Regionally Specific Image Enhancement of Non-Uniformly Illuminated Images

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***Abstract* – Images affected by non-uniform illumination typically display diminished image characteristics lacking in detail because of this defect. The conventional methodology of handling image defects is typically using global image enhancement techniques. These techniques prove to be ineffective or exhibit diminished efficiency in the enhancement of digital images due to the inherent effect of illumination within an image. Globally applied image enhancement techniques prove to be ineffective due to illumination when a method is applied to increase the intensity to brighten the darkened areas of an image. This can lead to undesirable results in areas of the image with proper illumination causing bright areas to be over intensified and ultimately being counter productive to the overall enhancement of the image. There are many methodologies which adapt to this specific issue by locally evaluating the image to apply techniques specific to the observed defect within a local region. The majority of local image enhancement techniques however focus on only the image intensity limiting the ability to determine areas of specific interest with respect to the identification of areas specifically affected by the deterioration of image details due to non-uniform illumination. The focus of this research is to expand upon the effectiveness of previous research which attempts to improve upon image enhancement through the identification of exposure regions determined through the evaluation of contrast and entropy in addition to image intensity.**

Index Terms: Non-uniform illumination, intensity, entropy, contrast, region determination, luminosity, dynamic range, under-exposed, well-exposed, over-exposed.

I. Introduction

When analyzing a nonuniform illuminated image, one must correctly identify the different regions of the images. The regions can be grouped into three main groups: underexposed, well exposed, and over exposed. The proposed method for identification of these regions begins with the introduction of additional image characteristics besides intensity. These additional characteristics used in the proposed method are entropy and contrast. The concept behind adding additional image characteristics when classifying regions in an image is to reduce errors in classifying images in the proper illuminated lightness value. Adding these additional image attributes allows us to locate more details inside of an image.

II. Proposed Method

The proposed method that was developed enhanced well known techniques such as ALEBRD, Backlit, Exposure 3R, Exposure 2R, and FIM, that only detect regions of illumination primarily based upon the presence of intensity. This introduces errors in correctly classifying the illuminated regions of underexposed, well exposed, and over exposed regions.

B. Intensity Classification

Illumination deals with the amount of exposure in different areas of the image. It can be calculated by obtaining the specific threshold value for the image. which is the average of the grey level values of all the pixels in the image. A pixel is underexposed if the intensity value is lower than the corresponding threshold value or overexposed when the intensity value is higher.

To accurately use intensity as a means of identification of different illuminated regions, a new way to calculate the threshold value was introduced, dealing with the global and standard deviation of the intensity of the image that is used to evaluate the region locally. This is done by taking the nonuniform illuminated image of size R x C, and converting the image into a Hue, Saturation, and Intensity Value (HSV) color model.

The intensity is used to calculate the average intensity of the region and the standard deviation intensity of the image used to determine the upper and lower threshold values, U_T and L_T respectively. The average intensity value and standard deviation of the region can be calculated by the following equations below.

$$V_a = \frac{1}{R \times C} \sum_{i=1}^{R} \sum_{j=1}^{C} V(i,j) \quad (1)$$

$$V_d = \sqrt{\frac{1}{R \times C} \sum_{i=1}^{R} \sum_{j=1}^{C} (V(i,j) - V_a)^2} \quad (2)$$

With the average intensity value and the standard deviation of the intensity, the two threshold values can be calculated by the equations seen below.

$$U_t = V_a + V_d \quad (3)$$

$$L_t = V_a - V_d \quad (4)$$

Once this is completed the intensity can be categorized into three main levels, low, medium, and high. The spectrum of the values is determined by using the local intensity, the lower threshold, and upper threshold limit. The three different intensity levels are quantified below.

$$Intensity, I = \begin{cases} I_{low} & if\ I < L_t \\ I_{med} & if\ L_t < I < U_t \\ I_{high} & if\ I > U_t \end{cases} \quad (5)$$

To again clarify, intensity is not the only form of methodology to accurately determine the correct exposure regions of the images. The intensity values are used in conjunction with the entropy and contrast levels.

B. Contrast Classification

Entropy is the next image attribute used to determine the correct illumination region. Entropy measures image information content. It describes to us how much randomness occurs in the image. In the proposed method discrete entropy is synonymous with the number of bits needed to encode the image data. A high/ low entropy value correlates to a high/low amount of information contained in that region. The introduction of entropy helps detect the well exposed regions of the image. Entropy is calculated using the formula below.

$$E_a = \frac{1}{N} \sum_{b=1}^{N} E_{local}(b) \quad (6)$$

E_{local} (b) is the entropy of a block sized m x n, and N is the number of blocks in an entire image. This scans through each block of the image and sums up the entropy value for each block of the image. The entropy is divided into two categories E_{low}, where the entropy values range from 0 to E_a -1, and E_{high} denoting the entropy values greater than or equal to E_a.

$$Entropy, E = \begin{cases} E_{low}\ if\ E_{local} < E_a \\ E_{high}\ if\ E_{local} \geq E_a \end{cases} \quad (7)$$

C. Contrast Classification

Contrast, the difference in luminance between an object and its surrounding region, is another image attribute needed to accurately develop an in-depth analysis of the illuminated regions. The contrast displays the different sections of grey levels in a region. A parameter needed to calculate the contrast of an entire image, C_a, C_{local} is derived.

$$C_{local} = \frac{1}{m \times n} \sum_{x=1}^{m} \sum_{y=1}^{n} G^2(x,y) - \left| \frac{1}{m \times n} \sum_{x=1}^{m} \sum_{y=1}^{n} G(x,y) \right|^2 \quad (8)$$

The average of the local contrast of the entire image, C_a is calculated by the following equation, similar to E_a.

$$C_a = \frac{1}{N} \sum_{b=1}^{N} C_{local}(b) \quad (9)$$

This calculation separates the contrast regions into an upper and lower region, denoted by the equation below.

$$Contrast, C = \begin{cases} C_{low} \ if \ C_{local} < C_a \\ C_{high} \ if \ C_{local} \geq C_a \end{cases} \qquad (10)$$

D. Exposure Region Classification

The final stage of the proposed method, groups the three image attributes together to classify each block of the image as either under exposed, well exposed, and over exposed. This is done based on knowing the entropy, contrast, and intensity levels, that were calculated with the previously stated equations. If entropy and contrast are high, then the region will always be well exposed. In this specific case, intensity has no effect on the overall region determination.

Entropy and contrast both demonstrate a high level of detail and a high derivative of grey values. Besides this one case of entropy and contrast both being high, all the other regions will be analyzed based on the intensity level. There are three other cases involved with the region determination.

Case one being when entropy and contrast are both low. Details that no high level of detail is present as well as an insignificant change in the grey level value was detected, therefore intensity can be solely used for evaluation of region determination. The second case would be low entropy and high contrast.

Case two correlates little to no detail in the pixel region, but a high change in the grey level value. Once again Intensity can be solely be used for region determination.

Case three occurs when entropy is high, and contrast is low. A high level of detail is displayed in the region, but a miniscule change in the grey level value is detected. Once again, the intensity level can be solely used for the region determination. The exposure region can be determined by the equation below.

$$Exposure\ Region, R = \begin{cases} under\ exposed & if I = I_{low} \\ well\ exposed & if I = I_{medium} \\ over\ exposed & if I = I_{high} \end{cases} \qquad (10)$$

Dividing an image into blocks, representing rows and columns, then analyzing three image characteristics, entropy, contrast, and intensity, by obtaining specific levels of these attributes based upon some threshold value. Followed by determining which image characteristics would be needed to determine accurately what the exposed region would be based upon the entropy and contrast level correlating to the four cases. After proceeding through that, finally using intensity to characterize the exposure region. This method has been tried and deemed highly accurate by individuals with great experience in the field of image processing.

III. Experimental Results

In the introduction and the proposed method, the concern of non-uniform illumination is the deterioration of the detail with respect to the image. During image acquisition there are many of reasons for non-uniform illumination to be present. The majority of image enhancement techniques are applied globally to an image with respect to the intensity (brightness) levels as determined on a global scale as well usually by converting an image to the HSV (HSI) color space and evaluating an image using the intensity channel exclusively.

The development of the region determination process used to develop the MATLAB code was derived from research “Local Neighborhood Image Properties for Exposure Region Determination Method in Nonuniform Illumination Images” [1]. As previously mentioned, the conventional methodologies used for image enhancement are based solely on intensity as an image attribute alone which can cause misidentification of exposure regions more, or less affected by non-uniform illumination. Furthermore, the global enhancement of images with non-uniform illumination complicate enhancement when global enhancement techniques are utilized due to the inherent inverse effect on areas of intensities directly of concern with respect to the specific enhancement technique.

Through the addition of image characteristics such as contrast which is simply the degree of difference between the brightest and darkest parts of the image, which inherently affects the dynamic range which is the ratio between the largest and smallest that a pixel within an image can assume, and the accuracy of regional classification is therefore improved. Over and under exposed regions within an image may suffer from the loss of image detail as a result of non-uniform illumination. In the primary research document used in the development of this research it is stated “Almost all exiting methods that introduced the region determination process can only detect two different regions, name, dark and bright, which inadequately represent the real exposure condition because the methods only consider intensity criteria to determine the region” [1].

To further evaluate the regional classification of the image the addition of entropy was also considered in establishing under-exposed, well-exposed, and over-exposed regions. The image entropy is a quantitative measure of data contained within an image pixel which was used in this method for further enhancement of the accuracy of exposure region determination. By considering the entropy, the classification of exposure region is also dependent on the amount of data contained within a spatial location (pixel) of an image.

The primary consideration in determining intensity specific regional analysis the measure of standard deviation was of great importance. Various types of global standard deviation calculations were measured. The standard deviation of the original V channel was measured to be 0.3192, however, one addition to this method was the use of histogram equalization. The standard deviation of the histogram equalized V channel was slightly lower at 0.2888.

Due to the decrease as a result of utilizing the histogram equalization function in MATLAB various other adaptive histogram equalization methods were used in experimentation. The use of adaptive histogram equalization proved to be effective in decreasing the standard deviation for a variety of distributions types. The Rayleigh distribution without clip limits on the V channel decreased the standard deviation to 0.2405, and when clip limits were added as a parameter for consideration the standard deviation dropped to 0.2190. Additional types of adaptive histogram equalization distributions were used such as the exponential and uniform distributions, however, these proved to be less beneficial increasing the standard deviation.

Utilizing the methodology described in the primary document inspiring this research the outcome of evaluating the intensity, contrast, and entropy was the output of an exposure region matrix identifying areas of under-exposed regions equal to 0, well-exposed regions equal to 1, and over-exposed regions equal to 2. To further enhance the ability of image enhancement the method used in this research was to block process the image conditionally applying user defined functions to either brighten or darken the original V channel.

The approach was to create a for loop with a nested if statement designed to evaluate the specific exposure regions identified in the exposure matrix which correlate to the V channel and apply user defined functions to manipulate the under-exposed and over-exposed regions while maintaining the values which were identified as well exposed regions.

Upon evaluation of the exposure matrix dependent evaluation of the V channel, measurements of the standard deviation were again assessed on the V channel to determine changes in the image intensity. The standard deviation of the exposure region dependent output matrix of the original V channel was measured to be 0.3145 which was slightly smaller than the standard deviation measurement of the original V channel; however, histogram equalization performed on the histogram equalized original channel prior to the exposure region dependent evaluation measured a slight increase in the standard deviation measuring 0.5% higher at 0.2922.

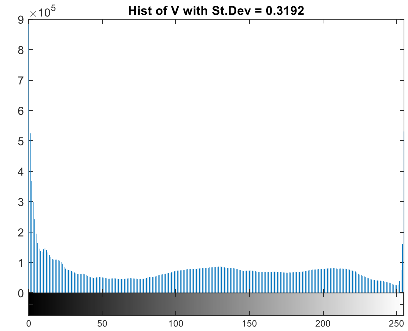
IV. Conclusions

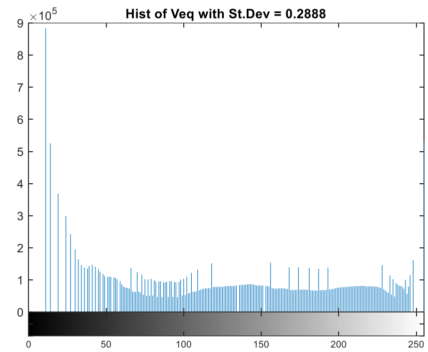
The primary measurement used to determine the effectiveness of identification of non-uniform illumination was standard deviation on the intensity channel associate with the image pre-processing and post-processing utilizing various methodologies as previously described in the experimental results section. The primary objective of this research was to further enhance the accuracy of exposure region identification through implementation of the proposed method utilizing MATLAB software as an analysis tool.

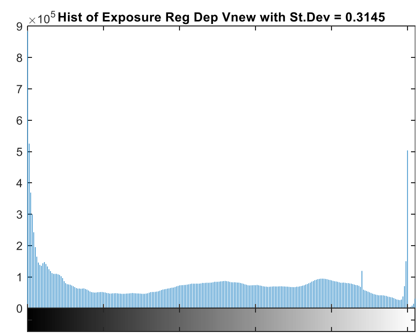
This research proved to be beneficial for the relative enhancement of the proposed method by using various forms of histogram equalization prior to developing the exposure region dependent output matrix; however, this enhancement of identification of non-uniform illumination induced the need for more advanced image enhancement techniques when utilizing the resulting exposure region dependent matrix for image reconstruction of the true color image post-processing.

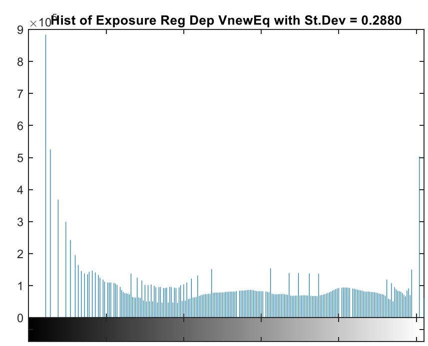
The following are examples of the V channel images

The following are the corresponding Histograms



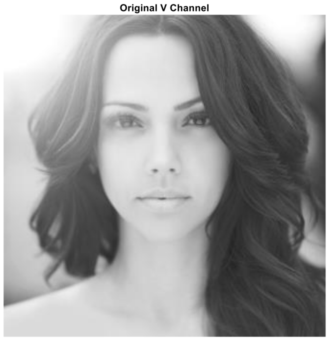




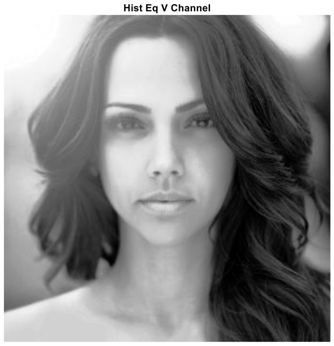


The Following are Examples of V Channel Images

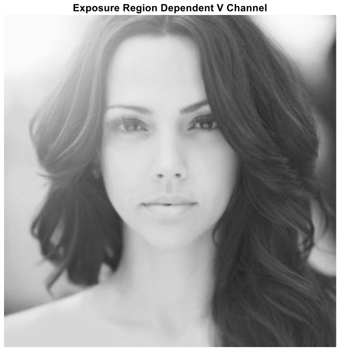
Original V Channel



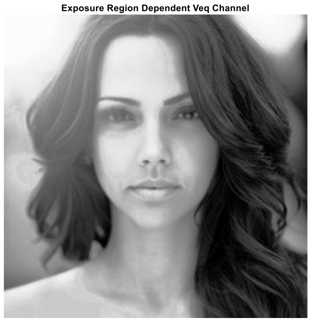
Hist Eq V Channel



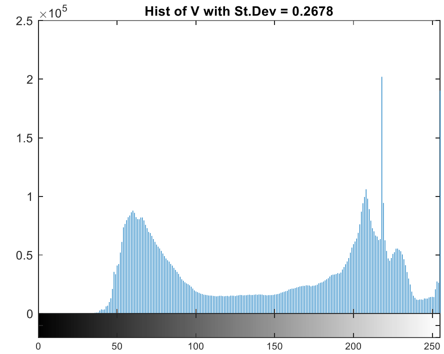
Exposure Region Dependent V Channel

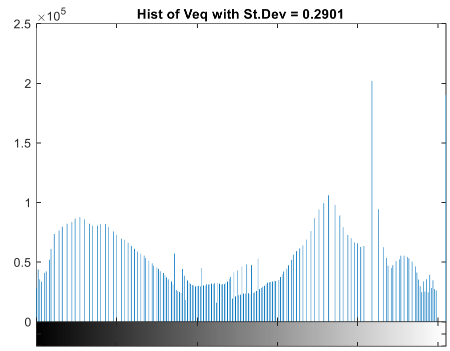


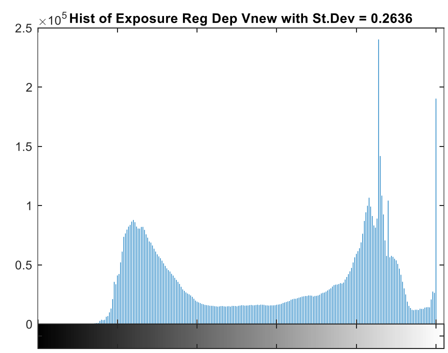
Exposure Region Dependent Veq Channel

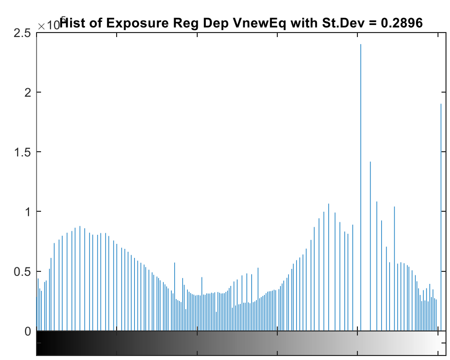


The Following are Corresponding Histograms



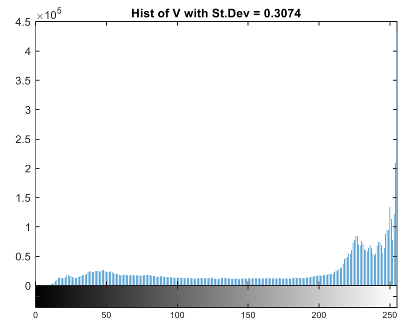


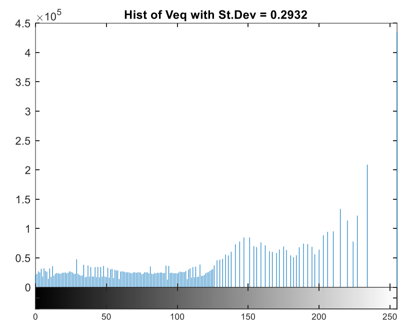


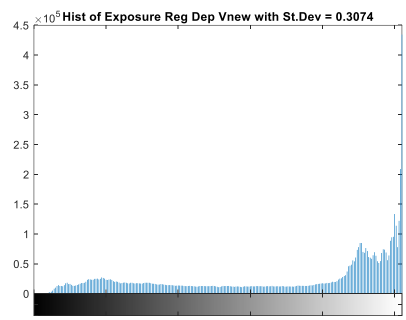


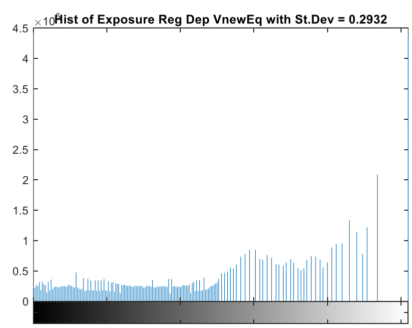
The Following are Examples of V Channel Images

The Following are Corresponding Histograms









Upon conclusion of the research done on the issue of regional identification of non-uniform illumination this research was successful in implementation and enhancement of the proposed method. The methodology used as the inspiration of this research was enhanced with the implementation of histogram equalization and in some cases such as the Rayleigh distribution histogram equalization became even more effective. However, while the process of exposure region identification was successful and improved upon the best results for image restoration and overall enhancement were best observed with localized enhancement techniques using spatial correlation between exposure regions and specific regions of interest within the image.

Further research and experimentation are necessary for further development of algorithms specific to this issue. More specifically, with the development of categories of sub-regions within the exposure regions identified would prove to be extremely beneficial in the overall enhancement methodologies specific to the proposed methodology. The improvement of the exposure region identification would also be further improved by creating subclasses of ranges specific to the attributes used in this methodology to determine more accurate identification as well as development of more advanced and defect specific local image enhancement.

V. Repositories

The two primary resources used for cohesion for the development of this project. Links to these sources are as follows:

https://drive.google.com/drive/u/0/folders/18r2hFWLRQ_eMkTqLXls-hWZrGSTlvh2l

https://github.com/th1622EE/DIP-Project-FA20

VI. References

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