.613
Expected values	0	0	0

Figure 4: These charts show the mean RGB values for squares on the color palette for each camera, taken from the histograms produced by ImageJ. We used these values to calculate the deviation between observed and actual RGB values, and summed these to determine “total deviation.”

VII. Summary[c]

The results of our study were quite different from our hypotheses, and we can attribute most of these discrepancies to human error. Firstly, our setup with a single light bulb did not fully and equally illuminate all parts of the color palette, contributing to deviating exposure. Another cause of RGB discrepancy was our stacking method. Typical stacking of RGB images also takes the sharpest portions of several exposures to reduce noise, whereas our stacking only utilized three filtered images to create the colored image. These circumstances and the resulting underexposed photos contributed to inaccurate RGB values, as we observed while calculating these deviations.

Using our data, we determined the relative color accuracy by comparing the total deviation between observed and true RGB values. We concluded that the iPhone 5s captured RGB values closest to the true values, while the iPhone 8 Plus had the lowest accuracy. In addition to the discrepancies between the smartphone cameras, the total deviation of B-values was larger than those of the R and G values, which we can attribute to the low exposure of our captured images.

VIII. References[A]

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