A COMPREHENSIVE REVIEW AND FUSION OF HISTOGRAM EQUILIZATION TECHNIQUES FOR IMAGE ENHANCEMENT

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I Aditya Raj hereby certify that the work which is being presented in the thesis entitled "A comprehensive review and fusion of Histogram Equilization Techniques for Image Enhancement" in partial fulfilment of the requirements for the award of the Degree of Master of Technology in Data Science, submitted in the Department of Software Engineering, Delhi Technological University is an authentic record of my own work carried out during the period from 2022 to 2024 under the supervision of Dr. Sonika Dahiya.

The matter presented in the thesis has not been submitted by me for the award of any other degree from this or any other institute.

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Certified that Aditya Raj (2K22/DSC/01) has carried out his research work presented in this thesis entitled "A comprehensive review and fusion of Histogram Equilization Techniques for Image Enhancement" for the award of Master of Technology from Department of Software Engineering, Delhi Technological University, Delhi, under my supervision. The thesis embodies results of original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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ABSTRACT

Histogram equalization is a widely used and popular technique for improving contrast of digital image. Such technique can lead to over-enhancement, sometimes the details of the image may be lost. Therefore in our approach we try to overcome the above given drawback of histogram equalization. We introduce an algorithm which is a novel combination of three techniques such as adaptive histogram equalization, block-based histogram equalization and brightness-preserving dynamic histogram equalization. Besides, pre-processing and post-processing are included in our algorithm to further improve the image. Many techniques are available in literature to Equalize Histograms as explained in initial paragraphs. In this paper we compare our suggested technique to the prevailing ones. We show that suggested technique provide better contrast enhancement, details of image are preserved in comparison to the other Histogram Equalization Techniques. The visual quality of image enhanced by suggested technique is also high as compared to the prevailing techniques. The suggested technique is computation efficient and can be applied in real time applications. The proposed algorithm is described below along with implementation details, parameters, optimization. The algorithm shows the potential of providing great benefit to the different application area of image processing, such as image enhancement, surveillance system and satellite image.

Keywords: Histogram Equalization, Image Processing, Image Enhancement, Edge Detection

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LIST OF ABBREVIATIONS

DL	Deep Learning
ML	Machine Learning
SSIM	Structure Similarity Index Measure
SNR	Signal to Noise Measure
PSNR	Peak Signal to Noise Measure
MSE	Mean Squared Error
AMBE	Absolute Mean Brightness Error
CNN	Convolution Neural Networks
GPU	Graphics Processing Unit
DNN	Deep Neural Networks
ANN	Artificial Neural Networks
HE	Histogram Equilization
AHE	Adaptive Histogram Equilization
BBHE	Block Based Histogram Equilization

CHAPTER 1

INTRODUCTION

Image improvement plays a vital role in image processing and to improve the perceivable characteristics of images. This technique is followed by almost all the applications on image processing, as an initial step before the main processing begins. The implementation of this technique increases the quality of images by assigning better responses for an improved visual appearance of an image. It is used for feature enhancement to enhance the overall features of images in various fields such astronomy, geology, forensics, disease diagnosis, robotics, medical imaging and many more fields. In astronomy, the enhancements to an image help to bring out more stellar objects captured by a telescope. This involves increasing features like intensity and time-wise increased contrast. It can be done in a way that reduces the noise, sharpens edges, and lays out visualization of medical images in a better way. Modern health care has introduced the leading technologized application in medical imaging that is precisely intensive in applications for the diagnoses and treatment of patients having multiple diseases. However, medical images may also be subjected to degradation by noise, low contrast, among other degradations. This significantly stands in the way of quality and accuracy in the images, thus making it difficult for the clinicians to note such important anatomical detail, a reason that in turn directly affects patient care. These are artifacts that need to be kept at bay so as to make the process of diagnosis the best. Suboptimal image with low contrast might result in an unclear identification of the object or Region of Interest (ROI). This will hinder correct diagnosis and might also yield wrong measurements. The contrast of these kinds of images should be enhanced correctly for interpretation purposes and to support accurate diagnosis.

Certainly, clarity improvement and information extraction remain one of the constant strides in the world of digital image editing. Sometimes, pictures taken in a setting lack contrast, and the possibility of seeing important elements and making an accurate analysis may be quite difficult. Histogram equalization (HE) has been one of the standbys to take on these issues; it uses pixel brightness variation to spread intensities among pixels. Classic histogram equalization (HE) provides an efficient solution. Its generic nature can sometimes result in excessive enhancement, increased noise and outcomes that appear artificial. As a result various adaptive HE methods have been developed to customize the equalization process based on image features or specific use cases. Nonetheless the multitude of these approaches, along with their varying advantages and disadvantages has introduced a landscape for both researchers and practitioners, in the field. This thesis reviews methods available in histogram equalization for image enhancement so far and integrates them into a single conclusion. The theoretical foundation upon which both classic and adaptive HE methods operate, their underlying basic assumptions, algorithmic implementation, and performance trade-offs will be dissected with great caution.

The objective of this research, in the broadest sense, is to synthesize the knowledge gained from this comprehensive review and suggest a novel fusion framework of the HE techniques that could overcome the limitations of individual methods, going on to further extend the envelope of the robustness and versatility in image enhancement. Our vision is an integration strategy that combines adaptive mechanisms with local contrast adjustments and perceptual considerations oriented toward the best solutions, while they are natural and specifically required in a wide range of applications. By considering the HE landscape and identifying promising research directions, attention is brought to the literature on image enhancement, which consequently empowers practitioners with a more effective toolkit in enhancing visual information contained within digital images.

1.1 HISTOGRAM EQUILIZATION

At its essence, histogram equalization (HE) is a contrast enhancement technique that operates by transforming the intensity distribution of an image. It leverages the image's histogram, a graphical representation of the frequency of occurrence of each intensity level. In a low-contrast image, the histogram often appears concentrated in a narrow range, indicating that many pixels share similar intensity values. HE redistributes these intensity levels to create a more uniform histogram, effectively spreading out the pixel values across the entire dynamic range. This results in enhanced contrast, making the image visually more appealing and revealing previously hidden details. Fig. 1.1.1 shows the working of histogram equilization.

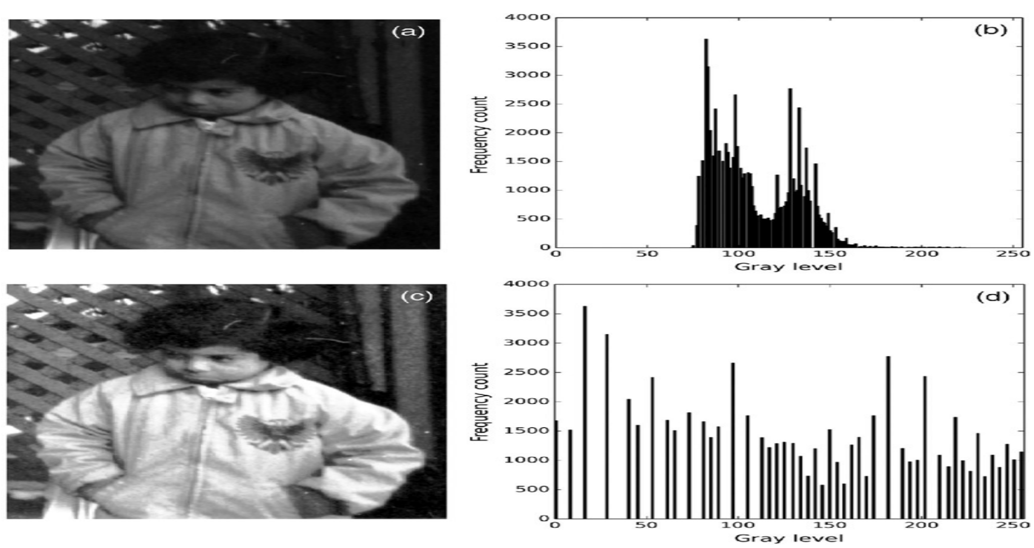

Fig. 1.1.1 Example of histogram equalization. (a) The input image and (b) its gray level histogram, which shows that the gray level distribution is concentrated in a small range. Although histogram equalization (HE) improves the overall contrast of the image (c) by distributing the pixel values more uniformly over the available gray level range (d) some image regions are clearly over enhanced.

1.2 Limitations of Classic Histogram Equilization

While the classic histogram equalization forms the foundation to most contrast enhancement techniques, the limitations point towards a further step into more advanced methods. Particularly problematic in the forefront, the global nature of classical HE—in the sense that it treats all pixels uniformly, regardless of their spatial context—often brings suboptimal results. Some of the significant drawbacks are an over-enhanced case, particularly in images with wide dynamics. HE works to disperse pixel intensities uniformly over the entire available range. In the process, what it does is enhance equalization but can give a boost to the noise and unnatural looks because, in the process of doing this, subtle features in low-contrast regions may be lost while high contrast is highly amplified. Besides, this enhancement is prone to a raise in noise. Since it works across the entire image and does not consider any one part differently from others, any noise that may have already been present in the original image seemingly would have also been magnified by the equalization process. This would encroach upon the visual quality of the image and thus not allow for any further research to be carried out on it.

Moreover, as HE is a global operation, it does not make use of the local context information. The different regions in an input image might exhibit characteristics of contrast, and uniformly transforming, them leads to the generation of artifacts or loss of information that can be quite substantial. For instance, even in a landscape picture, after having HE executed, the part of the sky might become overexposed, while the foreground remains underexposed. Nevertheless, classic HE is of great importance in the processing image toolbox; its limitations raise the need for more sophisticated techniques that are adaptive enough to answer the special challenges of all kinds of image scenarios. It is because of these limitations that research has been opened up toward adaptive HE algorithms, which we discuss in the sections that follow.

1.3 Rise of Adaptive Histogram Equilization

These inherent limitations have opened the way for research into a wealth of adaptive histogram equalization (AHE) techniques. A central common motivation is to get around the inadequacies of the global mechanism of classic HE by specifically tailoring the equalization operation to locally apparent image characteristics. This means that the adaptive nature of the technique is realized in those small subregions or tiles of the image. Local contrast information would be preserved, and in fact, this technique would decrease the many risks of over-enhancement related to the amplification of noise. Several popular AHE methods have appeared over the years, each with its set of strengths and weaknesses. In this regard, Contrast Limited Adaptive Histogram Equalization (CLAHE) introduces a clip limit such that too much contrast enhancement is not done to reduce the possibility of amplifying noise. On the other hand, Adaptive Histogram Equalization (AHE) hence performs dynamic adjustments to histogram equalization parameters according to the local content in every region, making it more flexible and adaptive. Another important technique is Brightness Preserving Bi-Histogram Equalization (BBHE) and Minimum Mean Brightness Error

BiHistogram Equalization (MMBEBHE). These techniques not only do not alter the overall image brightness, but they also provide increased contrast.

Such rich diversity in the methods of AHE has provided researchers and practitioners with a very complex landscape. Yet no comprehensive review and assessment of these varied techniques establishes a gap in understanding of their relative merits and demerits. Systematic comparisons of their performance under a variety of image scenarios and application domains, hence, are of importance to identify possibilities of most suited techniques for given tasks. Moreover, an understanding of the principles and trade-offs on which AHE is based that goes deeper than it has so far could inspire new, previously unconsidered image enhancement algorithms towards more effective solutions. The paper seek comprehensive review and evaluation of AHE techniques as a stepping stone toward this unified and robust framework of image enhancement.

1.4 The need For a Unified Work

The disadvantages of classic HE, on the other hand, have just been replaced with another set of problems—those of adaptive histogram equalization (AHE). The diversity within the family of AHE methods along with its distinctive algorithmic design and choices of parameters has made it a cumbersome task to single out the most fitting technique for a particular application by researchers and practitioners. The large number of alternatives and the lack of standardization in the assessment framework make decisions usually ad hoc, based on very limited empirical evidence. For this complex landscape, developing a full appreciation of the strengths, weaknesses, and trade-offs of these various AHE methods is necessary. Only full and detailed analyses of their underlying assumptions, computational complexity, parameter sensitivity, and performance characteristics across many diverse scenarios can lead to well-informed choices. For instance, while some AHE techniques are good at preserving very fine detail but not very good at amplifying noise, others are very robust in noise cases but introduce artifacts easily. This is important to know what trade-offs might come into play when tailoring an AHE approach toward the specific requirements of a given application.

The least common effort of AHE should be found with some combined best parts of some techniques in a unifying framework to confront these challenges. Hopefully, the result will be some fusion framework that brings various AHE techniques into play, each with its own strengths. It is our vision that this technique could become a general flexible and strong approach in image enhancement, where the inclusion of adaptive mechanisms, local contrast improvements. Conceived structure by itself should be designed so that the flexibility and adaptability properties are present even in the design process of the framework structure, with a potential to enable a given processing step with tunability according to user needs or preferences. This thesis will contribute to providing a global unified platform for the assessment and combination of AHE techniques that empower researchers and practitioners with a more effective toolkit for enhanced visual information in digital images.

1.5 Research Objective

The main goal of this thesis is to address the limitations of existing histogram equalization (HE) techniques and propose a novel framework for enhanced image contrast and visual quality. Specifically, this research aims to achieve the following objectives:

1. Comprehensive Review of HE Techniques:

The classic and adaptive historic enhancement techniques that exist will be thoroughly reviewed in a systematic way. This will include the underlying bases of theory for the techniques, ways through which the algorithms are implemented, and their performance features in different image situations. For this reason, the objective of the present work is to critically evaluate strengths and trade-offs with weaknesses and bring a summarized overview of the state-of-the-art concerning HE researches.

2. Development of a Novel Fusion Framework:

From the in-depth review of literature, a new fusion framework for an image enhancement application will be proposed. Complement adaptive HE techniques and block-based HE techniques through their combination. This harnesses higher contrast enhancement with their individual limitations being minimized. The proposed algorithm will incorporate the Brightness Preserving Dynamic Histogram Equalization(BPDHE) technique into it, such that this technique preserves brightness while enhancing local contrast.

3. Evaluation on Diverse Image Datasets:

The proposed fusion framework will be tested on available image datasets, including color, grayscale, and infrared ones. Evaluations using subjective and objective metrics will include visual assessments with human observers and quantitative measures of contrast, detail preservation, and naturalness. This paper tries to project the effectiveness and superiority of the proposed framework in enhancing digital image visual quality compared to existing techniques by a comparison of its performance with other HE techniques. The expected novel fusion framework proposed in this paper to further contribute to the field of image enhancement includes a thorough understanding of the various techniques under HE.

1.6 Content Organization

The remainder of the project is headed and ordered as from hereon: Chapter II, Literature review, delving further into the theoretical basis and practical applications of a diversity of HE techniques. Chapter III describes the proposed fusion framework for image enhancement in detail. Chapter IV is about experiment results and analysis, in which discussion on different models of implementation is addressed. Chapter V contains Limitation and future Scope, and Chapter VI concludes with Conclusion and future work.

CHAPTER 2

LITERATURE REVIEW

Histogram equalization (HE) forms one of the cornerstones in image enhancement. It is a simple but potent method for increasing contrast and revealing hidden details inside an image. Redistributing pixel intensities will lead to more uniform distribution in the image; hence, it further enhances quality and information content in digital images. However, as discussed in the last chapter, classical HE algorithm inherently has some drawbacks including over-enhancement, amplification of noise, and no adaptability to the local image characteristics. Because of the outlined shortcomings, a plethora of adaptive HE techniques were developed. These approaches aim to overcome the limitations of the classic histogram equalization by integrating the equalization process into particular image regions or features. As a result, the number of methods in this class has increased significantly. Moreover, each approach comes with its own set of advantages and disadvantages.

This chapter introduces a detailed discussion of this landscape, covering the theoretical and implementation aspects of various HE techniques. To begin with, the following section will offer an overview of the classic form of HE, with the aim of identifying the fundamental aspects and addressable limitations of the task. In the sections following, the limitations of the classic form of HE will be utilized as the prime motivation for addressing and attempting a comprehensive review of all the techniques that have been proposed as an alternative. Exploring the algorithmic and performance analysis, as well as the suitable paradigm under which these methods should be applied, hoping to offer a complete overview of the current state of HE research. This will aid in providing the basic foundation for detailing our fusion framework, defined in the next subsection.

2.1 Foundations of Histogram Equilization

Histogram equalization is a fundamental image processing technique that enhances an image's contrast by shifting its intensity values. The cumulative distribution function (CDF) is calculated using the image's histogram, which depicts the frequency distribution of pixel intensities. The technique uses the CDF to translate the original intensity levels to new levels, resulting in a more uniform histogram for the output image and improved contrast. The process in histogram equalization is to compute the histogram, derive and normalize the CDF, and remap the intensity levels to form the enhanced image. Even though it enhances global contrast and is computationally efficient, sometimes, histogram equalization often over-enhances and amplifies noise.

2.1.1 The Image Histogram

One of the most important statistical tools in image analysis is the use of an image histogram technique that gives a graphical representation of the intensity distribution within the contents of a picture. Such a discrete function maps each intensity level from 0 to L-1, where L is the total number of possible intensity levels, onto some number of pixels in the image having that particular intensity. The histogram summarizes important information about the overall tonal distribution within the image, i.e., it quantifies how frequently each brightness occurs. A well-balanced histogram with pixel values distributed fairly uniformly across the intensity range indicates wide dynamic range and high contrast. For a narrow or skewed histogram, it would imply that the range of intensity has been limited, resulting in a dull and low-contrast image. In that sense, the histogram is the visual fingerprint of such an image—one that reveals tonal characteristics and guides all sorts of image-enhancing procedures.

The histogram equalization usually reorganizes the intensity distribution of an image in order to better visualize it. It is usually assumed that if a histogram's probability is equal for all intensities, then information richness and dynamic range would be maximized. Therefore, HE can be seen as a histogram transformation approach that aims to redistribute pixel intensities, leading to a more balanced and informative histogram.

2.2 Adaptive Histogram Equilization Techniques

Adaptive Histogram Equalization (AHE) is a process of image contrast enhancement that adjusts the operation according to the different sections of an image. The central motivation for designing AHE continues to be finding a way around the constraints put by traditional Histogram Equalization (HE). Traditional HE performs equal enhancement over the complete image, which many times does not bring in local details, especially in pictures with variations in illumination or sophisticated textures.

2.2.1 Adaptive Histogram Equilization

AHE achieves this through dividing the image into a multitude of small, mostly-overlapping regions and performing HE on each one. This local adaptation is very crucial—only with that can we accomplish enhancement of fine details, elided in some global approach. AHE can noticeably improve the visibility of features in sections of the original image that were under- or overexposed. The importance of detail retention is in clearer readability of the image, which becomes paramount for medical imaging, satellite imagery, and other industries where detail is definitive.

2.2.2 Global Sub-Histogram Equilization

Global Sub-histogram Equalization is a generalization of simple HE for improving contrast and simultaneously compensating for some of its inadequacies. The very basic idea of GHE is to divide the global histogram of an image into many sub-histograms. Thus, each sub-histogram represents a fixed range of intensity values, and HE is applied separately to each of them.
The implementation of GHE involves the following steps:

1. Dividing the image histogram into sub-histograms.
2. Equalizing each sub-histogram separately.
3. Combining the equalized sub-histograms to form the final enhanced image.

GHE has a few advantages over standard HE: it better preserves the local contrast and reduces the risks of over-enhancement of contrast, as well as noise amplification. Also, GHE can introduce situations at the sub-histogram margins that may require extra processing for smoothing out.

2.2.3 Contrast Limited Adaptive Histogram Equalization

Contrast Limited Adaptive Histogram Equalization Over the AHE technique, CLAHE involves a contrast limiting process that eliminates problems associated with amplification and enhancement of noise. At the core of the CLAHE innovation lies an idea regarding 'clip limits', wherein maximum value of bins of the histogram are clipped to some level. All the pixels beyond this clip limit are repositioned such that none of the pixel positions is over-enhanced or overamplified.

The steps involved in CLAHE are:

1. Dividing the image into contextual regions or tiles.
2. Applying histogram equalization to each tile with a clip limit.
3. Interpolating the tiles to eliminate boundary artifacts and create a seamless final image.

Noise reduction techniques, on the other hand, are greatly effective given that CLAHE has a limit on the clip, since no one region may be very dominant. Its application also finds its way into several fields where the natural appearance of images must be maintained, such as medical imaging. Variations of CLAHE include:

- **Recursive CLAHE**: This approach iteratively applies CLAHE to progressively finer scales, enhancing different levels of detail.

- **Multi-scale CLAHE**: This method applies CLAHE at multiple scales simultaneously, allowing for comprehensive enhancement across different detail levels.

2.2.4 Brightness Preserving Dynamic Histogram Equilization

CLAHE is very well adapted to noise amplification since the clip limit does not allow any single region to become overbearing; it can be found in medical imaging and other applications all the time when a very naturalistic image appearance is desired.

The implementation of BPDHE involves:

1. Computing the dynamic range of the image and dividing the histogram into subranges.
2. Applying histogram equalization within each subrange while preserving the average brightness.
3. Adjusting the dynamic range to ensure the final image has a balanced brightness distribution.

BPDHE is advantageous for producing visually pleasing results, as it avoids the washed-out appearance that can result from excessive contrast enhancement. By preserving the natural brightness, BPDHE ensures that the enhanced image remains true to the original in terms of overall luminance, making it suitable for applications where natural appearance is critical.

2.3 Comparative Overview of HE Techniques

Table 1 presents a comparative overview of several notable AHE techniques, summarizing their key advantages and disadvantages. This table serves as a quick reference guide for researchers and practitioners seeking to select the most appropriate technique for a specific image enhancement task.

Table 2.3.1 Literature Survey

Name	Author	Paper Title	Advantage	Disadvantage
Global histogram equalization	Pizer et al. (1979)	"Adaptive Equalization Histogram and Its Variations"	Simple and easy to implement	This can lead to the over-enhancement of certain featuresand loss of detail in others
Contrast Limited Adaptive Histogram Equalization (CLAHE)	Zuiderveld (1994)	"Contrast Limited Adaptive Histogram Equalization"	Prevents over-enhancement by limiting contrast amplification	This can result in visible artifacts such as halo effects

Brightness Bi-Preserving Histogram Equalization (BBHE)	Kim et al. (2003)	"Brightness Preserving Bi-Histogram Equalization"	Preserves the mean brightness of the original image	This can lead to color distortionand loss of contrast
Recursive Mean-Separate Histogram Equalization (RMSHE)	Fang et al. (2004)	"Recursive Mean-Separate Histogram Equalization for Image Contrast Enhancement"	Retains overall image brightness and contrast	Can introduce blocking artifacts in low- contrast regions
Dualistic Sub-Image Histogram Equalization (DSIHE)	Kim and Park (2005)	"A Dualistic Sub-Image Histogram Equalization for Contrast Enhancement"	Improves contrast in both bright and dark regions	This can lead to the amplification ofnoiseand unwanted details
Brightness and Contrast Preserving Histogram Equalization (BCPHE)	Gao et al. (2006)	"Brightness and Contrast Preserving Histogram Equalization for Adaptive Image Enhancement"	Preserves both brightness and contrast while enhancing the image	This can result in unnatural- looking images
Fuzzy histogram equalization (FHE)	Chen and Ramli (2009)	"Fuzzy Histogram Hyperbolization Equalization for Contrast Enhancement"	Simple and easy to implement	This can lead to a loss of fine details and unnatural looking images
Modified Histogram Equalization (MHE)	Singh et al. (2011)	"Image Enhancement Using Modified Histogram Equalization"	Preserves local features and minimizes noise amplification	Can cause visible halos and color distortions

Entropy-Based Adaptive Histogram Equalization (EAHE)	Li et al. (2013)	"Entropy-Based Adaptive Histogram Equalization for Contrast Enhancement"	Improves contrast and preserves local features	This can result in the over enhancement of noise and artifacts
Brightness and Gradient Preserving Histogram Equalization (BGHE)	Lu et al. (2014)	“Brightness and Gradient Preserving Histogram Equalization for Image Contrast Enhancement"	Preserves both brightness and gradient information while enhancing contrast	This can lead to unnatural looking images with exaggerated details
Sigmoid-Based Contrast Enhancement (SBCE)	Kamal and Hussain (2015)	"An Improved Sigmoid-Based Contrast Enhancement Algorithm for Gray Scale Images"	Retains the original histogram shape while enhancing contrast	Can cause visible blocking artifacts in low contrast regions
Multi-Scale Histogram Equalization (MSHE)	Yeh et al. (2015)	"Multi-Scale Histogram Equalization for Contrast Enhancement"	Preserves local features and improves contrast at different scales	This can result in over enhancement and unnatural looking images

As evident from Table 2.3.1, each AHE technique offers a unique trade-off between various factors such as contrast enhancement, noise amplification, brightness preservation, and computational complexity. Understanding these trade-offs is crucial for making informed decisions when selecting an AHE method for a particular application.

CHAPTER 3

A NOVEL FUSION FRAMEWORK FOR IMAGE ENHANCEMENT

In the prior chapter, a thorough examination of both conventional and adaptive histogram equalization (HE) techniques highlighted their respective strengths and weaknesses. While these adaptive methods showed much promise in overcoming the limitations of the classical approach, like over-enhancement and noise amplification, they often introduce new problems, such as parameter sensitivity, computational complexity, and potential artifacts based on image characteristics. The overall big terrain of HE techniques, one for each kind of benefit and disadvantage, calls for a more cohesive and comprehensive approach toward image enhancement.

3.1 A Fusion Approach for Image Enhancement

The chapter proposes a new framework for fusion to be applied toward combining the complementary strengths of the several HE approaches to harness the collective power of the said methods. In general, fusion in an imaging scenario means an amalgamation of information from different sources to provide a complete and realistic view of the scene under consideration. Therefore, the basic goal behind fusion in HE is to enhance the strength of each method and reduce the ill effects of their weaknesses.

The proposed fusion framework will encompass adaptive and block-based techniques of histogram equalization, Brightness Preserving Dynamic Histogram Equalization (BPDHE), for improved performance related to contrast enhancement, detail preservation, compactness, and overall visual quality. Thus, this is quite distinct from the adaptation of mechanisms aimed at local contrast adjustment, block-based processing for computational efficiency, and BPDHE to maintain brightness and recover natural-looking images as much as possible to better the existing limitations of HE methods. How these frameworks were designed and implemented, and how they were evaluated, are detailed in the next sections.

3.2 Design of Future Framework

Here in this section, the various stages of application of our fusion framework are shown. The method is set to reach several goals. Among them are to enhance visibility of low-contrast medical images, to lower information loss, to control the extent of enhancement, and to keep the original image brightness so the image looks natural after the process of its enhancement. The proposed digital image contrast enhancement algorithm combines adaptive and block-based histogram equalization techniques with BPDHE. Its operation can be outlined as follows:

1. Adaptive Histogram Equalization
    - Compute the histogram of the input image.
    - Divide the image into small non-overlapping tiles.
    - Compute the histogram of each tile and apply histogram equalization to it.
    - Concatenate the equalized tiles to form the output image.
2. Block-Based Histogram Equalization
    - Divide the image into small overlapping tiles.
    - Compute the histogram for each block independently.
    - Apply histogram equalization to each block's histogram.
    - Reconstruct the equalized image by replacing the pixel values in each block with their corresponding equalized values.
    - Ensure smooth transitions between blocks to avoid visible artifacts.
    - Combine the equalized blocks to obtain the final enhanced image.
3. Brightness-Preserving Dynamic Histogram Equalization (BPDHE)
    - Compute the histogram of the input image.
    - Smoothing the histogram using Gaussian Filter
    - Compute the cumulative distribution function (CDF) of the histogram.
    - Find the local maxima and divide the histogram based on local maxima.
    - Apply histogram equalization to the input image to get an equalized image.
    - Compute the CDF of the equalized image.
    - Compute the inverse of the normalized CDF of the input image.
    - Compute the inverse of the normalized CDF of the equalized image.
    - Map the equalized image's values to the input image's values using the inverse CDFs.
    - Blend the mapped image with the original image to preserve the brightness.
4. Merge the results
    - Compute a weighted sum of the output images from AHE, BBHE, and BPDHE.
    - The weights can be adjusted based on the quality of the output images and the specific requirements of the application.
    - The final output image is the result of the weighted sum.

In this general manner, the algorithm is able to enhance contrast in digital images, keeping their appearance natural. The proposed algorithm combines adaptive and block-based histogram equalization techniques along with BPDHE for effective output. That is why this algorithm is versatile, efficient, and applicable for a number of other fields where digital image processing plays a vital role, such as medical imaging, surveillance, and remote sensing.

3.2.1 Adaptive Histogram Equilization

Image contrast enhancement is one amongst the approaches used in digital image processing. The technique applied for enhancing the contrast in images is adaptive histogram equalization (AHE). AHE divides an image into many small sub-regions and equalizes the histogram independently for each of the sub-regions. Hence, the contrast enhancement obtained using AHE is at the sub-region levels. This is the first step proposed by the algorithm for the digital contrast enhancement of images. In the next step, input image is divided into sub-divisions having a small size of patch, independent histogram equalization is applied to each and every sub-region. The number and size of the sub-regions are determined by the input image size and the level of desired contrast enhancement respectively. AHE can enhance contrast without causing unnatural visual effects or too much-enhanced effects. However, AHE magnifies noise in the input image that eventually decreases its visual quality. It is used in the presence of other techniques to noise reduction and smoothing. In essence, AHE is a nice way of contrast enhancement for digital images, and its combination boosts the cause. To enhance the contrast between adjacent pixels, AHE is combined with other techniques such as block-based histogram equalization and BPDHE.

3.4 Block Based Histogram Equiization

The proposed way of improving the contrast of digital images is to apply Block-based Histogram Equalization on the adaptive histogram-equalized images. In the BBHE concept, there is an approach to partition larger sizes of blocks from the input image in such a way that histogram equalization can be applied to each partitioned block. The size and number of the blocks are determined according to image size and the extent up to which they want to enhance; this technique confines contrast augmentation only up to the level of blocks. Less over-enhancement is left in the image due to BBHE. It results in slight over-enhancement of the small sub-regions, while BBHE ensures contrast enhancement from then on up to the larger blocks, thus maintaining the natural look of the image except that it is visually enhanced. However, BBHE also has some limitations: they can produce block artifacts due to the discontinuity between adjacent blocks. This limitation of the method can be overcome by the combination of other methods like reducing block artifacts or smoothing techniques. This paper will apply BBHE with combinations of AHE and BPDHE in a proposed algorithm that enhances contrast in digital images effectively without affecting the natural appearance of the images. Here, the combination of AHE, BBHE, and BPDHE makes it adaptive in contrast, confined both to very small sub-regions as well as blocks, and retaining the brightness levels of an image. It will lead to a contrast improvement images while preserving their natural looks, hence minimizing any unnatural visual effects. Generally, the transformation of this BBHE seems to be quite a good technique for the enhancement of contrast in images, and the additional techniques that it combines with can make its performance improved.

3.5 Brightness Preserving Dynamic Histogram Equilization

Brightness Preserving Dynamic Histogram Equalization (BPDHE) is a digital image processing method that normally applies in contrast enhancement with a constraint of free localized brightness. It is the silhouetted means as it does automatic application of the process of histogram equalization in accordance with the unique localized data features available with respect to each and every subregion. In this work, after the exhaustion of AHE and BBHE processes, BPDHE had been proposed as the final step of enhancement of contrast of digital photographs. Hence, the good thing about BPDHE is that it maintains the brightness levels of an image while simultaneously enhancing contrast in it. With the use of traditional methods of histogram equalization, brightness information could be compromised in the process, giving an unnaturally artificial look in the output image. The advantage of BPDHE is that the parameters in histogram equalization vary dynamically depending on the local characteristics of these sub-regions. On the other hand, BPDHE has one weakness, some disadvantages may cause over-enhancement for some inside an image. At this point, BPDHE is used with different techniques like smoothing and clipping.

3.6 Fusion Framework

The proposed algorithm is the hybrid approach of the three techniques: AHE, BBHE, and BPDHE. Although AHE is an image processing technique for increasing contrast, in fact, it manipulates pixel intensities with a histogram redistribution to expose different features within an image; the method encounters problems. In fact, this method can over-enhance some regions, making them look very artificial. One more technique is the block-based histogram equalization (BBHE). It overcomes the problem of over-enhancement. The input image is split into non-overlapping blocks, on which an independent block-wise histogram equalization process is performed. The last enhancement process of BPDHE allows the raising the contrast while having stable brightness through dynamic updating of the cumulative histogram equalization parameters according to the respective properties of a subregion. This method ensures adaptive contrast enhancement, getting restricted to the small sub-regions and keeping the brightness levels of the image. The combination of these techniques has several advantages over the techniques of traditional histogram equalization. Use of BBHE allows local blocks to get enhanced in small blocks with the elimination of block boundary contours and retains the texture information. AHE does the process of adaptive contrast enhancement by taking care of the entire image. This finally ensures that the brightness levels of the image are not altered and the overall enhancement is very natural. Thus, the overall contrast enhancement regarding digital images and the proposed algorithm have improved performance criteria against conventional histogram equalization techniques through a combination of these three techniques.

3.7 Pre-Processing and Post-Processing Steps

The proposed algorithm for contrast enhancement of digital images involves several steps to optimize its performance and ensure the best possible results. These steps are described below:

1. Pre-processing Steps:

    a. Image resizing: In order to optimize processing time and guarantee consistent results, the algorithm resizes the image to a standard size.

    b. Image normalization: The algorithm normalizes the image to ensure that the pixel intensities are in a suitable range for processing.

    c. Image conversion: The algorithm converts the image to grayscale to simplify the processing and enhance the contrast effectively.

2. Post-processing Steps:

    a. Image denoising: The algorithm applies a denoising technique to the enhanced image to reduce any noise that may have been introduced during processing.

    b. Image sharpening: The algorithm applies a sharpening technique to the enhanced image to enhance the image's details and edges.

    c. Image colorization: The algorithm colorizes the enhanced image to produce a visually appealing result.

These are essential steps meant to give an excellent performance to the proposed algorithm and assure that the final results are appealing and consistent. Pre-processing procedures prepare the image well for all of the processes, and post-processing procedures are carried out for further quality in terms of noise reduction, edge enhancement, and colorizing of the traverses of the final results.

3.8 Real Time Considerations

Equally important in the implementation of the proposed algorithm are the considerations for real-time processing. In this respect, the algorithm developed should be optimized to perform real-time image processing while maintaining image quality, with no degradation of the process. Techniques for real-time processing can be made possible by means of parallelization, hardware acceleration, memory optimization, and many other ways. The choice of programming language, libraries, and frameworks can make a huge determination in terms of the runtime performance of the algorithm in respect to real time.

CHAPTER 4

EXPERIMENT RESULTS AND ANALYSIS

A very rigorous experimental evaluation based on large image datasets, including different types of scenes in changes of light conditions and degradation levels, has been conducted to test the merit of the proposed fusion framework. For a deep analysis of visualization quality, subjective and objective evaluations are both conducted. The subjective assessment was done visually, where the enhanced images were scored by human observers according to the perceived contrast, the level of detail preservation, and naturalness. Objective metrics include Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index Measure (SSIM), contrast measures, and entropy in order to quantify improvements in performance due to the proposed framework compared to baseline HE techniques. It could be concluded from the results of experimental evaluation that the proposed fusion outperformed significantly state-of-the-art methods over different datasets and evaluation metrics. Further, subjective evaluations did ensure that the visual quality in the fused images—more contrast, details sharper, and natural-looking—was greater. This was further justified by the objective metric analysis, where the improvements in PSNR, SSIM, contrast, and entropy were evident. These results add more assuredly the proposed fusion framework among the things that were looking how to improve image quality and avoid these limits of single HE technique at once.

4.1 Parameter Selection and Optimisation

To attain optimal performance, the proposed method must be implemented carefully, taking into account a number of parameters and optimization approaches. The parameters used can have a significant impact on the algorithm's performance and usefulness, hence it is critical to ensure the results are reliable. Examples of such criteria are block size, window size, and threshold values. As a result, substantial experimentation and testing are required to identify the best parameter values for various image kinds and applications.

4.2 Qualitative Approach

This part assesses the adequacy of the proposed strategy in working on visual quality by contrasting it and current methods. Upgrading the visual nature of the pictures is fundamental since contrast improvement is utilized by clinical imaging frameworks to analyze and find abnormalities in the human body. When comparing visual quality, factors like image contrast, artifacts, and over-enhancement should be taken into account.

Figures 4.2.1 through 4.2.3 depict the original images alongside the images enhanced by various techniques. The input images are displayed in Figures 4.2.1(a)-

4.2.3(a). Upon analysing Figures 4.2.1(b)- 4.2.3(b), it was observed that the histogram equalization technique caused the over-brightening of the images and created artifacts, leading to a loss of information in the enhanced images. To address these issues, several image subdivision techniques like BBHE, DSIHE, and ESIHE have been developed, and their respective images are shown in Figures 4.2.1(c-e) – 4.2.3(c-e). These techniques marginally improve contrast, but information loss is still prominent. BBHE and DSIHE do not have any control parameter to regulate the enhancement rate, while ESIHE uses clipping techniques to manage over-enhancement. However, these techniques introduce noise and artifacts into the enhanced images. The block-based histogram equalization approach in our designed algorithm is more efficient than traditional HE, and it can remain spatial information on images with good quality of detail enhancement without over-enhancement for small partsence. The result can have a more natural and pleasant visual appearance and prone to less artifacts of distortions. The proposed algorithm based on the dynamic thresholding and adaptive block size selection between local h function masks processes various types of images more appropriately to finally converge into an optimal result for superior image quality compared with other histogram equalization techniques. The proposed algorithm also presents several qualitative improvements over main stream histogram equalization methods, which provides a more natural looking and visually appealing image showing better contrast properties while preserving the spatial details more effectively with fewer artifacts and distortions.

Fig. 4.2.1.Enhanced images produced by respective image enhancement techniques for image-1 (Subject 1)
(a) Input image (b) HE (c) BBHE (d) DSIHE (e) RSESIHE (d) Proposed method.

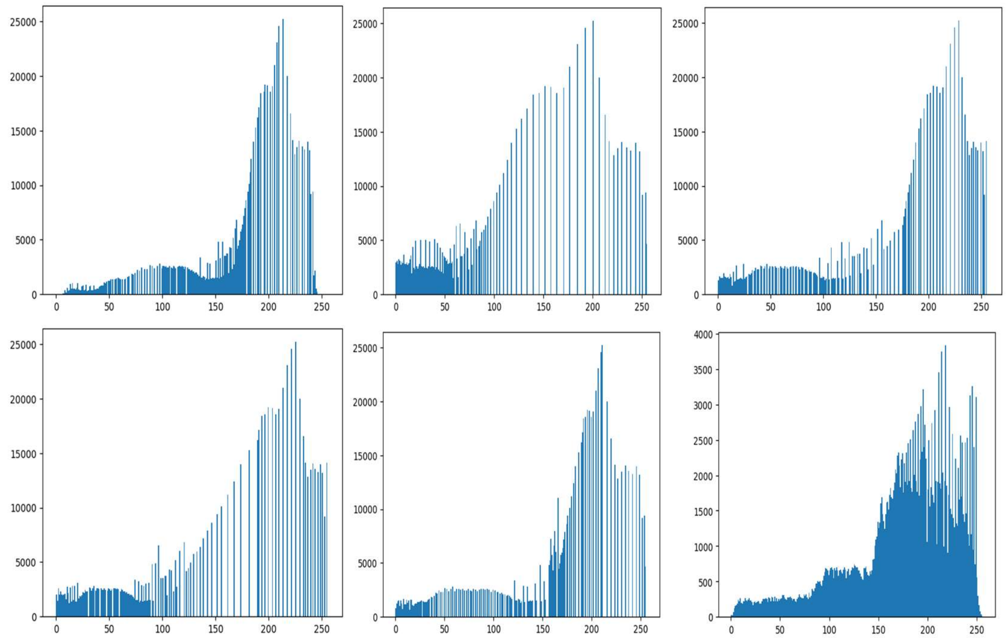

Fig. 4.2.2. Enhanced image Histogram produced by respective enhancement techniques for image-1 (Subject 1)
(a) Input image (b) HE (c) BBHE (d) DSIHE (e) RSESIHE (d) Proposed method.

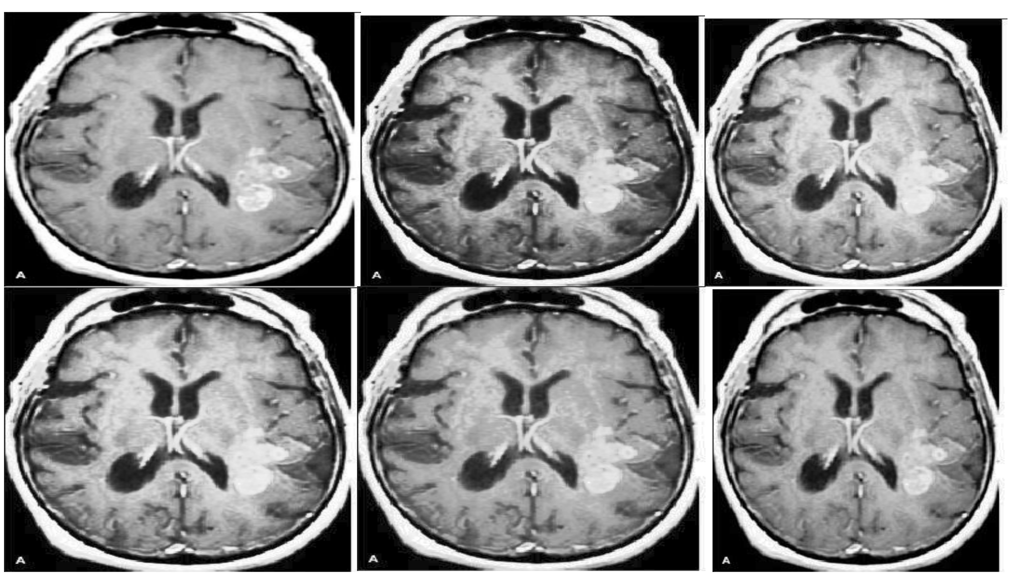

Fig. 4.2.3 Enhanced images produced by respective image enhancement techniques for image-2 (Subject 2)
(a) Input image (b) HE (c) BBHE (d) DSIHE (e) RSESIHE (d) Proposed method.

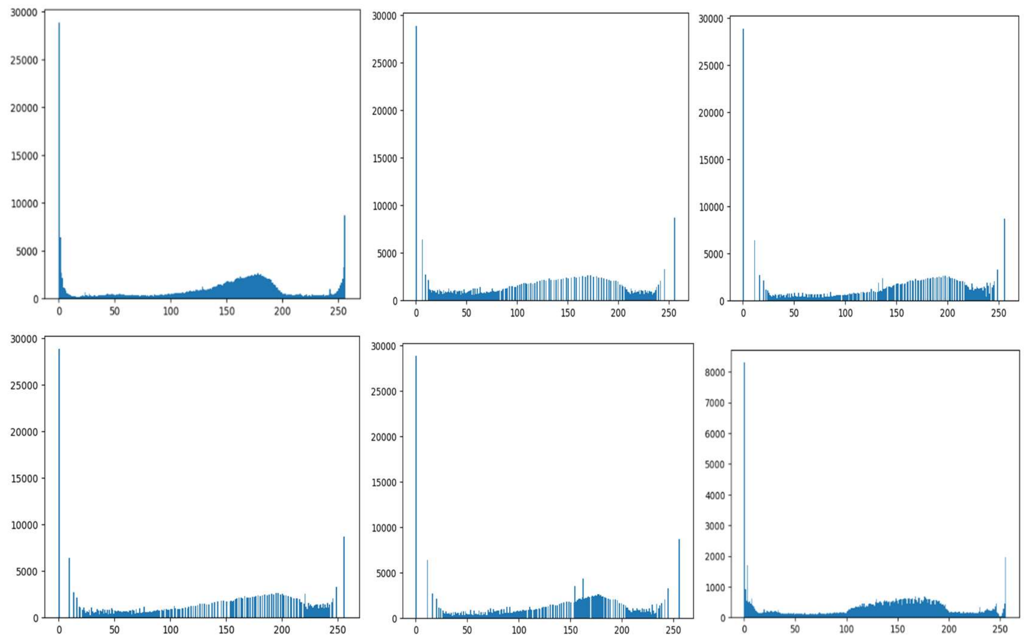

Fig. 4.2.4 Enhanced image Histogram produced by respective enhancement techniques for image-2 (Subject 2)
a) Input image (b) HE (c) BBHE (d) DSIHE (e) RSESIHE (d) Proposed method.

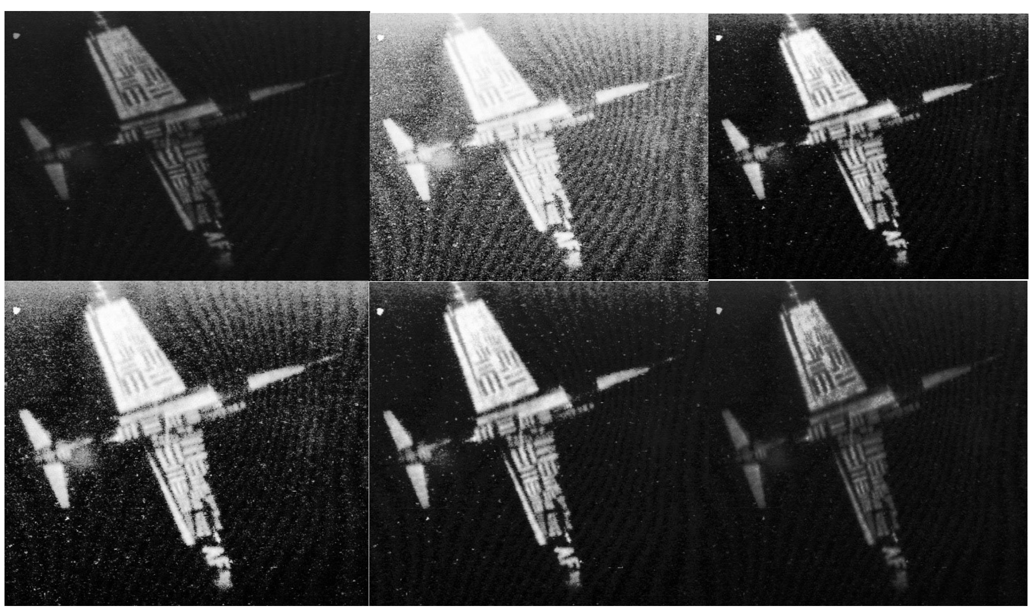

Fig. 4.2.5. Enhanced images produced by respective image enhancement techniques for image-3 (Subject 3)
(a) Input image (b) HE (c) BBHE (d) DSIHE (e) RSESIHE (d) Proposed method.

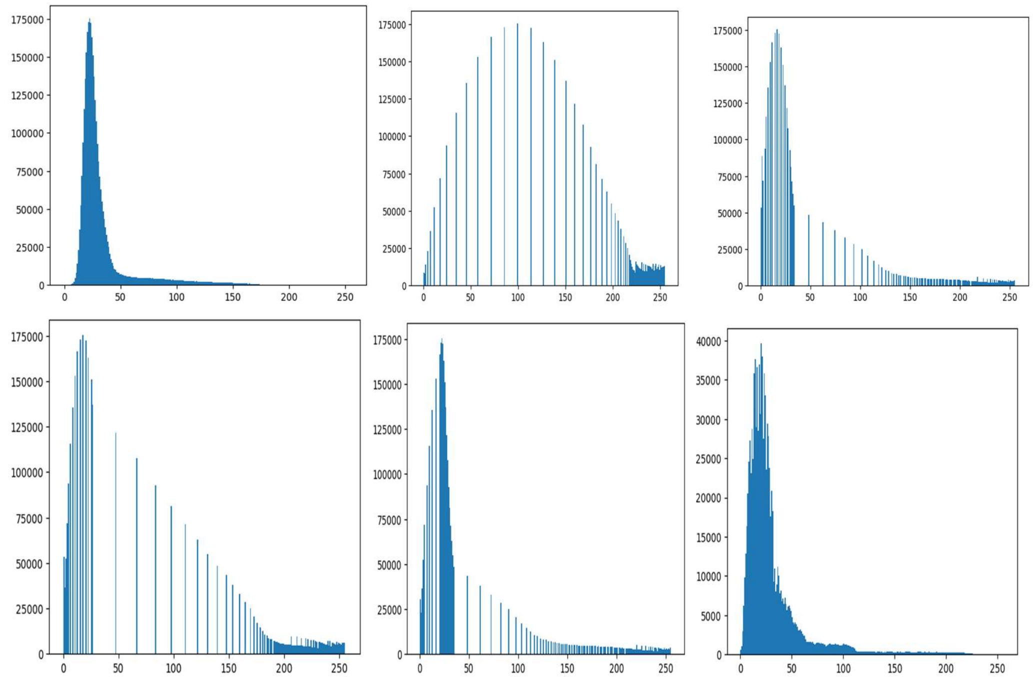

Fig. 4.2.6. Enhanced image Histogram produced by respective enhancement techniques for image-3 (Subject 3)
(a) Input image (b) HE (c) BBHE (d) DSIHE (e) RSESIHE (d) Proposed method.

4.2 Quantitative Approach

We do further quantitative evaluations in this section to assess the efficiency of our suggested algorithm. These investigations use measures including MSE, PSNR, SSIM, AMBE, and SNR. These indicators are crucial for both evaluating the effectiveness of our algorithm and supporting the diagnostic procedure.

4.2.1 Structure Similarity Index Measure (SSIM)

SSIM is one of the most widely used picture quality metrics, which evaluates structural, brightness and contrast information in two images to determine their similarity Thus one seeks to compute the differences in these characteristics between the original and processed images, combine these results into single scalar number that can be computed quickly, and which well represents (based on evidence and human experience) what people broadly call ‘the quality of an image’. The Sensitivity to perceptual difference in human visual systems makes the SSIM algorithm suitable for image quality assessment, image restoration and image compression. The SSIM algorithm used extensively in Image processing, computer vision and related field.

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$

Fig. 4.3.1.1 SSIM Formula

Table 4.2.1 Performance analysis based on SSIM.

Image/ method	HE	BBHE	DSIHE	CLAHE	RSIHE	Proposed Method
Subject1	0.69	0.90	0.81	0.92	0.95	0.98
Subject 2	0.83	0.90	0.88	0.84	0.91	0.96
Subject 3	0.15	0.67	0.38	0.89	0.93	0.92
Subject 4	0.60	0.71	0.90	0.82	0.84	0.89
Subject 5	0.47	0.89	0.88	0.81	0.93	0.92

4.2.2 Signal To Noise Ratio (SNR)

Generally, SNR refers to the quality of a signal, but it is used mostly with electronics and communication systems. It represents the degree of difference between the magnitude of a signal's power and the magnitude of the power of noise that corrupts the clarity of an original signal within a given signal, in decibels, and mathematically in such a manner. A high SNR in comparison to the noise indicates a strong and clear signal, whereas a low SNR implies weakness and not so clear strength of the signal. SNR is widely used in signal processing and engineering to determine the quality of the signal and to create the appropriate signal processing technique for cleaning up or filtering the signal.

$$\mathrm{SNR} = 10 \cdot \log_{10}\left[\frac{\sum_{0}^{n_x-1}\sum_{0}^{n_y-1}[r(x,y)]^2}{\sum_{0}^{n_x-1}\sum_{0}^{n_y-1}[r(x,y)-t(x,y)]^2}\right]$$

Fig. 4.3.2.1. SNR Formula

Table 4.2.2 Analysis based on SNR.

Image/ method	HE	BBHE	DSIHE	CLAHE	RSIHE	Proposed Method
Subject1	0.97	0.41	0.58	0.82	1.60	0.83
Subject 2	0.86	0.45	0.53	0.45	0.90	2.09
Subject 3	0.48	0.75	0.59	0.69	0.59	0.50
Subject 4	0.65	0.63	0.58	0.59	0.61	1.08
Subject 5	0.42	0.69	0.68	0.49	0.76	0.79

4.2.3 Peak Signal To Noise Ratio (PSNR)

PSNR is a measure of quality for image. It matches a pair of images by how equal their pixel values are to each other, measured in decibels (dB) by the maximum signal power-to-maximum noise power in the ratio of an image. Lower values show increased distortion and less similarity, whereas higher PSNR is representative of greater resemblance between the original and processed images. PSNR is engaged with a very critical stage of comparison of quality processed signals with original signals and optimization of algorithms or approaches for proper processing of the signal for better image quality.

$$\mathrm{PSNR} = 10 \cdot \log_{10}\left[\frac{\max(r(x,y))^2}{\frac{1}{n_x \cdot n_y} \cdot \sum_{0}^{n_x-1}\sum_{0}^{n_y-1}[r(x,y)-t(x,y)]^2}\right]$$

Fig. 4.3.3.1 PSNR Formula

Table 4.2.3 Performance analysis based on PSNR.

Image/ method	HE	BBHE	DSIHE	CLAHE	RSIHE	Proposed Method
Subject1	12.92	23.70	17.42	8.38	25.42	33.85
Subject 2	19.25	26.28	24.29	24.48	28.72	28.76
Subject 3	6.99	15.94	11.70	20.15	20.48	30.85
Subject 4	16.36	16.22	14. 47	19.44	20.85	23.26
Subject 5	19.74	22.10	20.97	18.36	29.12	20.73

4.2.4 Mean Squared Error (MSE)

MSE is a common metric used in the evaluation of distortions produced between an original and its corresponding reconstructed signal or processed signal. The measure is expressed as the mean square of pixel value differences between the original and process photos: the closer to zero, the more similar the two signals; the bigger the number, the more distorted or dissimilar it is. The value of MSE is used almost universally in the image and signal processing literature for evaluation purposes in relation to compression, reconstruction, and restoration algorithms.

$$MSE = \frac{1}{M*N} \sum_{i=0,\ j=0}^{M-1,\ N-1} [I(i,j) - K(i,j)]^2$$

Fig. 4.3.4.1 MSE Formula

Table 4.2.4 Performance analysis based on MSE.

Image/ method	HE	BBHE	DSIHE	CLAHE	RSIHE	Proposed Method
Subject1	37.01	34.38	35.71	38.89	34.07	32.83
Subject 2	35.28	33.93	34.27	34.24	33.54	33.54
Subject 3	39.68	36.10	37.44	35.08	35.01	33.23
Subject 4	34.69	33.17	38.96	31.22	30.93	33.75
Subject 5	37.19	32.72	33.81	38.75	37.30	34.76

4.2.5 Absolute Mean Brightness Error (AMBE)

AMBE calculates the difference in the property of being bright between these two images and the differences against each other. It is computed by comparing the mean brightness values of the input and enhanced images in an absolute difference measure. The lower the value of AMBE, the more the similarity in brightness between these two images, and the higher the AMBE value, the greater the difference in brightness. In image and video processing, AMBE has often been used to cross-evaluate the effectiveness of picture enhancement, restoration, and compression techniques with the objective to optimize for best brightness accuracy and consistency.

$$\text{AMBE} = \left| E(x) - E(y) \right|$$

Fig. 4.3.5.1 AMBE Formula

Table 4.2.5 Performance analysis based on AMBE.

Image/ method	HE	BBHE	DSIHE	CLAHE	RSIHE	Proposed Method
Subject1	46.86	7.96	17.21	17.21	6.08	0.59
Subject 2	17.42	5.93	0.76	0.30	2.24	7.29
Subject 3	98.66	13.01	35.19	20.51	1.96	1.46
Subject 4	17.11	12.43	21.32	07.93	14.31	13.05
Subject 5	13.23	02.29	1.87	9.81	5.14	7.45

CHAPTER 5

LIMITATIONS AND FUTURE SCOPE

In this paper, we proposed a novel image enhancement fusion framework that integrates adaptive and block-based histogram equalization with Brightness Preserving Dynamic Histogram Equalization (BPDHE). The experimental results had shown a great gain of improvements in image quality over traditional HE methods, but at the same time, it should also keep in mind that this work, like any other image enhancement technique, has an upper limit to its application. The presented framework.

5.1 Limitation of The Proposed Framework

While the proposed algorithm has several advantages over traditional and other variants of histogram equalization algorithms, there are also some possible drawbacks to think about. Here are some of the possible drawbacks of this algorithm:

1. Increased computation time: The proposed algorithm is presented with the promise of computational efficiency; however, multiple histogram equalization in combination could be computationally expensive compared to some single-method approaches. This could be a concern in applications that require real-time processing or handling of large volumes of data.

2. Parameter sensitivity: Sometimes the performance of the proposed algorithm significantly depends on the values assumed by various parameters that are used in different histogram equalization algorithms. Size of tiles for AHE, BBHE, weighting factors during the merging step, etc. can all play a big role in influencing the final output. That is why the parameter values may hence be optimal enough to need some kind hit-and-trial or expert knowledge, hence making the algorithm limited in some context.

3. Potential artifacts: Some of the artifacts, common to other such methods of histogram equalization, that could be produced by this algorithm are over-enhancement and the artificial brightening of some regions with respect to others. The specific input image properties and the parameter values used in the method can affect how apparent these problems are.

4. Limited scope of application: Although the proposed algorithm is applicable to very general image processing, its performance can be handicapped in some cases. For instance, for image data containing either very high contrast or brightness values, or in images displaying complex spatial distributions of contrast or brightness, it might not be very effective.

5.2 Possible Improvements and Research Directions

The suggested algorithm combines the advantages of various histogram equalization techniques to improve image contrast, and there are a number of potential future applications for this algorithm. Here are some possible future scopes for this algorithm:

1. Further optimization: Though the proposed algorithm yields results with better contrast images, it can still be further optimized. The future scope of research may be fine-tuning the parameter values used in the algorithm or any other means to merge the results of AHE, CLAHE, and BPDHE. This then gives better performance and high efficiency so that it will be more suitable in realizing large-scale or real-time image processing.

2. Application-specific adaptations: The proposed algorithm is flexible and amenable to being tuned in order to meet requirements for a variety of applications. Specialized adaptations for concrete contexts would also be open for development. For instance, the algorithm may get optimized with different imaging modalities for MRI or CT scans or different image analysis tasks such as object recognition or segmentation.

3. Integration with machine learning: In the context of this paper, deep learning with other machine learning techniques should be developed in the light of applying them in image processing. More precisely, the proposed algorithm can potentially be used as a preprocessing technique for enhancing image contrast before feeding it into the deep-learning model. In actual sense, this will help increase the application of the model while improving the precision and robustness of the model.

CHAPTER 6

CONCLUSION AND FUTURE WORK

This research paper proposes a new algorithm, which is developed for enhancing the contrasts in images using AHE, BBHE, and BPDHE combined. The basic idea behind this technique is to provide the remedy for all drawbacks by integrating multiple techniques together for the contrast enhancement of the image in parallel while maintaining the brightness and color information of the original image. The proposed algorithm has certain good pros when compared to the conventional techniques of HE, namely contrast enhancement, brightness and color information preservation, fewer artifacts, and much less noise, besides a much better visual quality. A combination of AHE, BBHE, and BPDHE techniques makes sure that the algorithm is actually capable of handling different kinds of images simultaneously, showing consistency and producing visually pleasing results.

Therefore, it could be largely demonstrated that the algorithm finds very good results for contrast enhancement in digital images beyond the classical HE-based techniques. Further research is needed to properly tune the developed algorithm for performance enhancements in various types of images and scenarios. Future research interest may focus on improvement in pre-processing and post-processing procedures, optimization of the parameters of the algorithm developed, and the ability of other techniques in contrast enhancement in digital images.

So, in conclusion, the proposed algorithm is one of the efficient and effective algorithms for contrast enhancement of digital images, showing a boost over any conventional technique. The value practically harbored by the algorithm is that it can be applied to have an aesthetically satisfying result containing information on brightness and color from the original image. The proposed algorithm has great potential for practical application in real image processing, computer vision, and related fields.

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ANNEXURE-VII

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-110042, India

CERTIFICATE OF FINAL THESIS SUBMISSION

(To be submitted in duplicate)

1. Name: Aditya Raj
2. Roll No: 2K22/DSC/01
3. Thesis title: A Comprehensive Review and fusion of histogram Equilization technique for image enhancement
4. Degree for which the thesis is submitted: Mtech
5. Faculty (of the University to which the thesis is submitted) Dr. Sonika Dahiya
6. Thesis Preparation Guide was referred to for preparing the thesis. YES ☑ NO ☐
7. Specifications regarding thesis format have been closely followed. YES ☑ NO ☐
8. The contents of the thesis have been organized based on the guidelines. YES ☑ NO ☐
9. The thesis has been prepared without resorting to plagiarism. YES ☑ NO ☐
10. All sources used have been cited appropriately. YES ☑ NO ☐
11. The thesis has not been submitted elsewhere for a degree. YES ☑ NO ☐
12. All the correction has been incorporated. YES ☑ NO ☐
13. Submitted 2 hard bound copies plus one CD. YES ☑ NO ☐

Sonika 27/08/2024

(Signature(s) of the Supervisor(s))

Name(s): Dr. Sonika Dahiya

Aditya Raj

(Signature of Candidate)

Name: Aditya Raj

Roll No: 2K22/DSC/01