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Quality Improvement for Invisible Watermarking using Singular Value Decomposition and Discrete Cosine Transform

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ABSTRACT

Image watermarking is a solution to protect digital images from issues such as copyright protection, ownership, authentication, fingerprinting, and so on.Image watermarking is a sophisticated method often used to assert ownership and ensure the integrity of digital images. **This research aimed** to propose and evaluate an advanced watermarking technique that utilizes a combination of singular value decomposition methodology and discrete cosine transformation to embed the Dian Nuswantoro University symbol as proof of ownership into digital images. Specific goals included optimizing the embedding process to ensure high fidelity of the embedded watermark and evaluating the fuzziness of the watermark to maintain the visual quality of the watermarked image. **The methods used in this research** were singular value decomposition and discrete cosine transformation, which are implemented because of their complementary strengths. Singular value decomposition offers robustness and stability, while discrete cosine transformation provides efficient frequency domain transformation, thereby increasing the overall effectiveness of the watermarking process. **The results of this study** showed the efficacy of the Lena image technique in gray scale having a mean square error of 0.0001, a high peak signal-to-noise ratio of 89.13 decibels (dB), a universal quality index of 0.9945, and a similarity index structural of 0.999. **These findings confirmed** that the proposed approach maintains image quality while providing watermarking resistance. In conclusion, **this research contributed** a new watermarking technique designed to verify institutional ownership in digital images, specifically benefiting Dian Nuswantoro University. It showed significant potential for wider application in digital rights management.

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1. INTRODUCTION

Image watermarking is a sophisticated method frequently employed to show ownership and ensure the integrity of digital snapshots [1]. By embedding imperceptible or semi-obvious identifiers without delay into the visual content material, watermarking serves as a virtual signature that unequivocally hyperlinks the picture to its rightful owner [2, 3]. This technique now not handiest deters unauthorized use and distribution but also allows traceability, permitting creators to guard their highbrow property rights inside the great panorama of digital media dissemination [4]. Moreover, by integrating these subtle markers into snapshots, stakeholders can set up a strong framework for copyright protection, fostering acceptance as true and duty in the virtual atmosphere [5]. Expanding on the idea of image watermarking as an essential method of saying possession, a few research have explored the domain of invisible watermarking strategies [6–8]. Unseen watermarking capabilities are more covert than overt watermarking, inserting distinct virtual signatures into images unseen to the naked eye but identifiable through state-of-the-art algorithms. With its innovative methodology, ownership may be verified past an affordable doubt, presenting further safety and authenticity confirmation. By easily integrating these imperceptible indicators, the look emphasizes the importance of growing techniques, strengthening the complex material of copyright safety, and reinforcing the consideration and responsibility standards discussed within the preceding dialogue [9, 10]. Combining Singular Value Decomposition (SVD) with Discrete Cosine Transform (DCT) is a famous technique [8, 11–14]. Using DCT, the watermark is hidden in the cover photograph so that it is not visible to the human device [15]. Using DCT, the method offers precedence to physical invisibility, ensuring that the naked eye will no longer see the implanted watermark. Simultaneously, SVD is integrated for two reasons: first, it enables the hiding of the watermark; 2nd, it is very important to enhance the excellent of the embedded cover image.

Khanam et al. [13] introduced an innovative blind symmetric image watermarking technique that harnesses the prowess of Singular Value Decomposition (SVD) in conjunction with the Fast Walsh-Hadamard Transform (FWHT) to fortify ownership protection. In the conclusive stages, these proprietary keys play an instrumental role, facilitating both the extraction of the embedded watermark and the subsequent verification of ownership rights. Empirical evaluations and simulation outcomes affirm the efficacy of the proposed methodology, showcasing its formidable resilience against an array of potential attacks. Notably, comparative analyses accentuate its superiority vis--vis contemporary state-of-the-art methodologies. Specifically, the Normalized Correlation (NC) achieved by Khanam et al.'s method is quantified as one, while the Peak Signal-to-Noise Ratio (PSNR) oscillates between 49.78 and 52.64. In juxtaposition, extant methods typically exhibit an NC ranging from 0.7991 to 0.9999, with PSNR values fluctuating between 39.4428 and 54.2599. Begum et al. [16] proposed a hybrid blind digital image watermarking technique combining DCT, DWT, and SVD to address the limitations of single transformation methods in meeting the design requirements of imperceptibility, robustness, security, and payload capacity. The watermark image is first encrypted using the Arnold map in their approach. Subsequently, DCT is applied to both the encrypted watermark and the host image, followed by DWT before SVD. This multi-transform approach ensures the watermark is securely and robustly embedded into the host image. The watermarked image is evaluated under various attacks, and experimental results demonstrate that this algorithm provides improved robustness, high imperceptibility, and enhanced security compared to state-of-the-art methods, achieving a PSNR of 57.6303 and an SSIM of 0.9984. Sofyan et al. [17] proposed watermarking processing using DCT and SVD. This technique aims to embed imperceptible watermarks into images, thereby preserving their integrity and authenticity. DCT facilitates an efficient transformation of image data into frequency components, providing a robust foundation for embedding nearly invisible watermarks in the human eye. Concurrently, SVD enhances this process by decomposing the image into singular values and corresponding vectors, enabling a more sophisticated watermarking methodology. Their study reports low average MSE values, ranging from 0.0058 to 0.0064, indicating minimal distortion in the watermarked images. Moreover, high PSNR values, ranging from 67.20 dB to 67.22 dB, underscore the high image quality maintained post-watermarking.

Previous research has not resolved some gaps, namely the limited robustness and imperceptibility of watermarks embedded using the existing techniques. Sofyan et al.'s approach, which utilized DCT combined with Basic Default SVD, did not fully address the need for enhanced resilience against various types of attacks and the requirement for higher image quality post-watermarking. **The difference between** this research and the previous one is the introduction of a modified parameter, integrating DCT with a Modified Parameter of Singular Value Decomposition (SVD). This modification aims to resolve the identified gaps by improving both the robustness and imperceptibility of the embedded watermarks. The modified technique demonstrates superior evaluation results, as evidenced by improved metrics such as Mean Squared Error (MSE), Peak Signal-to-Noise Ratio (PSNR), Universal Quality Index (UQI), and Mean Structural Similarity Index (MSSIM). Consequently, this approach yields higher image quality and more effective watermarking, showcasing a significant improvement over the original methodology proposed by Sofyan et al. **The contribution of this research** to the development of science lies in its ability to enhance digital rights management, protect intellectual property, and maintain the authenticity of multimedia content. By advancing watermarking technology, the research provides significant benefits in safeguarding digital assets, promoting fair use, and fostering trust in digital communications. **This research aim**s to propose and evaluate an advanced watermarking technique that utilizes a combination of singular value decomposition methodology and discrete cosine transformation to embed the Dian Nuswantoro University symbol as proof of ownership into digital images. Specific goals include optimizing the embedding process to ensure high fidelity of the embedded watermark and evaluating the fuzziness of the watermark to maintain the visual quality of the watermarked image.

2. RESEARCH METHOD

The proposed method begins by integrating the original RGB image with the watermark representation, specifically, the Logo of the University of Dian Nuswantoro, resulting in an image enriched with visible watermarking. It is pertinent to note that the intricacies and nuances of this visible watermarking aspect lie beyond the scope of this research, which is qualitative. Following acquiring this visibly watermarked image, the workflow progresses to applying the discrete cosine transform (DCT) technique. The primary objective at this stage is to diminish or eliminate the conspicuous watermark embedded during the preceding phase. After the DCT processing, a crucial optimization step follows, utilizing the capabilities of Singular Value Decomposition (SVD). This strategic employment of SVD plays a pivotal role in enhancing the effectiveness and quality metrics of the invisible watermarking mechanism. The flow of the proposed method is illustrated in Figure 1.

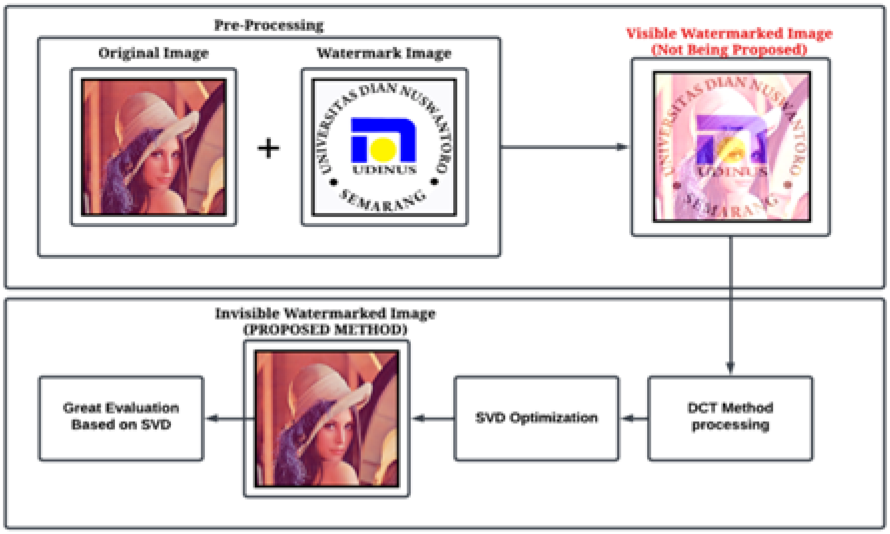
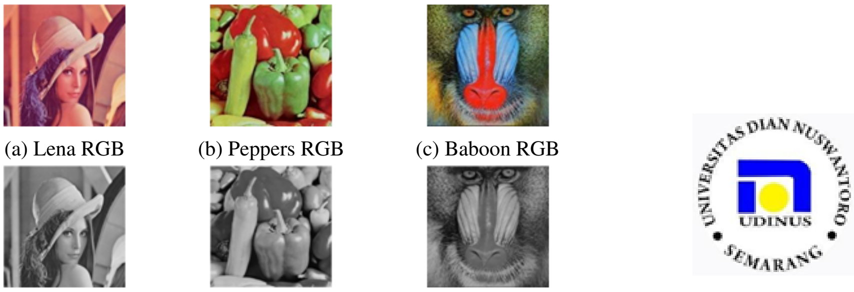


Figure 1. Our proposed scheme

2.1. Datasets

The data employed for this research encompasses a diverse set of relevant images. Images (a), (b), and (c) are color images (RGB) formatted at dimensions of $512 \times 512 \times 3$. Furthermore, images (d), (e), and (f) represent grayscale images, maintaining the identical dimensions of $512 \times 512 \times 1$. Additionally, image (g) features the logo of Universitas Dian Nuswantoro, designated as the watermark for the purposes of this study. Based on the sample dataset can be seen in Figure 2. it can be concluded that the variety of image types and watermarks used in this study are diverse and relevant.



(a) Lena RGB (b) Peppers RGB (c) Baboon RGB
(b) Lena Grayscale (e) Peppers Grayscale (f) Baboon Grayscale (g) Dian Nuswantoro University Logo

Figure 2. Sample datasets, (a) Lena RGB, (b) Peppers RGB, (c) Baboon RGB, (d) Lena Grayscale, (e) Peppers Grayscale, (f) Baboon Grayscale, (g) Dian Nuswantoro University Logo

DCT is a mathematical technique widely utilized in the realm of invisible watermarking to embed imperceptible watermarks within digital media content [8, 15]. By converting spatial image data into frequency components, DCT facilitates the insertion of watermark information in a manner that remains undetectable to the human eye. This transformation ensures that the embedded watermark is robustly integrated into the image, offering resilience against various distortions while preserving the visual quality of the original content for the DCT equation 1 and 2. This expression with respect to $x[m]$, where m is a specific sample index, we will get the partial derivative. The differentiation results in the expression of the cosine term with respect to m, as the summation and other constants are treated as constants in the differentiation process.

$$X[k] = \sum_{n=0}^{N-1} x(n) \cdot \cos\cos(\frac{\pi k(2n-1)}{2N}) \tag{1}$$

$$\frac{\partial X[k]}{\partial x[m]} = \cos\cos(\frac{\pi k(2n-1)}{2N}) \tag{2}$$

2.2. Singular Value Decomposition (SVD)

SVD is a foundational matrix factorization technique that plays a crucial role in various applications, including data compression, noise reduction, and signal processing [12, 13, 16, 18]. One of its primary utilities lies in enhancing the evaluation outcomes of matrices, such as improving metrics like SSIM, MSE, PSNR, and others. By decomposing a matrix into its constituent singular values and associated orthogonal matrices, SVD provides a comprehensive representation that enables researchers and practitioners to optimize and refine the quality metrics associated with matrix transformations and evaluations. The SVD Equation can be seen in 3, and based on SVD processing, it can be seen in Figure 3.

$$SVD = \frac{\Sigma_{i=1}(Image\_Size/n)^2 \mid D_i - D_{mid} \mid}{(Image\_Size/n)^2} \tag{3}$$

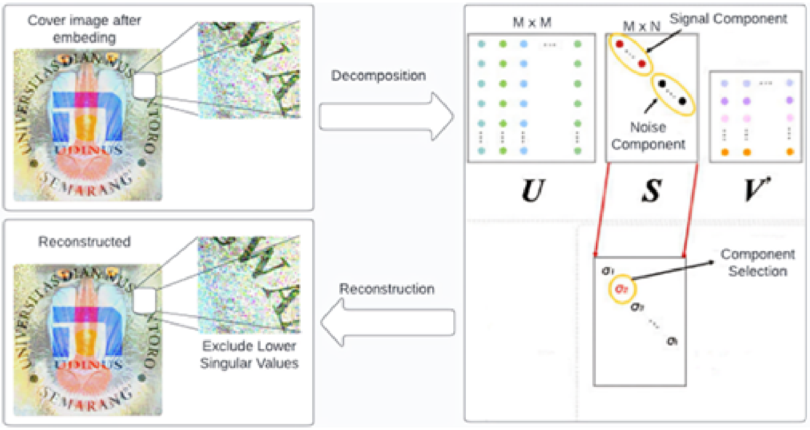


Figure 3. Proposed of SVD for image watermarking

2.3. Quality Measurement

Quality measurement in image watermarking is like using various tools to see how well an edited or transformed image matches the original [19, 20]. Think of the Mean Squared Error (MSE) as a way to average the differences between every pixel of the original and edited images. The Peak Signal-to-Noise Ratio (PSNR) is a measure that tells us how clear the transformed image is compared to any added noise or distortion. Then, we have the Universal Quality Index (UQI), which looks at things like brightness and contrast to give an overall score on how good the transformed image looks. Lastly, the Structural Similarity Index (SSIM) compares local patterns in both images, helping us understand how much of the original structure remains intact after editing. Based on quality measurement Equation 4, 5, 6 and 7.

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

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

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

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

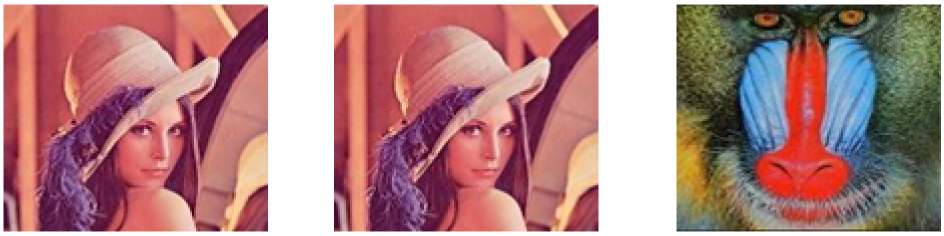
3. RESULT AND ANALYSIS

In this section, the first step in this research, the watermark embedding process, begins with initializing the watermark embedding algorithm. The algorithm can be seen in Table 1. Based on Algorithm 1 provided above, the results and discussion phase of the research, as mentioned above, prominently showcase the preliminary pre-processing step, as delineated in Figure 4. The graphical representation encapsulates a comparative analysis between various stages of image transformation. Specifically, panels (a) - (c) depict images that have undergone embedding procedures without the application of the Discrete Cosine Transform (DCT). In contrast, panels (d) - (f) present images subjected to the embedding process after incorporating the DCT methodology. In Figure 4, the visual results that come from using the DCT. These visuals give us a clear picture of how DCT techniques enhance or change certain aspects. To provide more specific details and numbers related to these transformations, refer to Table 2. It offers a structured breakdown, allowing for a more detailed analysis of the results achieved by applying DCT methods.

Table 1. Embedding Algorithm

Algorithm1: Embedding Algorithm
Start Algorithm Input: $Coverlmage(C), Watermarklmage(W), Alpha(\alpha)$ Output:$WatermarkedImage(C_w)$ Convert CoverImage and WatermarkImage to grayscale if they are RGB. Resize WatermarkImage to match the size of CoverImage. Divide CoverImage into non-overlapping 8x8 blocks. For each 8x8 block B in CoverImage: Apply DCT to block B to get DCT coefficients: $DCT\_B = DCT(B)$ Apply SVD to $DCT\_B : [U, S, V] = SVD(DCT\_B)$ End loop Convert WatermarkImage into a vector W_{vector} Scale $W_{vectorbyAlpha(\alpha)} : W_{scaled} = \alpha * W_{vector}$ Embed $W_{scaled} intothesingularvaluesS : Modifythesingularvalues : S_w = S + W_scaled$ Reconstruct the DCT coefficients with the modified singular values: $DCT\_B\_w = U * S\_w * V^{\wedge}T$ Apply inverse DCT to $DCT\_B\_wtogetthewatermarkedblockB\_w$ Replace the original block B in CoverImage with the watermarked block B_w Combine all watermarked blocks to form the $WatermarkedImage(C_w)$. Return $WatermarkedImage(C\_w)$ End Algorithm

(a) Embedded Lena without DCT (b) Embedded Peppers without DCT (c) Embedded Baboon without DCT



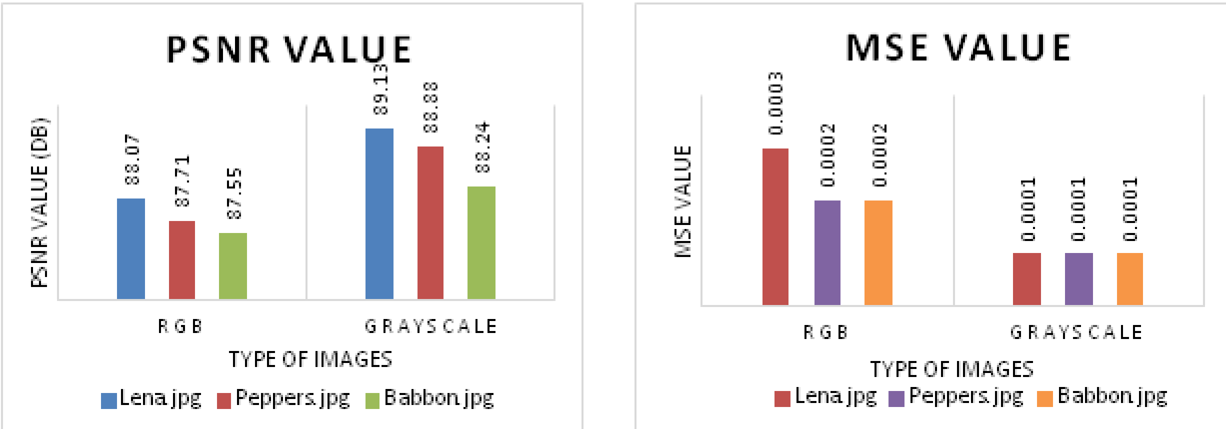
(d) Embedded Lena with DCT (e) Embedded Peppers with DCT (f) Embedded Baboon with DCT

Figure 4. Implementation and visual results based on DCT, (a) Embedded Lena without DCT, (b)Embedded Peppers without DCT, (c) Embedded Baboon without DCT, (d) Embedded Lena with DCT, (e) Embedded Peppers with DCT, (f) Embedded Baboon with DCT

Table 2. Results of quality measurement based on SVD

Testing Image	**Grayscale**				**RGB**			
	MSE	**PSNR**	**UQI**	**SSIM**	**MSE**	**PSNR**	**UQI**	**SSIM**
Lena	0.0001	89.13 dB	0.9945	0.999	0.0003	88.07 dB	0.9945	0.999
Peppers	0.0001	88.88 dB	0.9961	0.999	0.0002	87.71 dB	0.9961	0.999
Babbon	0.0001	88.24 dB	0.9917	0.999	0.0002	87.55 dB	0.9917	0.999

Figure 4 gives us the visuals, while Table 2 provides the numerical insights. Table 2 provides a detailed comparison of different image metrics for both grayscale and color (RGB) images. Looking closely, Lena stands out with the best scores in many areas. Specifically, the grayscale version of Lena has a low error rate (MSE) of 0.0001, a high clarity score (PSNR) of 89.13 dB, a quality index (UQI) of 0.9945, and an excellent structural similarity (SSIM) score of 0.999. Even in the color version, Lena maintains impressive scores, with a slightly lower MSE of 0.0003 and a PSNR of 88.07 dB, while UQI and SSIM remain unchanged at 0.9945 and 0.999. Figure 5 helps us understand how different datasets or methods stack up against each other when judged by these standards. Think of MSE as highlighting the differences between the original and edited data, giving us an idea of how close they are. On the other hand, PSNR gives a sense of how clear and high-quality those edits are. Figure 5 is like a roadmap, helping experts and anyone interested understand which methods or datasets perform better, all based on these MSE and PSNR benchmarks.



(a) (b)

Figure 5. A Comparison results between MSE and PSNR, (a)PSNR, (b)MSE

In evaluating our research against three other related studies, it becomes apparent that our research stands out prominently from the entirety of related research of the results presented in Table 3. Our research demonstrates significantly superior performance across metrics such as MSE, PSNR, UQI, and SSIM. This underscores the excellence and advancements in methodology that we have presented across several key areas. As such, this differentiation highlights the significance and effectiveness of our approach, positioning our research favorably among its contemporaries.

Table 3. Comparison results with related research

Researcher	Testing Image	Grayscale				RGB			
		MSE	**PSNR**	**UQI**	**SSIM**	**MSE**	**PSNR**	**UQI**	**SSIM**
Proposed Method	Lena	0.0001	89.13 dB	0.9945	0.999	0.0003	88.07 dB	0.9945	0.999
	Peppers	0.0001	88.88 dB	0.9961	0.999	0.0002	87.71 dB	0.9961	0.999
	Babbon	0.0001	88.24 dB	0.9917	0.999	0.0002	87.55 dB	0.9917	0.999
Yasmeen et al [7]	Lena	2.6882	43.84 dB		0.873	21.899	34.73 dB		0.771
	Peppers	-		-	-	-		-	-
	Babbon								
Khandelwal et al [18]	Lena		45 dB		1	Not Proposed			
	Peppers	-	(Average)	-	1				
	Babbon				1				
Sofyan et al [17]	Lena	Not Proposed				0.0004	82.34 dB	0.9945	0.9961
	Peppers					0.0003	82.72 dB	0.996	0.9952
	Babbon					0.0004	81.90 dB	0.9916	0.9965

The findings of this research are that the proposed watermarking technique, which integrates Discrete Cosine Transform (DCT) with a Modified Parameter of Singular Value Decomposition (SVD), significantly improves the robustness and imperceptibility of the embedded watermarks. For instance, when applied to the Lena image, the proposed method achieved a Mean Squared Error

(MSE) of 0.0001 and a Peak Signal-to-Noise Ratio (PSNR) of 89.13 dB, compared to Sofyan et al.'s method, which did not provide MSE but showed a lower PSNR of 82.34 dB. Similar improvements were observed with the Peppers and Baboon images, where the proposed method consistently outperformed the previous approach in terms of PSNR and other quality metrics like the Universal Quality Index (UQI) and Mean Structural Similarity Index (MSSIM). On the other hand, further insights into the advancements can be observed when comparing the proposed method to the research conducted by Yasmeen et al. and Khandelwal et al.. Yasmeen et al. achieved a PSNR of 43.84 dB and a Mean Structural Similarity Index (MSSIM) of 0.873 for the Lena image, which is significantly lower than the proposed method's PSNR of 89.13 dB and MSSIM of 0.999. This indicates that the proposed method offers superior image quality and watermark imperceptibility. Additionally, Khandelwal et al.'s approach resulted in an average PSNR of 45 dB for the Lena image, which is also lower than the PSNR achieved by the proposed method. Khandelwal et al. did not provide specific values for metrics such as MSE and UQI, but their method reported an MSSIM of 1.0, suggesting perfect structural similarity in some cases.

The results of this research **are supported** by the fact that Sofyan et al.'s [17] approach, while effective, did not achieve the same level of robustness and image quality. For example, their method produced a PSNR of 82.34 dB for the Lena image, which is significantly lower than the 89.13 dB achieved by the proposed method. The higher PSNR values and improved UQI and MSSIM scores in this research indicate better preservation of image quality and greater resilience to attacks. Thus, the findings underscore the effectiveness of the modified SVD parameters in enhancing watermarking performance, providing a significant advancement over the existing state-of-the-art techniques.

4. CONCLUSION

We have observed clear trends based on the Discrete Cosine Transform (DCT) and Singular Value Decomposition (SVD) methods. The DCT method, especially for grayscale images, produced standout results. For instance, with the Lena image, DCT yielded a remarkably low MSE of 0.0001 and an impressive PSNR of 89.13 dB. This trend continued with the Peppers and Baboon images, where DCT consistently outperformed with MSE values of 0.0001 and PSNR ratings of 88.88 dB and 88.24 dB, respectively. While the RGB results with DCT were commendable, the SVD approach also demonstrated strengths, offering competitive metrics. However, when comparing the two, DCT emerges as the more effective method, particularly for grayscale images, showcasing its superiority in preserving image quality. This research makes significant contributions to the field of digital image processing. First, by demonstrating the superiority of DCT in processing grayscale images, we provide strong evidence of this method's capability in maintaining image quality. This can serve as a reference for researchers and practitioners when selecting the optimal image processing method based on the type of images they handle. Additionally, by highlighting the relative strengths of SVD, we open opportunities for further research on when and how SVD can be used effectively.

For future research, exploring ways to refine and enhance the DCT and SVD techniques would be intriguing. Integrating these methods with newer technologies, such as machine learning or neural networks, could unveil exciting possibilities. Furthermore, testing these techniques across various datasets and real-world scenarios can provide a clearer picture of their true potential and limitations. By focusing on these aspects, future studies have the opportunity to push boundaries and uncover innovative applications in the field of digital image processing.

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6. DECLARATIONS

AUTHOR CONTIBUTION

Danang Wahyu Utomo: Conceptualization, Methodology, Writing Review & Editing. Folasade Olubusola Isinkaye: Validation and Interpretation. Christy Atika Sari: Validation and Editing.

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COMPETING INTEREST

The authors declare no conflict of interest. All authors are competent in the field of data security.

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