Watermarking for Images: A Comparative Study of DCT, DWT, and DFT Domain Embedding Techniques

Hiya Shah, Kaushika Rathod, Krish Chaudhari, Vansh Popat, Yashvi Jakharia

***Abstract*—This project adopts a digital image watermark embedding scheme which employs the Discrete Fourier Transform (DFT) in safeguarding copyright. The watermark is inserted in the frequency domain of the image by modifying the high magnitude DFT coefficients of the image. The lowest frequencies are not removed so that the visual quality of the image is not compromised. Once embedded, the inverse fourier transform is used to recover the entire image resulting in a watermarked image that has little perceptual distinctions.**

***Index Terms*—Watermarking, transformation, spatial domain, deep learning, GAN, extraction, imperceptibility**

I. Introduction

IN the digital era, the proliferation of multimedia content has rendered robust copyright protection mechanisms indispensable. The accessibility and rapid distribution capabilities enabled by modern technologies have escalated the risks associated with unauthorized alteration, replication, and piracy of digital assets, particularly images. To address the persistent threats posed by both intentional and inadvertent attacks, digital watermarking has emerged as a pivotal discipline within the domain of information security and content authentication.

Digital image watermarking involves the imperceptible embedding of proprietary information into host images, thereby facilitating efficient proof of ownership and authenticity verification across copyright protection, medical data exchange, e-governance, and emerging cyber physical applications. Advances in this field have encompassed both spatial and frequency domain schemes; while earlier spatial domain approaches prioritized imperceptibility, they suffered from limited embedding capacity and vulnerability to signal-processing operations such as compression and geometric distortions. The transition towards transform domain techniques, including discrete Fourier transform (DFT), discrete cosine transform (DCT), and discrete wavelet transform (DWT), has markedly enhanced the resilience of watermarking methods against common image manipulations, providing a more favorable trade-off between imperceptibility, robustness, and embedding capacity.

The human visual system (HVS) plays a significant role in determining the optimal domain and coefficients for watermark embedding. It has been observed that the HVS is inherently more sensitive to lower frequency modifications, while high-frequency coefficients may be suppressed under lossy processing. To mitigate quality degradation, advanced approaches exploit mid-frequency coefficients or utilize spread spectrum techniques, selectively embedding watermark signals in statistically significant regions of the transformed image . Notably, frequency domain watermarking; particularly DFT-based methods exhibit robust performance against various attacks, such as filtering, compression, scaling, and geometric alterations, thereby enabling blind or semi-blind extraction without the need for original reference images.

Traditional watermarking methods have demonstrated maturity, yet the field has rapidly expanded with the integration of machine learning and deep learning paradigms. Recent frameworks leverage convolutional neural networks to optimize embedding strength, localize regions of interest, and enhance watermark detection reliability, highlighting the transition towards intelligent watermarking systems. However, algorithmic complexity, embedding capacity, and resistance to novel manipulation strategies, such as those driven by adversarial attacks and deep-fake generation, remain open challenges.

This manuscript proposes a novel DFT-based watermarking system tailored for robust image authentication, copyright protection, and resistance to common signal-processing attacks. The approach synthesizes insights from conventional transform domain schemes and recent advances in learning-driven optimization, aiming to achieve high imperceptibility and watermark integrity under practical constraints.

II. Methodology

The watermark embedding procedure in the suggested Discrete Fourier Transform (DFT)-based digital watermarking system starts with a fast Fourier transform (FFT) that breaks down the original $\times$ image into its frequency components. Only the DFT coefficients with the highest magnitudes—apart from the lowest frequency components—are chosen for embedding in order to guarantee perceptual invisibility and robustness. A chosen watermark is also broken down into its frequency components. A modified coefficient set is produced by slightly altering the chosen DFT coefficients in accordance with a predetermined scaling rule in order to include this watermark. The final watermarked image is then created by recombining the modified coefficients using an inverse fast Fourier transform (IFFT).

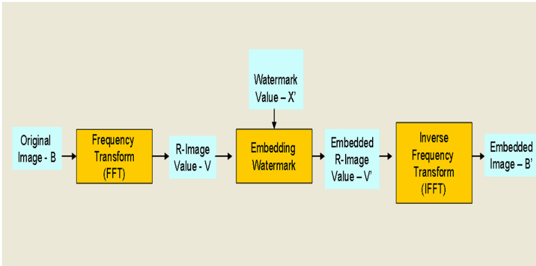

Fig. 1: DFT-based watermark embedding process [1].

III. Results

The DFT-based watermarking technique was applied on the original image as shown below, then we compared original image and the final watermarked image.

The goal was to verify whether the watermark could be embedded without distorting or visually changing the original image.

As we can see, both images looks identical and watermark is not visible which shows the image quality was not affected.

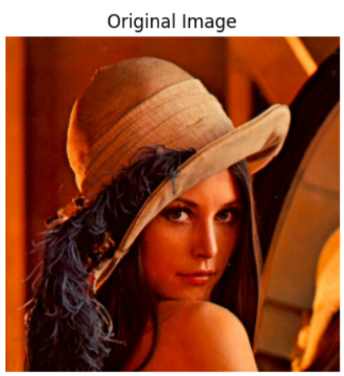

Fig. 2: Original image

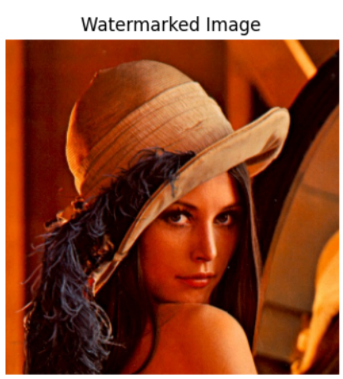

Fig. 3: Watermarked image

Fig. 4: Comparison of DFT-based watermark embedding process.

We also calculated PSNR (Peak Signal to Noise Ration) and SSIM (Structural Similarrity Index Measure) values which were:

PSNR : 51.68 dB
SSIM : 0.9981

A PSNR value above 40 dB indicates both images are strongly identical. And the SSIM value close to 1 indicates visual quality is preserved even after watermarking.

Also to analyze the pixel distribution of both images, histograms were plotted as seen in fig. 5 and fig. 6

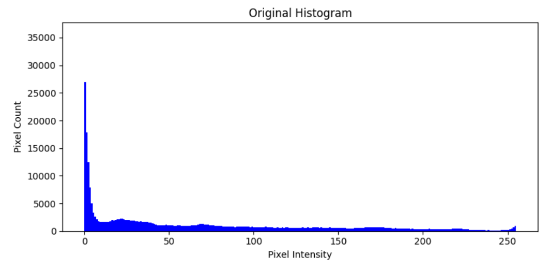

Fig. 5: Original histogram.

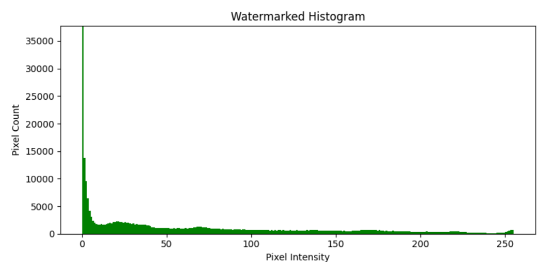

Fig. 6: Watermarked histogram.

Only a minor shifts in some regions were observed in the histogram, the slight variation near low intensity indicates few pixels became slightly darker after watermark embedding. Overall, the histogram shapes are similar, showing the image quality and intensity are almost unchanged.

IV. Conclusion

We were able to apply a DFT based system in this project to create watermarks in digital images that are invisible to their users to protect the copyright of the images. The watermark was embedded on the high-magnitude DFT coefficients to ensure that it caused minimal visual distortion and remained strong. The results of experiments and comparisons of histograms indicate that the pixel-intensity distribution does not change much, and it is possible to state that the image quality is not damaged. A PSNR of 40dB or more is further indication to show that the watermark cannot be perceived by the human eye. Therefore, the embedding technique based on DFT can be used to insert watermarks safely and without being noticed by others without affecting the visual quality of the image.

References

[1] C.-M. Pun, "A novel DFT-based digital watermarking system for images," in *Proc. 8th Int. Conf. Signal Process.*, Guilin, China, 2006, pp. –, doi: 10.1109/ICOSP.2006.345581.

[2] M. I. Khan, "Digital watermarking for image authentication based on DWT, DCT, and SVD," *arXiv preprint arXiv:1307.6328*, 2013.

[3] I. J. Cox, J. Killian, F. T. Leighton, and T. Shamoon, “Secure spread spectrum watermarking for multimedia,” *IEEE Transactions on Image Processing*, vol. 6, no. 12, pp. 1673–1687, 1997.

[4] B. Chen and G. W. Wornell, “Quantization index modulation: A class of provably good methods for digital watermarking and information embedding,” *IEEE Transactions on Information Theory*, vol. 47, no. 4, pp. 1423–1443, 2001.

[5] T. Pardhu and B. R. Perli, “Digital image watermarking in frequency domain,” in *Proceedings of the 2016 International Conference on Communication and Signal Processing (ICCSP)*, Tamil Nadu, India, Apr. 6–8, 2016, pp. 208–211.

[6] S. M. Darwish and L. D. S. Al-Khafaji, “Dual watermarking for color images: A new image copyright protection model based on the fusion of successive and segmented watermarking,” *Multimedia Tools and Applications*, vol. 79, pp. 6503–6530, 2020.

[7] X. Kang, Y. Chen, F. Zhao, and G. Lin, “Multi-dimensional particle swarm optimization for robust blind image watermarking using intertwining logistic map and hybrid domain,” *Soft Computing*, vol. 24, pp. 10561–10584, 2020.

[8] S. Boujerfaoui, R. Riad, H. Douzi, F. Ros, and R. Harba, “Image watermarking between conventional and learning-based techniques: A literature review,” *Electronics*, vol. 12, no. 1, Art. no. 74, Jan. 2023.