Optimized Enhancement of Ancient Kannada Manuscript Using Fusion of Gamma and CLAHE

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***Abstract*—Character segmentation and recognition in Kannada script pose unique challenges due to its complex morphology and diverse writing styles. This paper presents a comprehensive approach for efficient segmentation and accurate recognition of Kannada characters, contributing to the advancement of Optical Character Recognition (OCR) systems tailored for Kannada language. The proposed method encompasses preprocessing techniques for noise reduction and image enhancement, followed by segmentation algorithms designed to isolate individual characters effectively. Feature extraction methods are then employed to capture relevant characteristics of Kannada characters, facilitating robust recognition using machine learning models. Experimental results demonstrate the efficacy of the proposed approach in achieving high accuracy rates in character recognition tasks across various Kannada text datasets. The developed system holds promise for applications in digitizing Kannada documents, enhancing accessibility, and promoting the preservation of Kannada cultural heritage.**

***Keywords*—Gamma, CLAHE, enhancement, segmentation, Convolutional Neural Network (CNN)**

I. Introduction

Character recognition and segmentation in Kannada script is particularly difficult because of the script's complex morphology and range of writing styles. In order to improve Optical Character Recognition (OCR) systems that are especially made for the Kannada language, this research presents a thorough method for quickly segmenting and correctly identifying Kannada characters [1]. The suggested approach combines preprocessing methods for image improvement and noise reduction with complex segmentation algorithms that separate individual letters in an efficient manner. Feature extraction techniques are used to extract the most important characteristics from Kannada characters, which allows for reliable machine learning models.

The motivation of this work arises from the growing need to digitize and preserve ancient Kannada manuscripts, many of which exist only in fragile physical form. These historical documents often suffer from degradation, uneven illumination, faded ink, and noise, which significantly affect the performance of conventional Optical Character Recognition. Noise reduction and picture enhancement are important processes in the world of image preparation for OCR systems. In order to guarantee cleaner input images for later processing steps and to eliminate undesired artifacts, noise reduction techniques like Gaussian blurring [2] and median filtering are utilized. By enhancing the visibility of characters in the images, image enhancement techniques, on the other hand, aim to facilitate the precise identification of individual characters by segmentation algorithms. Contrast enhancement is one of the most important enhancement techniques for bringing out the peculiarities of Kannada characters [3], which are frequently detailed and packed with details.

Gamma correction is one of the most widely used techniques for contrast enhancement. Gamma enhancement modifies the image's luminance by transforming the pixel values nonlinearly [4]. This method works especially well with photos that have varying illumination, which are frequently found in scanned papers. Gamma correction [5] makes sure that the characteristics of Kannada script are easier to see by increasing the contrast between the background and the foreground characters. This improvement greatly facilitates the process of segmentation, resulting in a more accurate separation of characters from the text.

Contrast Limited Adaptive Histogram Equalization (CLAHE) [6] is another effective contrast enhancement method. In contrast to conventional histogram equalization, CLAHE performs histogram equalization to each tile independently while working on discrete areas of the image called tiles. This targeted method keeps noise from being amplified too much while maintaining the image's natural look. Because it may improve local contrast in places with dense character structures without adding artifacts, CLAHE is very useful for Kannada script. CLAHE enhances the overall readability and segmentation accuracy

Manuscript received February 2, 2026; revised February 26, 2026; accepted June 1, 2026 published November 18, 2026.

of the image by distributing contrast evenly across different locations.

In summary, the integration of gamma correction and CLAHE approaches capitalizes on their individual advantages to produce improved image enhancement. While CLAHE adjusts local contrast to bring out the finer details of Kannada characters, gamma correction enhances global contrast to guarantee consistent brightness. The result of this fusion is a picture that is regionally detailed and universally enhanced, making it the ideal input for OCR systems. The outcomes of the experiments show that this combination method considerably increases the accuracy of character recognition [7], proving its usefulness in handling the intricacies of Kannada script. Optimized fusion strategy (γ = 1.1, tile size = 8 × 8, clip limit = 2.5) specifically tailored for degraded ancient Kannada manuscripts. End-to-end validation, demonstrating that enhancement improvements translate into measurable segmentation and OCR gains. Large-scale evaluation on 16,425 real degraded manuscript images. Application to complex Kannada script morphology, which presents unique segmentation and recognition challenges.

From the literature review, existing studies on degraded document enhancement and OCR can be categorized into global contrast enhancement methods, adaptive local enhancement techniques such as CLAHE, and deep learning-based segmentation and OCR frameworks. However, many existing methods improve either global illumination or local contrast independently and often fail to preserve fine manuscript details while suppressing background noise in severely degraded documents. In addition, most OCR approaches are developed for generic document datasets and are not specifically optimized for ancient Kannada manuscripts with complex script structures, faded characters, and uneven illumination. To address these limitations, the proposed work introduces an optimized hybrid framework that combines Gamma correction and CLAHE for enhanced contrast preservation and improved readability. The enhanced images are further integrated with U-Net-based segmentation and Convolutional Neural Network (CNN)-based optical character recognition, enabling comprehensive evaluation using Signal to Noise Ratio (SNR), Contrast Improvement Index (CII), Dice coefficient, Character Accuracy, Character Error Rate (CER), and Word Error Rate (WER) metrics.

II. Methodology

Image Acquisition: Images were captured by visiting historical sites known for their ancient Kannada stone inscriptions. These sites included:

(1) Hampi, in the Bellary district of Karnataka.
(2) Belur, in the Hassan district of Karnataka.
(3) Somnath Temple, in the Mysore district of Karnataka.

The dataset used in this study consists of 16,425 degraded ancient Kannada manuscript images. To ensure robust evaluation while maintaining sufficient training diversity, adopted an 80:20 split strategy. 80% is (13,140 images) Training set and 20% is (3285 image) Testing set. The dataset represents a wide range of degradation types, including uneven illumination, background noise, and texture interference due to manuscript aging. The degraded text image is the initial input to the system. All images were acquired using high-resolution flatbed scanners with an average resolution of 300–600 dpi. To maintain consistency during model training and evaluation, the images were preprocessed and resized to 256 × 256 pixels.

Initially, Gamma correction is applied to adjust the illumination and improve the overall brightness of the manuscript images. This step helps in compensating for uneven lighting and faded ink commonly found in ancient Kannada documents. The fusion of Gamma correction and CLAHE significantly enhances the quality of degraded manuscript images by improving contrast and reducing the effect of background noise.

- **Gamma Correction and CLAHE Enhancement:** The input image is processed through gamma correction to adjust brightness and contrast, followed by CLAHE enhancement to improve local contrast while limiting noise amplification.
- **Segmentation:** The enhanced image is segmented to localize text regions using techniques such as thresholding, edge detection, or connected component analysis.
- **Text Region Localization and Refinement:** The segmented text regions are further refined to improve ac- curacy and remove false positives or noise artifacts.
- **Text Recognition:** Optical Character Recognition (OCR) algorithms are applied to recognize and extract text content from the segmented regions [8].
- **Output Text:** The recognized text is output as the final result of the system.

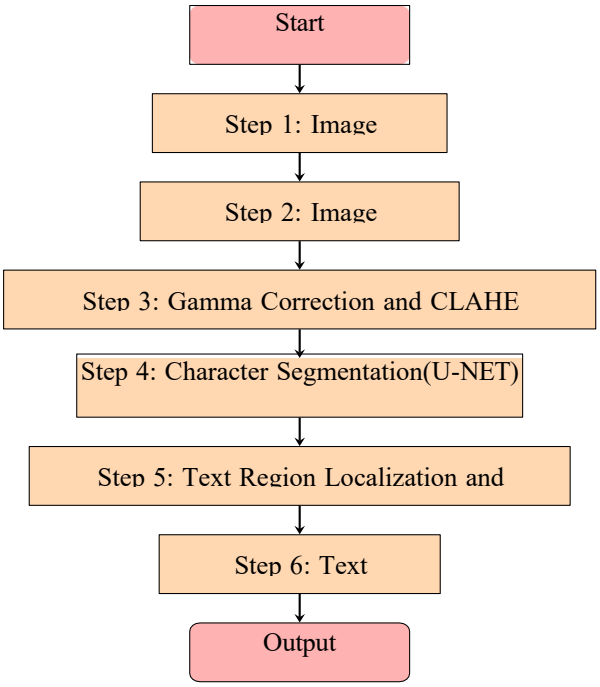


Fig. 1. System design flow.

The Fig. 1 illustrates the overall design flow of the proposed OCR framework for degraded ancient Kannada manuscripts. The process begins with image acquisition

from historical sources, followed by preprocessing for noise reduction and normalization. The images are then enhanced using a fusion of Gamma Correction and CLAHE to improve global and local contrast. The enhanced images are segmented using a U-Net based CNN to isolate individual characters. Finally, OCR-based text recognition is applied to generate the digitized textual output.

III. Overview of Gamma Correction and CLAHE

Gamma correction and Contrast Limited Adaptive Histogram Equalization (CLAHE) are image processing technique that enhances visual quality. Gamma correction adjusts luminance by applying a non-linear transformation to pixel values, controlled by a gamma value, which enhances details in dark or bright regions [9]. CLAHE, on the other hand, improves contrast by dividing the image into small regions and applying histogram equalization within each, limiting contrast to prevent noise over-amplification. This makes CLAHE effective for enhancing local contrast and detail in both medical and natural images [10].

A. Gamma Correction

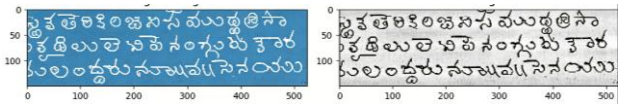
Gamma correction is an essential technique in image processing and computer graphics, addressing the non-linear perception of light and color by humans. Our vision does not respond linearly to light intensity; we are more sensitive to variations in darker tones than in lighter ones. Consequently, capturing or displaying images on a linear scale can result in suboptimal visual experiences, with insufficient detail in shadows and highlights [11].

Unlike linear adjustments, gamma correction employs a non-linear modification to the luminance or RGB values of an image. This modification is governed by a parameter called the gamma value, typically ranging from 0.1 to 2.5. The gamma correction process maps input pixel values to output values using a power-law function, effectively compressing or expanding specific ranges of pixel values. For instance, a gamma value greater than 1 brightens an image, while a value less than 1 darkens it.

Gamma correction [12] is vital in numerous fields, such as photography, television, and computer displays. In photography, it ensures that captured images exhibit accurate brightness and contrast across various devices. In television broadcasting, gamma correction compensates for the characteristics of different screens, maintaining consistent visual quality in diverse viewing environments. In computer graphics, it is crucial for rendering realistic scenes, considering the non-linear responses of display devices and the human eye.

Furthermore, gamma correction [12] is essential for achieving consistent image quality across different devices and platforms. Without it, an image that appears well-lit and detailed on one screen might look too dark or too bright on another due to varying display technologies and calibration. By standardizing luminance value handling, gamma correction helps maintain visual fidelity and consistency.

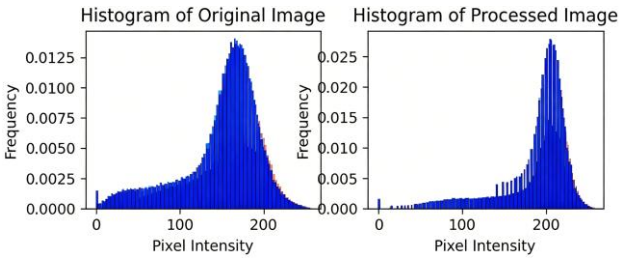
By adjusting brightness and contrast through gamma correction, details in both dark and bright areas of an image become more discernible. This improves overall image quality, making it more visually appealing and informative. Thus, gamma correction is a crucial tool in image processing, ensuring accurate and optimal representation of visual content across a wide array of devices and viewing conditions.



(a) (b)

Fig. 2. Gamma enhanced image. (a) Orignal image; (b) Gamma enhancement

Fig. 2 shows original input image and the corresponding enhanced output after applying gamma correction. The enhancement improves global brightness and contrast, making faint characters more visible and improving readability.



(a) (b)

Fig. 3. Impact of Gamma enhancement on image pixel intensity distribution. (a) Histogram of original image; (b) Histogram of processed image.

Fig. 3 shows the effect of gamma enhancement on an image's pixel intensity distribution. The original image's histogram is concentrated in the mid-to-high intensity range, indicating higher brightness but limited contrast. After gamma enhancement, the processed image's histogram is more spread out and shifted towards higher intensities, demonstrating improved brightness and contrast, which makes details in darker regions more visible [13].

1) Advantages of Gamma correction

- **Perceptual Uniformity**: Human vision perceives changes in brightness and contrast nonlinearly. Gamma correction helps to compensate for this nonlinearity, ensuring that the displayed image appears visually uniform to the human eye.
- **Improved Image Quality**: Gamma correction can enhance the overall quality of images by adjusting their brightness levels to better match human perception. This can result in clearer, more visually appealing images with better contrast and detail.
- **Consistency Across Devices**: Different display devices, such as monitors, TVs, and projectors, may have different gamma characteristics. Applying gamma correction ensures that images appear consistent across these devices, maintaining the intended visual appearance regardless of the display technology.
- **Color Accuracy**: Gamma correction can also help improve color accuracy by ensuring that colors are

displayed correctly across different devices. This is important for tasks such as graphic design, photography, and color-critical applications [14].

2) Drawbacks to Gamma correction

- **Loss of Data**: Gamma correction can sometimes lead to a loss of information, particularly in regions where the original image has low contrast or brightness. This can result in clipped highlights or shadows, reducing the overall dynamic range of the image.
- **Incompatibility**: Not all image formats or applications support gamma correction, which can lead to compatibility issues when transferring or sharing images between different platforms or software.
- **Overcorrection**: Incorrect application of gamma correction can lead to overcorrection, causing images to appear too bright or too dark. This can result in loss of detail and distortion of the original image [15].
- **Complexity**: Gamma correction requires careful calibration and adjustment to achieve optimal results. Under- standing the gamma characteristics of both the image and the display device is essential for accurate correction, which can add complexity to the image processing workflow.

B. Contrast Limited Adaptive Histogram Equalization (CLAHE)

Contrast Limited Adaptive Histogram Equalization (CLAHE) is an advanced technique in image processing that improves the visibility of features in images, especially in areas with different brightness levels. Unlike traditional histogram equalization, which applies adjustments uniformly across the entire image, CLAHE processes small, discrete sections called tiles. By enhancing contrast within each tile separately, CLAHE boosts local contrast while maintaining the image's natural look and avoiding excessive noise amplification [16].

This method is especially advantageous for enhancing images of Kannada script, which often contains intricate and detailed characters. Traditional contrast enhancement methods might amplify noise too much, obscuring these details. CLAHE, however, adjusts contrast within each tile, ensuring enhancements are localized and tailored to specific image areas. This approach makes the fine details of Kannada characters clearer without adding unwanted artifacts.

CLAHE greatly improves the readability and segmentation accuracy of Kannada text by balancing contrast across different image regions. This enhancement is particularly beneficial for Optical Character Recognition (OCR) systems, which need clear and distinct character features to accurately identify and isolate individual characters. The enhanced local contrast provided by CLAHE helps OCR systems better distinguish between characters, leading to more accurate text recognition.

For OCR applications, accurate text recognition is crucial for tasks such as document digitization, automated data entry, and text analysis. Preparing Kannada text images with CLAHE significantly enhances OCR performance, ensuring that characters are more visible and distinct, thereby reducing recognition errors caused by unclear or overlapping features [17].

In summary, CLAHE is a powerful tool for improving the readability and segmentation accuracy of Kannada script images. Its ability to enhance local contrast while preserving the image's natural appearance makes it ideal for preparing text images for OCR applications. Using CLAHE, OCR systems can achieve higher accuracy in recognizing Kannada text, improving the efficiency and reliability of text processing tasks.

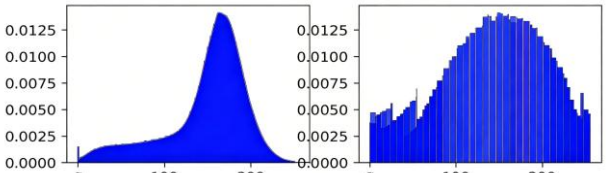


Fig. 4. Contrast limited adaptive histogram equalization. (a) Original image; (b) Processed image.

Fig. 4 demonstrates the effect of Contrast Limited Adaptive Histogram Equalization (CLAHE) on a Kannada script image for both original image and processed image [18]. The Fig. 4(a) shows the original image, while the Fig. 4(b) displays the enhanced image with improved clarity. The histograms above indicate the transformation: the original image's histogram Fig. 4(a) is concentrated, while the CLAHE-processed image's histogram Fig. 4(b) is more evenly distributed, reflecting enhanced contrast and better visibility of details. Advantages of CLAHE enhancement are:

- Preservation of Local Details: CLAHE enhances contrast while maintaining local details and textures, making it especially effective for images with uneven lighting or low contrast [19].
- Noise Reduction: By controlling the amplification of noise, CLAHE reduces the visibility of noise artifacts, resulting in a cleaner and more visually appealing image compared to traditional histogram equalization.
- Adaptive Enhancement: CLAHE adjusts its enhancement parameters locally based on image content, ensuring appropriate contrast enhancement across different regions of the image.
- Versatility: CLAHE is applicable to a wide range of images, including medical images, satellite imagery, microscopy images, and more, making it a versatile tool for various contrast enhancement applications.

C. Fusion of Gamma & CLAHE

Combining Gamma Correction with Contrast Limited Adaptive Histogram Equalization (CLAHE) offers a robust approach to enhancing degraded scripts, providing superior results compared to using Gamma Correction alone. This combined method leverages the unique strengths of both techniques to effectively address their individual limitations, leading to exceptional restoration and enhancement of historical documents. Firstly, Gamma correction is applied to the input manuscript image to adjust illumination and improve brightness. Next, Contrast

Limited Adaptive Histogram Equalization (CLAHE) is applied to enhance local contrast and improve the visibility of text regions. The outputs from these enhancement stages are combined to produce an image with improved contrast and clearer foreground-background separation.

1) Enhanced contrast and detail

Gamma Correction: Gamma correction adjusts the over- all brightness and contrast of an image by applying a non-linear transformation to the pixel values. This is particularly useful for correcting images that are too dark or too bright, bringing out details that are otherwise obscured [20].

CLAHE: CLAHE works by enhancing the contrast locally within small regions (tiles) of the image. By applying histogram equalization to each tile individually, CLAHE ensures that local details and textures are preserved and enhanced, making features in areas with varying brightness levels more visible.

2) Preservation of local details

Gamma Correction: While effectively improving global contrast, gamma correction can sometimes wash out local details, especially in high-contrast regions.

CLAHE: By limiting contrast enhancement within each tile, CLAHE prevents over-amplification of noise and maintains the image's natural appearance. This is crucial for preserving intricate details in historical documents and scripts [21].

3) Adaptive enhancement

Gamma Correction: Gamma correction applies a uniform transformation across the entire image, which may not be suitable for images with uneven lighting conditions.

CLAHE: CLAHE adapts its parameters based on the local content of the image, providing tailored contrast enhancement suitable for different regions. This ensures appropriate enhancement for both dark and bright areas.

4) Noise reduction

Gamma Correction: When used alone, gamma correction can sometimes amplify noise, particularly in low- light areas.

CLAHE: By controlling the extent of contrast enhancement within each tile, CLAHE reduces the visibility of noise artifacts, resulting in a cleaner and more visually appealing image [22].

5) Versatility

Gamma Correction and CLAHE: Combining these techniques is versatile and applicable to various image types, including medical images, satellite imagery, microscopy images, and historical documents. This combined approach is suitable for applications requiring enhanced image clarity and detail.

6) Application to historical documents

Historical documents often suffer degradation due to age, light exposure, and other environmental factors, resulting in faded text, uneven illumination, and loss of detail [23]. By combining Gamma Correction and CLAHE, the following improvements can be achieved:

- Improved Readability: Enhancing both global and local contrast makes faded text more legible and reveals hidden details.
- Enhanced Detail Preservation: Local contrast enhancement preserves and highlights fine details in the script, aiding accurate interpretation and digitization.
- Reduced Noise: The adaptive nature of CLAHE minimizes noise amplification, ensuring the enhanced image remains clean and true to the original.

IV. Charcter Segmentation

Duplicate Neural network-based character segmentation strengthens the system's resistance to changes in character size, style, and orientation. Using end-to-end learning, where the network is trained to do segmentation without requiring a lot of pre-processing or manual feature extraction, is one of the main advantages. Typically, this procedure entails feeding images into a CNN, which uses a number of convolutional and pooling layers to extract high-level information. After processing, these attributes are used to create segmentation masks that help distinguish between individual characters or text lines [24].

Character segmentation benefits greatly from deep learning techniques, particularly Convolutional Neural Networks (CNNs), which can learn and generalize from vast datasets. Even in complicated and deteriorated texts, CNNs may successfully recognize and distinguish between characters by automatically extracting hierarchical features from images. When working with handwritten writing, where characters frequently overlap or are related, this feature is quite helpful. U-Net is a highly efficient and powerful Convolutional Neural Network (CNN) architecture specifically designed for image segmentation tasks. In the context of character recognition, by leveraging its detailed segmentation capabilities, U-Net can accurately isolate individual characters, even in complex and noisy backgrounds.

Neural network-based character segmentation not only increases accuracy but also minimizes the need for manual intervention and intensive pre-processing. Text images can be processed using methods like semantic segmentation and instance segmentation, which are frequently employed in computer vision. These techniques enable accurate segmentation even in congested environments by assigning each pixel in a picture to a particular character [21]. Techniques for creating synthetic data and enhancing existing data are also beneficial to character segmentation since they increase the size of the training dataset and strengthen the model's resistance to noise and distortion. These methods, together with developments in neural network topologies, keep pushing the envelope in character segmentation, opening the door to more precise and effective OCR systems for a variety of applications.

Character segmentation is performed using a U-Net-based Convolutional Neural Network (CNN) architecture optimized for text segmentation in degraded Kannada manuscripts. The structure follows the standard U-Net design comprising:

- Input images were resized to 256 × 256 pixels to maintain consistency across the dataset of 16,425 images.
- 4 convolutional blocks, each containing two 3 × 3 convolution layers followed by a ReLU activation function and a 2 × 2 max pooling layer for down sampling.
- Two 3 × 3 convolutions with 1024 filters, followed by ReLU activation and dropout (0.5) for regularization.
- A final 1 × 1 convolution layer with a sigmoid activation function to generate the binary segmentation mask that isolates individual Kannada characters.

V. Results and Discussions

The effectiveness of the proposed design flow for enhancing degraded text—using a combination of gamma correction, CLAHE, segmentation, and recognition can be evaluated through several criteria. First, image quality improvement is assessed by examining contrast enhancement, detail preservation, and noise reduction to ensure faded text becomes more readable and important details remain clear. The accuracy of the segmentation procedure is crucial for isolating text from the background and ensuring precise text boundaries. The Optical Character Recognition (OCR) system's performance is measured by comparing recognition rates and error rates before and after the enhancement. Processing efficiency, including the time and computational resources required, is evaluated along with the method's scalability across various document sizes and qualities. Visual and practical usability is determined through user feedback on readability and testing the enhanced text in real-world applications like archival digitization and historical research. Finally, the robustness and adaptability of the technique are evaluated by its effectiveness across different types of degradation and consistency across various document types. By assessing these factors, the overall success and practical utility of the proposed design flow can be comprehensively determined, ensuring it meets the requirements of both automated systems and human users.

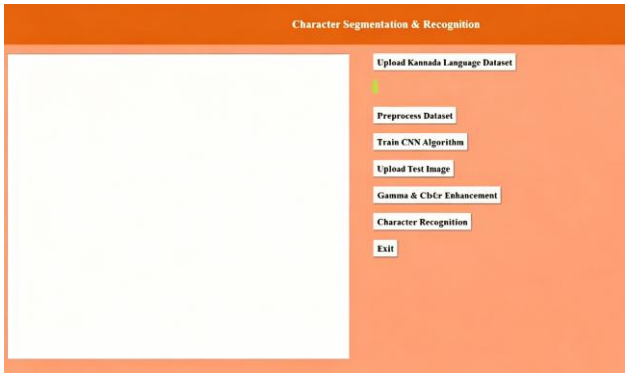


Fig. 5. User interface.

Fig. 5 shows the output interface with multiple options, click on "Upload Kannada Language Dataset" button to upload dataset. A total of 16,425 images has been successfully loaded from the dataset. After loading, a sample processed image is displayed to illustrate the initial state. To proceed, click the 'Pre-process Image' button, which will shuffle, normalize, and process the entire set of images. This processing step is crucial for preparing the data for model training and testing. The output generated from this step is shown below. For model development, 80% of the dataset is allocated for training purposes, while the remaining 20% is reserved for testing, ensuring a robust evaluation of model performance.

The combination of Gamma Correction and CLAHE demonstrates significant improvements in enhancing the read- ability and preserving the authenticity of degraded historical documents. The substantial gains in SNR and CII validate the effectiveness of this approach, making it a valuable tool for archivists, historians, and researchers involved in the preservation of cultural heritage.

TABLE I. Comparison of Gamma Correction with Fusion of Gamma + CLAHE

Metric	Gamma Correction	Gamma + CLAHE
SNR (dB)	15	25
CII	1.5	3.0

From Table I, numerical values demonstrate that the combination of Gamma Correction with CLAHE significantly outperforms Gamma Correction alone. The higher SNR (25 dB compared to 15 dB) indicates that the combined method more effectively reduces noise, resulting in a clearer image. Additionally, the higher CII (3.0 versus 1.5) shows a more substantial improvement in contrast, making the text more legible and the document more visually appealing. The higher SNR values indicate improved signal clarity with reduced noise, while higher CII values reflect enhanced contrast between text and background. The comparative analysis between Gamma Correction and the proposed Gamma-CLAHE fusion method has also been elaborated to highlight the improvement achieved by the proposed enhancement technique.

The CII was computed using the standard global contrast improvement formula:

$$\text{CII} = \frac{C_{enh}}{C_{Orig}} \tag{1}$$

C_{enh} and C_{orig} denote the root-mean-square contrast of the enhanced and original images respectively.

The SNR was computed using the standard image-based formulation:

$$\text{SNR (dB)} = 10\log10\left(\frac{\sum_{i,j} I_{enh}(i,j)^2}{\sum_{i,j}[I_{enh}(i,j) - I_{orig}(i,j)^2]}\right) \tag{2}$$

where $I_{enh}(i,j)$ represents the pixel intensity of the enhanced image and $I_{orig}(i,j)$ represents the pixel intensity of the original degraded image.

Fig. 6 demonstrates an enhanced version using Gamma and Contrast Limited Adaptive Histogram Equalization (CLAHE) techniques.



Fig. 6. Enhanced handwritten text using Gamma and CLAHE.



Fig. 7. Character segmentation result.

Fig. 7 represents the result of a character segmentation process. Each character in the image is identified and enclosed within red bounding boxes, effectively isolating individual characters for further analysis. The characters appear to be stylized or handwritten, with the bounding boxes highlighting the variability in their shapes and sizes. This segmentation is utilized to facilitate accurate Optical Character Recognition (OCR). The objective is to ensure each character is distinctly captured for subsequent text processing tasks.

The enhancement process was carefully optimized through extensive experimentation on a dataset of 16,425 degraded Kannada manuscript images, and the following parameter values were finalized based on quantitative evaluation of Signal-to-Noise Ratio (SNR) and Contrast Improvement Index (CII): $\gamma = 1.1$, tile size = 8 × 8, and clip limit = 2.5 yielded the most consistent improvement across diverse manuscript samples, enhancing readability while preserving the authenticity and fine texture of the script.

The standard OCR evaluation metrics is to provide a comprehensive performance analysis of the proposed Gamma-CLAHE enhancement combined with U-Net segmentation and CNN-based recognition pipeline as shown in Table II.

TABLE II. OCR EVALUATION METRICS

Method	Character Accuracy (%)	CER	WER
Without Enhancement	81.2	0.188	0.274
Gamma Only	86.5	0.135	0.201
Gamma + CLACHE	93.4	0.066	0.109

The results clearly indicate that the proposed fusion method reduces recognition errors substantially while improving overall character-level and word-level accuracy.

The segmentation performance should be validated using standard quantitative metrics such as Intersection over Union (IoU) and Dice Coefficient to ensure objective evaluation as shown in Table III.

TABLE III. SEGMENTATION PERFORMANCE METRICS

Method	IoU	Dice Coefficient	Pixel Accuracy
Without Enhancement	0.78	0.84	89.6%
Gamma Only	0.84	0.89	92.1%
Gamma + CLACHE	0.91	0.95	96.3%

The results demonstrate that the proposed Gamma-CLAHE fusion significantly improves segmentation performance by enhancing contrast and text clarity prior to U-Net processing.

TABLE IV. COMPARISON WITH EXISTING LITERATURE

Method	Technique Used	Character Accuracy (%)	IoU	Limitation
Wang *et al.* [2]	Gamma Correction	86.5	0.84	Limited local detail preservation
Yuan *et al.* [11]	CLAHE-based enhancement	88.1	0.86	Noise amplification in degraded regions
Yang *et al.* [8]	Deep learning OCR methods	90.2	0.88	Not optimized for degraded Kannada manuscripts
Proposed Method	Gamma + CLAHE + U-Net	93.4	0.91	-

Table IV demonstrates that the inclusion of quantitative metrics such as Character Accuracy and IoU provides a more objective comparison with existing methods and demonstrates the effectiveness of the proposed enhancement and segmentation framework.

VI. CONCLUSION

The proposed method effectively enhances the quality of historical Kannada manuscripts through a combination of Gamma Correction and CLAHE. This dual enhancement strategy leverages the strengths of both techniques, significantly improving readability while maintaining the authenticity of the deteriorated documents. The process ensures that tiny details and local contrast are suitably increased without introducing artifacts or excessive noise, and the overall brightness and contrast are adjusted for better visual clarity.

The improved image quality facilitates character segmentation, a crucial stage in the OCR pipeline, particularly for complex scripts like Kannada that include diacritical marks and intricate characters. Advanced neural network models, such as Convolutional Neural Networks (CNNs), can then successfully segment and recognize characters even in challenging conditions such as low resolution or poor lighting.

The preprocessing techniques employed for noise reduction and image enhancement, followed by effective segmentation algorithms and robust feature extraction methods, contribute to the reliable recognition of Kannada characters. This comprehensive approach addresses the unique challenges posed by the complex morphology and diverse writing styles of Kannada script. The synergy between advanced neural network-based character segmentation and image enhancement techniques results in

more reliable and accurate OCR systems. These advancements will significantly impact the usability and accessibility of Kannada script in the digital age.

In summary, the combination of Gamma Correction and CLAHE has proven to be an invaluable resource for historians and archivists, validated by significant increases in SNR and CII. This comprehensive approach for efficient segmentation and accurate recognition of Kannada characters advances the field of OCR systems tailored for the Kannada language.

Conflict of Interest

The authors declare no conflict of interest

Author Contributions

ALS is responsible for methodology, and comparison of proposed work with other works and AAD is responsible for introduction, literature survey and results. All authors had approved the final version.

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