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"A COHESIVE FRAMEWORK FOR NON-LINEAR IMAGE ENHANCEMENT THROUGH HISTOGRAM SPECIFICATION TO OPTIMIZE VISUAL QUALITY OF IMAGE"

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Abstract

Histogram specification is an advanced digital image processing technique designed to enhance the visual quality of images. It employs non-linear image enhancement methods to adjust pixel values, resulting in improved contrast, brightness, and overall visual quality. After the non-linear enhancement, histogram specification fine-tunes the brightness and contrast levels to meet desired standards. This process allows for selective modification of various image characteristics based on specific requirements. For color images, the RGB color space is typically used, but for better human perception, RGB values are often converted into HSV values. In HSV, the H component represents the color's spectral composition, S indicates color saturation, and V denotes brightness or luminance. The proposed method includes two primary processes: adaptive intensity enhancement and contrast enhancement. Adaptive intensity enhancement uses a specially designed nonlinear transfer function to adjust bright areas while enhancing darker regions. Contrast enhancement adjusts each pixel's intensity based on the characteristics of surrounding pixels. This dissertation introduces a novel hybrid approach, combining non-linear image enhancement methods with dynamic restoration. Through comprehensive evaluation using metrics like Bit Error Rate, Mean Difference, Peak Signal to Noise Ratio, and Mean Square Error, this method has shown superior performance, making it a highly effective technique for image enhancement and restoration.

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I. INTRODUCTION

1.1 Image:

Images can be either 2-Dimensional, like a photograph captured by a digital camera or a screen display, or 3-Dimensional, such as a physical model or sculpture. They can be produced using optical devices like lenses, microscopes, or cameras, and can also occur naturally, such as the reflection on a water surface or as perceived by the human eye. The term "image" is also applied more broadly to include any 2-D representation, such as maps, pie charts, or abstract artwork. In this broader context, images can be created manually through techniques like drawing with pencils or paints, sculpting, or painting, as well as through printing using printers, computer graphics, or a combination of these methods.

1.2 Digital image processing:

Digital images are made up of pixels, with each pixel representing a specific color at a single point in the image—essentially functioning as a tiny dot of color. By measuring the color at numerous points in an image, a digital approximation can be created, which allows for the reconstruction of a likeness to the original image. Pixels, although small like grains in traditional photography, are arranged systematically in rows and columns and store information differently.

Digital image processing involves the electronic manipulation of data in a two-dimensional array of numbers, which represents a quantized image. A true image forms on a sensor when an energy emission strikes it with enough intensity to generate an output. This energy can come from various sources; when it falls within the visible light spectrum, it's known as visible light. Some images only reflect electromagnetic radiation, while others generate their own, a phenomenon known as radiance.

1.3 Image Enhancement:

Image enhancement [12] primarily focuses on improving images for better viewing, thereby providing enhanced input for digital image processing methods. The main goal is to modify an image's characteristics to make it more suitable for a specific task and observer. During this process, certain image attributes are adjusted, with the choice of which characteristics to alter being tailored to the specific task. Factors such as the human visual system and the observer's familiarity introduce a significant amount of subjectivity into the selection of enhancement methods. Numerous techniques can enhance a digital image without compromising its integrity. Image enhancement involves a set of methods designed to either improve the visual appearance of an image or prepare it for analysis by humans or digital devices. The primary objective of these techniques is to process an image so that the results are more suitable for a particular application than the original image. Enhancement methods are often used to increase the contrast of images that are either too dark or too light. These techniques include operations that either enhance the image's appearance for human viewers or transform the image into a format better suited for machine processing. Overall, image enhancement addresses image processing operations that improve the quality of an image to overcome the limitations of the human visual system.

Fig.1.3 (a). Before enhancement (b). After enhancement

1.2.1 Image enhancement techniques can be divided into three broad categories:

i. Spatial domain methods.

ii. Frequency domain methods (DFT).

iii. iii). Fuzzy Domain.

1.4 Non-Linear Enhancement:

Existing methods for image enhancement often face challenges where the information in the image becomes degraded after enhancement. To address this issue, the enhancement focuses on both luminance and contrast of the Value (V) component in the HSV color space. The non-linear transfer function used for luminance enhancement is uniform across all pixels; however, since different regions of an image can vary significantly in illumination—some areas being darker and others brighter—the enhancement must be adapted to these variations. To achieve this, the Value component of the image is divided into smaller overlapping blocks. The non-linear transfer function is then determined for each pixel within these blocks to enhance luminance effectively. During contrast enhancement, the adjustment for each pixel is based on its value as well as the values of neighboring pixels. This approach ensures that contrast is improved while preserving the image information.

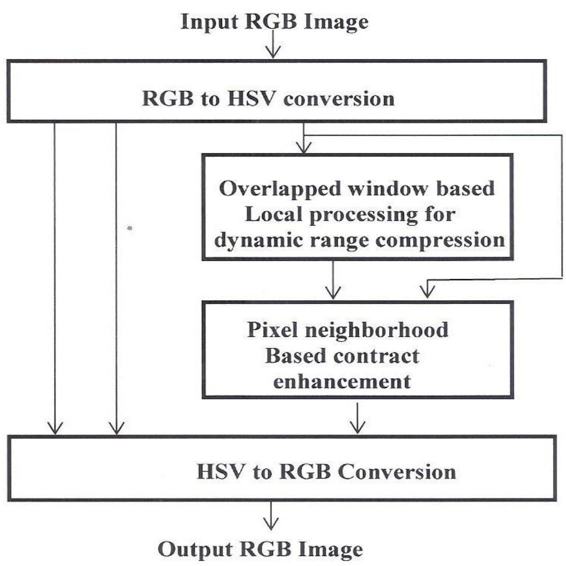

Figure 1.4. How non-linear image enhancement works

In color image processing, RGB is the standard color space, but HSV is more aligned with human visual perception, where Hue (H) represents color, Saturation (S) indicates color purity, and Value (V) denotes brightness or luminance. The process involves transforming the RGB values of the image into the HSV color space. Luminance enhancement, often referred to as dynamic range compression, is the preliminary step to improve images captured under low light conditions. This is achieved using a specifically designed non-linear transfer function applied to the Value component of the input image.

1.5 Histogram Specification:

The Dynamic Histogram Specification (DHS) algorithm, which builds upon traditional Histogram Specification (HS) techniques, is designed to enhance contrast while preserving the original histogram characteristics. The DHS method achieves this by extracting differential information from the input histogram and applying additional parameters such as frame direct current and gain control to fine-tune the processing. Compared to other histogram modification-based algorithms, the proposed DHS approach is more logically structured and effectively enhances contrast. Its simplicity makes it particularly practical for use in electronic devices, including mobile handsets. Approaching histogram specification as an optimization problem involves finding a gray level mapping that best approximates the desired histogram based on the original image histogram. While direct methods are straightforward, statistical modeling provides both the mapping and a deeper understanding of the histogram specification process.

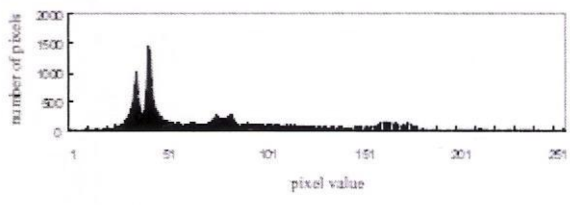

Figure 1.5(a). Original Histogram

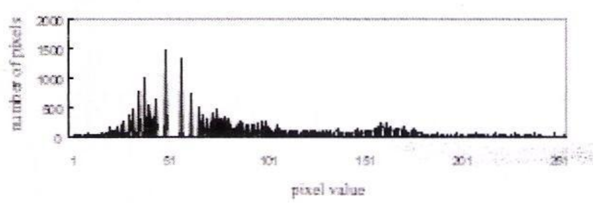

Figure 1.5(b). Histogram Specification

II. LITERATURE REVIEW

The objective of the literature review is to find and explore the benefits of image enhancement algorithms and also what are the different problems in existing algorithms and techniques.

Kim et al. (2024) [1] have discussed that the intensity of scene can be altered following the histogram equalization, which is because of the flattening attribute of the histogram equalization. KIM (1997) [6] proposed histogram equalization referred to as mean preserving bi-histogram equalization to conquer the disadvantage of the histogram equalization. The essence of the proposed algorithm is to conserve the mean intensity of an image while the contrast is enhanced. Given method initially breaks an input image into two sub-images based on the mean of the input image. One of the sub-images is the set of specimens that are less than or equal to the mean whereas the other one is the set of specimens greater than the mean.

Tae et al. (2025) [2] have suggested a block-overlapped histogram equalization system for enhancing contrast of image sequences using various applications such as video door phone, security video cameras. The conventional histogram-based contrast enhancement technique is limited in real time application due to a large computational and storage requirement and it also exhibit quality degradation caused by possible loss of infrequently distributed pixel intensities, which may result in disastrous loss of important information. Tae et al. (1998) [2] proposed a contrast enhancement system for image sequences which can enhance local contrast with suppressing undesired noise amplification based on spatio-temporal processing.

Yueet et al. (2022) [3] have elaborated a non-linear image enhancement method based on Gabor filters, which allows selective enhancement based on the contrast sensitivity function of the human visual system. The selective enhancement of the given approach is especially suitable for digital television applications to improve the perceived visual quality of the images due to various reasons, including interpolation.

Nyamlkhagva et al. (2024) [5] have discussed a new method called Brightness Preserving Weight Clustering Histogram Equalization that can simultaneously preserve the brightness of the original image and enhance visualization of the original image. Given method assigns each nonzero bit of the original image's histogram to a separate cluster, and computes each cluster's weight. To reduce the number of clusters, three criteria are used (cluster weight, weight ratio and widths of two neighboring clusters) to merge pairs of neighboring clusters. The clusters obtain the equal partitions as the result image histogram. At last, transformation functions for each cluster's sub-histogram are calculated, and the sub-histogram's gray levels are mapped to the result image by the equivalent transformation functions.

Fan et al. (2023) [6] have elaborated a new method for image contrast enrichment which is especially suitable for multiple-peak images. The given method has been used to remove the two disadvantages ofHE algorithm i.e. firstly the input image has been convolved by a Gaussian filter with optimum parameters. Then, the original histogram has been divided into various areas by the valley values of the image histogram. The given method out performs others on the aspects of simplicity and adaptability. The result demonstrates that the proposed algorithm has good performance in the area of image enrichment. Due to its simplicity, it can be realized by simple hardware and consumer electronics.

Md, Foisal et al. (2025) [7] have proposed a method of medical image enhancement based upon non-linear technique and the logarithmic transform coefficient histogram equalization. Logarithmic transform histogram matching uses the truth that the relation between stimulus and perception is logarithmic. A measure of improvement based on the transform has been used as a tool for evaluating the performance contrast measure with respect of the proposed enhancement technique. This method improves visual quality of images that contain dark shadows due to limited dynamic range of imaging like x-ray images.

Kwok et al. (2023) [8] have discussed a strategy of local sector improvement by histogram equalization. In given strategy the image has been first divided into sectors and they are independently enhanced by histogram equalization; intermediate images are then provoked recursively by making use of this approach and a resultant image has been obtained by a weighted-sum aggregation on the basis of an intensity gradient measure. Local sectors with higher contrast dominate the others thus achieving overall global contrast improvement. An enhanced image is then produced where the intermediate images are repeatedly averaged using a weight-sum strategy.

Cheng et al. (2025) [9] have suggested a novel approach for the detection of over- enhancement. Firstly, the causes for generating over - enhancement has been analyzed in detail, then an objective and effective criterion has been presented. The experimental results demonstrate that the given approach can locate the over enhanced areas accurately and effectively, and provide a quantitative criterion to assess the over-improvement levels well. The given method

III. PROBLEM DEFINITION

The non-linear enhancement algorithm utilizes the HSV color space to improve image quality, focusing exclusively on the Value (V) component for intensity adjustments since the Hue (H) and Saturation (S) components generally do not require modification. The proposed method includes two key processes: adaptive intensity enhancement and contrast enhancement. Adaptive Intensity Enhancement: This process employs a specially designed non-linear transfer function that reduces the intensity of bright regions while enhancing the intensity of darker areas. Contrast Enhancement: This process adjusts the intensity of each pixel based on its surrounding pixels to improve overall contrast. However, enhancing only the intensity may not always yield the best results, as it affects image sharpness but does not address color strength, which is also crucial for comprehensive image enhancement. To address this limitation, the non-linear enhancement technique is combined with histogram specification. Histogram specification adjusts not only intensity but also color and saturation, leading to more effective results. In this integrated approach, histogram specification is applied to the Hue (H) and Saturation (S) components while maintaining the non-linear enhancement for the Value (V) component. This combination ensures improved image quality by enhancing both intensity and color attributes.

3.1 Objectives:

The main objective is to improve the result of the proposed algorithm over existing enhancement algorithms. To quantize the quality of proposed algorithm following sub-objective are selected.

1. The main aim of this work is to implement a non-linear image enhancement technique.
2. To further refine non-linear color enhancement, a new integrated approach has been introduced. This method combines non-linear enhancement with histogram specification, focusing specifically on the Hue (H) and Saturation (S) components.
3. The effectiveness of the proposed algorithm is validated through a series of experiments using a standardized image dataset.
4. The performance of the proposed technique is evaluated by comparing its Detail Variance (DV) and Background Variance (BV) against those of existing non-linear image enhancement methods.

IV. PROPOSED METHODOLOGY

4.1 Methodology Used**:**

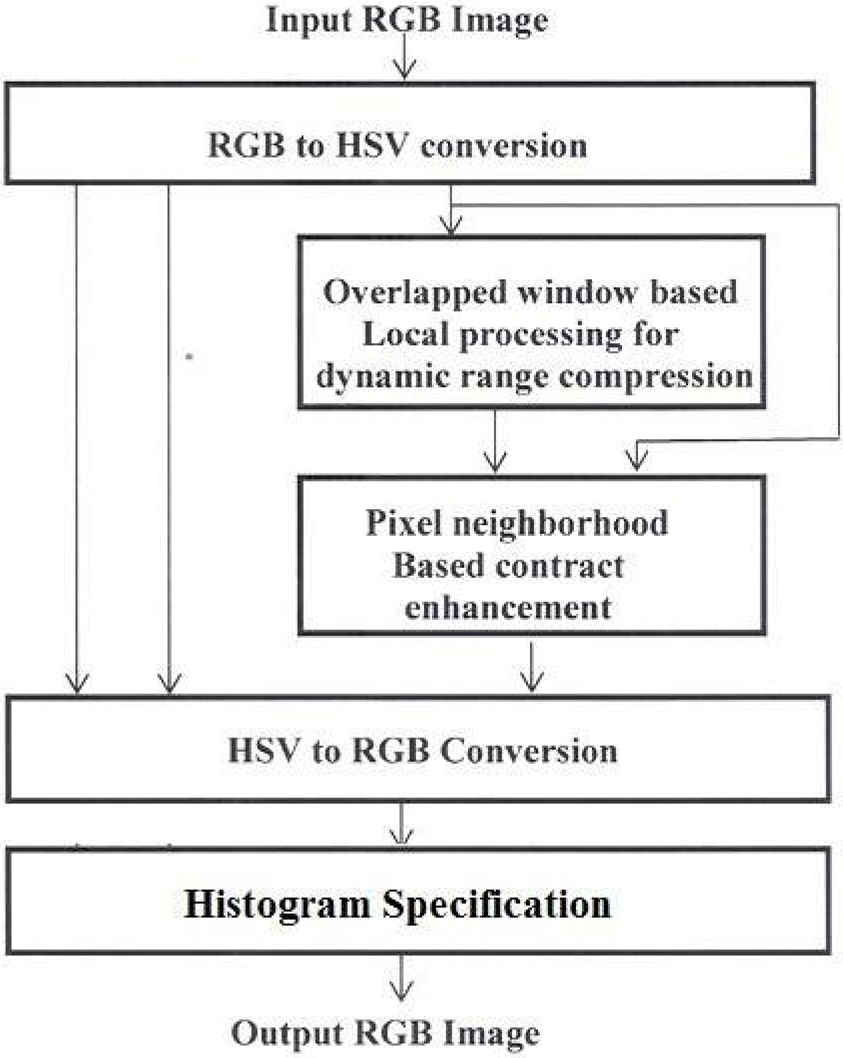

Fig. 4.1. Flowchart of Methodology Used for Proposed Algorithm

V. EXPERIMENTAL RESULTS

5.1.1 Performance Parameters

In order to implement the proposed algorithm whole of the implementation is done in MATLAB using image processing toolbox. We have considered multiple parameters for proving the betterment of the proposed technique. All the considered parameters are purely based on the Enhancement of the Image. Each and every single parameter is far better in terms of thenumerical calculations and it is being proved in the form of Proper tables and figures below. Numerous specific Graphs have been obtained by the authentic implementation in the MATLAB processing tool. Following are the parameters based upon which we have implemented our proposed technique and proved the betterment of the results

- Bit Error Rate (BER)
- Peak Signal to Noise Ratio (PSNR)
- Mean Difference (MD)

- Mean Square Error (MSE)
- Bounded Variation (BV)
- Detailed Variance (DV)

5.2 Performance evaluation (Tables and Graphs):

As BER needs to be minimized, so in Figure 5.1 it is clearly shown that BERis less in our case therefore proposed algorithm is providing better results.

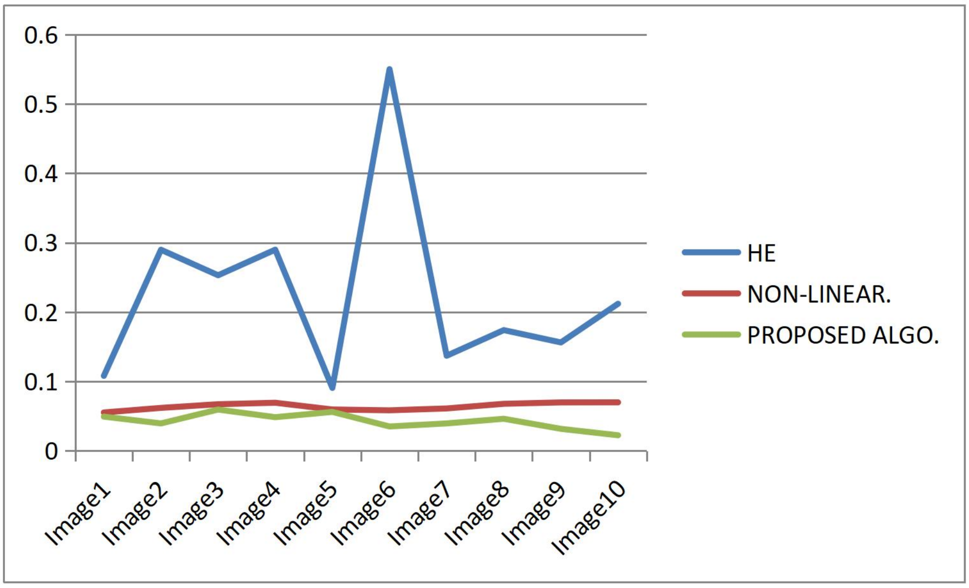

Fig.5.1. BER Evaluation

5.3 Mean Difference

As Mean Difference needs to be minimized so it is clearly shown in Figure 5.9are clearly shown that Mean Difference is less in our case.

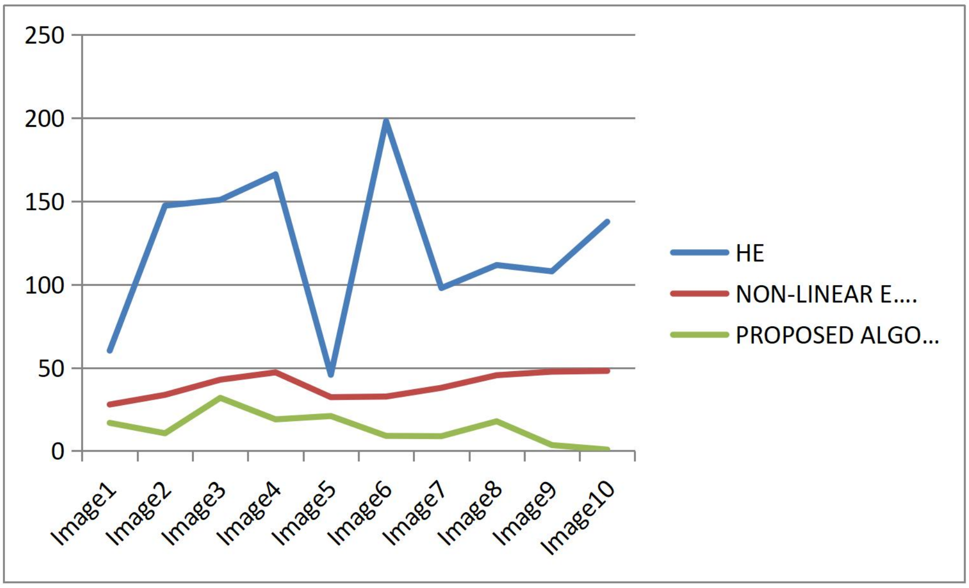

Fig. 5.2 Mean Difference Evaluation

5.4 PSNR

As PSNR needs to be maximized. So, our goal is to increase PSNR as much as possible and it isclearly shown in Figure 5.3.

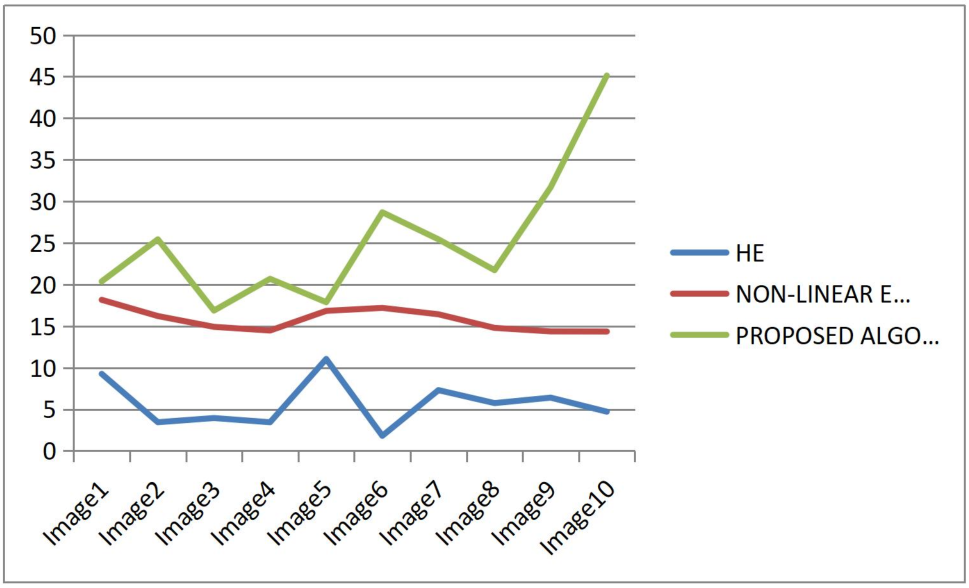

Fig 5.3 PSNR Evaluation

5.5 MSE

As MSE need to minimize, so our goal is to reduce them MSE as much as possible. And it isclearly being shown in Figure 5.4.

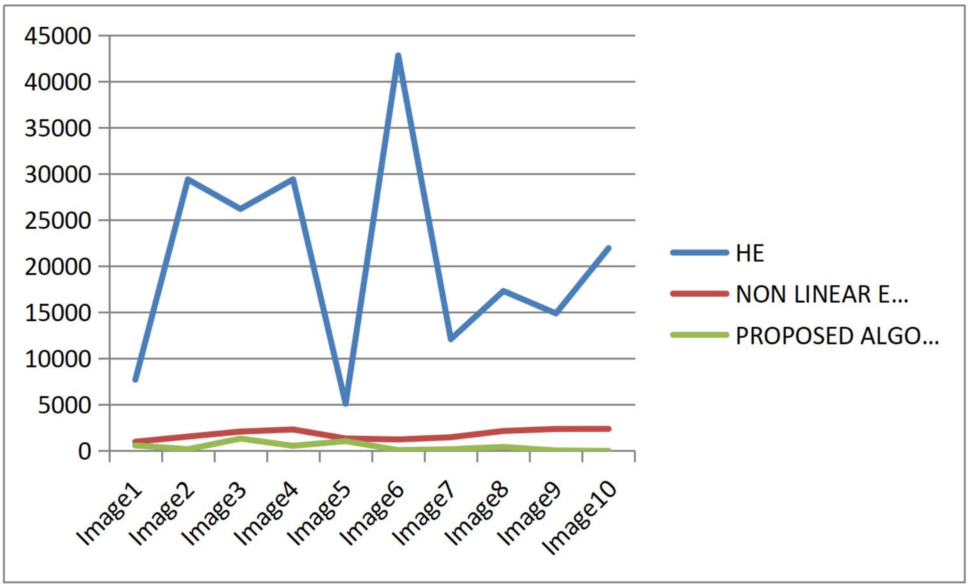

Fig. 5.4. MSE Evaluation

5.6 BV

As BV (Bounded Variation) needs to minimize, so it is clearly shown in Figure 5.5 are that the BV is less in our case therefore proposed algorithm is providing better results.

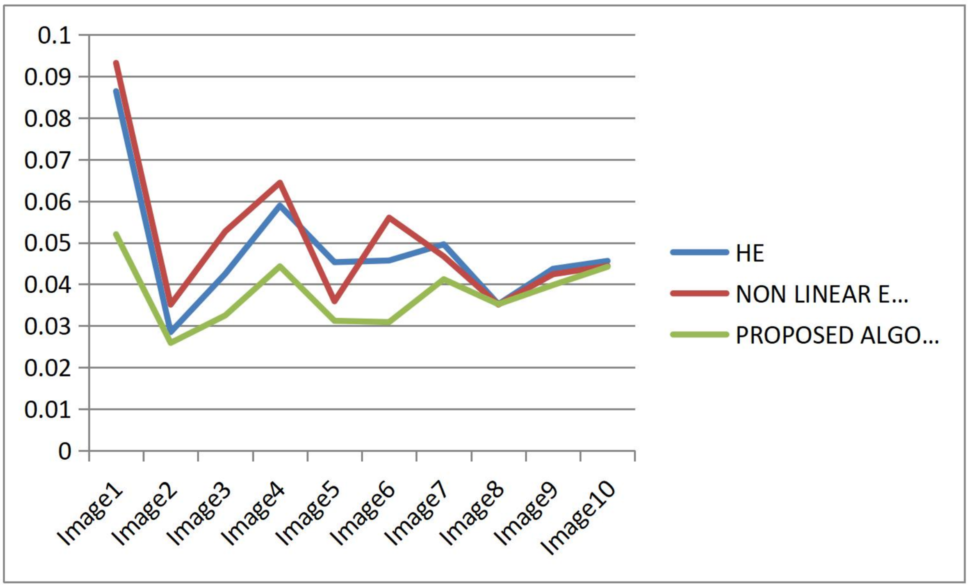

Fig 5.5 BV Evaluation

5.7 DV

As DV (Detailed Variance) need to be maximized it is clearly shown in Figure 5.6 that DV is maximum in our case therefore proposed algorithm is providing better results.

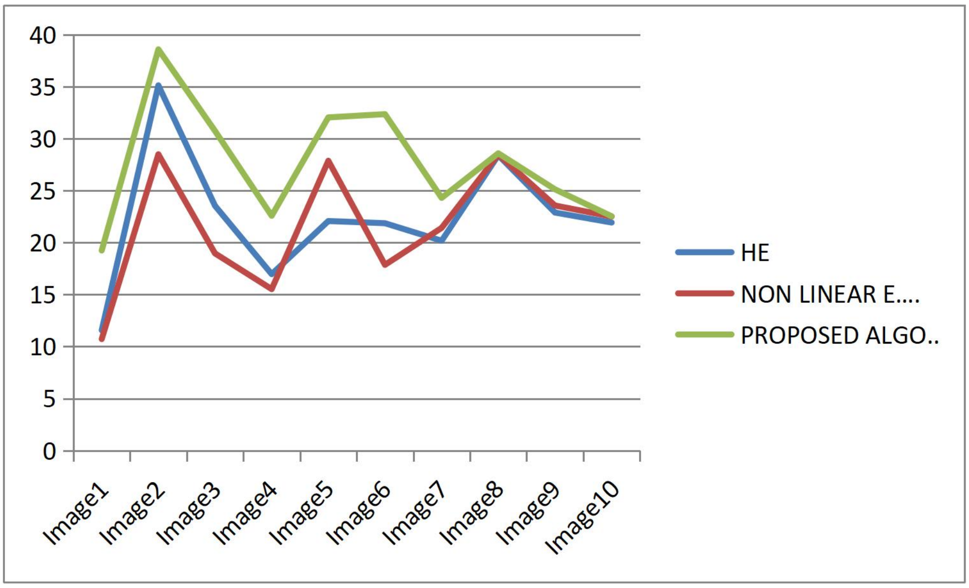

Fig 5.6 DV Evaluation

VI. CONCLUSION

6.1 Conclusion and Future Work:

The application of image enhancement techniques is crucial in digital image processing. This dissertation showcases the effectiveness of non-linear image enhancement for improving the quality of blurred images through light source enhancement. It explores various methodologies for image enhancement, emphasizing their role in enhancing image quality and visibility, particularly for degraded images. A range of techniques has been developed to improve digital image quality by refining and extracting useful information while minimizing noise and artifacts. Image enhancement functions as a tool to reduce noise, eliminate artifacts, and highlight important features, thus aiding in analysis, interpretation, and practical application. The primary goal of this dissertation is to address the limitations of current image enhancement methods and introduce a novel technique aimed at improving the detailed variance in images. The proposed method has been implemented in MATLAB using the image processing toolbox and has demonstrated significant improvements in image quality across various test cases.

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