Original Article
ISSN (Online): 2582-7472

ShodhKosh: Journal of Visual and Performing Arts
May 2024 5(5), 473–479

REVIEW OF GAMMA CORRECTION TECHNIQUES IN DIGITAL IMAGING

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ABSTRACT

Gamma correction is a crucial process in digital imaging systems, aiming to compensate for the nonlinear relationship between input signal and luminance output. This paper provides a comprehensive review of various gamma correction techniques employed in digital imaging systems. It covers both traditional methods and recent advancements, outlining their principles, advantages, and limitations. The review encompasses techniques such as power-law gamma correction, piecewise gamma correction, and adaptive gamma correction. Furthermore, it discusses the influence of gamma correction on image quality metrics, color reproduction, and perception. The paper also explores the challenges and future directions in gamma correction research, including the development of real-time adaptive algorithms and integration with machine learning approaches. Overall, this review serves as a valuable resource for researchers, engineers, and practitioners in the field of digital imaging systems, offering insights into the current state-of-the-art techniques and potential avenues for further advancements.

Keywords: Adaptive Gamma Correction (AGC), Adaptive Histogram Equalization (AHE), Contrast Enhancement (CE), Global and Local Adaptive Gamma Correction (GLAGC).

DOI
10.29121/shodhkosh.v5.i5.2024.1902

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

1. INTRODUCTION

Gamma correction is a fundamental process in digital imaging systems, crucial for achieving accurate and perceptually pleasing reproduction of images and videos. It compensates for the nonlinear relationship between the input signal values and the resulting luminance output, which is inherent in many imaging devices and display technologies. The nonlinear gamma correction curve adjusts the brightness levels to match the human visual system's response, ensuring that the displayed images appear natural and visually consistent.

Over the years, various gamma correction techniques have been developed to address different challenges and requirements in digital imaging applications. Traditional methods, such as power-law gamma correction, have been widely used for their simplicity and effectiveness. However, with the advancement of technology and the increasing demand for high-quality imaging, new approaches, including adaptive gamma correction and piecewise gamma correction, have emerged to provide more sophisticated and flexible solutions.

A comprehensive review of gamma correction techniques in digital imaging systems. It aims to provide an overview of the principles, advantages, and limitations of different gamma correction methods. Additionally, the review discusses the impact of gamma correction on image quality metrics, color reproduction accuracy, and visual perception. Furthermore, it explores the challenges existing techniques face and identifies potential directions for future research and development in gamma correction. In this paper, we are going to provide an overview of widely used Gamma correction methods

2. METHODS OF GAMMA CORRECTIONS

Somasundaram and P. Kalavathi (2009) address the challenge posed by the luminance non-linearity inherent in many medical imaging devices, which can impact the efficacy of subsequent image processing techniques. Recognizing the importance of image enhancement as a preprocessing step in medical image analysis, the authors propose a novel automatic method for contrast enhancement based on gamma correction.

Their method involves calculating a global gamma value using the image's cumulative histogram, without requiring specific knowledge of the imaging device. The proposed technique is evaluated using MR brain images and CT scan images, with performance comparison against three popular contrast enhancement techniques using the Peak Signal-to-Noise Ratio (PSNR) measure (Neha Chauhan et. al. 2013).

The authors report that their method yields higher PSNR values compared to existing techniques such as Histogram Equalization (HE), Intensity Adjustment (IA), and Adaptive Histogram Equalization (AHE). They highlight the simplicity and efficiency of their approach, suggesting its potential as a straightforward preprocessing technique for medical image processing. Moreover, they suggest that this method could easily be extended to general grayscale images, further enhancing its applicability beyond medical imaging contexts. Overall, the paper presents a promising approach to addressing contrast enhancement challenges in medical image analysis, offering potential improvements in image quality and subsequent processing outcomes.

Pedram Babakhani et al. (2015) present an innovative approach for automatic gamma correction based on the average brightness of images. Gamma correction is a crucial preprocessing step in image processing, especially in scenarios where the imaging device or environmental lighting conditions are suboptimal. The proposed technique estimates the gamma correction without prior knowledge of these factors, leveraging the average brightness of the image.

The method involves determining the appropriate gamma value by transforming the average brightness to the center of the histogram. This estimation is achieved through simple calculations based on logarithmic functions. The paper discusses the advantages of using average brightness as a representative sample for estimating gamma, highlighting its simplicity and efficiency.

Experimental results demonstrate the effectiveness of the proposed method in enhancing image quality, particularly in terms of preserving details and improving dynamic range. Comparative analysis against existing techniques reveals that the proposed method achieves comparable or superior results while requiring significantly less execution time.

Furthermore, the paper emphasizes the potential practical applications of the proposed method, suggesting its implementation as an ASIC (Application-Specific Integrated Circuit) in photography or printing devices. This implies scalability and adaptability to real-world image processing systems, ehancing their performance and efficiency.

Pedram Babakhani et al. propose a method that estimates a power that transports the average amount of brightness to the center of the histogram. This method extends the estimated power for gamma correction. This power can be chosen as global gamma for gamma correction. We suppose a gamma which changes the average of brightness to ½, then gamma is estimated based on the following equations:

$$X^{y}=1/2$$

$$Y=\log_{x} ½$$

$$Y = \log_{10} ½ / \log_{10}x$$

$$Y = -0.3 / \log_{10}x$$

X is average brightness and X ∈ [0 1]. In the equations, 1/2 is the center of histogram brightness which is global for any format.

Overall, the paper contributes a valuable technique for automatic gamma correction, offering a balance between simplicity, efficiency, and effectiveness in enhancing image quality. Its potential for practical implementation makes it a promising solution for various image-processing applications.

Anitta K Varghese (2015) introduces an innovative technique that combines weighted averages of the original image, histogram equalization, and gamma correction to enhance image contrast while maintaining brightness levels. This method addresses the common issue of over- or under-enhancement, which can lead to unnatural images. The authors validate their approach through an extensive experimental study using metrics such as absolute mean brightness error (AMBE), peak signal-to-noise ratio (PSNR), entropy, and structural similarity index matrix (SSIM). Results indicate that the proposed method outperforms existing techniques in both brightness preservation and contrast enhancement. The method's strengths lie in its ability to maintain image brightness and improve visual quality across various conditions, making it versatile for multiple applications, including digital photography and medical imaging. However, the paper does not discuss the computational complexity or execution time, which are crucial for practical use, especially in real-time applications. Overall, this study provides a significant contribution to image processing, offering a balanced and effective solution for enhancing image quality. Future work could focus on optimizing the method for real-time applications and exploring integration with machine learning to improve adaptability and performance further.

The results section compares various contrast enhancement techniques, specifically focusing on histogram equalization, brightness-preserving bi-histogram equalization, and the proposed adaptive gamma correction system. These methods are evaluated using a range of images and assessed with several image quality measurement tools, including Absolute Mean Brightness Error (AMBE), Peak Signal-to-Noise Ratio (PSNR), Entropy, and Structural Similarity Index Matrix (SSIM).

Shanto Rahman et.al. (2016) provides a comprehensive solution to the problem of image contrast enhancement. The adaptive nature of the proposed gamma correction technique is a significant advancement over traditional methods, as it customizes the enhancement process based on the specific characteristics of each image. This leads to more visually pleasing results, which is well-supported by both qualitative and quantitative evaluations in the study.

The classification of images into categories based on statistical data is a notable innovation, allowing the enhancement process to be more targeted and effective. Moreover, the paper highlights the practicality of AGC by demonstrating its low computational complexity, making it suitable for integration into real-time applications.

In conclusion, the paper successfully presents a novel and effective method for image enhancement, addressing the limitations of existing techniques and offering a robust solution for various applications. The thorough evaluation and promising results make a strong case for the adoption of AGC in image processing tasks.

Yuanping Zhou et al. (2019) presents an innovative approach to enhance the quality of medical images, which is crucial for accurate diagnosis and treatment. The authors propose an improved version of the World Cup Optimization (WCO) algorithm, integrated with Gamma correction, to optimize image contrast. This method addresses the limitations of traditional techniques that often fail to manage the complexities inherent in medical imaging. By optimizing the Gamma parameter based on entropy and edge content, the proposed method ensures better image clarity and detail. The paper includes a thorough evaluation, comparing the proposed method against five state-of-the-art techniques using various performance metrics, such as contrast, CNR, EME, WPSNR, and homogeneity. The results indicate that the new approach significantly enhances image quality compared to existing methods. This advancement holds promise for real-world applications in medical diagnostics, potentially improving patient outcomes. However, further validation with a broader range of medical images and a detailed analysis of computational efficiency for real-time application could strengthen the findings. Overall, the paper contributes significantly to the field of medical image processing by offering a robust and effective solution for contrast enhancement.

Farah Shabana et al. (2020) explore a novel approach to enhance image details and information content using an adaptive gamma correction technique optimized by swarm optimization. The primary goal is to improve image contrast effectively and efficiently. Gamma correction is known for maintaining mean brightness and producing natural-looking images by selecting an optimal gamma value. This research leverages Particle Swarm Optimization (PSO) to determine this optimal gamma value, aiming for a rapid and accurate solution. The authors compare their proposed method with Linear Contrast Stretching (LCS) and Histogram Equalization (HE), focusing on the number of iterations required.

Simulation results indicate that the swarm optimization-based method significantly improves image contrast and enriches information content more quickly than the traditional techniques.

The study also introduces the Firefly Optimization technique, applying it within the adaptive gamma correction framework. By optimizing the gamma value for various image resolutions, the method enhances image clarity and reduces the number of iterations needed. Testing across different datasets reveals that the proposed algorithm outperforms others in terms of image quality, information retention, and computational efficiency. This advancement is particularly notable for its ability to optimize both simple and complex images swiftly, making it a valuable contribution to the field of image processing and enhancement.

Wenyong Yu, et al. (2021) introduce an innovative algorithm designed to tackle the common issues of low contrast and uneven illumination in real-world images, which can significantly hinder detail visibility and pattern recognition. The proposed method, GLAGC (Global and Local Adaptive Gamma Correction), leverages Retinex theory and employs discrete wavelet transform to extract illumination characteristics from images.

The algorithm introduces two novel features: the spatial luminance distribution feature for adaptive gamma correction of locally uneven lighting, and the global statistical luminance feature for global low illumination adjustment. These features are derived from a training set with varying illumination conditions, using the maximum entropy criterion to estimate the relationship between image exposure levels and these features. This dual-gamma correction approach allows the algorithm to adaptively enhance images based on their specific illumination characteristics.

Additionally, the method includes a process for preserving edge smoothness in the high-frequency subband and an adaptive stabilization factor to reduce low-illumination noise following wavelet reconstruction. Experimental results validate the effectiveness of GLAGC, showing that it achieves comparable or superior results in terms of efficiency and quality compared to state-of-the-art methods. The algorithm not only enhances image adaptability and naturalness but also demonstrates promise for automatic gamma factor determination for specific camera setups by learning from a limited number of captured images, making it a significant advancement in the field of image processing and illumination correction.

Navleen S Rekhi (2022), the authors address the challenge of image degradation under poor lighting conditions or improper acquisition settings, leading to low contrast, poor brightness, and overall poor visual quality. To address this issue, the paper proposes a novel method based on gamma correction with a self-adaptive value tailored to the intensity scale of the image.

The proposed approach involves transforming the image to the HSI (hue, saturation, intensity) color space and applying a multi-scale wavelet transform to the intensity component. The gamma scale is computed using a combination of a reformed scale constant from the logarithm function and Minkowski distance measure. Additionally, a wavelet-based denoising technique is employed to suppress high noise coefficients, further enhancing image quality.

Evaluation of the proposed method focuses on visual appearance, information content, signal-to-noise ratio, and universal image quality index. Experimental results demonstrate the efficacy of the approach, particularly in improving visibility, reducing noise, and enhancing contrast in low-visibility images with non-uniform illumination. Compared to histogram equalization and other recent algorithms, the self-adaptive gamma scale proves superior in retaining texture features.

The study concludes that the proposed EAGL algorithm offers fast adaptability to variations in shadow from moderately to low-illuminated images, resulting in effective visibility and improved image quality. This highlights the significance of the method in enhancing images affected by poor lighting conditions, ultimately contributing to better visual perception and interpretation.

Jong Ju Jeon and Il Kyu Eom (2023) present an efficient and fast method for enhancing low-light images. Their approach utilizes an atmospheric scattering model based on an inverted low-light image to derive a transmission map, which is then converted into a function of the average and maximum values of the original image using the gamma correction prior. This conversion helps overcome the challenge of estimating the saturation of the original image. Additionally, the authors propose a pixel-adaptive gamma value determination algorithm to prevent under- or over-enhancement.

The proposed method does not require training or refinement processes, resulting in computational simplicity. Simulation results demonstrate that their low-light enhancement scheme outperforms state-of-the-art approaches in terms of both computational simplicity and enhancement efficiency.

In summary, the paper introduces a spatially adaptive transmission map derived from mixed color spaces, utilizing the gamma correction prior to efficient low-light image enhancement. The proposed method demonstrates promising performance across various low-light scenarios and outperforms existing approaches. The authors also suggest avenues for future research, including improving parameter estimation accuracy and exploring machine learning-based enhancement techniques.

3. TABULAR SUMMARY

In this section, we have conducted a tabular comparison of all the methods discussed thus far. This comparison primarily aims to summarize the advantages and disadvantages of the various gamma correction techniques

Authors	Year	Challenge	Solution	Evaluation	Contribution
Somasundaram and P. Kalavathi	2009	Luminance non-linearity in medical imaging devices	Gamma correction using cumulative histogram	Higher PSNR than HE, IA, AHE on MR brain and CT scan images	Simple and efficient method for medical and general grayscale images, enhancing preprocessing steps
Pedram Babakhani et al.	2015	Poor lighting and suboptimal imaging conditions	Gamma correction based on average brightness	Improved image quality and dynamic range, faster execution time compared to existing techniques	Practical method with potential ASIC implementation for photography and printing devices
Anitta K Varghese	2015	Over- or under-enhancement in contrast and brightness preservation	Weighted averages, histogram equalization, gamma correction	Outperformed existing techniques in AMBE, PSNR, entropy, SSIM metrics	Versatile method for digital photography and medical imaging, though real-time performance not discussed
Shanto Rahman et al.	2016	Need for adaptive image contrast enhancement	Adaptive gamma correction based on image characteristics	Effective enhancement with low computational complexity, suitable for real-time applications	Robust solution for image enhancement with significant improvements in visual quality
Yuanping Zhou et al.	2019	Complexities in medical imaging for accurate diagnosis	Improved WCO algorithm with gamma correction	Superior performance in contrast, CNR compared to five state-of-the-art techniques	An effective method for medical image contrast enhancement, improving diagnostic accuracy
Farah Shabana et al.	2020	Enhancing image details and information content	PSO and Firefly Optimization in Adaptive Gamma Correction	Improved contrast and information retention, faster than LCS and HE	Efficient method for rapid and accurate enhancement of both simple and complex images
Wenyong Yu et al.	2021	Low contrast and uneven illumination in real-world images	GLAGC algorithm using Retinex theory and wavelet transform	Effective in various illumination conditions, superior to state-of-the-art methods	Advanced adaptive illumination correction method applicable to diverse imaging scenarios
Navleen S Rekhi	2022	Image degradation under poor lighting	Self-adaptive gamma correction with multi-scale	Superior visibility, noise reduction, and contrast enhancement	Fast and effective method for enhancing poorly lit

		and improper acquisition	wavelet transforms	compared to recent algorithms	images, improving visual perception
Jong Ju Jeon and Il Kyu Eom	2023	Efficient low-light image enhancement	Atmospheric scattering model with gamma correction prior	Outperformed state-of-the-art in computational simplicity and enhancement efficiency	Promising low-light enhancement method with potential for future improvements in parameter estimation

4. CONCLUSION

Recent advancements in gamma correction techniques underscore the significance of adaptive methods to address imaging challenges across various fields. Adaptive gamma correction dynamically adjusts based on image content, leading to enhanced quality and visibility under diverse lighting conditions. Studies, such as those by Somasundaram and Kalavathi, and Shanto Rahman, highlight the effectiveness of content-aware adjustments in maintaining naturalness and improving image details.

Efficiency and simplicity are critical, ensuring high-quality enhancement suitable for real-time applications. Pedram Babakhani et al., and Jong Ju Jeon and Il Kyu Eom emphasize computationally efficient methods that do not require extensive resources. The use of advanced optimization techniques like Particle Swarm Optimization and Firefly Optimization, as demonstrated by Farah Shabana et al., further enhances adaptability and performance.

These methods find applications in medical imaging, low-light conditions, and general photography, showcasing their versatility. Validated through metrics like PSNR, AMBE, SSIM, and entropy, these techniques prove effective in improving contrast, detail preservation, and overall image quality.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

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