Image Enhancement Techniques: A Review of SVD, DWT, and Hybrid Methods

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ABSTRACT

Image enhancement is a crucial aspect of digital image processing, aiming to boost the visual quality of an image or to provide a more suitable representation for further analysis. This review examines a variety of contemporary and traditional enhancement Holistic approach and Frequency domain techniques, and their combined implementations. These techniques are assessed for their effectiveness in areas such as medical imaging, satellite data evaluation, surveillance systems, and applications related to night-time driving. The strengths and weaknesses of each method are discussed, backed by experimental results and performance metrics. Furthermore, the usefulness of MATLAB as a platform for prototyping and evaluation is emphasized, highlighting its importance in the development and testing of image enhancement algorithms.

KEYWORDS

Image Enhancement, Singular Value Decomposition (SVD), Discrete Wavelet Transform (DWT) Discrete Cosine Transform (DCT).

INTRODUCTION

Image enhancement and reconstruction is an essential process aimed at improving image quality of low- contrast image in digital analysis [1]. It serves as a foundational pre-processing step across a range of applications, including medical diagnostics, satellite imagery, and intelligent transportation systems. The primary objective of enhancement is to improve image features such as contrast, sharpness, and edges while minimizing noise, all while preserving brightness to support subsequent processing and decision-making activities. Modern image enhancement techniques have shifted from traditional spatial domain methods to more sophisticated higher-order transform domain approaches. Among these, Singular Value Decomposition (SVD) [16] has emerged as a key mathematical tool due to its effectiveness in separating luminance data from geometric structure. SVD-based enhancement, as demonstrated by Demirel and Anbarjafari [11], can adjust image intensity levels without compromising the integrity of the visual content. Another significant advancement is the use of Discrete Wavelet Transform (DWT), which decomposes images into frequency sub-bands to allow for localized enhancement of image details. DWT proves particularly effective in applications like watermarking and enhancing images taken in low-light conditions, as explored in the research by Kallel et al. [7] and Bhandari et al. [8]. Hybrid approaches that combine

SVD and DWT leverage the strengths of both methods, offering robust enhancement while maintaining structural integrity. Such techniques are particularly effective in challenging scenarios, including the enhancement of dark satellite images [8], medical computed tomography scans [7], and images captured during night driving [6]. Additionally, techniques like adaptive gamma correction and knee transfer functions further enhance quality by dynamically adjusting to the characteristics of the image. Edge enhancement methods also play a critical role in applications requiring precise boundary detection, particularly those utilizing extended gradient operators with singular value properties [5]. MATLAB has proven to be a valuable platform for simulating these algorithms, providing strong analytical capabilities and efficient prototyping tools [12].

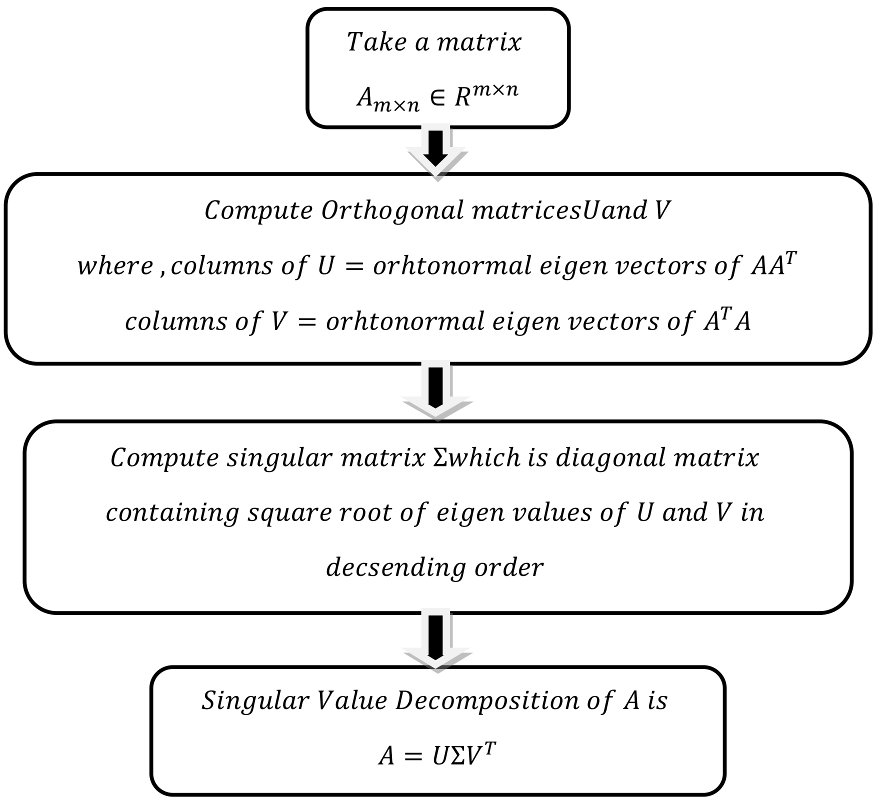

Figure 1: Flowchart of Singular Value Decomposition (SVD)

REVIEW OF PAPERS:

Demirel, H. et al. [11] presented a new contrast enhancement method named Singular Value Equalization (SVE), which makes use of the singular value decomposition (SVD) of images to maintain brightness and histogram shape and improve visual quality.

In contrast to the distortion and loss of crucial data in traditional GreyscaleHistogram Equalization (GHE), SVE equalizes the singular value matrix and regenerate the image in a way that does not lose the important properties of the original image, thus delivering sharper and more natural images. The authors empirically verify their method visually and quantitatively with the Kullback-Leibler distance (KLD) measure, showing that SVE maintains more information and provides improved contrast enhancement than GHE.

In the paper by Fahad, S. at al. [1] authors developed a Modified singular value decomposition (MSVD) technique to improve low-contrast and low-resolution CCTV images. This MSVD method performed better than existing singular value decomposition, discrete wavelet transform-singular value decomposition, and stationary wavelet transform techniques. The authors evaluated the performance of their approach using image entropy, peak signal to noise ratio (PNSR), mean square error (MNE), contrast measurement, time computation, structure similarity index measurement, and image enhancement factor. The proposed method for improving CCTV images involves several steps: acquiring CCTV video recordings, converting the videos into frames, extracting features from high and low-quality images, applying SVD to both types of images, transforming these images into three matrices using SVD, setting athreshold at the diagonal value of the Σ matrix, using MSVD, replacing good quality image values with the diagonal values of low-quality images, and finally producing an enhanced image. The study focuses on human facial images obtained from low-quality CCTV video streams. The evaluation metrics include Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), entropy, contrast, time computation, structure similarity index measurement, and image enhancement factor. This research presents a promising method for enhancing low-quality CCTV images, supported by solid theoretical grounding and thorough validation. Its simplicity, along with improvements over existing methods, makes it a significant addition to image enhancement and security. Addressing limitations, such as expanding to colour images and various real-world conditions, could enhance its practical impact.

Atta, R., et al. [10] presented a new image enhancement technique that uses Discrete Cosine Transform (DCT) pyramid decomposition and Singular Value Decomposition (SVD) to enhance low-contrast satellite images effectively without degrading the brightness and natural look. In contrast to conventional histogram equalization and previous SVD-based techniques, which tend to lead to over-enhancement or inferior contrast enhancement, the new approach computes a weighted sum of singular matrices derived from the low sub band of the DCT pyramid and its histogram-equalized counterpart. The method enhances contrast, enhances edges, and preserves the natural appearance of the image without causing visual artifacts. Experimental outcomes, both subjective evaluation and objective measurements such as entropy, enhancement measure (EME), and absolute mean brightness error (AMBE), show that the approach well surpasses traditional methods like GHE, LHE, SVE, DWT-SVD, and DCT-SVD, particularly for mid-brightness images. In summary, this study presents a computationally efficient and visually better solution for satellite image enhancement from low-contrast images.

Atta, R., et al. [9] introduced an improved image enhancement technique. This method combines Singular Value Decomposition (SVD) with Global Histogram Equalization (GHE) to enhance image contrast while keeping brightness intact. Unlike traditional SVD-based methods that merely scale singular values and often struggle with mid-range brightness images, the proposed technique uses a weighted sum of singular matrices from the original and adjusted images. This results in a more natural-looking output with improved contrast and fewer visual artifacts. The paper shows through visual comparisons and objective metrics like entropy, standard deviation, enhancement measure (EME), and absolute mean brightness error (AMBE) that the method surpasses classical approaches like GHE, Local Histogram Equalization (LHE), and other SVD variants in both contrast enhancement and brightness preservation. Overall, this study significantly contributes to image processing by effectively balancing contrast enhancement with a natural appearance in low-contrast images.

Bhandari A. et al. [8] described a novel approach to dark and low-contrast satellite image enhancement based on the implementation of a knee transfer function and gamma correction in a DWT–SVD framework. The authors successfully complement the weaknesses of standard enhancement methods, including Gamma correction and standard histogram equalization, by introducing an adaptive solution that maintains edge details alongside enhancing visibility and contrast overall, particularly in adverse low-light environments. The method is properly outlined and relies on multi-scale and multi-dimensional signal processing methodologies. The DWT usage provides good separation of image components into various frequency bands, and SVD application on the low-frequency subband captures the illumination detail quite well. With the adaptive intensity transformation through knee transfer functions and gamma correction. The technique smartly increases the tonal range without causing any artifacts or losing significant edge information. Large-scale quantitative tests based on measures like PSNR, SSIM, FSIM, MSE, and measures of fidelity establish the superiority of the new method over existing work, both traditional methods and state-of-the-art methods. The results reveal a dramatic improvement in image quality, especially for images with extremely low mean intensities, affirming the effectiveness of the approach for dark satellite images. Nevertheless, the paper might be improved with more elaboration on computational complexity and processing time, which are significant factors for real-time systems. While the technique demonstrates satisfactory results on multispectral satellite imagery, validation on various datasets, sensor types and environmental conditions would enhance the claims of robustness. In general, this work is a significant contribution to the satellite image enhancement domain as it delivers a flexible and robust solution that can recover details from very dark images. It holds practical applicability to remote sensing, surveillance, and environmental monitoring where image quality matters.

Kallel, F., et al. [7] introduced a unique adaptive gamma correction algorithm that works with discrete wavelet transform and singular value decomposition (DWT-SVD-AGC) to enhance the contrast of non-contrast CT images. This method addresses the limitations of traditional contrast enhancement techniques, which often require manual adjustments and can lose important image details. The proposed method decomposes the input image into multiple frequency sub-bands using DWT, applies SVD to the low-low (LL) sub-band to adjust its singular values for better contrast, and dynamically changes the gamma correction parameters based on the statistical properties of the processed image. Experimental results show that this algorithm outperforms existing techniques, including GHE and other DWT-based methods, in enhancing overall image visibility and detail preservation, especially in low-contrast medical images that are crucial for accurate diagnosis. The approach's automatic parameter adjustment increases its adaptability and applicability across different CT scan datasets, providing a promising solution in medical image processing with potential benefits in diagnostic accuracy without introducing artifacts or excessively brightening the images. More validation on larger and more varied image datasets is essential to fully confirm its clinical effectiveness and generalizability.

Jiali Tang et al. [5] introduced a new method for edge detection by combining singular value decomposition (SVD) with gradient operators. It extends the Sobel operator to eight directions. Recognizing the weaknesses of traditional gradient-based methods, particularly their sensitivity to noise, the authors utilize the stability and structural features of singular values within local image blocks to improve detection reliability. This method addresses a major challenge in image processing: accurately identifying edges in noisy conditions while maintaining computational efficiency. The proposed methodology includes representing the original image as a matrix and applying singular value decomposition (SVD) to local image blocks around each pixel. This helps extract essential structural features. By breaking each block into singular values, the algorithm uses the maximum singular value to highlight edge areas, as sudden changes in local image structure influence these values. To reinforce edge detection reliability, the gradient information of each pixel is evaluated based on the stability of the singular values, extended to eight directions with specific convolution templates. The gradient thresholds are set adaptively by combining global and local statistical analyses using image histograms and Bernsen's method, enabling accurate differentiation of edge pixels from noise or background. Pixels that exceed the adaptive gradient threshold are marked as edges, yielding a detailed edge map that reduces noise while preserving edge integrity.

Razak, M. K. A., et al. [3], proposed a secure and solid watermarking method. This approach combines a modified non-separable Haar wavelet transform (NSHWT), singular value decomposition (SVD), Arnold's cat map scrambling, and the Rabin-p cryptosystem to embed secret binary or color watermarks in color images. By replacing traditional DWT with a more effective NSHWT and embedding watermark data in the LL sub-band using SVD, the method ensures strong invisibility and resilience against image processing and geometric attacks. Scrambling parameters encrypted with the Rabin-p cryptosystem enhance security, making unauthorized extraction of the watermark difficult. Extensive evaluations using PSNR, SSIM, and NC metrics across various image attacks show that the proposed method significantly outperforms existing DWT-SVD techniques in robustness, efficiency, and watermark capacity, making it a highly effective solution for secure digital image watermarking.

Shen, J., et al. [6], presented an innovative Retinex-based image enhancement method called Adaptive Attenuation Quantification Retinex (AAQR). This method aims to improve driver face detection in challenging nighttime lighting. It adjusts image brightness dynamically while keeping facial detail, leading to higher detection accuracy compared to many state-of-the-art algorithms. Tested on 900 images across three lighting types (Up-Down, Left-Right, and Mixed), AAQR achieved detection rates of up to 91% with a balanced computational cost (0.25 seconds per image), making it fit for near-real-time applications in driver monitoring systems. While AAQR outperformed several methods under mixed lighting, its performance in edge-case conditions was somewhat limited, and the study would benefit from using a larger dataset and potential integration with infrared techniques. Overall, this paper adds significant value to automotive safety and driver assistance systems by enhancing fatigue detection capabilities at night.

Ijemaru, G. K., et.al [12], delivered a compelling evaluation of MATLAB's image processing techniques, firmly establishing its superiority over traditional methods. Key advantages include ease of implementation, streamlined debugging, enhanced data analysis, and impressive visualization capabilities. MATLAB's robust functionality enables advanced operations such as image cropping, denoising, blur removal, and sharpening, with simulations effectively showcasing its prowess. The study incorporates empirical models that employ 2D-DCT for image compression and feature extraction, underscoring MATLAB’s exceptional suitability for tasks like color detection, segmentation, and recognition. Furthermore, it surveys existing research on MATLAB applications in areas like medical engineering, image enhancement, and object classification, demonstrating its incredible versatility. The system design leverages MATLAB’s strengths in matrix processing, with practical code implementations facilitating a variety of image transformations. Overall, this paper convincingly presents MATLAB as a powerful, efficient, and accessible platform for an extensive array of digital image processing applications, providing invaluable insights for both researchers and practitioners alike.

Sikandar, S. et al. [2] presented an effective hybrid approach to content-based image retrieval (CBIR) by combining deep learning and machine learning methods. They use transfer learning with two pre-trained convolutional neural networks, ResNet50 and VGG16, to extract detailed feature representations from images. These features are then merged to improve the system's ability to differentiate images, tackling common issues like the semantic gap in CBIR. One of the key strengths of this study is the feature fusion, which takes advantage of both models to capture various visual traits, potentially leading to more accurate image retrieval. Additionally, using KNN with Euclidean distance as a similarity measure makes the system straightforward and efficient, making it suitable for real-world applications. The inclusion of a web interface demonstrates the system's practicality and usability. Evaluating the approach across multiple datasets, including natural and specialized images, shows its robustness and versatility. Achieving a reported 100% precision demonstrates the system's effectiveness; however, more details about dataset sizes and experimental conditions would strengthen the findings. Future work could focus on scalability, robustness in varying image conditions, and comparisons with other top methods for better contextualizing performance improvements. This study offers valuable insights into hybrid CBIR systems, showing that effective feature fusion and transfer learning can greatly enhance image retrieval accuracy. It marks a noteworthy step toward smarter and more efficient multimedia retrieval systems.

CONCLUSION

This review highlights the diversity and depth of contemporary image enhancement approaches, especially those leveraging SVD, DWT, and their hybridizations. The studies demonstrate significant progress in enhancing low-quality, low-contrast, and high-noise images across fields such as surveillance, medical imaging, satellite imagery, and automotive systems. Tools like MATLAB and techniques like adaptive gamma correction and multi-directional edge detection show the versatility and scalability of modern image enhancement algorithms. Future research should continue integrating classical methods with AI-driven approaches for robust, real-time enhancement systems adaptable to diverse and dynamic imaging conditions.

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