Image Enhancement In MATLAB Using Computer Graphics

Prashant Singh
Dept. of Masters Of Computer Application
Sardar Patel Institute Of Technology
Mumbai, India

Dr. Aarti Karande
Dept. of Masters Of Computer Application
Sardar Patel Institute Of Technology
Mumbai, India

***Abstract*—**Image enhancement plays a pivotal role in computer vision, seamlessly blending the realms of art and science. Its significance is underscored in various applications, including high-quality digital imaging, where the goal is to reveal hidden details and enhance contrast in low-quality images. The tech- niques employed in image enhancement offer a versatile toolkit for addressing challenges such as noise reduction, degradation, and blurring. This comprehensive overview combines insights from various research papers, presenting a spectrum of image enhancement techniques and algorithms, with a particular focus on spatial domain methods. By synthesizing these perspectives, this paper serves as a valuable resource for researchers and practitioners striving to develop efficient solutions in the field of digital image processing.

Keywords: Multi-Scale Retinex (MSR), Luminance Inversion, Image Manipulation, Image Recovery, Spatial and Frequency Spectrum Domain, Histogram.

I. Introduction

Enhancing images is crucial across various applications, encompassing medical diagnosis, distant sensing, and computer vision. This research addresses the enhancement of grayscale images and explores various image processing techniques to improve their quality. The objective is to empower users to enhance images based on their specific requirements.

Image enhancement exercises a pivotal role in enhancing the interpretability and perceptual quality of images for human viewers, while also serving as a foundation for more advanced algorithmic image manipulation techniques. The aim of image refinement is to refine the visual representation of an image without compromising its integrity. To achieve this, a diverse set of techniques is available, categorized into two main divisions: Spatial Techniques and Frequency Techniques.

Spatial domain techniques involve direct manipulation of image pixel values for desired enhancements, whereas frequency domain methods entail transforming the image into the frequency domain using Fourier Transform. Enhancements are subsequently performed in this transformed domain, and the final improved image is obtained through an Inverse Fourier transform.

The applications of image enhancement span a multitude of fields where image comprehension and analysis are essential, such as medical image analysis and satellite imagery interpretation. Essentially, image enhancement involves converting an image 'f' into an altered version 'g' employing a transformation function 'T.' In this framework, the pixel values of the original image 'f' and the improved image 'g' are represented as 'r' and 's,' respectively, and their connection is expressed by:

$$s = T(r)$$

To ensure consistency with the grayscale spectrum, the transformation outcomes are remapped into the [0, L-1] range, where 'L' denotes a power of 2 (e.g., 2^8 for an 8-bit image, resulting in pixel values ranging from 0 to 255).

In this paper, we conduct a thorough review of different image enhancement approaches, such as Contrast Expansion, Histogram Matching, its advanced adaptations, Multi-resolution Transformation, Stochastic Response, and the innovative Fuzzy Gray Scale Improvement Technique.

II. Literature Review

This section presents the research conducted by notable authors in the field, accompanied by a concise overview of diverse approaches to Image Processing.

A. Reference 1: "Chromosome Image Contrast Enhancement Using Adaptive, Iterative Histogram Matching" (2011)

This study introduced a novel method aimed at enhancing chromosomal contrast, specifically focusing on banding patterns. The innovative technique, termed adaptive and iterative histogram matching (AIHM), involves the creation of a reference histogram. This reference histogram, against which the initial image is aligned, is generated through specific operations applied to the histogram of the substantive image.

B. Reference 2: "Contrast Enhancement of Dark Images Using Stochastic Resonance" (2012)

This paper proposed a technique utilizing random signal amplification to enhance extremely underexposed images. An equation has been devised to determine the optimal threshold for this method. The low-contrast image is systematically enhanced by introducing Gaussian noise with incrementally higher standard deviations until achieving peak quality.

C. Reference 3: "Nonlinear Transfer Function-Based Local Approach for Color Image Enhancement" (2011)

This work introduced a novel approach for enriching chromatic images. Their method is centered around the use of nonlinear transfer functions and pixel neighborhood information to preserve image details. Notably, this technique exclusively targets the luminance (V) component in the HSV color space. The approach involves maintaining the original hue (H) and saturation (S) components unaltered, thereby securing the integrity of the color balance within these elements.

The enhancement process for the V channel comprises two main steps. Initially, the image's luminance component (V) undergoes subdivision into smaller, overlapping blocks. Within each of these blocks, luminance enhancement is applied to every pixel utilizing a nonlinear transfer function. The subsequent phase involves individual pixel manipulation and refined tuning the contrast of the image based on the central value of the pixel and the values of its neighboring pixels. Finally, the ultimate RGB image is reconstructed by combining the initial H and S component images with the enhanced V component image.

D. Reference 4: "Edge-Adaptive JPEG Image Compression"

This paper discusses image compression, an advanced iteration of the widely used JPEG compression standard, which upholds commendable compression efficiency, low computational complexity, and minimal memory usage. Although standard JPEG already provides respectable compression with minimal quality loss, edge-adaptive JPEG pushes the boundaries further. This method enhances visual quality and achieves more efficient reduction in image file sizes at the same bit rate. By incorporating visual activity analysis through Canny edge detection, segmenting the image employing quadtree decomposition, and subjecting each channel to the discrete cosine transform (DCT), it accomplishes variable bit-rate compression with minimal degradation in quality.

E. Reference 5: "Adaptive Image Enhancement Method for Correcting Low-Illumination Images"

This paper introduces an innovative color image correction approach for improving images with low illumination, addressing issues of uneven illumination and adaptability. The proposed algorithm demonstrates improvements in color balance, detail preservation, and visibility in dark areas. However, limitations exist, and future efforts are suggested for enhancing real-time performance and extending the applicability to video images.

III. Methodology

A. Negative Transformation

The negative transformation, also known as negation or inversion, is a straightforward yet impactful method for improving images. It's based on the concept that reversing pixel values can produce a photographic negative effect.

1) Operation: For each pixel, the operation involves subtracting the original pixel value from the maximum possible pixel value. In an 8-bit grayscale image (0 to 255), the operation is:

$$\text{new\_pixel\_value} = 255 - \text{original\_pixel\_value}$$

2) Example: If a pixel initially had a value of 100, the negative transformation would change it to 155 (255 - 100).

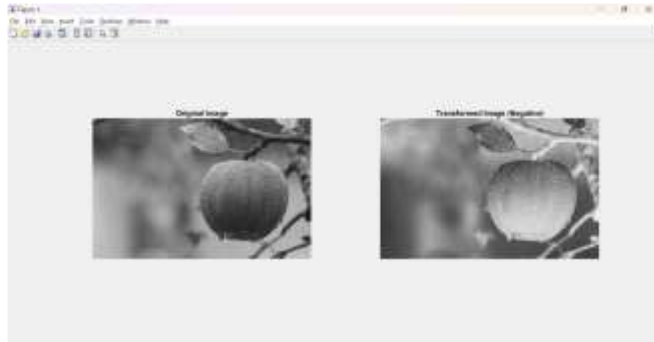

Fig. 1. Negative-transformation.

B. Log Transformation

The log transformation enhances image contrast by stretching pixel values. It is based on the idea that our eyes perceive changes in luminance on a logarithmic scale.

1) Operation: For each pixel, the operation involves applying a logarithmic function to the original pixel value. The formula is:

$$\text{new\_pixel\_value} = c \cdot \log(1 + \text{original\_pixel\_value}) \quad (1)$$

where c is a constant.

2) Example: A pixel with an original value of 50 may transform to approximately 100, depending on the chosen c value.

Fig. 2. Log transformation

C. Gamma Adjustment Technique

The power-law transformation, also known as gamma correction, allows for contrast adjustment. It's based on the power-law function and is used to emphasize or suppress specific intensity levels.

1) Operation: For each pixel, the operation involves raising the original pixel value to a power (gamma). The formula is:

$$\text{new\_pixel\_value} = c \cdot (\text{original\_pixel\_value}^{\gamma}) \quad (2)$$

where c is a constant, and γ regulates the extent of enhancement.

2) Example: A pixel with a value of 100 and a gamma of 2 will result in a new value of 10,000.

D. Exponential Transformation

The exponential transformation enhances contrast but provides more control with adjustable parameters. It is particularly useful for image enhancement with complex characteristics.

1) Operation: This transformation begins by normalizing the pixel values to the range [0, 1]. It then raises the normalized value to the power of gamma and scales it with a constant 'c.' The operation is:

$$\text{new\_pixel\_value} = c \cdot (\text{normalized\_pixel\_value}^{\gamma}) \quad (3)$$

2) Example: With $c = 1$ and $\gamma = 0.5$, a pixel with an original value of 0.5 would transform to approximately 0.25.

E. Gray-level Slicing

Gray-level slicing is an image enhancement technique used to emphasize specific intensity ranges while suppressing others. It's particularly useful for highlighting specific features within an image.

1) Operation: For each pixel, gray-level slicing involves comparing its original value to specified threshold values. Pixels with values below a lower threshold are assigned a minimum value (e.g., 0), while pixels surpassing an upper threshold are set to a maximum value (e.g., 255).

2) Example: If the lower threshold is 50 and the upper threshold is 200, any pixel with a value below 50 becomes 0, and any pixel above 200 becomes 255.

Fig. 3. Gray-level transformation.

F. Contrast Enhancement

Contrast enhancement aims to expand the variability in pixel values in an image to maximize the difference between light and dark areas, thus improving overall image quality.

1) Operation: The operation involves linearly scaling pixel values using the formula:

$$\text{new\_pixel\_value} = \frac{\text{original\_pixel\_value} - \text{min\_value}}{\text{max\_value} - \text{min\_value}} \times 255 \quad (4)$$

where min_value and max_value are the lower and upper bounds pixel in the original image.

2) Example: If the original pixel values range from 50 to 200, the transformation scales them to occupy the entire 0 to 255 range.

Fig. 4. Contrast Enhancement

G. Mean Filter

The mean filter, employed in spatial domain techniques, serves the purpose of smoothing images and reducing noise. It functions by implementing local averaging, replacing each pixel in the image with the mean value derived from its neighboring pixels within a defined neighborhood.

1) Operation:

- Define a neighborhood centered on the target pixel.
- Calculate the mean (average) value of all pixel intensities within the neighborhood.
- Replace the target pixel's intensity with the calculated mean.

2) Example: In a 3x3 mean filter, each pixel's value is updated to the average of the pixel values within its 3x3 neighborhood. This reduces noise and produces a smoothing effect.

H. Median Filter

The median filter is another spatial domain technique for noise reduction and image smoothing. It substitutes every pixel with the median value derived from its adjacent pixels within a designated vicinity. The median is robust against outliers and preserves edges better than the mean filter.

1) Operation:

- Define a neighborhood centered on the target pixel.
- Collect the pixel intensities within the neighborhood.
- Determine the median intensity value from the collected values.
- Replace the target pixel's intensity with the median value.

2) Example: Within a 3x3 median filter, the value of each pixel is substituted with the median of the pixel values found in its surrounding 3x3 neighborhood.This effectively reduces noise while preserving edges.

I. Image Compression: JPEG

Image compression, particularly through JPEG (Joint Photographic Experts Group) compression, is employed to diminish the file size of images while preserving an acceptable level of visual quality. The principles of quantization and lossy compression form the foundation of JPEG compression.

1) Operation:

- Break the image into blocks (typically 8x8 pixel blocks).
- Employ a discrete cosine transform (DCT) on each block to transform it into a frequency-domain representation.
- Quantize the DCT coefficients by discarding some of the less important data.
- Encode the quantized data using Huffman coding or arithmetic coding.

2) Example: Higher compression levels discard more data, resulting in smaller file sizes but potentially reduced image quality. Lower compression levels retain more detail but result in larger file sizes.

J. Histogram Equalization

It aims to enhance the contrast in an image while preserving the luminosity of both the foreground and background. It achieves this by applying histogram equalization separately to different regions.

1) Operation:

- Divide the image into background and foreground regions using a threshold.
- Apply histogram equalization to the background and foreground regions separately.
- Combine the enhanced background and foreground regions to create the final image.

2) Example: By preserving background brightness, this technique ensures that important details in both the darker and brighter regions of the image are retained after enhancement.

Fig. 5. Histogram Equalization

K. Stochastic Resonance

Stochastic resonance is a noise-based image enhancement technique that iteratively adds controlled noise to an image. This noise is then smoothed to enhance image details and contrast.

1) Operation:

- Add random noise to the image.
- Apply a smoothing filter (e.g., Gaussian filter) to the noisy image.
- Calculate the disparity between the images with noise and those that have been smoothed.
- Improve the image by reintegrating the difference with the original image.

2) Example: Over multiple iterations, this process pro- gressively enhances image contrast and clarity through noise manipulation.

L. Local Enhancement with Nonlinear Transfer Function

ENHANCEMENT IN HSV COLOR SPACE: The enhancement process is exclusively utilized on the luminance (V) element within the HSV color image, ensuring the preservation for color equilibrium amid the H (hue) and S (saturation) elements. To elevate the luminance, a two-step approach is employed. Initially,The V component image is fragmented into intersecting blocks, and for every individual pixel within these blocks, a non-linear transfer function is applied for luminance enhancement. Subsequently, In the subsequent phase, every pixel undergoes additional enhancement for modifying the contrast, taking into account the value of the central pixel and its neighboring pixel values. Ultimately, the initial H and S component images, coupled with the refined V component image, are transformed into the final RGB representation. The local approach employing a nonlinear transfer function is used to enhance local regions of an image independently. It's particularly useful when different parts of an image require different enhancement strategies.

1) Operation:

- segmenting the image into non-overlapping portions. lo- cal regions or windows.
- For each region, apply a custom nonlinear transfer func- tion that adjusts the pixel intensities within that region.
- Combine the enhanced regions to create the final en- hanced image.

2) Example: This technique allows for localized contrast adjustments, ensuring that each part of the image receives the most appropriate enhancement.

M. Multi-Scale Retinex (MSR) and Luminance Inversion

Objective: The Multi-Scale Retinex (MSR) technique is employed to augment the image's contrast by decomposing it into multiple scales and applying a non-linear operation to each scale. Luminance inversion, achieved by inverting the luminance channel in the YCbCr color space, is an essential pre-processing step to ensure effective application of the MSR technique.

Methodology:

- **MSR Algorithm:**
  1) **Decomposition:** The input image's luminance chan- nel is decomposed into multiple scales to capture both global and local contrast information.

Fig. 6. Nonlinear Transfer Function

2) **Non-Linear Operation:** A non-linear operation is applied to each scale to enhance the contrast, typically involving logarithmic transformations.

- **Luminance Inversion:**
  – The inversion of the luminance channel is performed to ensure that the MSR technique enhances the details and edges within the hazy regions effectively.

Color Recovery

Objective: Color recovery aims to restore the color information in the dehazed image, ensuring a visually appealing and natural appearance.

Methodology:

- **Color Channel Adjustment:**
  – The color channels are adjusted based on the scales computed during the MSR step.
  – Logarithmic operations are applied to the color channels, followed by raising the result to a power to achieve color recovery.

Adaptive Gamma Correction

Objective: Adaptive Gamma Correction is introduced to dynamically adjust the gamma parameter based on the content of the image, specifically the ratio of white and gray pixels.

Methodology:

- **Gamma Correction Adjustment:**
  – The gamma correction parameter is adaptively adjusted to enhance or reduce the brightness of the image.
  – The adjustment is contingent on the ratio of white and gray pixels, providing adaptability to varying hazy conditions.

Contrast-Limited Adaptive Histogram Equalization (CLAHE)

Objective: CLAHE is applied to further enhance the contrast in the color channels while limiting the amplification of noise.

Methodology:

- **CLAHE Algorithm:**
  – Adaptive Histogram Equalization with Contrast Limitation is a non-linear image refinement method.
  – It improves contrast by redistributing pixel intensities while limiting the amplification of noise.

Seamless Stitching

Objective: Seamless stitching involves integrating the dehazed regions obtained from the previous steps with the original hazy image.

Methodology:

- **Stitching Process:**
  – Dehazed regions are selectively combined with the original hazy image based on the regions classified as white and gray.
  – This process ensures a seamless integration of the enhanced regions while preserving the original content.

Fig. 7. Defogged Image

N. Low Light Image Enhancement

Image Complement

Objective: The complement of the intensity image (A_{Inv}) is computed, aiming to enhance certain features or alter the image's appearance.

Methodology:

- **Complement Operation:**
  – The imcomplement function is applied to in- vert the luminance values of the initial image (grayImage), creating the complemented image (A_{Inv}).

Haze Reduction

Objective: The low-light areas in the inverted image (A_{Inv}) are made to appear hazy using the imreducehazefunction.

Methodology:

- **Haze Reduction:**
  – The imreducehaze function is applied to the inverted image (A_{Inv}), making low-light areas appear hazy. This operation might be used to simulate atmospheric effects or enhance certain visual characteristics.

Further Image Complement and Enhancement

Objective: The complement of intensity image (B_{Inv}) is computed again after the haze reduction, potentially to restore the original appearance.

Methodology:

- **Complement Operation:**

   – The complement of the intensity image obtained after haze reduction (B_{Inv}) is computed using imcomplement.

Further Haze Reduction with Optional Parameters

Objective: To improve the haze reduction results, the imreducehaze function is called again, this time specifying optional parameters.

Methodology:

- **Haze Reduction with Parameters:**
   – The imreducehazefunction is called with specified optional parameters, such as the method and contrast enhancement, to fine-tune the haze reduction process.

Denoising

Objective: To address potential noise introduced during the enhancement process, the imguidedfilter function is used for noise removal.

Methodology:

- **Guided Image Filtering:**
   – The imguidedfilter function is employed to remove noise from the enhanced image (B_{Imp}), which is particularly important in low-light condi- tions where images may have high noise levels.

Fig. 8. Low light Enhanced Image

O. Statistical Analysis of Color Channels of underwater images

Objective: The statistical properties of each color channel (Red, Green, and Blue) in the input image are analyzed to compute essential parameters for subsequent enhancement steps.

Methodology:

- **Channel Statistics:**
   – Minimum (Smin), maximum (Smax), mean (Smean), and the proportion of pixels with intensity less than or equal to 40 (P) are computed for each color channel independently.

Adaptive Pixel Intensity Adjustment

Objective: The pixel intensities in each color channel are adaptively adjusted based on statistical properties, aiming to enhance image features and compensate for underwater color distortions.

Methodology:

- **Adaptive Adjustment:**
   – Pixel intensities are adjusted based on statistical properties of each channel.
   – The adjustment is dependent on the mean intensity (Smean) and the proportion of pixels with low intensity (P).
   – Two cases are considered: one where the mean intensity is below 128 and another where it is above 128, leading to different adjustment formulas.

Color Space Conversion and Adaptive Histogram Equalization

Objective: The adjusted image undergoes transformation into the LAB color model, and adaptive histogram equalization is applied to the luminance channel.

Methodology:

- **Color Space Conversion:**
   – The adaptively adjusted image is converted from RGB to LAB color space using rgb2lab.
   – The luminance channel (L) is extracted for further processing.
- **Adaptive Histogram Equalization:**
   – The luminance channel is subjected to adaptive histogram equalization using adapthisteq.
   – The equalized luminance channel is then integrated back into the LAB color space.

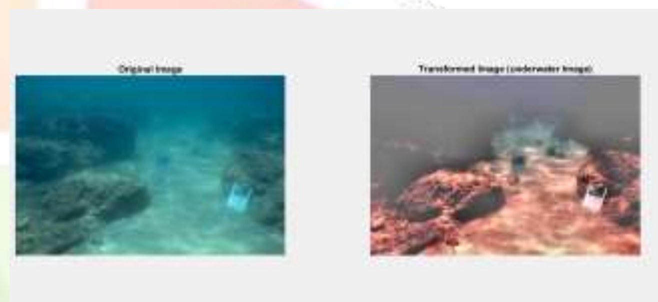

Fig. 9. Under water Enhanced Image

P. RGB to Grayscale Conversion

Objective: The objective of converting RGB to grayscale is to change a hued image, expressed in the Red-Green-Blue color model, into a grayscale image, where each pixel is denoted by a singular intensity value.

Theory: In the RGB color model, an image is composed of three channels: Red, Green, and Blue. Each channel represents the intensity of its respective color. Grayscale images, on the other hand, have a single channel representing overall intensity or luminance. The conversion is typically done using a weighted sum of the RGB values at each pixel, emphasizing the human eye's sensitivity to different colors:

$$Y = 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B$$

In this context, Y denotes the luminance, while R, G, B represent the red, green, and blue values of a pixel, respectively.

The rgb2gray function used in the code likely implements a similar conversion, providing a grayscale representation of the original image. Grayscale images simplify subsequent processing tasks, reduce computational complexity, and retain crucial structural information. .

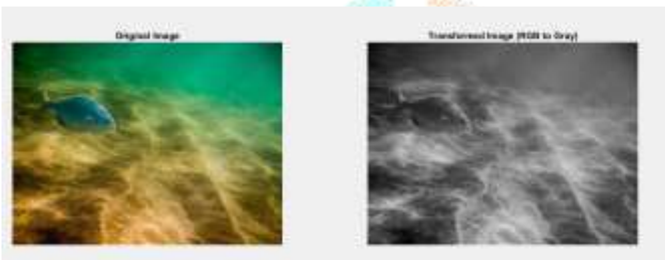

Fig. 10. RGB to gray

Q. Custom Image Resizing

Objective: Custom image resizing allows the user to adjust the dimensions of an image, either scaling it up or down, based on specific height and width requirements.

Theory: The procedure of resizing an image entails interpolation to establish the brightness values of pixels in the resized image, relying on the original pixel values.

Widely used interpolation methods encompass nearest-neighbor approximation, linear blending, and cubic convolution interpolation. Nearest-neighbor interpolation assigns the value of the nearest pixel in the source image, whereas bi-linear and bi-cubic interpolations calculate the weighted average of nearby pixels, yielding smoother outcomes.

The resized image, represented by the y_custom variable, is a modified version of the original grayscale image, allowing users to adapt images to specific spatial requirements. This operation is crucial in various applications, such as preparing datasets for machine learning models or adjusting image sizes for display purposes.

Fig. 11. Resized image

TABLE I
IMAGE ENHANCEMENT TECHNIQUES

Sr. No.	**Paper Title**	**Author(s)**	**Methodology Employed**	**Pros & Cons**
1	Image enhancement using background brightness preserving histogram equalisation	T.L. Tan, K.S. Sim and C.P. Tso	Equalization of Histogram	Preserve the backdrop luminosity. Less suitable for RGB images.
2	Chromosome Image Contrast Enhancement Using Adaptive, Iterative Histogram Matching	Seyed Pooya Ehsani, Hojjat Seyed Mousavi, Babak.H.	Dynamic Iterative Histogram Alignment	Optimal representation for streaking patterns. Results in undesired blurring along edges and borders.
3	Edge-Adaptive Jpeg Image Compression	DR. THIDA AUNG	DCT (discrete cosine transform)	This technique works well for image compression.
4	Contrast enhancement of dark images using stochastic resonance	R.K. Jha, P.K. Biswas, B.N. Chatterji	Random Signal Amplification	The enhanced image exhibits no color loss or spots. The method is specifically employed for very low-contrast images.
5	Nonlinear Transfer Function-Based Local Approach for Color Image Enhancement	Deepak Ghimire and Joonwhoan Lee	Local Function-Based Methodology	The enhanced image maintains its original color without any alterations.
6	Adaptive Image Enhancement Method for Correcting Low-Illumination Images	WenchengWanga, ZhenxueChenb, XiaohuiYuanc, XiaojinWua	Image Complement and Haze Reduction	Contributes to improving visibility, adjusting image characteristics, and reducing potential noise introduced during the enhancement process.
7	Fast Region-Adaptive Defogging and Enhancement for Outdoor Images Containing Sky	Z. Li, X. Zheng, B. Bhanu, S. Long, Q. Zhang, Z. Huang.	Multi-Scale Retinex (MSR) and Luminance Inversion	Used for image dehazing / image defogging / image enhancement for images of outdoor scenes especially containing sky.
8	Underwater Image Enhancement	Xueyang Fu, Zhiwen Fan, Mei Ling, Yue Huang, Xinghao Ding	Color correction, contrast enhancement.	A two-step image enhancement procedure that is both effective and efficient for individual underwater images.

IV. Limitations:

While the presented techniques offer valuable insights, it's crucial to acknowledge their limitations. JPEG compression may lead to quality loss, and higher compression levels may not be suitable for all scenarios. Histogram Equalization might not perform well in cases of extreme brightness variations. Stochastic Resonance's effectiveness is dependent on noise parameters. Local Enhancement may struggle with global adjustments. MSR might be computationally intensive. Low Light Image Enhancement techniques may introduce artifacts, and Statistical Analysis may be sensitive to outliers.

V. Conclusion

In this paper, we have explored and implemented various image enhancement techniques to address challenges such as blurriness, noise, and adjustments to brightness and contrast in image processing. The presented techniques cover a spectrum of transformations, including negative transformation, log transformation, power-law transformation, exponential transformation, gray-level slicing, contrast enhancement, mean and median filtering, image compression, contrast enhancement using stochastic resonance, a local approach employing a nonlinear transfer function, contrast enhancement using histogram equalization, RGB to grayscale conversion, custom image resizing, defogging, underwater image enhancement, and low-light enhancement.

A critical review of these techniques reveals valuable insights into their individual strengths and limitations. For example, methods like Retinex have shown superior performance compared to traditional histogram equalization. The diverse set of techniques allows for the enhancement of images subjected to different degradations, providing a comprehensive toolkit for image processing applications.

In conclusion, this research contributes to the understanding of image enhancement techniques and their applications. Modern approaches, such as the stochastic resonance-based contrast enhancement and the nonlinear transfer function-based local approach, demonstrate promising results. Selecting the right technique hinges on the unique attributes of the image and the enhancement objectives in mind. With the ongoing evolution of technology, these discoveries open avenues for continued progress and the creation of innovative techniques in the dynamic realm of image manipulation.

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