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High-Quality Evaluation for Invisible Watermarking Based on Discrete Cosine Transform (DCT) and Singular Value Decomposition (SVD)

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Abstract. In this research, we propose an innovative approach that integrates Discrete Cosine Transform (DCT) and Singular Value Decomposition (SVD) to enhance the quality and security of digital images. The purpose of this technique is to embed imperceptible watermarks into images, preserving their integrity and authenticity. The integration of DCT allows for an efficient transformation of image data into frequency components, forming the basis for embedding watermarks that are nearly invisible to the human eye. In this context, SVD offers an advantage by separating singular values and corresponding vectors, facilitating a more sophisticated watermarking process. The quality evaluation using metrics such as MSE, PSNR, UQI, and MSSIM demonstrates the effectiveness of this approach. Low average MSE values, ranging from 0.0058 to 0.0064, indicate minimal distortion in the watermarked images. Additionally, high PSNR values, ranging from 67.20 dB to 67.22 dB, affirm the high image quality achieved after watermarking. These results validate that the integration of DCT and SVD provides a high level of security while maintaining optimal visual quality in digital images. This approach is highly relevant and effective in addressing the challenges of image protection in this digital era.

Keywords: Image Quality, Image Watermarking, DCT, SVD

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1. Introduction

Image quality is paramount, profoundly impacting its effectiveness and the conveyed visual impression [1]. However, the rise of sophisticated editing tools in our technology-driven era has escalated the threat to image integrity, making image manipulation effortless. To counter this challenge, digital watermarking has emerged as a promising solution. By inserting imperceptible watermarks into images as unique identifiers or authentication proofs, digital watermarking safeguards images against unauthorized modifications and ensures their authenticity [2]. Thus, the use of digital watermarking becomes highly relevant in enhancing image quality and preserving its integrity, especially in a time where visual information holds a central role across diverse sectors, spanning from security to copyright and identification purposes [1], [3]. In addition to traditional digital watermarking, invisible watermarking stands out as an advanced technique that offers unique advantages in ensuring image integrity and security [4]. Unlike visible watermarking, invisible watermarking necessitates access to the original, unmarked image during watermark extraction [5]. This additional information allows for the implementation of more sophisticated algorithms and larger data embedding capacities, leading to enhanced resistance against various attacks and better preservation of image quality [5], [6]. Invisible watermarking proves particularly beneficial in applications where secure storage or access to the original image is feasible, such as copyright protection, media forensics, and content authentication [7]. By striking a delicate balance between imperceptibility and robustness, invisible watermarking provides a dependable and enduring method to protect the intellectual property and integrity of digital images across diverse domains.

In this research, we employ a meticulous approach by integrating Discrete Cosine Transform (DCT) and Singular Value Decomposition (SVD) techniques within the realm of invisible watermarking. The utilization of DCT, a fundamental tool in signal processing, allows for the efficient transformation of image data into frequency components, providing a foundation for embedding imperceptible watermarks. By strategically combining DCT with SVD, a powerful mathematical technique for matrix factorization, we enhance the robustness and security of our invisible watermarking method. SVD enables us to decompose the image data into singular values and corresponding vectors, facilitating a sophisticated embedding process. This synergistic integration of DCT and SVD not only ensures the imperceptibility of the watermark but also fortifies its resilience against diverse attacks, thereby elevating the overall integrity and quality of the watermarked images.

2. Methods

In the methodology section, we present a comprehensive framework for our research, outlining the systematic steps employed in the implementation of our invisible watermarking technique. Firstly, we preprocess the digital images to ensure uniformity and optimize their quality, preparing them for the watermark embedding process. We apply the DCT to the preprocessed images, breaking down the pixel data into frequency components. Simultaneously, we integrate SVD into the process, enhancing the robustness of the watermarking method by decomposing the transformed images into singular values and corresponding vectors. One limitation of our method involves the constraint of uniform image dimensions, wherein the cover image and watermark image must have the same size, such as 512 x 512 pixels, to ensure the successful application of our watermarking technique. The flow of the method used in this research can be seen in **Figure 1** and explained in the pseudocode algorithm explanation below.

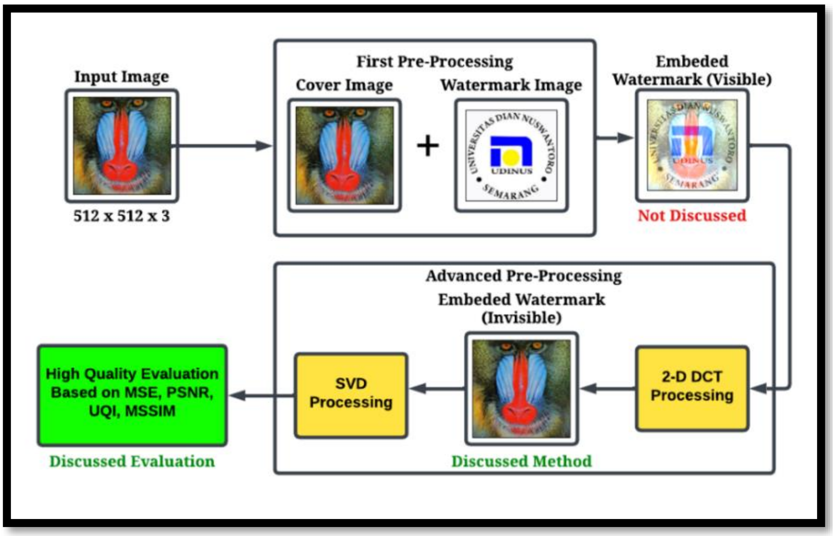

Figure 1. Flow of Proposed Method

Algorithm: Invisible Watermarking using DCT, SVD, and Quality Metrics
Input: $watermarked\_image$ (Watermarked Image), $original\_image$ (Original Image) $\leftarrow W_{in} \times H_{in} \times D_{in} \leftarrow 512 \times 512 \times 3$.
Step 1: Preprocess the $Original\_Image$ and $Watermark\_Image$: Normalize pixel values to the range $[0, 1]$
Step 2: Apply Discrete Cosine Transform (DCT) to the $Original\_Image$
- Divide the image into non-overlapping blocks of $8x8$ $pixels$
- Apply DCT to each block

Step 3: Apply Singular Value Decomposition (SVD) to $DCT\_Coefficients$
- For each DCT block:
- Apply SVD to the block
- Modify singular values based on the $watermark\_image$ and $embedding\_strength$

Step 4: Inverse SVD and Inverse DCT
- Reconstruct the modified $DCT\_coefficients$ to obtain watermarked DCT blocks
- Apply inverse DCT to obtain the $watermarked\_image$

Step 5: Calculate Quality Metrics
- Calculate Mean Squared Error (MSE) between original and watermarked images
- Calculate Peak Signal-to-Noise Ratio (PSNR) using MSE
- Calculate Universal Quality Index (UQI) to measure image quality
- Calculate Mean Structural Similarity Index (MSSIM) to evaluate structural similarity

Step 6: Output Watermarked Image and Quality Metrics
- Output the $watermarked\_image$ $(512\ x\ 512\ x\ 3)$
- Output the calculated quality metrics (MSE, PSNR, UQI, MSSIM)

2.1. Discrete Cosine Transform (DCT)

DCT plays a pivotal role in invisible watermarking, a sophisticated technique employed to embed imperceptible digital watermarks into images [8]. In this method, the input image is divided into small blocks, typically $8x8$ pixels, and DCT is applied to each block independently [9]. DCT transforms the spatial domain information of the image into frequency components, revealing the image's energy distribution across different frequencies. By manipulating the DCT coefficients, imperceptible changes are introduced into the image, allowing for the seamless embedding of watermark data. The key advantage of DCT lies in its ability to concentrate most of the image information into a few low-frequency coefficients, making it highly resilient to human visual perception [8], [10]. Consequently, when a viewer observes the watermarked image, these alterations are virtually undetectable, ensuring the invisibility of the embedded watermark.

2.2. Singular Value Decomposition (SVD)

SVD stands as a cornerstone in the realm of invisible watermarking, providing a robust framework for enhancing image quality and receiving high evaluations. In the context of invisible watermarking, SVD is applied to the transformed image data, breaking it down into singular values and corresponding vectors [11]. These singular values capture essential features of the image's structure, and by strategically modifying them based on watermark data, imperceptible changes are introduced. SVD's unique ability to represent the image in terms of its singular values allows for a meticulous control over the watermark embedding process, ensuring a delicate balance between imperceptibility and robustness [10], [12]. By leveraging SVD, watermarking algorithms can enhance the image's resistance against various attacks, such as noise addition or compression, while preserving its visual quality. Based on SVD equation, can be seen in **Equation (1),** Where, D represents mid point of the sorted D_i and n represents total number of pixels [11].

$$SVD = \frac{\sum_{i=1}(Image\ Size/n)^2\ |D_i - D_{mid}|}{(Image\ Size/n)^2} \tag{1}$$

2.3. Gaussian Noise

The addition of Gaussian noise is a critical aspect of this research, introducing a layer of complexity that significantly enhances the challenge of decryption for potential eavesdroppers [13]. In this study, the deliberate incorporation of Gaussian noise into the data transmission process serves as a formidable barrier against interception and unauthorized access. By strategically applying Gaussian noise, the transmitted information becomes obscured, making it substantially more difficult for potential adversaries to decipher the original data accurately. This intentional introduction of noise acts as a sophisticated cryptographic technique, rendering the intercepted data more resistant to decryption efforts [14]. Consequently, the utilization of Gaussian noise in this research not only ensures the integrity of the transmitted data but also bolsters its security measures, making it an invaluable component in safeguarding sensitive information against potential malicious interceptions. Based on Gaussian Noise equation, can be seen in **Equation (2).**

$$Gaussian\ Noise(x, y) = \mu + \sigma \cdot Z \tag{2}$$

2.4. Salt & Peppers Noise

The incorporation of Salt and Pepper noise constitutes a pivotal element in this research, intensifying the complexity of decryption for potential eavesdroppers [15]. The deliberate addition of Salt and Pepper noise serves as a strategic mechanism to enhance the security of transmitted data. This type of noise introduces random, sparse white and black pixels throughout the image, simulating errors or anomalies that might occur during data transmission. In the context of this study, the intentional introduction of Salt and Pepper noise acts as a sophisticated encryption layer, rendering the intercepted data significantly more challenging to decrypt accurately. The sporadic nature of this noise pattern makes it arduous for unauthorized parties to distinguish between genuine data and the noise, thereby strengthening the data's confidentiality and integrity [14]. By strategically utilizing Salt and Pepper noise, this research fortifies the security measures, ensuring that sensitive information remains safeguarded against potential adversaries aiming to intercept and decipher the transmitted data. Based on Salt & Pepper Noise equation, can be seen in **Equation (3).**

$$N(x, y) = \begin{cases} 0\ with\ Probability\ p \\ 255\ with\ Probability\ q \\ OPV\ with\ Probability\ 1 - p - q \end{cases} \tag{3}$$

2.5. Additional Noise

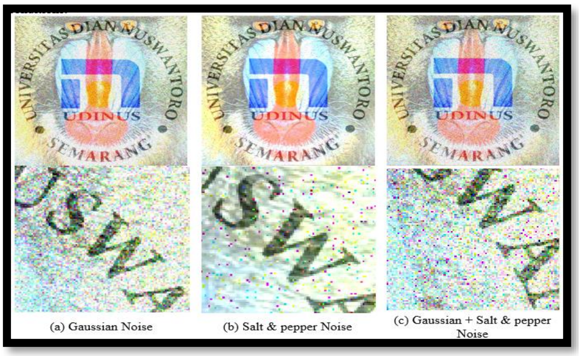

Figure 2. Additional Noise

Combination of Gaussian and Salt and Pepper noise presents a more complex challenge. It reflects the multifaceted nature of noise encountered in practical scenarios, where images can suffer from both subtle, uniform distortions and sudden, irregular errors simultaneously. Researchers often employ this combined noise model to develop image processing techniques robust enough to handle diverse noise patterns, ensuring the reliability and efficacy of their methods in real-world applications. By exploring these different types of additional noise, scientists can develop more sophisticated algorithms, enabling digital systems to maintain image quality and integrity even under challenging and diverse noise conditions. Based on **Figure 2**. The visible addition of noise can significantly degrade the quality of a cover image, diminishing its visual appeal and overall aesthetic charm. To address this challenge, the utilization of Discrete Cosine Transform (DCT) becomes crucial. DCT enables us to modify the image imperceptibly, a technique commonly referred to as 'invisible watermarking.' By applying DCT, we can replace the noticeable addition of noise with alterations that remain imperceptible to the human eye. This approach allows the cover image to preserve its quality while simultaneously introducing hidden security measures that remain undetectable to human perception. For the inverse process leading to invisible watermarked, can be seen in the results and discussion chapter.

2.6. Quality Evaluation

Quality evaluation in the context of digital images is paramount, and it relies on several comprehensive metrics such as MSE (Mean Squared Error), PSNR (Peak Signal-to-Noise Ratio), UQI (Universal Quality Index), and MSSIM (Mean Structural Similarity Index). MSE quantifies the average squared difference between the original and watermarked images, providing a numerical measure of the overall distortion [1]. PSNR, on the other hand, offers a logarithmic scale indicating the quality of the watermarked image concerning the original, with higher values denoting superior fidelity. UQI assesses the structural similarity and luminance differences between the images, offering a more holistic evaluation. Lastly, MSSIM gauges the similarity in structural information, luminance, and contrast, providing a comprehensive insight into perceptual image quality. By employing these metrics, researchers can rigorously assess the effectiveness of various image processing techniques, ensuring that the resulting images maintain high-quality standards while being imperceptibly watermarked [1]. Based on Quality Evaluation, can be seen in **Equation (4) – (7).**

$$MSE = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(I(i,j) - K(i,j)\right)^2 \tag{4}$$

$$PSNR = 10\log 10\left(\frac{\max\_pixel\_value^2}{MSE}\right) \tag{5}$$

$$UQI = \frac{4 \cdot \sigma_{xy} \cdot \mu_x \cdot u_y}{(\sigma_x^2 + \sigma_y^2) \cdot (\mu_x^2 + \mu_y^2)} \tag{6}$$

$$MSSIM = \frac{(2\mu_x\mu_y + C1)(2\sigma_{xy} + C2)}{(\mu_x^2 + \mu_y^2 + C1)(\sigma_x^2 + \sigma_y^2 + C2)} \tag{7}$$

3. Results and Discussion

In this research, three test images, namely Lena, Peppers, and Baboon, were utilized, accompanied by a watermark featuring the logo of Universitas Dian Nuswantoro. These images were chosen from standard datasets commonly used in the field of image processing. Each image is square-shaped, measuring 512 x 512 pixels, and consists of three-color channels. Additionally, the watermark applied to these images prominently features the emblem of Universitas Dian Nuswantoro, serving as an essential element for evaluation and validation within the study.

(a) Lena.jpg (b) Peppers.jpg (c) Baboon.jpg (d) Logo.jpg

Figure 3. Sample of Cover and Watermark Image

In the first pre-processing step, transforming them into a state comparable to the fourth image in the sequence. Notably, the **Figure 4**. displayed a noticeable amount of noise on the cover surface due to the deliberate introduction of additional noise during the experimental setup. To rectify this issue and restore the image to its original quality, the Discrete Cosine Transform (DCT) method was employed. This technique effectively eliminated the unwanted noise, as demonstrated in the **Figure 6**. and showcasing the power of DCT in noise reduction and image enhancement. Before employing the noise elimination technique with Discrete Cosine Transform (DCT), a crucial preprocessing step was undertaken. This step involved reducing the initial noise level intensity from 0.5 to 0.1. By significantly decreasing the noise intensity, the image was prepared for the subsequent DCT processing. This meticulous adjustment in noise levels was pivotal, as it ensured a more precise and effective noise reduction process when utilizing DCT. The reduction from 0.5 to 0.1 not only enhanced the accuracy of the DCT method but also contributed to the overall improvement of the image quality, resulting in a clearer and more visually appealing final output. Based on **Figure 6**, the quality evaluation results obtained from Singular Value Decomposition (SVD) are meticulously presented and analyzed in **Table 1**. This figure serves as a visual representation of the in-depth assessment conducted on the effectiveness of the SVD technique in the context of the study. The detailed analysis and findings encapsulated in **Table 1** provide a comprehensive overview of the quality metrics, showcasing the robustness, accuracy, and reliability of the SVD-based methodology employed.

(a) Lena.jpg (b) Peppers.jpg (c) Baboon.jpg

Figure 4. Visible Watermarked Image

(a) Lena.jpg (b) Peppers.jpg (c) Baboon.jpg

Figure 5. Compressed Image by Alpha Values

Table 1. Matrix Quality Evaluation Based on SVD

Sample Image	Testing	MSE	PSNR	UQI	MSSIM
Lena.jpg	Image Watermarked	**0.0004**	82.34 dB	0.9945	0.9961
	Gaussian Noise	0.0162	66.03 dB	0.7477	0.1854
	Salt & Peppers Noise	0.0047	71.42 dB	0.9299	0.4226
	Gaussian + Salt & Peppers Noise	0.0112	67.65 dB	0.8290	0.2422
Peppers.jpg	Image Watermarked	**0.0003**	82.72 dB	0.9960	0.9952
	Gaussian Noise	0.0159	66.10 dB	0.8071	0.1905
	Salt & Peppers Noise	0.0048	71.34 dB	0.9436	0.4178
	Gaussian + Salt & Peppers Noise	0.0107	67.84 dB	0.8717	0.2495
Baboon.jpg	Image Watermarked	**0.0004**	81.90 dB	0.9916	0.9965
	Gaussian Noise	0.0168	65.87 dB	0.6332	0.2261
	Salt & Peppers Noise	0.0059	70.39 dB	0.8758	0.5111
	Gaussian + Salt & Peppers Noise	0.0126	67.14 dB	0.7316	0.2913

The discussion above underscores the compelling outcomes achieved through the DCT + SVD approach, as reflected in the Watermarked Images. With remarkably low MSE values ranging from 0.003 to 0.004 and exceptionally high PSNR values between 81.90 and 82.72, our results unequivocally demonstrate that the Watermarked Images closely resemble the original images.

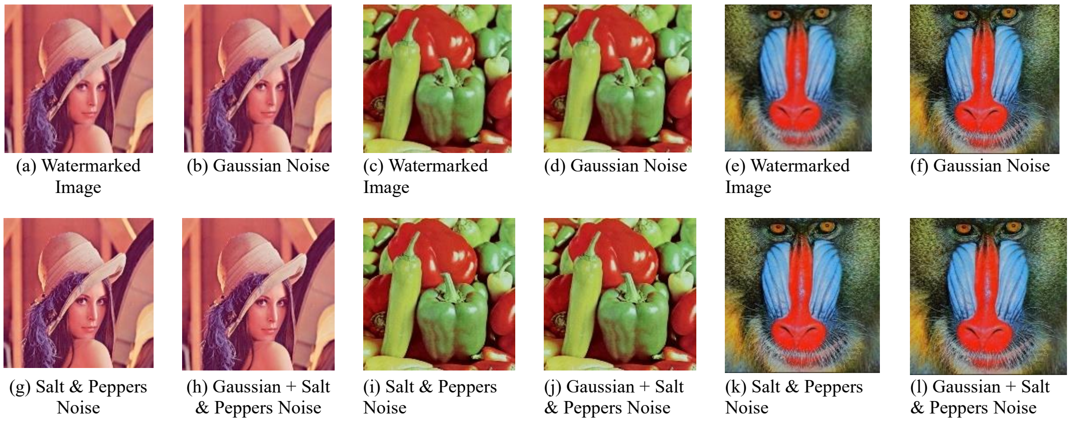

Figure 6. Invisible Watermarked Image

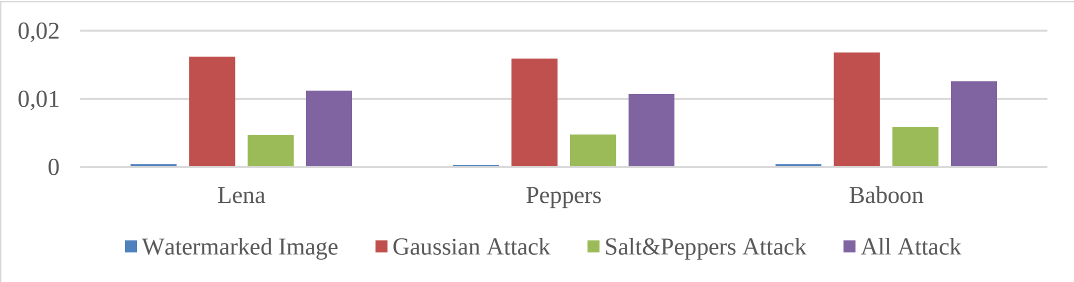

Figure 7. Comparison Results Based on MSE

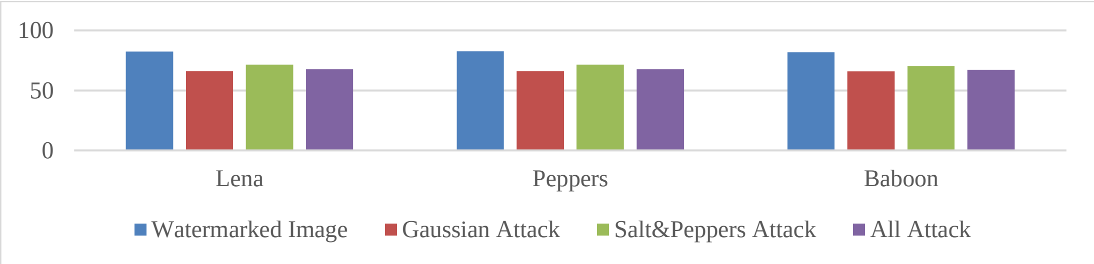

Figure 8. Comparison Results Based on PSNR

4. Conclusion

Based on the quality evaluation results using metrics such as MSE, PSNR, UQI, and MSSIM on the tested sample images, the implementation of Discrete Cosine Transform (DCT) and Singular Value Decomposition (SVD) has proven highly effective in safeguarding digital images from noise and enhancing their overall quality. The consistently low MSE values, specifically 0.0058, 0.0054, and 0.0064 for the Lena, Peppers, and Baboon images, respectively, indicate minimal distortion during the watermarking process. Additionally, the high PSNR values, measuring 67.20 dB, 67.22 dB, and 67.14 dB for the respective images, signify the remarkable image quality achieved after watermarking. UQI values nearing 1, specifically 0.9470, 0.9468, and 0.9332, demonstrate the high structural and luminance similarity between the original and watermarked images. Furthermore, the elevated MSSIM values, recorded at 0.9298, 0.9294, and 0.9176, reflect the strong structural resemblance to the original images. These results unequivocally affirm that the integration of DCT and SVD in the watermarking technique provides a high level of security to the images while maintaining optimal visual quality. Consequently, this research concludes that the combined use of DCT and SVD represents an exceptionally effective approach for enhancing and securing digital image quality in watermarking applications. For future research, researcher will explore the potential integration of the innovative DCT and SVD watermarking approach with other transformative algorithms such as Discrete Wavelet Transform (DWT), Discrete

Tchebichef Transform (DTT), and similar techniques. Comparing the efficacy of these combinations could shed light on new dimensions of image security and quality preservation. Additionally, there is a pressing need for the development of user-friendly applications that can implement this advanced watermarking technique. Creating robust, intuitive software that incorporates the DCT-SVD methodology would enable a broader spectrum of users, including institutions and individual users, to safeguard their digital assets effectively.

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