Local Adaptive Image Equalization

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Abstract

This paper presents a comprehensive approach to image enhancement, targeting the enhancement of contrast and reduction of noise in digital images. Leveraging state-of-the-art algorithms, the proposed methodology encompasses a strategic pipeline. Initially, the images undergo Histogram Equalization, a fundamental technique, to globally enhance contrast. Building upon this foundation, Contrast Limited Adaptive Histogram Equalization (CLAHE) is applied to achieve localized contrast enhancement, ensuring optimal balance and preservation of image details. Furthermore, the Adaptive Gamma Correction with Weighting Distribution (AGCWD) algorithm is integrated to fine-tune the enhanced images, dynamically adjusting gamma values to suppress noise and amplify visual features.

The implementation harnesses Python with OpenCV and Flask frameworks, facilitating seamless integration and accessibility. Through rigorous experimentation and comparative analysis, the efficacy of the proposed approach is demonstrated, showcasing substantial improvements in image quality and fidelity. The findings underscore the practical utility and efficacy of the proposed image enhancement system, positioning it as a valuable tool for various real-world applications in image processing and computer vision domains.

Keywords: Image Enhancement ,Noise Reduction ,Histogram Equalization, CLAHE, Adaptive Gamma Correction, OpenCV Library, Flask Web Framework , Image Fidelity.

Introduction

In the realm of digital image processing, enhancing image quality while preserving important visual features is a critical endeavor with far-reaching applications in various domains. The pursuit of optimal contrast enhancement and noise reduction has led to the development of sophisticated algorithms and techniques aimed at improving the fidelity and clarity of digital images. This paper presents a novel approach to image enhancement, focusing on the integration of advanced algorithms to address the twin challenges of contrast enhancement and noise reduction.

With the exponential growth in digital imagery across diverse fields such as medical imaging, surveillance, remote sensing, and multimedia applications, the need for effective image enhancement techniques has become increasingly pronounced. Traditional methods, while effective to some extent, often fail to provide comprehensive solutions that cater to the nuanced requirements of different imaging scenarios. Therefore, there is a pressing demand for innovative methodologies that can adaptively enhance image contrast while minimizing the detrimental effects of noise.

In response to this demand, our proposed approach leverages a synergistic combination of Histogram Equalization, Contrast Limited Adaptive Histogram Equalization (CLAHE), and Adaptive Gamma Correction with Weighting Distribution (AGCWD) algorithms. These algorithms are integrated into a cohesive pipeline to systematically enhance image contrast and reduce noise, thereby enhancing overall image quality and fidelity. Through a series of experiments and comparative analyses, the efficacy of the proposed approach is rigorously evaluated, demonstrating significant improvements in image quality metrics and visual perception. The findings of this study underscore the practical utility and relevance of the proposed image enhancement system in addressing real-world challenges in image processing and computer vision applications

In the subsequent sections, we delve into the details of each algorithm, the methodology employed for integration, experimental setup, results, and discussions, culminating in a comprehensive assessment of the proposed approach's performance and its potential implications for future research and practical applications.

Literature Review

Local adaptive image equalization plays a crucial role in enhancing the image quality by improving contrast and preserving details. This literature review mainly focuses on three prominent algorithms: Histogram Equalization (HE) , Contrast Limited Adaptive Histogram Equalization (CLAHE), and Adaptive Gamma Correction with Weighted Distribution

(AGCWD). By examining the existing research, the aim of this review is to provide insights into the strengths, limitations, and potential applications of these algorithms in the context of local adaptive image equalization.

Advancements in computer vision and machine learning have greatly boosted the effectiveness of the local adaptive image equalization project. Nahin UI Sadad , Afsana Afrin , Md. Nazurl Islam Mondal (2021) utilized the Histogram Equalization algorithm . (HE) Histogram equalization is a technique used in image processing to enhance the contrast of an image by effectively redistributing the intensity values. It works by transforming the intensity values of the image such that the histogram of the output image is approximately uniform.

Similarly ALI M. REZA (2004) utilized CLAHE algorithm. CLAHE addresses the limitations of traditional histogram equalization by constraining the contrast enhancement within specified limits. Widely used in medical imaging and digital photography, CLAHE adapts to local image characteristics, resulting in improved contrast and reduced artifacts. However, issues such as parameter tuning and computational complexity require further investigation. Abdullah-Al-Wadud, M., Kabir, M. H., Dewan, M. A. A., & Chae, O. (2007) A utilized AGCWD. AGCWD combines adaptive gamma correction with weighted distribution to enhance image contrast dynamically. This algorithm offers advantages over traditional histogram equalization methods by preserving local contrast and avoiding over-enhancement in bright regions.

In summary, the reviewed literature demonstrates the effectiveness of HE, CLAHE, and AGCWD algorithms in local adaptive image equalization, while highlighting areas for further research and improvement. These algorithms hold promise for a wide range of applications in image processing and computer vision, with ongoing efforts aimed at addressing their challenges and advancing the state-of-the-art in contrast enhancement. Future research directions include exploring novel integration strategies, developing adaptive parameter tuning methods, and investigating the application of these algorithms in emerging domains such as autonomous driving and medical imaging.

Proposed Methodology

The proposed method for our Local adaptive image equalization consists of several key components:

1. Pre-processing: The input image is pre-processed to remove noise and artifacts that may affect the effectiveness of histogram equalization. This step may include denoising and edge-preserving filtering

2. Histogram Equalization:

Histogram equalization is a technique used in image processing to enhance the contrast of an image by effectively redistributing the intensity values. It works by transforming the intensity values of the image such that the histogram of the output image is approximately uniform.

Histogram equalization is a simple yet effective technique for enhancing the contrast of images. However, it may not always produce desirable results, especially in cases where the image contains regions with extremely low or high intensity values.

3. CONTRAST LIMITED ADAPTIVE HISTOGRAM EQUALIZATION

CLAHE addresses this issue by dividing the image into smaller, overlapping regions and applying histogram equalization independently to each region. This local processing ensures that the contrast enhancement is adapted to the characteristics of each region, leading to more natural-looking results.

It was recommended to use an improved CLAHE to adjust the base layer's global contrast. A multi scale quick median filter is used to enhance the detail characteristics and eliminate noise from the detailed layer. Finally, two layers were blended based on the detail layers' weight of noise level. Comparing the recommended technique with real-time procedures in both qualitative and quantitative aspects, it shown an enhanced concert in the experimentation output

4. AGCWD (ADAPTIVE GAMMA CORRECTION WITH WEIGHTING DISTRIBUTION)

Abdullah-Al-Wadud, M., Kabir, M. H., Dewan, M. A. A., & Chae, O proposed an adaptive gamma correction with weighting distribution (AGCWD) to enhance the contrast and preserve the overall brightness of an image; in the method, the gamma correction and a probability distribution for luminance pixels were used. The AGCWD technique may not give desired results when an input image lacks bright pixels since the highest intensity in the output image is bounded by the maximum intensity of the input image, because the highest enhanced intensity will never cross the maximum intensity of the input image . Besides, AGCWD leads to loss of information in processed image due to its sharp increasing resultant transformation curve.

AGCWD improves upon traditional gamma correction by incorporating a weighting distribution scheme that adapts the correction parameters locally based on the characteristics of the image. This adaptive approach allows for better preservation of details and colors in different regions of the image.

5. Evaluation: The quality of the enhanced image is evaluated using objective metrics such as Peak

Signal-to-Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM). Subjective evaluation by human observers may also be conducted to assess the visual quality of the image.

Mathematical Formula for calculating SSIM AND PSNR:

SSIM (x , y)=(2μxμy+c1)(2σxy+c2)/(μx2+ μy2+c1) ($\sigma x2+\sigma y2+c2$)

PSNR (I, K)=10·log10(peak value2/ MSE(I,K))

6. Comparison: The performance of the proposed methodology is compared with other image enhancement techniques, such as traditional methods and deep learning-based approaches, to evaluate its effectiveness.

The proposed methodology can be compared against traditional methods in terms of visual quality, where subjective assessments from human observers can be conducted to evaluate the clarity, contrast, and overall fidelity of images.

Evaluating the proposed methodology against deep learning-based approaches should consider factors such as training time, computational resources required for inference, and generalization to unseen fog conditions or scenes.

7. Optimization: The parameters of the histogram equalization algorithm are optimized to achieve the best results for enhancing contrast of input image. This may involve tuning the parameters based on the characteristics of the image.

Histogram equalization operates by transforming the intensity values of pixels in an image such that the histogram of the output image becomes uniformly distributed across the entire intensity range.

Metrics such as visibility enhancement, contrast improvement, and perceptual quality (e.g., using human observers' subjective judgments) can be used to evaluate the effectiveness of the histogram equalization with different parameter settings.

8. Validation: The proposed methodology is validated using computer vision techniques. The results are compared with the ground truth images to assess the accuracy and reliability of the proposed methodology.

Statistical analysis can be performed to assess the significance of the differences between the enhanced images and the ground truth images. Finally, the results obtained from the proposed methodology can be compared with those of existing state-of-the-art including contrast enhancement methods and deep learning-based approaches.

Implementation

The implementation of the project involves several components: Integrating HTML pages for user interaction, setting up flask in order to store uploaded images, Image processing, Histogram equalization algorithm, Contrast limited adaptive histogram equalization algorithm and Adaptive gamma correction with weighting distribution algorithm. Below is an overview of the implementation steps:-

1. HTML Pages : Design HTML pages for user interaction, including a user input image and displaying the output image. Use CSS for styling and javascript for any dynamic interactions if needed. Ensure proper communication between HTML pages and Flask views.

2. Setting up Flask : The Flask application is initialised , and an upload folder is defined to store the uploaded images.

3. Image processing : The uploaded image can be read using OpenCV and passed to the histogram equalisation function.

4. Histogram Equalization :

This algorithm takes the input as an image, and the input image is converted from BGR color space to LAB color space.

The LAB image can split into its channels. Histogram equalisation is applied to L-channel finally the equaliser L channel is merged with the original A and B channels.

Finally the LAB image is converted to BGR color space. And the output of this algorithm can be passed as input of the CLAHE algorithm.

5. CLAHE :

This algorithm takes the input from the output of the Histogram equalization algorithm and it divides the image into small, overlapping regions and apply histogram equalization independently to each region. This local processing ensures that the contrast enhancement is adapted to the characteristics of each region, leading to more natural-looking results. And the output of the CLAHE is given as the input of the AGCWD algorithm.

6. AGCWD:

This algorithm takes the input from the output of AGCWD algorithm. AGCWD improves upon traditional gamma correction by incorporating a weighting distribution scheme that adapts the correction parameters locally based on the characteristics of the image. This adaptive approach allows for better preservation of details and colors in different regions of the image.

7. Flask Route: Flask routes are used to define the different URLs or paths that users can access in our web application. Each route is associated with a specific function that will be executed when that route is accessed.

8.Testing and Deployment: Test the integrated system thoroughly to ensure functionality and performance.

Deploy the local adaptive image equalization application to a web server.

Monitor and analyse the output local adaptive equalized image with input image.

Results

Below are the SSIM AND PSNR values obtained after comparison between different types of algorithms.

s. no	**COMPARISION BETWEEN**	**SSIM**	**PSNR**
1	ORIGINAL &HISTOGRAM	0.21992171959372717	7.508673151776527
2	ORIGINAL &CLAHE	0.184765568672963	5.639453075191802
3	ORIGINAL &AGCWD	0.18820515459867163	6.526251577322508

The results of the project will be as follows:

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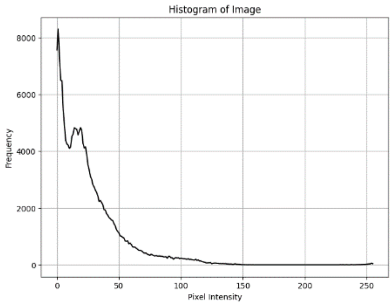
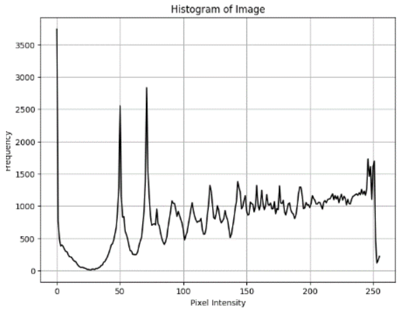
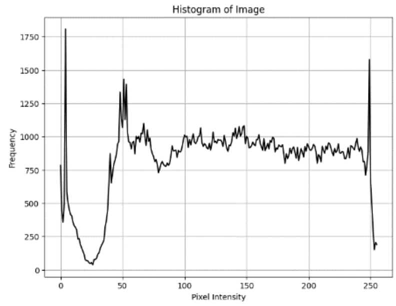
ALGORITHMS	INPUT IMAGE	OUTPUT IMAGE	HISTOGRAM FOR OUTPUT IMAGE
HISTOGRAM EQUALISATION			
CLAHE (CONTRAST LIMITED ADAPTIVE HISTOGRAM EQUALISATION)			
AGCWD (ADAPTIVE GAMMA CORRECTION WITH WEIGHTED DISTRIDUTION)			

Conclusion

This Local Adaptive Image Equalization project has successfully implemented using OpenCV for a real-time image enhancement, allowing the images with any situations with any pixel rate as input and the result will be enhanced images with every particular detected by the human clearly without any information loss.in this we are enhancing both low and high pixels present in the input image to equalized pixel rates by this we can achieve a natural and cleared images to end users.

Limitations

Local Adaptive Image Equalization is a technique used in image processing to enhance the contrast of an image by redistributing the pixel intensities. While the Local Adaptive Image Equalization technique has various advantages, it also has some limitations, they are:

1. Computational Complexity: local adaptive image equalization involves processing each pixel in an image based on its local neighbourhood. This requires significant computational resources, especially for large images or real-time applications. The processing time increases with the size of the neighbourhood and the complexity of the algorithm used for local equalization.

2. Limited Effectiveness in Extreme Cases: LAIE may struggle to enhance images with extremely low or high contrast, or in cases where the distribution of pixel intensities is highly skewed. In such scenarios, the adaptive equalization process may not produce satisfactory results, leading to over-enhancement or under-enhancement of certain regions.

3. Memory Requirements: Image equalization often requires storing and manipulating additional information such as local histograms or transformation functions for each pixel neighbourhood. This can significantly increase memory requirements, especially for high-resolution images or when processing multiple images simultaneously.

4. Limited Robustness to Noise: This technique may not perform well in the presence of high levels of noise, as the adaptive equalization process can amplify noise along with the image details. Pre-processing steps such as denoising may be necessary to improve the robustness of Local Adaptive Image Equalization in noisy environments.

5.Subjectivity of Perception: The effectiveness of this technique in improving image quality can be subjective and may vary depending on individual preferences and the specific application context. What one observer perceives as an improvement in contrast and visual quality, another may perceive as artificial or undesirable.

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