“Medical Image Enhancement using CLAHE Algorithm”

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Abstract

Medical image processing is challenging because captured images often suffer from noise and low contrast. The quality of medical images depends on factors like equipment age, illumination, and operator experience. To improve contrast, this work uses **CLAHE** techniques. The method adaptively adjusts fusion rules for optimal enhancement. First, CLAHE enhances local contrast and highlights key features. **SNR** and **entropy** are used to evaluate performance. Results show that adaptive fusion effectively improves visual content under varying conditions. The approach enhances global and local contrast, making anatomical and vascular structures more distinguishable. It provides robust, artifact-free enhancement suitable for real-world medical imaging applications [2].

Introduction

Medical images from MRI, CT, sonography, and X-rays often suffer from noise and low contrast. Contrast enhancement, using methods like **CLAHE**, improves image quality for better disease identification. This paper proposes an adaptive enhancement method using spatial domain CLAHE, improving both local contrast and structural details across diverse medical images [2].

Methodology

The CLAHE-based (Contrast Limited Adaptive Histogram Equalization) retinal image enhancement method follows a structured workflow aimed at improving diagnostic clarity. It begins with preprocessing, where illumination across the retina is equalized to address brightness and contrast variations, and noise-reduction filters are applied to suppress artifacts that might conceal subtle details. Once the image is prepared, the CLAHE algorithm is adaptively applied to enhance local contrast within small regions while avoiding excessive noise amplification. As a result, fine retinal vessels, capillaries, microaneurysms, and pathological features become sharper and more discernible.

1. **Input Image Decomposition:** The color fundus image is first separated into its RGB channels. CLAHE is applied mainly on the **Green (G) channel**, which carries the most vascular information (see Figure 1). This separation allows focused enhancement on the channel that best highlights the retinal structures, minimizing unnecessary noise amplification in the red and blue channels.
2. **Tile-based Processing:** The selected channel is divided into small, contextual tiles (e.g., 8×8 or 16×16 pixels). Each tile undergoes histogram calculation to assess the local intensity distribution (see Figure 2).
3. **Histogram Clipping:** To prevent noise amplification, the histogram of each tile is clipped at a predefined **clip limit**, redistributing excess pixels uniformly across bins.
4. **Bilinear Interpolation:** After CLAHE is applied to all tiles, bilinear interpolation is used to smooth tile boundaries and remove block artifacts, producing a final enhanced G’ channel.
5. **Channel Merging:** The enhanced G’ channel is merged back with the original R and B channels to produce the final contrast-enhanced color retinal image.

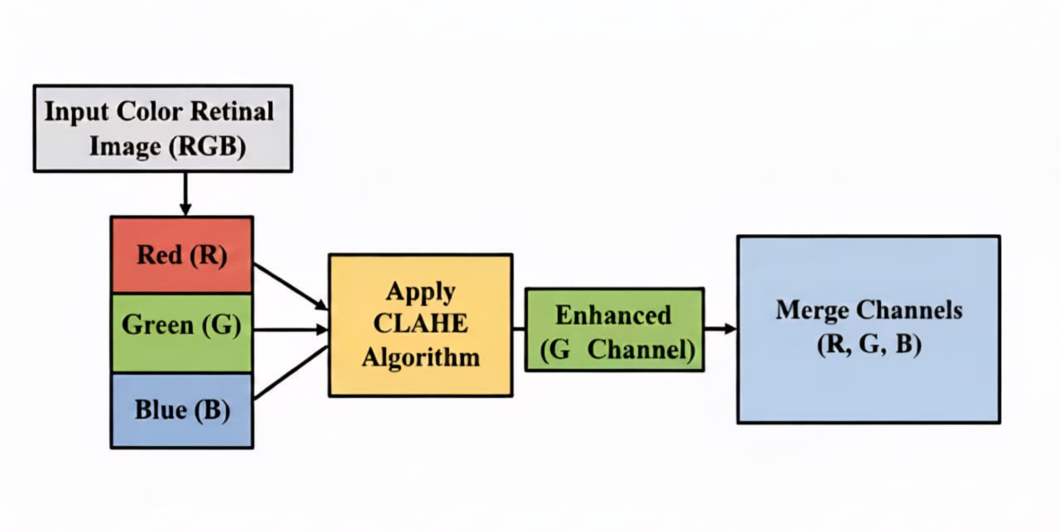

Figure 1. RGB channel decomposition and CLAHE application on the Green channel.

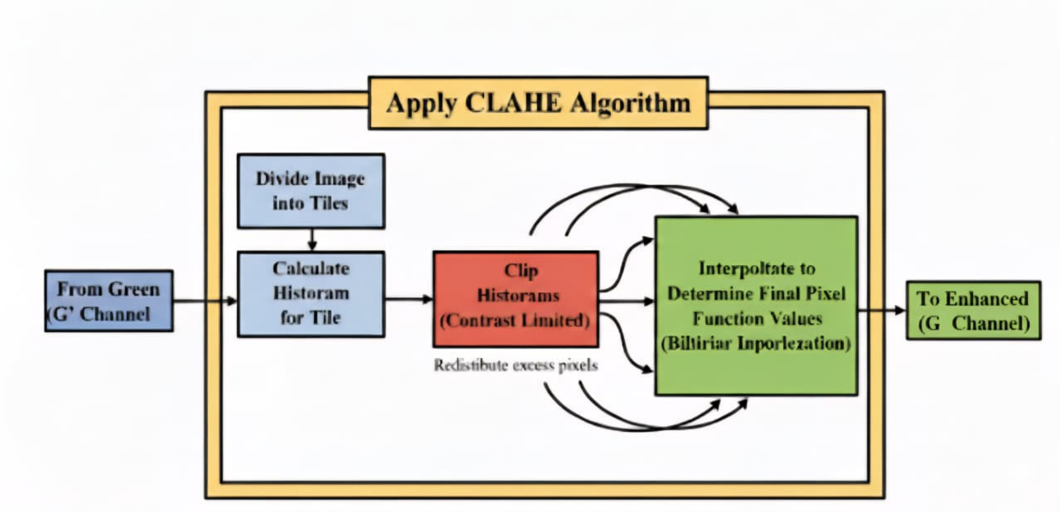

Figure 2. Tile-based CLAHE algorithm illustrating histogram clipping and interpolation.

Algorithm Analysis

The CLAHE algorithm enhances retinal images by redistributing pixel intensities based on local histograms while controlling noise amplification. The mathematical basis can be summarized as follows:

- **Gray Level Transformation:** For a uniform distribution, the transformed gray level g is computed as:

$$g = [g_{\max} - g_{\min}] \cdot P(f) + g_{\min} \tag{1}$$

where $g_{\max}$ and $g_{\min}$ are intensity limits, and $P(f)$ is the cumulative probability distribution of pixel intensity f.
- **Distribution Variants:** - For exponential distribution:

$$g = g_{\min} - \frac{1}{\alpha} \ln\big(1 - P(f)\big) \tag{2}$$

- For Rayleigh distribution:

$$y = P(f(x)) = \int_0^x \frac{u}{b^2} e^{-\frac{u^2}{2b^2}}\, du \tag{3}$$

- **Tile-based Processing:** The image is divided into contextual tiles. Each tile’s histogram is equalized independently, ensuring local contrast enhancement.
- **Clip Limit Parameter (α):** To suppress noise, histograms are clipped at a predefined limit. Excess pixels are redistributed, preventing over-enhancement of bright or dark regions.
- **Interpolation:** Bilinear interpolation blends neighboring tiles to avoid blocky artifacts, producing a smooth enhanced channel (G’).

Summary: CLAHE transforms conventional global histogram equalization into a localized and adaptive process by dividing the image into smaller regions and selectively enhancing contrast within each. This approach preserves fine details often lost with global methods, while the contrast-limiting mechanism prevents over-amplification and suppresses noise in homogeneous areas. By tuning parameters such as the clip limit factor α and choosing an appropriate distribution type (Uniform, Exponential, or Rayleigh), CLAHE achieves a balance between visibility enhancement and noise control.

Experiments and Results

We evaluated CLAHE on two modalities: **retinal fundus images** and **brain MRI scans**. **Retinal Fundus Images:** The original image exhibited poor illumination and weak vessel visibility. After CLAHE, vessels and lesions became more prominent, enabling better diagnostic interpretation. The histogram shows redistribution of intensities, indicating improved local contrast and dynamic range. The histogram comparison shows how pixel intensities are redistributed, with darker vessels pushed to lower intensities and brighter structures enhanced, resulting in improved dynamic range [3].

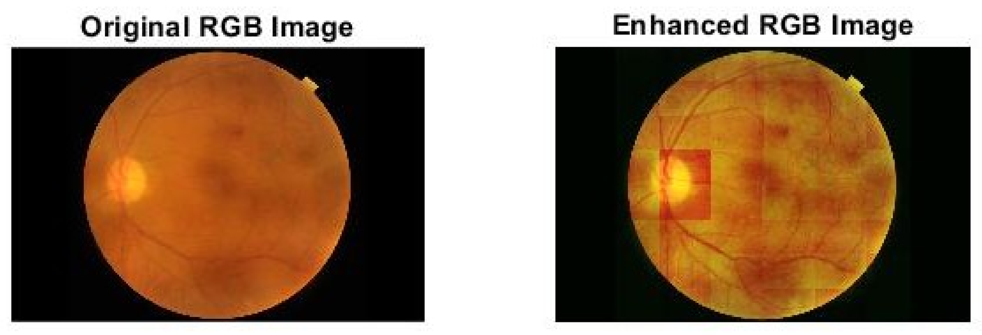

Figure 3. Retinal image before/after CLAHE

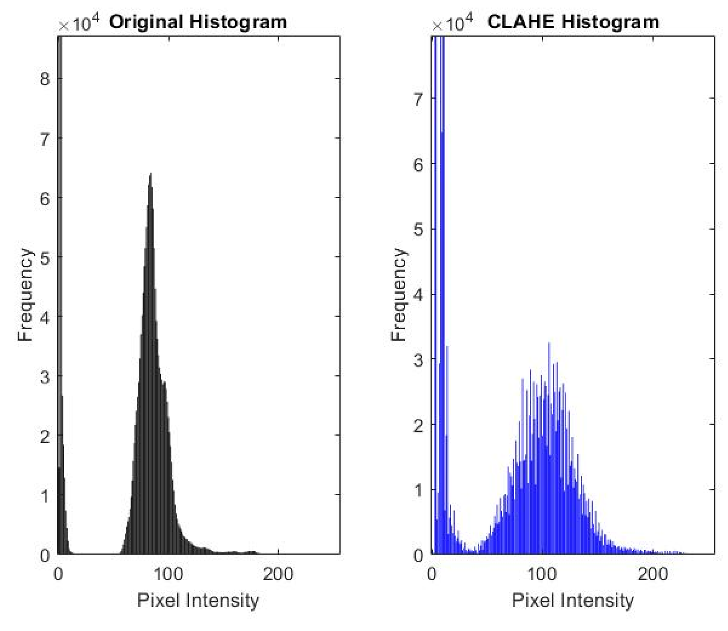

Figure 4. Histogram comparison of Retinal image before/after CLAHE

Important Point

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Experiments and Results

Brain MRI Images: The original image suffered from low contrast between white and gray matter regions. CLAHE enhanced local tissue boundaries and highlighted structural details, while suppressing noise via clipping. Histogram analysis confirms more uniform intensity distribution after enhancement [1].

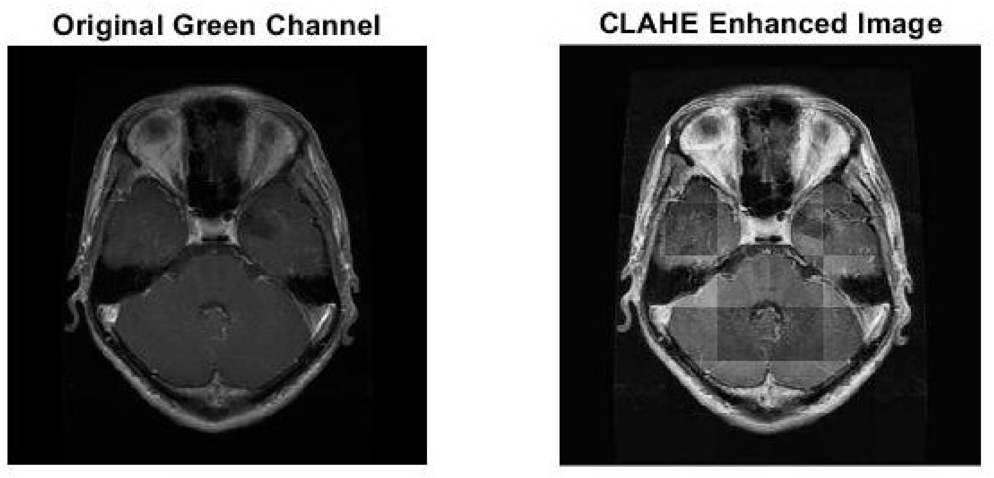

Figure 5. Brain MRI image before/after CLAHE

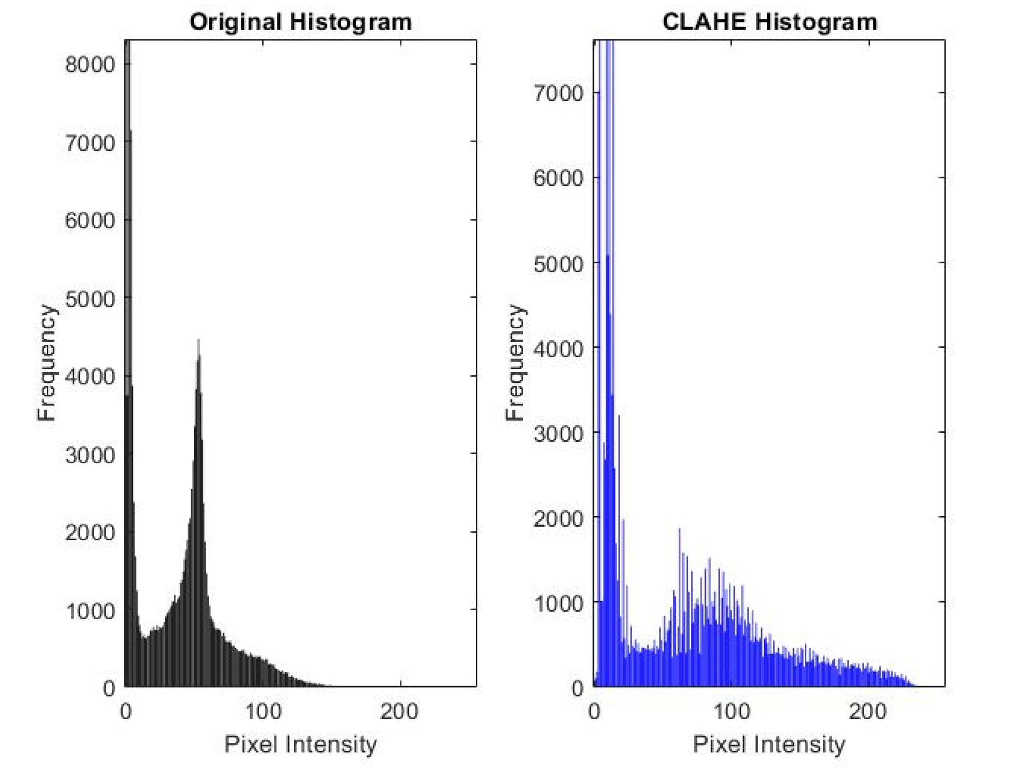

Figure 6. Histogram comparison of Brain MRI image before/after CLAHE

Applications

- Retinal disease detection – enhances visibility of vessels, lesions, and optic disc.
- Brain MRI analysis – improves contrast for gray/white matter and abnormality detection.
- Preprocessing for deep learning – provides better input for CNN-based classifiers.
- Tele-ophthalmology – useful in low-light and portable imaging systems.
- Other medical imaging – applied in CT, MRI, and X-rays for clinical interpretation.

Conclusions

CLAHE enhances local contrast while effectively suppressing noise amplification, making it a valuable tool in medical image processing. It has demonstrated strong performance on both retinal fundus and brain MRI images, improving the visibility of fine structures such as vessels, lesions, and tissue boundaries. This enhancement significantly aids in clinical diagnosis and serves as a robust preprocessing step for automated analysis, supporting more accurate and reliable interpretation of medical images.

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References

[1] Sarika B. Patil and B. P. Patil. Retinal fundus image enhancement using adaptive clahe methods. *Journal of Seybold Report*, 15(9):315–320, 2020. Accessed: 2025-09-24.

[2] Brij Bhan Singh and Shailendra Patel. Efficient medical image enhancement using clahe enhancement and wavelet fusion. *International Journal of Computer Applications*, 167(5):1–6, 2017. Accessed: 2025-09-24.

[3] Andriyan B. Suksmono, Agus W. Setiawan, Tati R. Mengko, and Oerip S. Santoso. Color retinal image enhancement using clahe. In *Proceedings of the International Conference on ICT for Smart Society*, pages 315–319, 2013. Accessed: 2025-09-24.