Comparison of Color Image Processing Techniques in RGB and HSV Domains

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***Abstract*—Color images are represented in two primary formats: RGB and HSV. RGB representation has intensity values for the colors red, green, and blue, while HSV has levels for hue, saturation, and value or intensity. Grayscale processing techniques such as filtering and equalization are accomplished by applying the effect to one or all of these channels. Techniques such as edge detection can be significantly different in color processing, while others such as color correction are specific to color and applied only to certain color channels as needed. For the techniques that can be done in RGB or HSV, there is often one domain that is more suitable for a processing technique due to minimizing color distortion and noise. This paper analyzes the results from each technique on a set of test images and when applicable, which color representation is ideal for processing.**

Keywords—color, RGB, HSV, filtering, Butterworth, deblurring, sharpending, correction, histogram, homomorphic, Gaussian, edge detection

I. Introduction

This project uses different techniques for corrections in an image and examines the benefits and limitations of these techniques, the effects they have on color content, and which color domain is ideal for each of the processing techniques. The first step of each processing technique was to determine which images were appropriate for each technique, either to display the positive effects or limitations of the technique.

The frequency domain techniques used included deblurring and high boost filtering, using both the low pass and high pass implementations of the first order Butterworth filter. Some non-linear spatial processing techniques include histogram equalization, color correction, and color enhancement. Homomorphic filtering mixes both non-linear processing and frequency domain filtering to compensate for excess shading in images and utilizes a Gaussian high pass filter. The techniques often displayed radically different results for each of the images processed, with some limitations of the methods only emerging with one of the test images.

II. Deblurring/Sharpening

The first technique for processing of color imaging was use of a high pass first order Butterworth filter with added constant (1) in order to enhance the high frequency content of the image.

$$H(u,v) = \frac{1}{1+[D_0 / D(u,v)]^{2n}} + c \qquad (1)$$

The added constant is necessary to maintain intensity in the image, as the DC bin, which is removed by the filter, contains the average intensity of the image. The first order Butterworth filter is suitable for image correction because its smooth roll off in the frequency domain prevents ringing in the spatial domain.

For the first test image, the high pass filter was successful in removing blurring and adding clarity to the image. This can be seen by comparing details such as the feathers on the peacock, details on the chair and tree, and the grass (Fig. 3). However, in the second test image (Fig. 4), the high pass filter was not as successful in reducing blurring. While there is a noticeable change in high frequency content, the overall image is still blurry. This can be attributed to the two different causes of blurring: a picture being out of focus, and movement of the camera during the exposure, causing doubling of the image to be seen. Because an out of focus picture causes uniform blurring of an image, it is easy to fix with filtering. A blurred exposure will cause a shift of the image in a certain direction, and even with boosted high frequency content, the image will still appear blurry.

Fig. 1. 1st Order Butterworth High Pass Filter

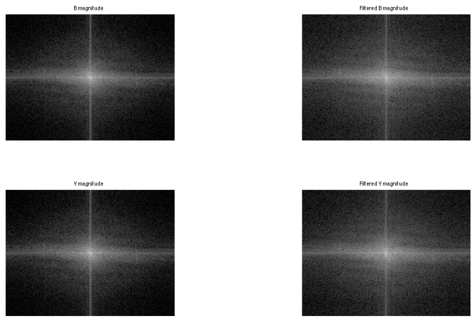
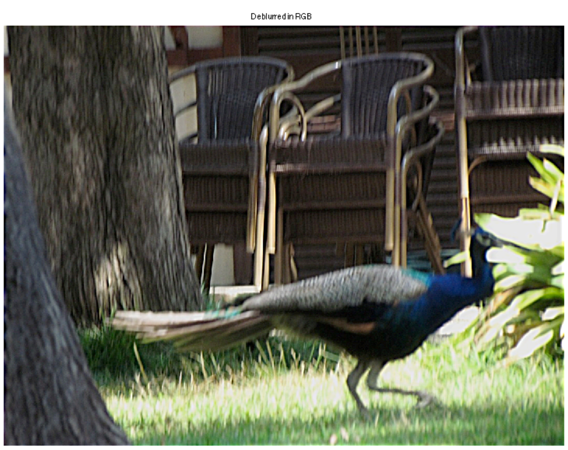


Fig. 2. Normalized Magnitudes of images for inputs (left) and filtered outputs (right) with blue channel (top) and HSV intensity (bottom)



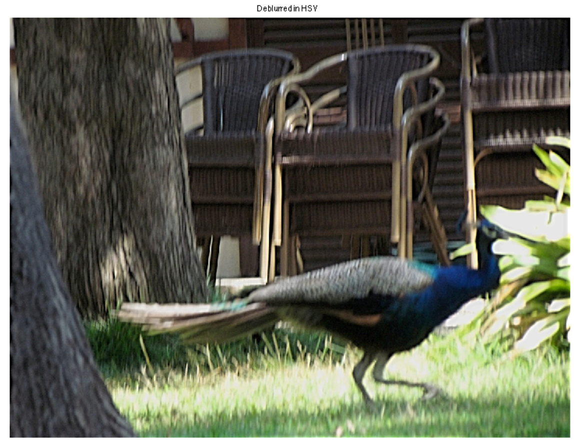


Fig. 3. Test Image 1 with original (top) RGB domain filtered (middle) and HSV domain filtered (bottom).

Fig. 4. Test Image 2 with Original (top), RGB processed (middle) and HSV proeessed (bottom).

Comparisons of the RGB and HSV processed images show little difference between the results. Many times with HSV, the Hue and Saturation channels should remain unprocessed to avoid color distortion, as the data is stored differently than intensity. This is the case with filtering, as high pass filtering of the hue and saturation channels will lead to undesired distortion. The reason the results are exactly the same for RGB and HSV is that the same filter is used for each channel of RGB. Because the signals and filters are all linear, R,G,B channels being processed and concatenated after processing has the effect as processing the intensity for all three channels summed prior to filtering, as in the HSV model, due to the superposition principle.

III. High boost Filtering

The second form of processing is similar to deblurring, except that the high pass filtered version of the image is not added to a constant in the frequency domain, but instead the low pass version of the signal is subtracted from some multiple of the original signal in the spatial domain.

$$f_{hb}(x,y) = Af(x,y) - f_{lp}(x,y) \tag{2}$$

In both test images, the high boost filtering successfully makes the details of the picture much clearer. However, one of the drawbacks of sharpening and high pass filtering in images can be seen clearly in these two images. While most of the energy of an image lies in the lower end of the frequency spectrum, the energy of random noise is spread equally throughout the entire spectrum. This means that by boosting the high frequency content, a significant amount of noise is being added to the image as well. It may be desirable to perform de-noising after high boosting.

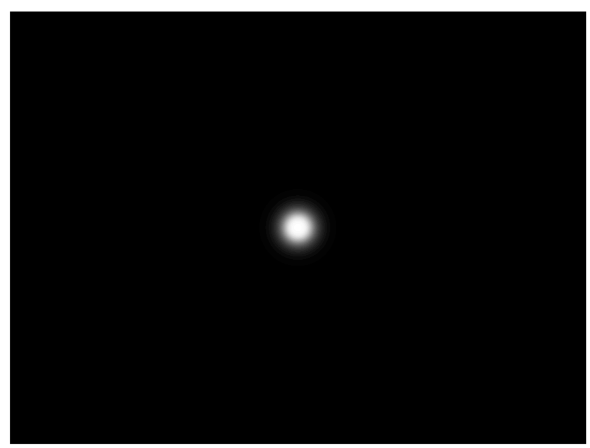


Fig. 5. Low-pass Butterworth filter whose processed image is subtracted from multiple of original image to create a high boost.

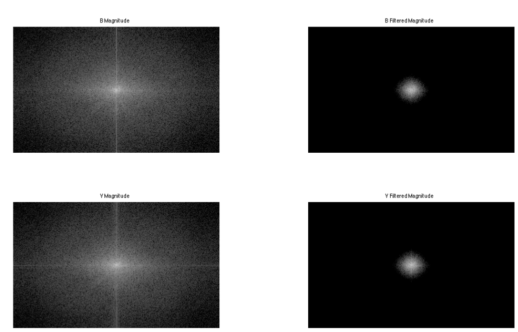


Fig. 6. Original magnitudes (left) and filtered magnitudes (right) for blue channel (top) and intensity channel (bottom).

Fig. 7. Test Image 1 with original image (top), RGB processed image (middle) and HSV processed image (bottom).

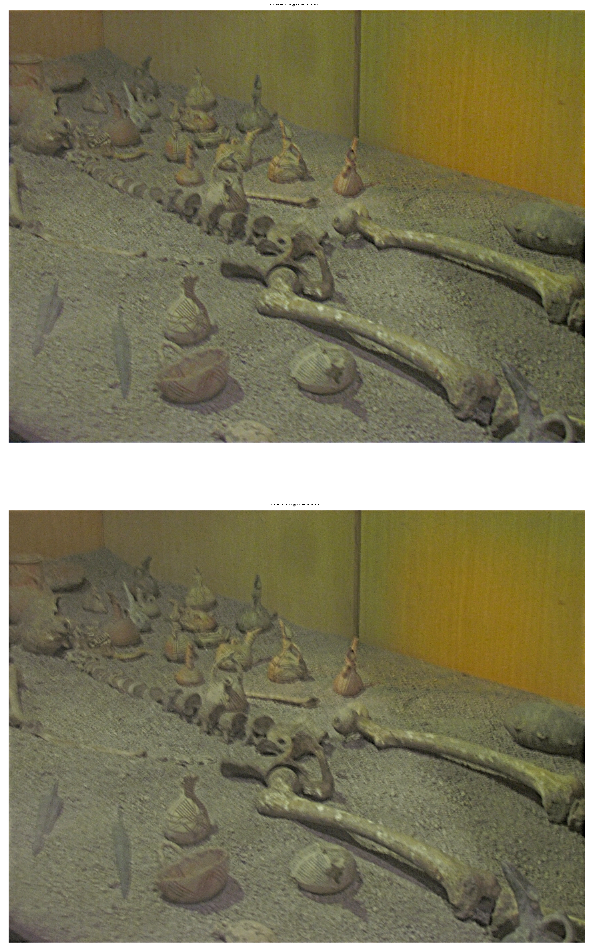


Fig. 8. Test image 2 with original image (top), RGB processed image (middle) and HSV processed image (bottom).

As with the deblurring technique in the first part, there is no visible difference in HSV and RGB processing. This is again due to superposition and that the exact same processing is occurring whether the channels are summed before or after filtering.

IV. Color Tone Correction

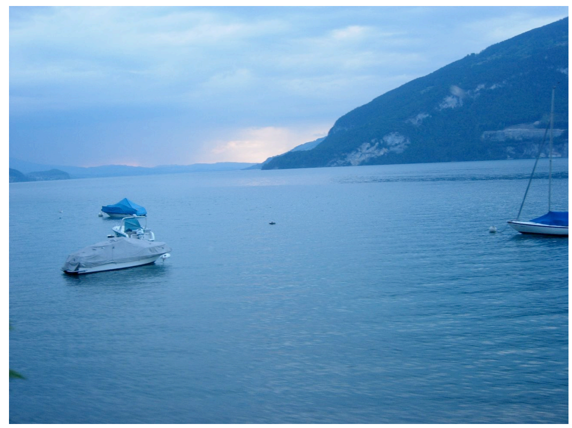
While the previous methods were performed in the frequency domain, color tone correction is a non-linear operation performed in the spatial domain. Non-linear correction functions are exponential functions (3).

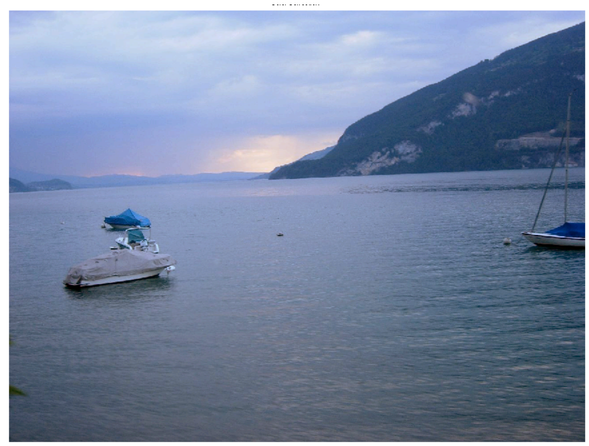
$$f_b(x,y) = f(x,y)^c \tag{3}$$

For a normalized double color value (0-1), boosting is done with a decimal power c between 0 and 1. For the same normalized value, lowering the overall value is done with the decimal power c being greater than one. These non-linear functions are used instead of addition or subtraction, so the intensity remains in the same 0-1 range, but the intensity levels in between are either mapped to higher or lower values. Changing the overall saturation value in an image can be done either by applying the same function to each channel in RGB, or applying the function to the saturation channel in HSV. For this portion of the project, color correction on individual channels, followed by saturation boost in the HSV domain was applied. Since the outcome of this correction is highly dependent on the content of the image, the powers for the transform of each image's intensity must be done by hand until the image looks as desired.

Fig. 9. Test image 1 with original (top), color correction (middle), and color correction + saturation reduction (bottom).

In the first test image, the entire image is tinted with greenish blue (Fig. 9). In order to compensate for this, the blue and green channel intensities are squared, while the square root of the red channel is taken. Since the intensity values are normalized, the blue and green channels will be attenuated and the red channel boosted. While the image overall still has a green tint, the color range is much larger, with details such as the seaweed and wood appearing much more brown that before. Next, the image is converted to the HSV domain and the saturation channel is transformed. Because the image already had very vivid color due to it being taken underwater, it would appear more natural and have the details easier to see if the saturation were actually attenuated. To do this, a power function of 1.5 is applied to the saturation channel. The result is a much more naturally image with the true color of objects more easily perceived.





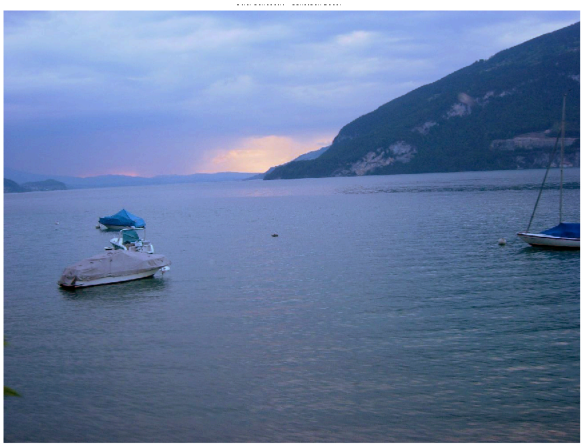


Fig. 10. Test image 2 with original (top), color correction (middle), and saturation increase (bottom).

Because the second test image was taken out of water, it will be processed much differently. The image appears tinted slightly blue, though not as extreme as test image 1 (Fig. 10). Powers of 1.3, 1.8, and .85 are applied to the red, green, and blue channels, respectively. Since the color offset is not as extreme, the powers can be closer to 1, which will transform the intensity less than in the first test image. After the color correction, the color tones in the image still appear as if they could be more vivid. To achieve this, a power of .85 is applied to the saturation channel, making the image more vivid and appealing to the viewer.

V. Homomorphic Filtering

In order to process images with shaded regions, non-linear processing must be applied to the image. One method of improving shading effects is done through homomorphic filtering. Homomorphic filtering is based on the representation of an image as a product of reflection and illumination. By taking the natural log of the image, these components can be split into a sum.

$$f(x,y) = i(x,y)r(x,y) \tag{4}$$

$$z(x,y) = \ln i(x,y) + \ln r(x,y) \tag{5}$$

A filter is applied in the frequency domain representation of the natural logarithm of the image and the image is converted back to its original form using an exponential function.

$$g(x,y) = e^{s(x,y)} = e^{i'(x,y)+r'(x,y)} \tag{6}$$

This model allows high frequency and low frequency components of an image to be treated separately. One common filter used in homomorphic filtering is a high pass Gaussian filter.

$$H(u,v) = (\gamma_H - \gamma_L)[1 - e^{-c(D^2(u,v)/D_0^2)}] + \gamma_L \tag{7}$$

Because the logarithm is a non-linear function, the amount of attenuation the function performs is dependent on the size of the input value. A coefficient is applied during the natural log and exponential functions, which essentially determines how much the logarithmic function compresses the intensity values. The following modifications were made to equations (5) and (6)

$$z(x,y) = \frac{\ln \alpha i(x,y)}{\alpha} + \frac{\ln \alpha r(x,y)}{\alpha} \tag{8}$$

$$g(x,y) = \frac{e^{\alpha s(x,y)}}{\alpha} \tag{9}$$

The parameters α, γ_H, γ_L, and D_0 were modified until the desired shading of the images was achieved. The parameters set for the two images were $\alpha=2$, $\gamma_H = 2.9$, $\gamma_L = 0.5$, and $D_0 = 50$.

Fig. 11. Gaussian high pass filter used in homomorphic filtering.

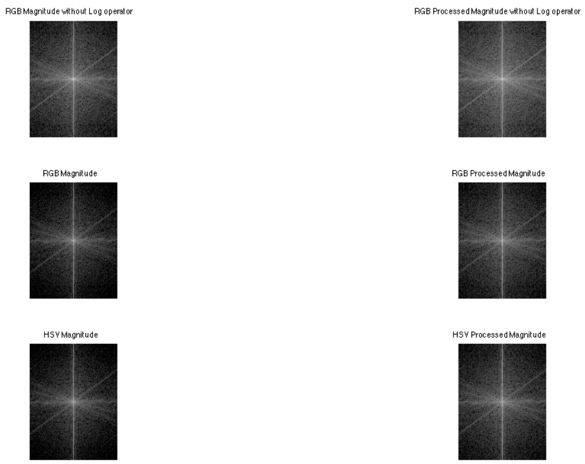


Fig. 12 Normalized magnitude without log operator before conversion (top), RGB representation (middle) and HSV representation (bottom). Unfiltered images on left and filtered images on right.

Fig. 13. Test Image 1 with original (top), RGB processed (middle), and HSV processed (bottom).

Fig. 14. Test Image 2 with original image (top), RGB processed image (middle) and HSV processed image (bottom).

By looking at both the test images, it can be seen there is very little difference in use of the RGB or HSV models. This supports the claims from the earlier processing tests, which suggest that processing done with linear signals and linear filters will be identical whether the signals are summed before or after processing, due to superposition. The small differences in hue and intensity in the two images can be attributed to the non-linearity of the logarithmic and exponential functions. The amount of dynamic range compression applied by the logarithmic function is dependent on the level of the input. This can be seen in test image 2, where there is equal amounts of illumination in the previously dark regions in both results. However, in the HSV image, the clouds are less washed out than in the RGB version. This is because the Intensity level is higher than each of the three individual RGB channels, so the dynamic range of the image is compressed more by the logarithmic function. The difference in hue between the two models could be regarded as distortion in the RGB model, because the difference in intensity mapping for each channel results in a different hue than in the original image. Due to these two reasons, the HSV model is slightly preferred, though the negative effects of the RGB model are not as present as in other methods, such as histogram processing.

VI. Histogram Processing

Another form of non-linear spatial processing for image correction is histogram processing. While color correction functions are applied by trial and error based on results, histogram equalization is a function that maps intensities so the number of pixels at each intensity value is uniform. A histogram is generated by first creating an array of length all possible intensity values, with the number of each pixel at each value inside of the array. The histogram must be equalized with the mapping function $s = T(r)$, where r is the input pixel value and s is the output pixel value. The criteria for mapping a normalized histogram are a mapping that monotonically increases, and has all output values within the interval [0,1].

Histogram processing is a useful form of processing for improving the overall dynamic range of the image. If an image is too dark, too light, or does not have enough contrast, histogram processing will make naturally improve the contrast of an image. Because the histogram is created based on the given image data, no parameters need to be set within the histogram function.

Fig. 15. Red, Green, and Blue channels pre-processing (top) and with histogram equalization applied (bottom) for test image 1.

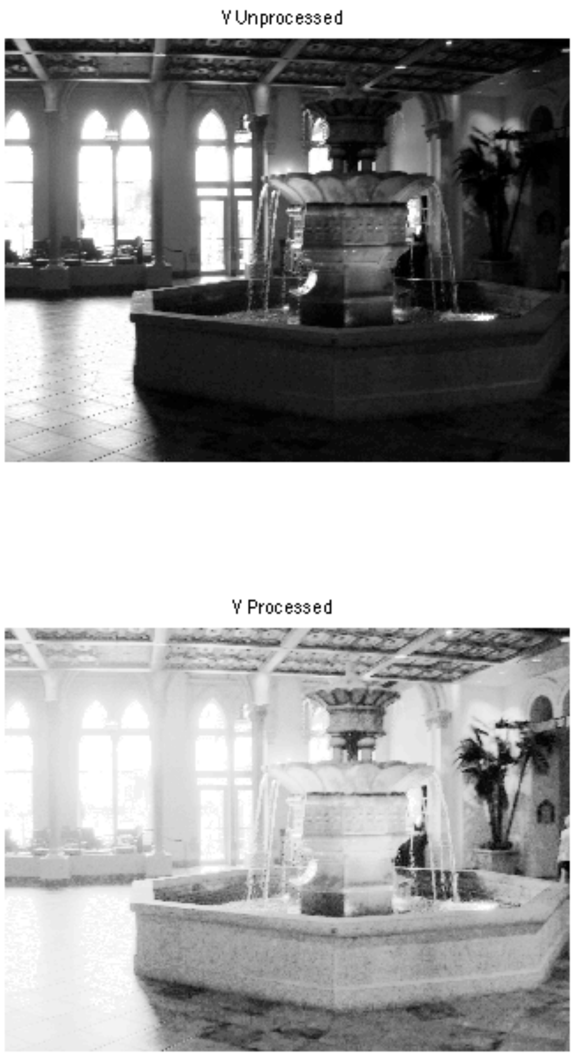


Fig. 16. Intensity channel unprocessed (top) and with histogram equalization applied (bottom) for test image 1.

Fig. 17. Test Image 1 with original image (top), RGB (middle) and HSV (bottom).

Histogram processing has significantly different results in the HSV and RGB domains. This can be clearly seen in both of the test images. The first test image is too dark, so the dynamic range must be expanded upward using histogram processing (Fig.17). The difference in the HSV and RGB results is the HSV result appears to be much more balanced in terms of both color and intensity. Meanwhile, the RGB version appears washed out, and has different patches that are tinted red, green and blue. The RGB image also exhibits significantly more noise than the HSV image. There are a variety of reasons why processing the V channel in the HSV domain is much more beneficial than attempting to process the R,G,and B domains. When the image is viewed as separate R,G,and B intensities, the overall intensity for each channel is much lower, but will still be normalized to equal occurrence at each intensity (Fig. 15). Once the three normalized channels are summed, the overall intensity of the image is too high. Another issue is that when intensity in images with very low intensities is boosted too much, the noise in the image will increase severely. This can be especially problematic when an image has a very low intensity for a particular color.

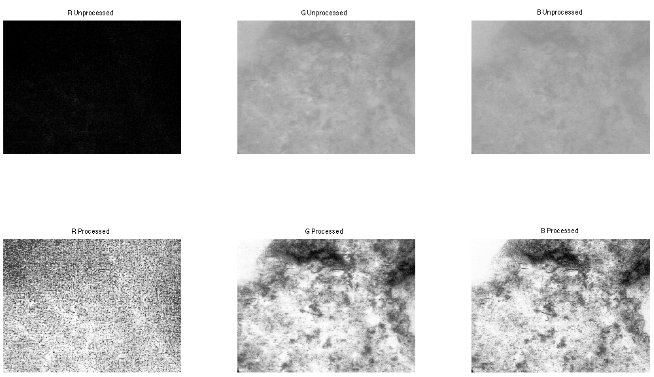


Fig. 18. Red, Green, and Blue channels pre-processing (top) and with histogram equalization applied (bottom).for test Image 2.

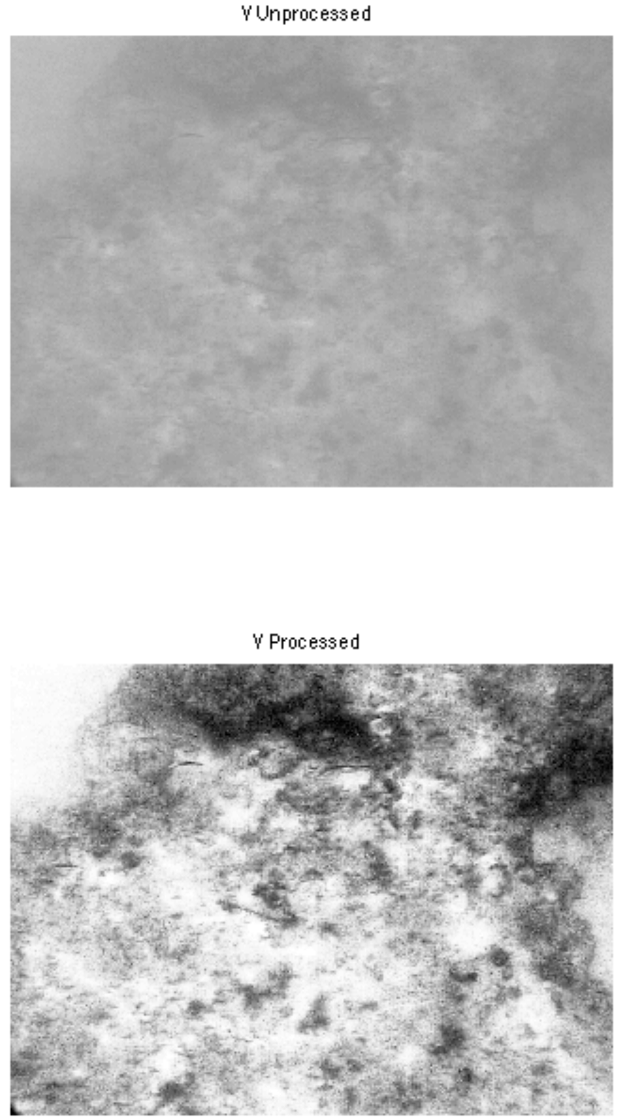


Fig. 19. Intensity channel unprocessed (top) and with histogram equalization applied (bottom) for test image 2.

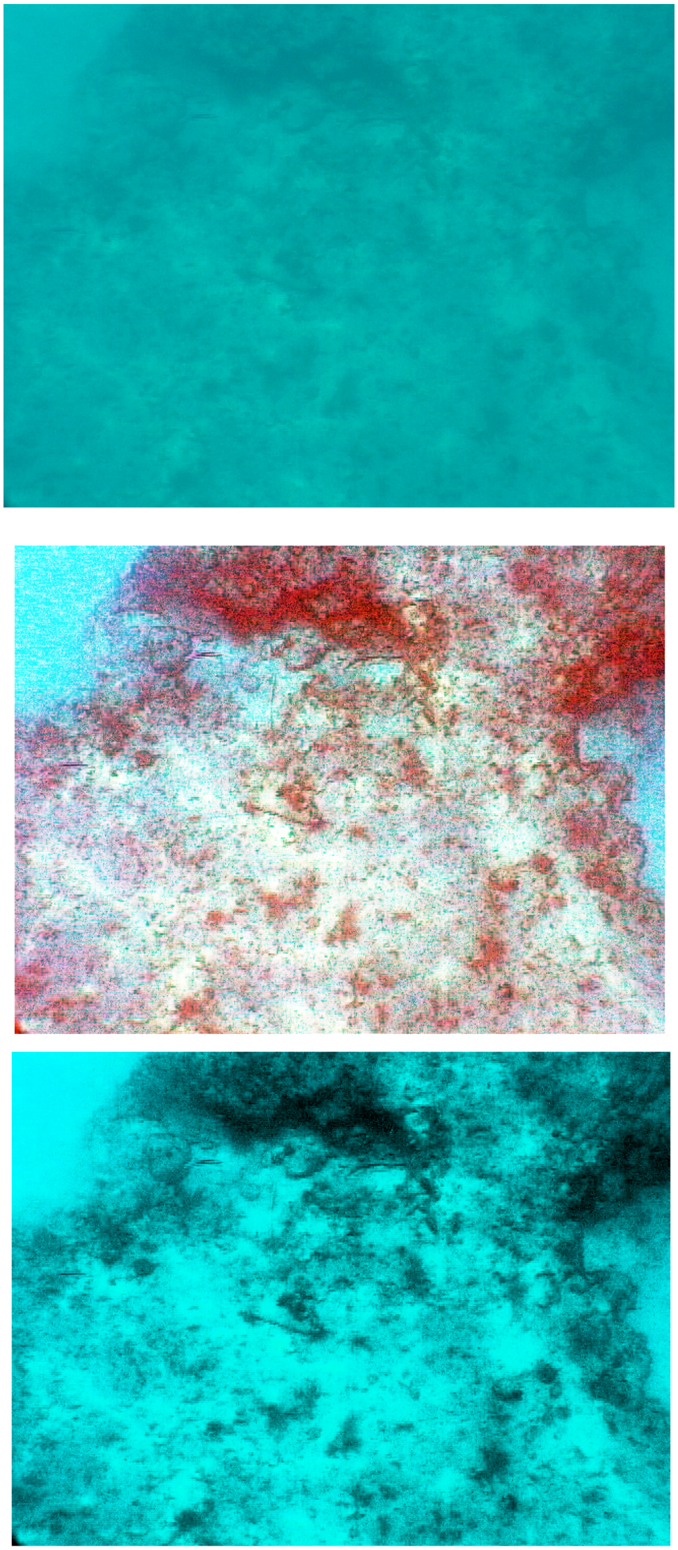


Fig. 20. Test Image 2 with unprocessed image (top), RGB processed image (middle), and HSV processed image (bottom).

In the second test image, the natural color of the image is a bluish green. By attempting to normalize the red channel, which is not supposed to be in the image at equal levels, both noise and color distortion are introduced to the image (Fig. 18,20). Color distortion to some degree will always occur in the RGB model, because the histogram functions will map new and different intensity values for all three channels, which will change the ratio of each value. By processing the intensity of the HSV model, the color content of the image can be preserved and the dynamic range is still increased. In both test images, the HSV image is free of all the problems present in the RGB image.

VII. Edge Detection

Edge Detection in the HSV domain, applied to the Value channel is equally as straightforward as edge detection in grayscale. Edge Detection in RGB is much more complicated due to many of the reasons mentioned in previous parts of the project. However, there are methods for compensating for potential inaccuracies and obtaining accurate edge detection. The easiest method for edge detection in RGB would be to find the X and Y gradient for each channel and sum the gradients all together. However, based on results from both test images, this method was not entirely effective, as there are gaps in the edges, instead of a solid line outlining them. A much more effective method for edge detection in the RGB domain is done using the Magnitude of Maximum change model:

$$u = \frac{\partial R}{\partial x} r + \frac{\partial G}{\partial x} g + \frac{\partial B}{\partial x} b \tag{7}$$

$$v = \frac{\partial R}{\partial y} r + \frac{\partial G}{\partial y} g + \frac{\partial B}{\partial y} b \tag{8}$$

$$g_{xx} = u.u = \left|\frac{\partial R}{\partial x}\right|^2 + \left|\frac{\partial G}{\partial x}\right|^2 + \left|\frac{\partial B}{\partial x}\right|^2 \tag{9}$$

$$g_{yy} = v.v = \left|\frac{\partial R}{\partial y}\right|^2 + \left|\frac{\partial G}{\partial y}\right|^2 + \left|\frac{\partial B}{\partial y}\right|^2 \tag{10}$$

$$g_{xy} = u.v = \left|\frac{\partial R}{\partial x}\right|\left|\frac{\partial R}{\partial y}\right| + \left|\frac{\partial G}{\partial x}\right|\left|\frac{\partial G}{\partial y}\right| + \left|\frac{\partial B}{\partial x}\right|\left|\frac{\partial B}{\partial y}\right| \tag{11}$$

$$M = ((g_{xx} + g_{yy}) + \sqrt{(g_{xx} - g_{yy})^2 + 4g_{xy}^2})/2)^{1/2} \tag{12}$$

The results of the use of this model were a much more defined edge for each object. However, as with other methods, the success of the processing methods is dependent on the images used to process. The first test image had much higher success than the second, as the second has a much fainter edge detected using magnitude of maximum change. This is due to the blurriness of the second image, which makes a lighter gradient because the content of the image is changing slower, unlike at a sharp edge. Because of this, use of sharpening before edge detection can be a valuable form of pre-processing in order to get the best image possible.

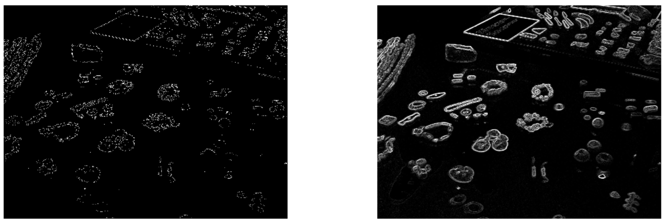


Fig. 21. Edge detection for Test Image 1 using sum of three gradients (left) and magnitude of maximum change (right).

Fig. 22. Edge detection for Test Image 2 using sum of three gradients (left) and magnitude of maximum change (right).

VIII. Conclusion

Testing of various image processing techniques on different types of photos showed the strengths and weaknesses of each technique, and well as emphasizing the importance of choosing the proper domain for processing color images in. The limitations of these methods were also discovered, as it is important to use appropriate input images for each technique. In general, techniques solely using linear filtering can be performed on images in either domain with the same results. Effects using non-linear processing exhibited less color distortion and noise when performed on the V channel of HSV as opposed to RGB. This is due to only one channel being processed, and because the hue and saturation channels are not edited. In some cases, there are methods to overcome the negative effects of RGB processing, such as edge detection, where the magnitude of maximum change method can be applied to obtain an accurate edge detection. The one technique where RGB processing is necessary is in color correction. While processing of the hue channel is possible, changes can be easily made by applying non-linear power functions to the RGB channels as needed. This project stressed not just understanding and ability to apply techniques, but to use them tastefully and as necessary to improve the appearance and clarity of real images.