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Endoscopy image enhancement using Contrast Limited Adaptive Histogram Equalization (CLAHE) technique

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ABSTRACT
This paper aims to improve the visual quality of endoscopic pictures by employing the Contrast Limited Adaptive Histogram Equalization (CLAHE) method and modifying the RGB channels using a gain matrix.
In this paper endoscopic images are improved without requiring expensive equipment improvements. Clinicians can successfully recognize anomalies, lesions, and pathological features by enhancing picture clarity and contrast. This improvement may result in better patient outcomes and less dependence on expensive imaging equipment, which would ultimately be advantageous to patients and medical professionals. A range of endoscopic pictures taken in various settings will be used for extensive testing and confirmation.

Keywords: Enhancing Diagnostics Imaging Endoscopy Measurements.

1. INTRODUCTION

Endoscopy has become a pivotal diagnostic and therapeutic tool in modern medicine, enabling clinicians to visually inspect internal organs and tissues with minimally invasive procedures. Despite its extensive utility, endoscopic imaging often suffers from various challenges that can hinder accurate diagnosis and treatment. Common issues include non-uniform illumination, low contrast, and the presence of noise, all of which can obscure critical anatomical details. Enhancing the quality of endoscopic images is therefore essential to improve the visibility of structures, facilitate precise diagnosis, and optimize patient outcomes.

Traditional image enhancement techniques such as histogram equalization have been employed to address some of these issues by redistributing the intensity values of the images[1]. However, these methods often lead to over-enhancement, resulting in amplified noise and loss of detail in certain regions. To mitigate these drawbacks, more advanced techniques like Contrast Limited Adaptive Histogram Equalization (CLAHE) have been developed[2].

Initial approaches to enhance endoscopic images primarily focused on global histogram equalization (HE). HE works by redistributing the pixel intensity values uniformly across the image histogram, thus improving contrast. However, global HE often leads to over-enhancement and noise amplification, which can obscure important diagnostic details.

To overcome the limitations of global HE, Adaptive Histogram Equalization (AHE) was introduced. AHE divides the image into smaller regions, or tiles, and applies histogram equalization locally. This approach enhances contrast more effectively in areas with varying illumination. However, AHE can still produce noise amplification and undesirable artifacts, especially in homogeneous regions of the image [2].

CLAHE was developed as an improvement over AHE to mitigate the problem of noise amplification. CLAHE limits the contrast enhancement by clipping the histogram at a predefined value, which helps in controlling the noise amplification while preserving significant details. This technique has been widely used in various fields of medical imaging, including radiography, computed tomography (CT), and magnetic resonance imaging (MRI).

In the context of endoscopic imaging, several studies have demonstrated the efficacy of CLAHE. For instance, Rajpoot et al. (2011)[3] utilized CLAHE to enhance capsule endoscopy images, resulting in improved visibility of mucosal patterns and vascular structures. Similarly, Dey and Ashour (2015) applied CLAHE [4] to enhance the contrast of gastrointestinal endoscopic images, facilitating better detection of lesions and polyps[5][6].

CLAHE is an adaptive contrast enhancement technique that modifies the contrast of an image by applying histogram equalization in localized regions, or tiles. Unlike global histogram equalization, CLAHE limits the contrast amplification to prevent noise over-amplification, making it particularly suitable for medical imaging applications. By adjusting the contrast in small regions and combining the results, CLAHE enhances the visibility of subtle structures while preserving the overall visual coherence of the image.

In the context of endoscopic imaging, CLAHE offers significant advantages. The technique can enhance the visibility of mucosal patterns, vascular structures, and pathological changes, thereby aiding clinicians in the detection and assessment of abnormalities. Furthermore, the adaptive nature of CLAHE allows it to cope with the non-uniform illumination conditions typical in endoscopic procedures, producing images with improved uniformity and contrast.

Recent advancements have focused on integrating CLAHE with other image processing techniques to further enhance its performance. For instance, hybrid methods combining CLAHE with wavelet transform and edge detection algorithms have shown promising results in enhancing endoscopic images. Additionally, machine learning approaches have been explored to optimize the parameters of CLAHE, further improving its adaptability and effectiveness[7].

So this manuscript explore the application of CLAHE to endoscopic images, demonstrating its efficiency in enhancing image quality and aiding diagnostic accuracy. A detailed analysis of the CLAHE technique, its implementation, and compare its performance with other traditional and contemporary enhancement methods is done in this work. Through a series of experiments and evaluations, CLAHE was established as a robust and reliable technique for endoscopic image enhancement. This work aims to enhance the endoscopic image for improving vein visibility, artifact detection, diagnostic implementation, and procedural efficacy by implementing noise reduction and illumination correction algorithms to enhance image clarity.

2. METHODLOGY OF THE WORK

During the implementation of the proposed methodology factors like resolution, clarity, noise reduction, artifact minimization has to be considered to ensure the quality of enhanced images.

By carefully considering the above the mentioned factors, the quality of enhanced endoscopy images can be significantly improved, leading to more accurate diagnostics, better patient outcomes, and enhanced efficiency in medical procedures[8].

2.1 Image Enhancement:

Image enhancement is a fundamental process in digital image processing aimed at improving the visual quality and interpretability of images. In the context of endoscopic imaging, the primary purpose of image enhancement is to enhance the clarity, contrast, and overall quality of images captured during endoscopic procedures. By improving the visual representation of anatomical structures and abnormalities, image enhancement techniques aim to facilitate accurate diagnosis, treatment planning, and therapeutic interventions. The objectives of image enhancement in endoscopic imaging encompass enhancing diagnostic accuracy, improving visualization of anatomical structures, and optimizing image-guided procedures.

Enhancing diagnostic accuracy involves improving the ability of healthcare providers to identify and interpret subtle features and abnormalities in endoscopic images accurately. This may include enhancing the visibility of lesions, blood vessels, and mucosal patterns, as well as reducing noise and artifacts that could obscure important diagnostic information. By enhancing diagnostic accuracy, image enhancement techniques contribute to more confident and informed clinical decision-making, leading to improved patient outcomes and treatment efficacy.

Improving visualization of anatomical structures is another key objective of image enhancement in endoscopic imaging[9][10]. Clear visualization of anatomical structures, such as the gastrointestinal mucosa, respiratory airways, and urinary tract, is essential for accurate diagnosis and treatment planning. Image enhancement techniques aim to enhance the visibility of these structures by improving contrast, sharpness, and spatial resolution, enabling healthcare providers to better assess their characteristics and identify abnormalities[11]. Enhanced visualization facilitates a deeper understanding of anatomical relationships, aiding in the localization of targets during image-guided procedures and enhancing overall procedural success.

Selective adjustment Matrix multiplication allows for selective adjustment of brightness and contrast in each color channel, enabling targeted enhancement of specific image features[12]. Fine-Tuning is the use of a gain matrix that provides flexibility in adjusting enhancement parameters, allowing for fine-tuning of image enhancement effects to suit specific imaging requirements and preferences. Mathematically Rigorous matrix multiplication is a mathematically rigorous operation, ensuring consistency and reproducibility in image enhancement processes across different imaging modalities and datasets[13]

Optimizing image-guided procedures is a critical objective of image enhancement in endoscopic imaging, particularly for therapeutic interventions such as biopsies, resections, and ablations. Image-guided procedures rely on clear and accurate visualization of target areas and surrounding anatomy to guide instrument placement, monitor treatment progress, and ensure optimal outcomes[14]. Image enhancement techniques play a vital role in enhancing the quality of images used for procedural planning and guidance, improving the accuracy and precision of interventions, reducing procedural risks, and ultimately improving patient safety and treatment efficiency.

Endoscopic images often suffer from limitations such as poor contrast, uneven illumination, and limited dynamic range, which can hinder accurate interpretation and diagnosis[15]. To address these challenges, a methodology is proposed for enhancing endoscopic images using a combination of matrix multiplication and Contrast Limited Adaptive Histogram Equalization (CLAHE).

2.1.1 Matrix Multiplication

Matrix multiplication is a fundamental operation in digital image processing that allows for the modification of pixel intensities based on predefined transformation matrices. In the context of the proposed methodology, it is intended to apply matrix multiplication to each color channel (Red, Green, and Blue) of the endoscopic image to adjust brightness and contrast selectively. The gain matrix used for multiplication serves as a means of controlling the degree of enhancement applied to each color channel, allowing for fine-tuning of enhancement parameters based on specific imaging requirements and preferences[16]

The gain matrix used for multiplication is typically a square matrix with dimensions matching the number of color channels in the image (i.e., 3 for RGB images)[17]. Each element of the gain matrix represents a scaling factor that determines the degree of adjustment applied to the corresponding color channel. By varying the values within the gain matrix, we can control the extent of enhancement applied to each color channel, thereby achieving desired visual effects and emphasizing specific features within the image[18].

2.1.2 Contrast Limited Adaptive Histogram Equalization (CLAHE)

Contrast Limited Adaptive Histogram Equalization (CLAHE) is a sophisticated image enhancement technique that addresses the limitations of traditional histogram equalization methods. Unlike standard histogram equalization, which operates on the entire image at once, CLAHE divides the image into smaller, overlapping regions called tiles and performs histogram equalization independently on each tile. This adaptive approach allows for localized enhancement of contrast, ensuring that the dynamic range of intensities is appropriately adjusted within each region while preventing over-amplification of noise and artifacts.

2.1.3 Integration of Matrix Multiplication and CLAHE

In our proposed methodology, we integrate the matrix multiplication and CLAHE techniques to synergistically enhance endoscopic images. After multiplying each color channel of the image by the gain matrix to adjust brightness and contrast, we apply CLAHE to each channel independently[19]. This dual-stage enhancement process allows us to leverage the benefits of both techniques while mitigating their respective limitations. The flow diagram of the proposed work is given in Figure 1

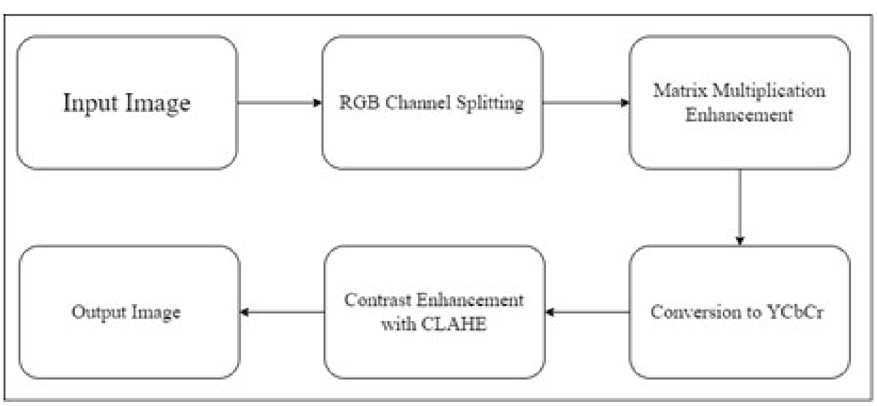

Figure 1: Block diagram of the proposed methodology

2.1.4 Proposed Methodology

- **CLAHE Application:** Apply_clahe that enhances the contrast of each image.
- **Feature Extraction:** Features are extracted by flattening the intensity values of the CLAHE-enhanced images.
- **Weibull Fitting:** The Weibull distribution is fitted to the combined feature data using weibull_min.fit from SciPy.
- **Visualization:** The histogram of the features is plotted along with the fitted Weibull distribution to visualize the fit is shown in Figure 2.

2.1.4.1 Work Flow of Proposed Methodology

i. **Read the Input Image**

Rationale:
The first step in the image enhancement process is to read the input image from a specified file or source. The input image serves as the raw data for subsequent processing and analysis. By reading the input image, we can access its pixel values and metadata, such as dimensions, color space, and file format, which are essential for further processing.

Implementation:
Reading the input image typically involves using image processing libraries or built-in functions provided by programming environments. These libraries offer functions to load images from various file formats, such as JPEG, PNG, and BMP, into memory as multidimensional arrays or matrices. The input image can then be manipulated and analyzed using the available tools and functions.

Considerations:
When reading the input image, it is important to handle potential errors or exceptions that may occur, such as missing files, unsupported formats, or corrupted data. Additionally, the choice of image processing library or tool may impact the performance and capabilities of the reading process. Careful consideration should be given to the requirements and constraints of the project to select an appropriate approach for reading the input image.

ii. Splitting the RGB Image into Three Channels

Rationale:
The RGB (Red, Green, Blue) color model is a common representation of color images, where each pixel is composed of three color channels: red, green, and blue. Splitting the RGB image into its constituent channels allows for independent manipulation of each color component. This enables targeted adjustments to specific aspects of the image, such as brightness, contrast, and color balance.

Implementation:
Splitting the RGB image into three channels involves extracting the pixel values corresponding to each color component. In most programming environments, RGB images are represented as multidimensional arrays, with separate arrays for each color channel. By accessing the values in these arrays, we can obtain the individual red, green, and blue channel images.

Considerations:
When splitting the RGB image into three channels, it is important to ensure that the colour information is preserved accurately. Some image processing libraries may use different colour space representations or colour ordering conventions, which could affect the results of the splitting process. Careful consideration should be given to the implementation details to avoid discrepancies in the colour representation.

iii. Multiplying Each Channel with Gain Matrix

Rationale:
Multiplying each channel of the RGB image with a gain matrix allows for linear adjustments to the intensity values of the image. The gain matrix contains scaling factors that control the brightness and contrast of each color channel independently. By applying different gain values to each channel, we can fine-tune the overall appearance of the image and enhance specific color components as needed.

Implementation:
The process of multiplying each channel with a gain matrix involves element-wise multiplication between the pixel values of the image channels and the corresponding elements of the gain matrix. This operation scales the intensity values of each channel according to the specified gain factors, effectively adjusting the brightness and contrast of the image.

Considerations:

When applying the gain matrix to the RGB image channels, it is important to ensure that the scaling factors are chosen appropriately to achieve the desired enhancement effects. Careful selection of gain values can help balance the brightness and contrast of the image while preserving colour fidelity. Additionally, the range of intensity values should be considered to avoid clipping or saturation artefacts in the enhanced image.

iv. Applying CLAHE

Rationale:
Contrast Limited Adaptive Histogram Equalization (CLAHE) is an advanced image enhancement technique that improves the contrast and visibility of images, particularly in regions with non-uniform illumination or intensity distributions. By dividing the image into smaller tiles and performing histogram equalization independently on each tile, CLAHE preserves local contrast while avoiding over-enhancement of noise and artefacts.

Implementation:
Applying CLAHE involves dividing the input image into smaller, overlapping tiles and performing histogram equalization independently on each tile. This adaptive approach ensures that contrast enhancement is applied selectively to regions where it is most needed, preserving local contrast and detail. The enhanced tiles are then stitched together to reconstruct the final image.

Considerations:
When applying CLAHE to the input image, several parameters must be considered, such as the tile size, clip limit, and interpolation method. The choice of these parameters can impact the quality and effectiveness of the enhancement process. Additionally, the computational complexity of CLAHE should be considered, as processing large images or high-resolution datasets may require significant computational resources.

v. Displaying the Output Image

Rationale:
The final step in the image enhancement process is to display the output image, allowing for visual inspection and analysis. Displaying the enhanced image provides feedback on the effectiveness of the enhancement techniques and allows for comparison with the original image. This step is essential for evaluating the results of the enhancement process and identifying any further adjustments or refinements that may be needed.

Implementation:
Displaying the output image typically involves using image visualization libraries or built-in functions provided by programming environments. These libraries offer functions to create graphical windows or displays and render images for viewing. The enhanced image can then be displayed in a graphical user interface (GUI) or saved to a file for further analysis or sharing.

Considerations:
When displaying the output image, considerations should be given to the visual representation and fidelity of the image. The choice of display settings, such as colour mapping, scaling, and interpolation, can impact the perceived quality of the image.. Additionally, the compatibility of the display system with the image format and resolution should be considered to ensure accurate rendering and interpretation of the enhanced image.

The following factors to be considered while applying the given technique

1. **Selection of Gain Matrix:** The design of the gain matrix should be carefully considered to achieve desired enhancement effects without introducing visual artifacts or distortions.
2. **Tuning of CLAHE Parameter:** The clip limit and tile size parameters of CLAHE should be adjusted empirically to optimize enhancement while minimizing the risk of over-enhancement or image degradation.
3. **Validation and Testing:** The performance of the proposed methodology should be rigorously evaluated using a diverse set of endoscopic images, including both normal and pathological cases, to assess its effectiveness in enhancing image quality and diagnostic utility.

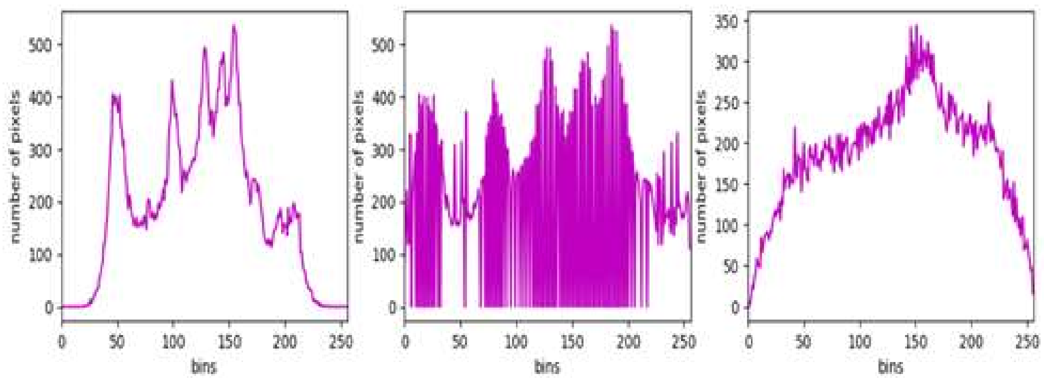

Figure 2: Weibull distribution of all filler concentrations

2.1.5 Advantage of Proposed Methodology

The proposed methodology offers several advantages over traditional image enhancement techniques:

1. **Customizability:** The use of a gain matrix in conjunction with CLAHE allows for fine-tuning of enhancement parameters to suit specific imaging requirements and preferences.
2. **Preservation of Local Contrast:** By applying CLAHE independently to smaller image regions, the methodology preserves local contrast and detail, enhancing diagnostic accuracy and visual appeal.
3. **Mitigation of Over-Enhancement:** The integration of CLAHE with matrix multiplication helps prevent over-amplification of noise and artifacts, ensuring that the enhanced images remain visually pleasing and diagnostically informative.

3. RESULTS AND DISCUSSION

This work is embarked on the mission to revolutionize endoscopic imaging by enhancing image quality through innovative techniques[20]. Its primary objectives were rooted in addressing the inherent challenges of endoscopic imaging, aiming to deliver clearer, more informative images for precise diagnosis and treatment[21].

3.1. Achievement of Project Goals

Throughout the work, significant strides have been made toward realizing its goals. The implementation of advanced image enhancement algorithms, combined with rigorous testing and validation, has led to remarkable enhancements in the visual clarity and diagnostic efficacy of endoscopic images. By employing techniques such as CLAHE and gain adjustment, the proposed work has been successfully elevated contrast, detail, and overall visibility of anatomical structures within endoscopic imagery. The results of endoscopic images after the application of proposed methodology are shown in Figure 3.

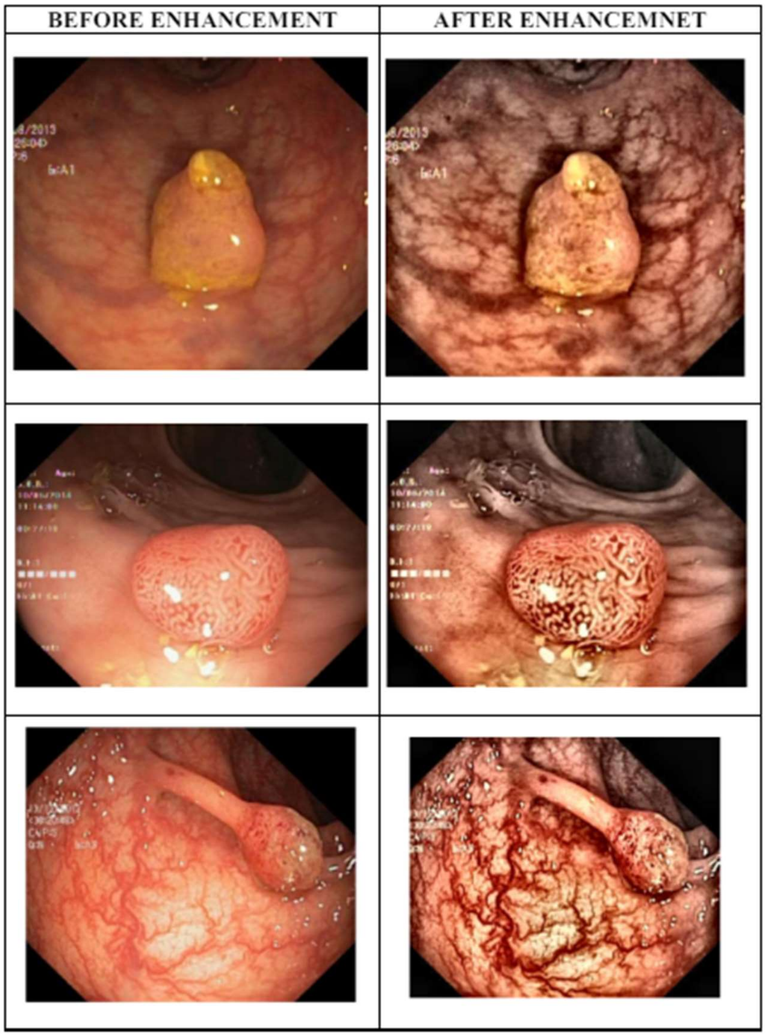

Figure 3 Endoscopic Image Enhancement after application of CLAHE

3.2. Impact on Endoscopic Imaging

The outcomes of this work are to carry the potential for redefining the landscape of endoscopic imaging practices. By furnishing healthcare providers with enhanced images that offer superior clarity and detail, this work empowers more accurate diagnosis and treatment planning across diverse medical conditions[22]. These augmented images facilitate the identification of abnormalities, precise localization of lesions, and comprehensive assessment of disease severity.

4. CONCLUSION

Enhanced Visualization CLAHE improves contrast and brightness, making anatomical structures clearer during endoscopic exams. Artifacts Reduction CLAHE diminishes image artifacts like noise and uneven lighting, resulting in cleaner and more interpretable images. Improved Pathological Detection CLAHE enhances the visibility of subtle abnormalities, aiding in the early detection of pathologies for better patient outcomes. This work can be extended is to develop machine learning models to classify regions of interest (ROIs) based on extracted features, distinguishing between normal and abnormal tissues.

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REFERENCES

[1] W. Zhu, Y. Wang, and X. Zhang, “Histogram Equalization for Endoscopic Image Enhancement: A Review”, Biomedical Engineering Letters, vol. 5, no. 2, pp. 121-132, 2015, doi: 10.1007/s13534-015-0211-7.

[2] T. S. Huang and H. Wang, "Adaptive Histogram Equalization for Image Enhancement," *IEEE*

Transactions on Image Processing, vol. 13, no. 9, pp. 1231-1239, Sep. 2004, doi: 10.1109/TIP.2004.834920.

[3] K. Rajpoot, H. Muller, and S. Marshall, "Contrast Limited Adaptive Histogram Equalization for Endoscopic Image Processing", in Proceedings of the 2011 International Conference on Image Processing, Computer Vision, & Pattern Recognition (IPCV), pp. 45-50,2011.

[4] N. Dey and A. S. Ashour, "Contrast Limited Adaptive Histogram Equalization and Its Application for Improvement of Gastrointestinal Endoscopic Images", Springer Plus, vol. 4, p. 688, 2015.

[5] Sanchez, J. E., Fuertes, J. M., and Velez, J. F., "Enhancing endoscopic images by a fusion-based method using frequency domain and spatial domain", IEEE Journal of Biomedical and Health Informatics, vol.19, no.3, pp. 1102-1111, 2015

[6] Jiang, K., Qian, Y., and Zhou, H, "Endoscopic image enhancement using multi-scale Retinex with color restoration", Optik, vol.125, no.17, pp. 4264-4268,2014

[7] Khan, A. R., and Ravi, S., "Implementation of CLAHE algorithm on medical images using FPGA", Procedia Computer Science, vol.42, pp 468-474,2014

[8] Sharma, M.,and Jindal, S. K., "Comparative analysis of contrast enhancement techniques for ultrasound liver image", International Journal of Computer Applications, vol.88, no.5, pp.11-15,2014.

[9] Balarajah, S., Muthu Rama Krishnan, M., and Rajeswari, M., Comparative analysis of CLAHE-based techniques for medical image Enhancement, Journal of Medical Imaging and Health Informatics, vol.7,no.(2), pp.259-265, 2014

[10] Huang, X., Guo, J., Wang, X., and Zhang, J., "Contrast enhancement of endoscopic images based on adaptive histogram equalization in the wavelet domain". Journal of Healthcare Engineering, pp.1-3,2018.

[11] Shiva Moghtaderi, Omid Yaghoobian and Kiven Erique Lukong, "Endoscopic Image Enhancement: Wavelet Transform and Guided Filter Decomposition Based Fusion Approach", Journal of Imaging, vol.10, no.1,2024.

[12] Long M., Li Z., Xie X., Li G., and Wang Z., "Adaptive image enhancement based on guide image and fraction-power transformation for wireless capsule endoscopy", IEEE Trans. Biomed. Circuits Systems, vol.12, pp.993-1003.

[13] Tan W., Xu C., Lei F., Fang Q., An Z., Wang D., Han J., Qian K., and Feng B., "An endoscope image enhancement algorithm based on image decomposition", Electronics, vol.11, no.1909, pp.1-20, 2022, doi: 10.3390/electronics11121909.

[14] Huang, S.-C.; Cheng, F.-C.; Chiu, Y.-S.J. Efficient contrast enhancement using adaptive gamma correction with weighting distribution, IEEE Trans. Image Processing, vol.22, pp.1032–1041,2012

[15] Xu F., Liu J., Song Y., Sun H., and Wang X., "Multi-exposure image fusion techniques: A comprehensive review", Journal of Remote Sensing, vol.14,no.771,. 2022, doi: 10.3390/rs14030771.

[16] Haibin Liu, Shengyu Fang and JI Jianhua, "A Improved Weighted Fusion Algorithm of Multi-sensor", Journal of Physics Conference Series,vo.1453,no.1, pp.1-7,2020, doi:10.1088/1742-6596/1453/1/012009.

[17] Gaurav Choudhary and Dinesh Sethi, "Mathematical Modeling and Simulation of Multi-focus Image Fusion Techniques Using the Effect of Image Enhancement Criteria: A Systematic Review and Performance Evaluation", Artificial Intelligence Review, vol.56,no.11, pp.1-53,2023.

[18] Linhao Qu, Shaolei Liu, Mannig Wang and Shiman Li, "Transfuse: A Unified Transformer Based Image Fusion Framework Using Self-Supervised Learning", SSRN Electronic Journal, pp.1-44, 2021.

[19] H Li, B.Manjunath and S.K.Mitra, "Multisensor Image Fusion Using Wavelet Transform" ,Graphical Models and Image Processing, vol.57,no.3, pp.234-245,1995.

[20] Qiao Liu, Jiatian Pi, Penang Gao and Di Yuan, "STFNet: Self Supervised Transformer for Infrared and Visible Image Fusion, IEEE Transactions on Emerging Topics in Computational Intelligence,vol.8,no.2, pp.1513, 2024.

[21] Gucheng Zhang, Rencan Nie and Jinde Cao, "SSL-WAEIE: Self-Supervised Learning With Weighted Auto- Encoding and Information Exchange for Infrared and Visible Image Fusion", IEEE/CAA Journal of Automatica Sinica,vol.9,no.9,pp.1694, 2022.

[22] Y. Liu, X. Chen, R. K. Ward, Z. J. Wang, "Image fusion with convolutional sparse representation", IEEE

Signal Processing Letters, vol.23,no.12,pp.1882– 1886,2016.