MZUZU UNIVERSITY

CONTROLLED ILLUMINATION OF A DARK IMAGE USING HISTOGRAM EQUALIZATION

BY

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Abstract

Image enhancement defined as the process of adjusting digital images so that the resulting image is more suitable for display or further analysis. It is one of the most important requirements in Digital Image Processing as it makes an image useful for various application, such as medicine and Geographic Information Systems. While a vast number of image enhancement algorithms have already been developed, the majority of these algorithms have not addressed the issue of controlled illumination and its associated enhancement factor. This study was computer based, which involved a controlled illumination and was implemented in python programming environment. The algorithm used was successful, despite the observed flaws in the enhanced image. The problems seen in the image quality was attributed to used limitations in the algorithm.

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Chapter 1

INTRODUCTION

This chapter provides background information, a statement of the problem, objectives, and significance of the study.

1.1 Background information

Different images contain a lot of different crucial information that can be useful in various ways. This information can be extracted or obtained from a particular picture with the help of technique called image processing [3]. Image processing is a computer-based process that help to extract the necessary information from an image. It is extension of standard signal processing which is a very important field of applied physics. Image processing has several applications such as transportation, moving object tracking, biomedical imaging and remote sensing [17]. Modern computer vision and image processing applications require images with high quality visibility to achieve the designated tasks properly [3]. However, in most cases images acquired in low light conditions are blemish, as they suffer from low visibility due to numerous defects. The defects arise from a range of uncontrolled conditions like indoor lighting, night-time lighting and cloudy weather. Under these conditions the image quality is destroyed due to noise. The poor quality of such an image might also degenerate the performance of the computer vision and multimedia systems algorithms, that are primarily designed to process high quality input images [1]. Thus, it is highly required to improve the quality of such images to become suitable for further processing for machines and interpretation for humans [2]. The primary aim of dark image enhancement is to recover acceptable quality images in terms of brightness, contrast and color without introducing any undesirable effects; so that the enhanced images appear better and become more suitable for many image-related applications [3]. Hence, an image algorithm is employed. Therefore, this study attempts to utilize a minimum number of steps in a dark image illumination.

1.2 Statement of the problem

While a vast number of image enhancement algorithms have already been developed, the majority of these algorithms have not addressed the issue of controlled illumination and its associated enhancement factor. This study, therefore uses histogram equalization to control illumination in a dark image.

1.3 Main Objective

The main objective of this study was to illuminate a dark image using histogram equalization.

Chapter 2

LITERATURE REVIEW

This chapter provides relevant literature to the study on a controlled illumination of a dark image using histogram equalization technique.

2.1 Theoretical Background

The theorem principle of histogram equalization (HE) is that through cumulative distribution function maps the original image into an enhanced image a specific intensity value. The histogram equalization aims to achieve uniform distribution of pixel intensities by effectively spreading out the most frequent intensity values. This result in improved contrast and visual quality image Zhang [12]. HE is one of the most popular image enhancement techniques for improving image quality. It is considered as simple and effective method to brighten and improve image quality, but also acknowledge with many short falls. Despite that HE brightens an image, but useful image details are lost [8].

2.2 Color models

Color model explains how the colors are represented and specifies the components of color space [5]. Color models model describes colors according to a certain specification and are used for different applications such as; computer graphics and image processing [5]. RGB color model (RGB: Red, Green, Blue) is the most used color model for computer graphics; it is an additive color model: the lights red, green, and blue are combined to create other colors [5]. In digital image processing, color segmented based on color information. Input color image is enhanced using median filter to remove noise and smoothing the color image. The purpose of color image segmentation is that each segment will have pixel that similar to pixel in its own segment and different to pixel in other segment One of the ways to segment color in digital images is using three-dimensional color data [6].

2.3 Image intensity

A digital image is a two- dimensional array of light gives the intensity of the image at the point (x,y) and the function as f(x, y) are represented as discrete values. These values are usually integers, so the image will consist of 0 and 1 ranging from 0 to 255 for each color channel (red, green, and blue) for a color 8-bit image [14]. Each point in the image denoted as f (x, y) coordinates is referred to as a pixel. Where a pixel is the smallest cell of information in the image. It contains the values of the intensity level corresponding to the detected irradiance [6].

2.4 Image Histogram

In Digital Signal Processing (DSP), a number of pixels (frequencies) of the same intensity values are stored in a histogram array, which is commonly called a ”bin”. A histogram is a graphical representation of the frequency distribution of the pixel values in an image. It shows how many pixels have a certain intensity level, from 0 (black) to 255 (white) for a grayscale [14]. A histogram is a representation of a frequency distribution. The histogram of a digital image with G total possible intensity levels in the interval [0, G - 1] [8] is defined as the discrete function:

$$p(r_k) = \frac{n_k}{n} \tag{2.1}$$

Wherer_k is the intensity level in the original raw image n_k is the number of pixels in the image whose intensity level is n is the total no of pixels.

2.5 Histogram equalization

Histogram equalization is a process that modifies the histogram of an image so that it becomes more uniform, meaning that each intensity level has approximately the same number of pixels. What the histogram equalization technique does is that it changes the pdf of a given image into that of a uniform probability density function that spreads out from the lowest pixel value (0 in this case) to the highest pixel value ($L-1$) [14]. This can be achieved quite easily if the pdf is a continuous function. However, since we are dealing with a digital image, the PDF will be a discrete function. Let’s suppose we have an image x, and let the dynamic range for the intensity r_k varies from 0 (black) to L1 (white). This PDF can be approximated using the probability based on the histogram $p(r_k)$ as shown in equation (2.2)

$$\mathrm{pdf}(x) = p(r_k) = \frac{\text{total pixels with intensity } r_k}{\text{total pixels in image } (x)} \tag{2.2}$$

From the PDF, we can obtain the cumulative density function (CDF) as follows:

$$(S)_k = T_{r_k} = \sum_{j=1}^{k} P_r(r_k) \tag{2.3}$$

For $k = 1, 2, \ldots, L$, where $(S)_k$ is the intensity value of the output image, r_k is the pixel intensity of the input image, and the intensity value of the output image corresponds to the value of the input image. The output of a pixel from the histogram equalization operation is given by the CDF of the image:

$$p(s_k) = \sum_{k=0}^{L-1} p(r_k) \tag{2.4}$$

To get the value of $p(s_k)$, it needs to be multiplied by $L-1$ and then rounded to the nearest integer.

2.6 Normalized Histogram

The normalized cumulative distribution function transforms the CDF of the original image to a desired CDF by remapping the grayscale distribution through back projection [16].

2.7 Image Contrast

Kumar [8] defines an image as a matrix of square pixels (picture elements) arranged in columns and rows. It is a 2D function $f(x,y)$, where x and y are spatial coordinates, and the amplitude of f at any pair of coordinates (x,y) is called the intensity or gray level of the image [8]. The contrast of an image, describing the difference in gray levels of two adjacent pixels lying in different regions, can be affected by poor illumination and quality. To increase image quality, contrast is stretched by increasing the dynamic range of gray levels in the image [8].

De Saint [16] emphasizes the need to control the enhancement factor in image contrast, which is a critical parameter in the histogram equalization algorithm as it determines the degree of image enhancement. The enhancement factor is determined empirically based on the specific image and desired enhancement level. Visual inspection of the enhanced images is used to find the optimal value that provides the best balance between contrast improvement and artifact reduction [15].

Chapter 3

MATERIALS AND METHODS

This chapter covers the methodology employed to realize Image enhancement using Histogram Equalization in Python. It outlines and illustrates the materials, methods, and algorithms used. All the steps presented and in this study were carried out and implemented in Python libraries such as OpenCV and NumPy. OpenCV uses NumPy, especially for mathematical and numerical calculations. Python programming language is a user-friendly high-level software and a language suitable for image processing.

3.1 Algorithm Processing steps

3.1.1 Splitting color channels

Image enhancement aims at quality of the input image. For more effective and further processing of the image, the image color is split from its distinct colors into RGB color channels. Here, each color channel is processed individually and then concentrated to form a single enhanced color image. RGB color model is the most used color model for computer graphics [5]. The red, green, and blue colors are combined to create other colors.

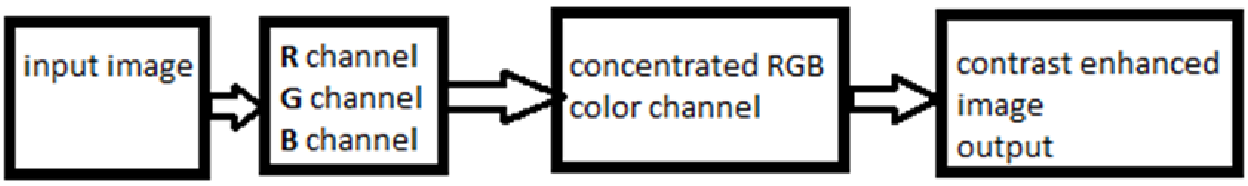

Figure 3.1: block diagram of color quantization [6]

3.1.2 Obtain Intensity of the Image at Each Coordinate

Images are characterized by a certain intensity distribution, achieved through histogram specification. To achieve the desired contrast adjustment, intensity values are obtained at each coordinate of the image pixel by pixel. The contrast of the input image determines each level of brightness for the Cumulative Histogram. The information obtained is further used by a histogram and disperses out the most common intensity values to produce a contrast-improved image.

3.1.3 Compute the Cumulative Distribution Function (CDF) of Each Channel

An image can be enhanced by remapping the intensity values using a histogram. The enhanced image, with an equalized histogram, ideally has an equal number of pixels at each gray level. However, in practice, this can only be achieved by an approximation. The approximation is done by summing the equalized histogram cumulatively to form a Cumulative Distribution Function (CDF) [10]. The histogram equalization redistributes the pixel intensity values evenly while accumulating the frequencies (number of each pixel) at each intensity value. The CDF mathematical formula is shown in equation (3.1):

$$\mathrm{CDF}(k) = \sum_{I=0}^{K} P(I(x,y) = i) \tag{3.1}$$

Where $P(I(x,y) = i)$ is the probability that the intensity of the pixel at coordinate (x, y) in an image is equal to a specific value i.

3.1.4 Normalize the CDF

Image normalization is a process in image processing that changes the range of pixel intensity values. Its main purpose is to keep images within desired pixel value ranges, often more familiar to human normal senses. The normalized CDF is calculated using equation (3.2):

$$\mathrm{CDF}(k) = \frac{\mathrm{CDF}(K)' - \mathrm{CDF\ min}}{\mathrm{MAX} - 1} \tag{3.2}$$

Where $\mathrm{CDF}(k)$ is the new value of the cumulative distribution function for a specific pixel value k after enhancement, $\mathrm{CDF}(K)'$ is the original cumulative distribution function value for the pixel value k, CDF min is the minimum value of the original cumulative distribution function, and $\mathrm{MAX} - 1$ is the maximum pixel value in the image.

3.1.5 Utilize the Normalized CDF with a Controlled Enhancement Factor α

The traditional histogram equalization (HE) method equation 2.3 is used with the introduction of another parameter α in equation (3.3):

$$\text{CDF}(k) = \text{round}\left(\frac{\alpha(L-1)}{MNX \times \text{CDF}_{\text{nom}}}\right) \tag{3.3}$$

Where:

$\text{CDF}(k)$ is the Cumulative Distribution Function at a specific intensity(k)

α is the scaling factor that controls the enhancement contrast, within the range $\min \leq \alpha \leq \max$

L is the total number of pixel levels in the image

MNX is the maximum and minimum pixel values in the image

CDF_{nom} is the normalized cumulative distribution function

In order to utilize the normalized CDF to redistribute intensities, the transformation function with the enhancement factor α is used to control the degree of enhancement.

The process of enhancing the image, involved varying the value of enhancement parameter . In this case, the -value was chosen empirically by observing the output image. The used -values used for the first image sample, as indicated in the next chapter labeled a1, a2 and a3 were 0, 0.2 and 0.7 respectively. The same -values were also used in a similar process for the second image sample. To obtain a clear image, as -values was adjusted up to 0.7, beyond which the image was not clear.

Chapter 4

RESULTS AND DISCUSSIONS

In this part of the study, obtained results from the observed findings are demonstrated along with discussion of the results.

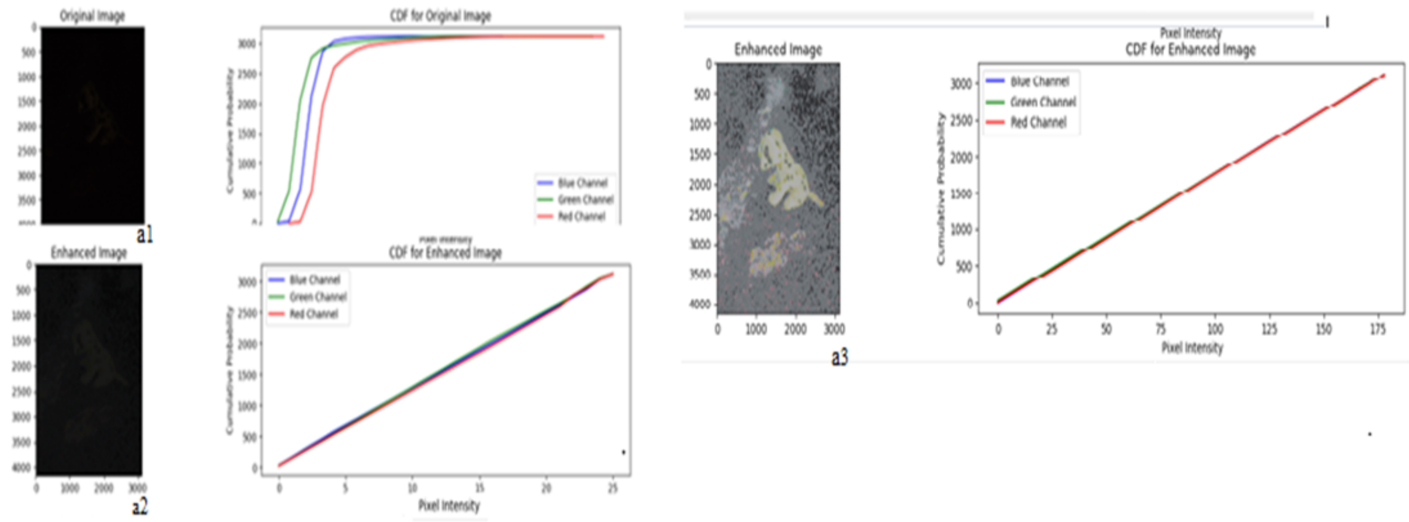

Figure 4.1: Images used in the study (a1)-(a3)

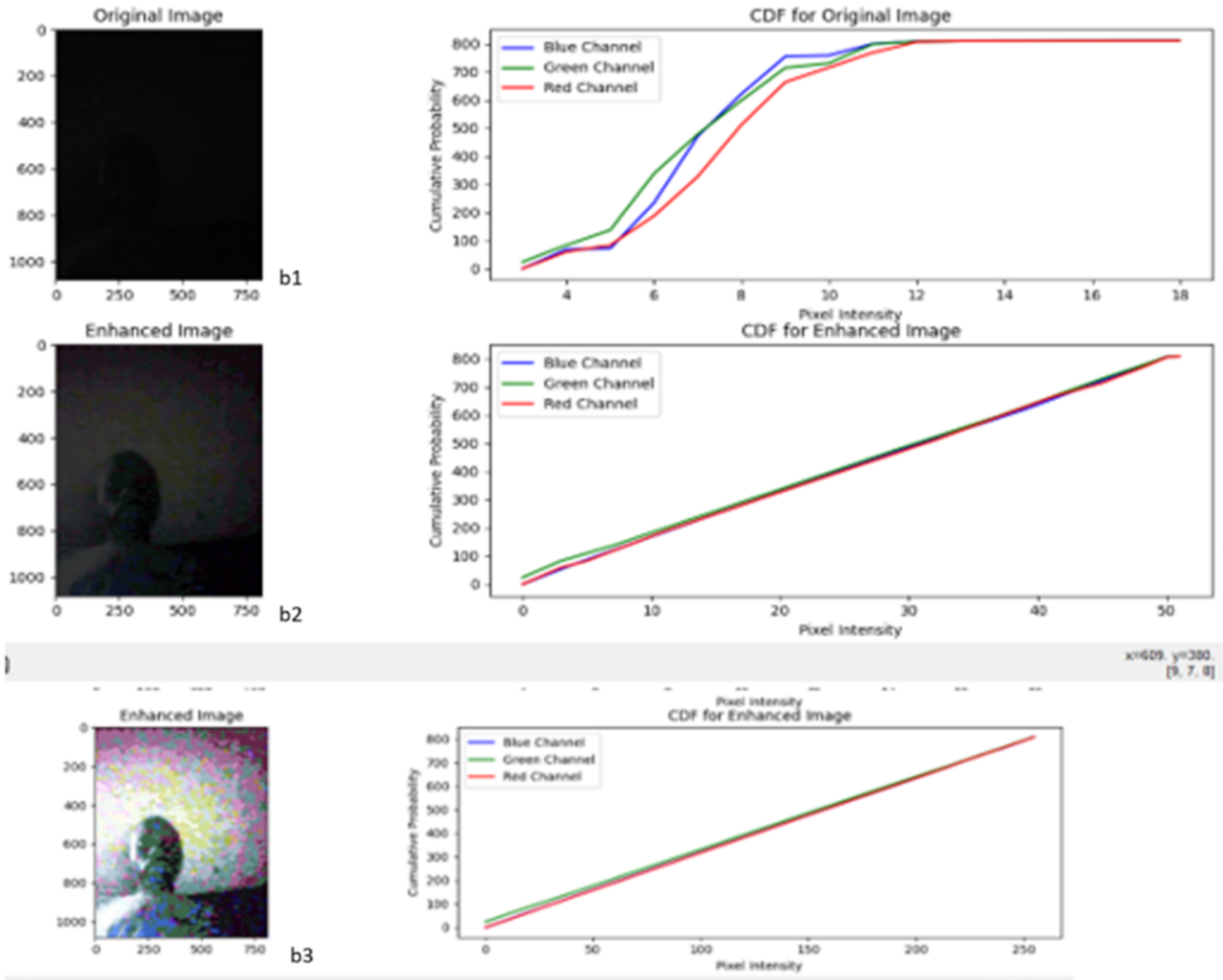

Figure 4.2: Images used in the study (b1)-(b3)

As seen, image a1 is completely dark and obscured, a2 is comparatively brighter and reveals some information and finally image a3 is brighter and more detailed. The image's correspond graphs shows a non-linear in for image a1 and linear for but not supper imposed for a2, while a3 is linear almost but not superimposed. A similar trend also applies for images b1, b2 and b3 respectively. The behavior for the trend, is explained by the physics behind histogram equalization. Here, the histogram equalization manipulates the image by remapping the pixel intensity values to obtain uniform (flat) histogram. Further, the out image is represented by close contrast values. The process allows areas of lower local contrast values in the dark image to gain a higher on the histogram.

The results obtained the study demonstrates that the algorithm successfully recovered the image from darkness. However, the recovered image the resulting image had a number of problems, as seen from images in 4.1 (a1)-(a3) and 4.2 (b1)-(b3) respectively. As evidenced from the seen images, the enhanced images did not look natural as it lacked color, and had a lot of artifacts. The poor quality is attributed to poor design limitation. Hence, the image had poor quality. The image brightness was increased, but the resulting image suffered more artifacts. This shortfall was also reported from a similar study by Chin [11]. An image to look natural and pure, it has to have enough color saturation. This suggest that a possible explanation to the resulting image's poor color quality is that it lacked color saturation. The resulting image experience loss of details increased artifact as seen from the resulting images findings; is associated with loss of information details due to over enhancing some areas and under enhancing others within the image. From 4.1 [a1]-[a3] the images subjected to different enhancement factor random values are show with increased brightness. Each increase in brightness however is noted with increased artifacts. This similar experience was also noted by Zhang [12], who reported that a higher enhancement factor in a histogram equalized image results in more destructive contrast enhancement, potentially leading to a higher risk of introducing artifacts such as noise amplification. Conversely, a lower enhancement factor may result in a more constrained contrast improvement. The theoretical principle of histogram equalization, via cumulative distribution function assumes to map the original image into an enhanced image, with uniform pixel intensity distribution. Noticeably, from the study, the findings are inconsistence with the theory, which in agreement with Zhang [12]; who also obtained similar practical results.

Chapter 5

CONCLUSIONS AND RECOMMENDATION

In this study, the intended controlled illumination of a dark image using histogram equalization is realized. In addition, through the proposed method largest amount of details is shown in the enhanced image. However, practical experimental result's observation demonstrates flaws in the in the resulting image. In a way that the technique whilst increasing the enhancement it also introduced artefacts and loss of details, hence minimizing image quality. It was argued that lack of image quality was due to limitation in the design of the technique. This paper had made an effort of pointing out the need for enhancement control parameter in the used technique. The study observation findings suggest therefore, a more effective method to achieve better results could be employed. In future, the researcher recommends further improvements on the used technique.

Chapter 6

REFERENCES

[1] Dr Prasad, S. Athane A. (2021).Image Enhancement Based on Opencv Using Python 2.7. International Advanced Research Journal in Science, Engineering and Technology. Vol 8, No.5, 2021.India [2] Pratim, P. et al.,(20218). Contrast Enhancement of Low-light Image Using Histogram Equalization and Illumination Adjustment. Seoul, Korea. Retrieved from https://www.researchgate.net/publication/324257398

[3] Al-Ameen, Z.(2018).Nighttime image enhancement using a new illumination boost algorithm.IET-Institution Of Engineering and Technology Jounals. Nineveh, Iraq. [4] Gonzalez, R., Eddins, C., Woods, R. E. (2004). Digital image processing second. Beijing: Publishing House of Electronics Industry, 455.

[5] Meskaldji, K. et al.,(2014). Color Quantization and its Impact on Color Histogram Based Image Retrieval.Beijin. [8] Kumar, P.(2014).Image Enhancement Using Histogram Equalization and Histogram Specification on Different Color Spaces. India illumination boost algorithm. IET Image Processing, 10.1049/iet-ipr.2018.6585. Retrieved from www.ietdl.org

[10] Guptal, P. et al.,(2017). Histogram Based Image Enhancement Techniques: A Survey. International Journal of Computer Sciences and Engineering. Vol.5, No. 6, 2017. Retrieved from: www.ijcseonline.org [9] Javad, S. et al.,(2020).Adjustable Contrast Enhancement Using Fast Piecewise Linear Histogram Equalization. ICIGP Singapole. https://doi.org/10.1145/3383812.3383830 [11] Tejas, A.,Ketan, C.,Kalpesh, D., Rupali Bora, S.(2020) Low Light Image Enhancement for Dark Images. International Journal of Data Science and Analysis. Vol. 6, No. 4, 2020, pp. 99-104. doi: 10.11648/j.ijdsa.20200604.11. Retrieved from http://www.sciencepublishinggroup.com/j/ijdsa [12] Zhang, L Wu, D.(2020) A Mobile Robot Recognize Blurred Targets via an Improved Histogram

Equalization. Conference Series: Materials Science and Engineering.Harbin, China. [13] Banik, P.P. et al.,(2018).Contrast Enhancement of Low-light Image Using Histogram Equalization and Illumination Adjustment. Seoul, Korea. Retrived from: https://www.researchgate.net/publication/324257398 [14] Dorothy, R. et al.,(2015). Image enhancement by Histogram equalization. In I cml (Vol. 1, pp. 409). [15] Goodyear, C. et al.,(2006).Performance-based Image Enhancement Methodology: An Investigation of Contrast Enhancement Algorithms. Air Force Research Laboratory. Consortium Research Fellow Program. USA. Retrieved from Defense Technical Information Center (.mil). https://apps.dtic.mil [16] De Saint, E. (2016) Image enhancement using histogram manipulation. 165 (2019) 391–398. Retrieved from https://adventures-in-186.tumblr.com/post/154168028601/image-enhancement-using-histogram-manipulation