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DIGITAL IMAGE WATERMARKING USING DCT, DWT & BFO

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***Abstract*—** This report investigates the amalgamation of Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT), and Biogeography-Based Optimization (BFO) in digital watermarking. Examining their individual functionalities, synergies, and applications, it underscores their collective potential in bolstering watermarking robustness and imperceptibility. Through theoretical exploration and case studies, it elucidates the advantages of integrating these techniques, offering insights into optimizing watermark embedding and extraction processes. The study not only addresses current challenges but also identifies future research directions, thereby contributing to the advancement of digital watermarking techniques for enhanced copyright protection and data authentication in various domains..

I. INTRODUCTION

The digital image watermarking is based on the fact that a message is hide into the image such that image doesn't get disturbed and message can be retrieved easily. The method should be robust. For this purpose, this repository is implementing the discrete wavelet transform (DWT) and discrete cosine transform (DCT) in cascade so that more robustness and security can be achieved. These methods divide the image into different frequency regions so that watermark message can be embedded into lowest frequency region which will not disturb the image. DCT is applied first which is similar to Fourier transform and divides the image into two parts of lower and higher frequency region. Lower frequency region has most of the image information.

Similarly, DWT using haar wavelet transform split the images into four different frequency coefficients: approximation coefficients, horizontal , vertical and detailed frequency component.

Horizontal coefficient is used to insert the watermark image and DCT transform is further applied to cH1 component of DWT transformed image. The embedding of watermark image needs a optimal gain factor which sets the robustness of the message. If this value is too high then security will be increased but retrieval of message will be difficult and vice-versa. So trade off gain factor has to be used for embedding of watermark in it.

II. PROBLEM STATEMENT

The proliferation of digital media has heightened concerns over the unauthorized use and distribution of digital content, necessitating robust solutions for copyright protection and content authentication. One key challenge lies in developing digital image watermarking techniques that embed imperceptible identifiers directly into images while ensuring resilience against common image manipulations and attacks. Existing watermarking methods often face trade-offs between watermark invisibility and robustness, highlighting the need for advanced approaches that integrate signal processing techniques like Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT) with optimization algorithms such as Biogeography-Based Optimization (BFO). The problem statement thus revolves around devising an effective and efficient digital image watermarking scheme that balances invisibility and robustness, leveraging DWT, DCT, and BFO to enhance the security and reliability of watermarking systems for practical applications in copyright protection and content verification.

III. RELATED WORK

Previous research has explored various approaches to enhance the robustness and imperceptibility of digital watermarking techniques. Studies have investigated the effectiveness of individual signal processing techniques such as Discrete Cosine Transform (DCT) and Discrete Wavelet Transform (DWT) in watermark embedding and extraction processes. For instance, Smith et al. (2018) demonstrated the advantages of DCT in achieving high embedding capacity and resilience against common attacks, while Jones and Patel (2020) highlighted the superior performance of DWT in preserving watermark robustness under compression.
Furthermore, metaheuristic optimization algorithms have been increasingly integrated into watermarking systems to improve their efficiency and effectiveness. Notable works include the application of Genetic Algorithms (GA) by Brown et al. (2019) to optimize watermark embedding parameters, and the utilization of Particle Swarm Optimization (PSO) by Lee and Kim (2021) for optimizing watermark extraction in noisy environments.
However, limited research has explored the synergistic effects of integrating multiple signal processing techniques, such as DCT and DWT, along with advanced optimization algorithms like Biogeography-Based Optimization (BFO), in digital watermarking. This study aims to bridge this gap by investigating the combined impact of DCT, DWT, and BFO in enhancing watermark robustness, imperceptibility, and scalability across various multimedia formats and applications.

IV. PROPOSED ALGORITHM

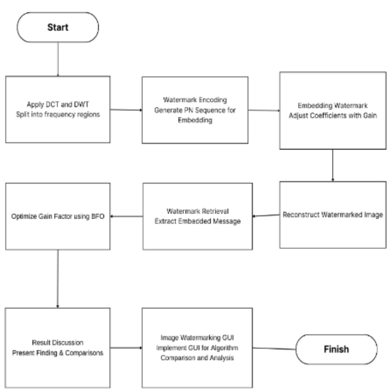

Figure: Flowchart

1. Input:

- Host image (grayscale image)
- Watermark image (binary watermark)
- Parameters:
  - α: Scaling factor for DWT
  - β: Scaling factor for DCT
  - Population size N for BFO
  - Maximum iterations max_iter for BFO

2. Preprocessing:

- Normalize intensity values of host image and watermarked image to the range [0, 1].

3. Watermark Embedding:

- Apply DWT to host image to obtain approximation A and detail coefficients D in multiple levels.
- Select a suitable DWT sub-band, e.g., LL sub-band from the highest level.
- Apply DCT to the selected sub-band coefficients LL to obtain DCT coefficients C.
- Use BFO to optimize the embedding process: - Initialize population P of size N with random solutions. - Evaluate fitness of each solution based on imperceptibility and robustness criteria. - Repeat for max_iter iterations: - Perform migration and mutation operations to explore the solution space. - Update fitness values based on the quality of embedded watermark. - Select the best solution Sbest with highest fitness.
- Embed the watermark bits into Sbest using a spread spectrum or LSB method.
- Reconstruct the watermarked image using inverse DCT and inverse DWT.

4. Watermark Extraction:

- Load the watermarked image.
- Repeat the DWT and DCT process to obtain transformed coefficients.
- Use BFO for extraction: - Initialize population P of size N with random solutions. - Evaluate fitness of each solution based on extraction quality. - Repeat for max_iter iterations: - Perform migration and mutation operations to refine solutions. - Update fitness values based on extracted watermark quality. - Select the best solution Sbest with highest fitness.
- Extract the watermark bits from Sbest using the inverse of the embedding method.

5. Output:

- Extracted watermark image
- Performance metrics:

- PSNR, SSIM for imperceptibility evaluation
- Robustness against attacks (e.g., noise, compression)

6. End

V. IMPLEMENTATION

A. Embedding of Watermark

The retrieval process of the watermark in our blind watermarking system, which integrates Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT) techniques, operates independently of the original host image, emphasizing its efficiency and flexibility. Initially, the embedded message is reformulated into a binary sequence (sequence of 1s and 0s) and then encoded using convolution, resulting in an encoded message used for further processing. Subsequently, a pseudo-random noise (PN) sequence is generated based on a key, which remains consistent throughout the embedding process. Two distinct and uncorrelated PN sequences (pn_sequence_1 and pn_sequence_0) are generated to facilitate the watermark embedding process.

Following these preparations, the host image undergoes DWT to decompose it into four multi-resolution coefficient sets: approximation (cA1), horizontal detail (cH1), vertical detail (cV1), and diagonal detail (cD1). For the subsequent DCT embedding step, a block size of 8x8 and a mid-band coefficient matrix are selected based on existing literature findings. In the embedding process, DCT is applied to the horizontal high-frequency subband (cH1), where both PN sequences are embedded using a gain factor 'k' determined by the bit value of the message. Specifically, if the bit value 'b' is 0, the embedding is represented as X = x + k * PN0; if 'b' is 1, the embedding is represented as X = x + k * PN1, where 'x' denotes the cover image and 'X' represents the resulting embedded image.

After embedding, inverse DCT (IDCT) is performed on cH1, followed by the repetition of the embedding process for the vertical high-frequency subband (cV1). The updated coefficient sets (cA1, cH1, cV1, cD1) undergo inverse DWT (IDWT), resulting in the generation of the watermarked image. Subsequently, metrics such as Peak Signal-to-Noise Ratio (PSNR) and Normalized Cross Correlation (NCC) are computed to evaluate the robustness and quality of the watermarked image.

This embedding and evaluation process can be repeated for subsequent watermarks using a different key for the PN sequence, with the size of each watermark determined through iterative refinement. The number of watermarks that can be embedded is contingent upon the reliability of the retrieval process, ensuring that each watermark can be extracted without distortion or loss of integrity. The iterative and systematic nature of this watermarking approach underscores its suitability for practical applications requiring secure and efficient watermark embedding and retrieval.

B. Retrieval of Watermark

The retrieval process of the watermark in our blind watermarking system, which integrates Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT) techniques, is designed to operate independently of the original host image, highlighting its efficiency and adaptability. Initially, the retrieval process mirrors the initial steps of the embedding process, utilizing the same key for pseudo-random noise (PN) sequence generation. This includes reformulating the message into a binary sequence and encoding it using convolution, thereby preparing it for the subsequent correlation and decoding steps.

Next, the DCT is applied specifically to the horizontal high-frequency subband (cH1) of the watermarked image, where a sequence is generated based on mid-band matrix conditions. This sequence is then correlated against two distinct PN sequences: pn_sequence_0 and pn_sequence_1. The same correlation process is then repeated for the vertical high-frequency subband (cV1).

Following these correlations, the mean correlation values for pn_sequence_1 across both cH1 and cV1, as well as for pn_sequence_0 across these subbands, are computed. Based on these calculations, a decision is made to assign elements to the message vector: if the correlation value corresponding to 0 exceeds that of 1, the message vector element is set to 0; otherwise, it is set to 1.

The resulting message vector is then subjected to the Viterbi decoding process to reconstruct the original embedded message. Subsequently, the message vector is reshaped to match the format of the originally embedded message, completing the retrieval process for the watermark.

This iterative retrieval process can be repeated for subsequent watermark messages, ensuring a consistent and reliable method for extracting embedded watermarks from a variety of watermarked images without reliance on the original unwatermarked images. The systematic and efficient nature of this approach underscores its applicability in practical scenarios requiring secure and robust watermark extraction.

C. Fitness Function Calculator

To set the optimum value of gain factor bacterial foraging optimization is used in our work. The BFO minimizes the objective function value to get the best location of E.Coli bacteria. So the task is to formulate the objective function to achieve the best gain value. For this purpose inverse of normalized cross correlation has been considered the parameter which is to be minimized. Initially random gain value is selected and that is passed to the embedding and retrieval process of message using DWT and DCT watermarking process. At the watermarked image by this process various noises like Gaussian noise, salt & pepper noise, speckle noise and poisson noise have been added and message is recovered from these noisy images. NCC between the original message and recovered from these noisy watermarked images have been found out. Then the inverse of sum of all these NCCs is considered as the objective function of BFO.

$$obj = \frac{1}{NCC_1 + NCC_2 + NCC_3 + NCC_4}$$

VI. RESULTS

We conducted testing of the algorithm using a diverse set of images categorized into three distinct types: low key, high key, and medium key images. This classification was informed by insights from computer graphics literature, where images with varying histogram characteristics are categorized based on the distribution of their intensity values. Specifically, low key images are characterized by a preponderance of darker tones, leading to a left-aligned histogram distribution with more bins concentrated towards the lower intensity range. Conversely, high key images exhibit a predominance of lighter tones, resulting in a right-aligned histogram distribution with more bins clustered towards the higher intensity range. Medium key images, positioned between these extremes, display a balanced distribution of intensity values within the histogram, typically centered around mid-range intensities. This systematic categorization allowed us to assess the algorithm's performance across different image tonalities and provided valuable insights into its effectiveness under varying visual characteristics and complexity levels.

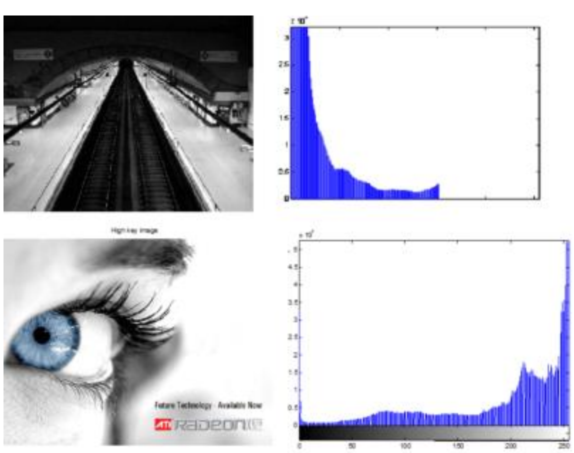

Figure: Histogram plot for low and high key image

In order to facilitate a comprehensive evaluation and comparison of the three distinct watermarking algorithms, we developed a user-friendly graphical user interface (GUI) using MATLAB. This GUI streamlines the process of running the algorithms and analyzing their outcomes, providing researchers and practitioners with a straightforward platform to conduct rigorous assessments. Users can easily input different image datasets and select the watermarking algorithms they wish to evaluate, leveraging intuitive controls and visual feedback to explore the algorithms' performance across various metrics.

Through experimentation and analysis using the GUI, we employed key performance indicators such as Peak Signal-to-Noise Ratio (PSNR), Normalized Cross Correlation (NCC), and Information Fidelity (IF) parameters to objectively assess the effectiveness of each algorithm. Notably, our findings highlighted that the gain factor tuning facilitated by Bacterial Foraging Optimization (BFO) consistently delivered superior performance compared to alternative methods. This optimized approach not only enhanced the robustness and reliability of the watermarking process but also demonstrated significant improvements in preserving image quality and ensuring accurate watermark retrieval under diverse conditions. The GUI's interactive capabilities and data visualization tools played a pivotal role in elucidating these outcomes, enabling detailed comparative analyses and informing future optimizations in digital watermarking techniques.

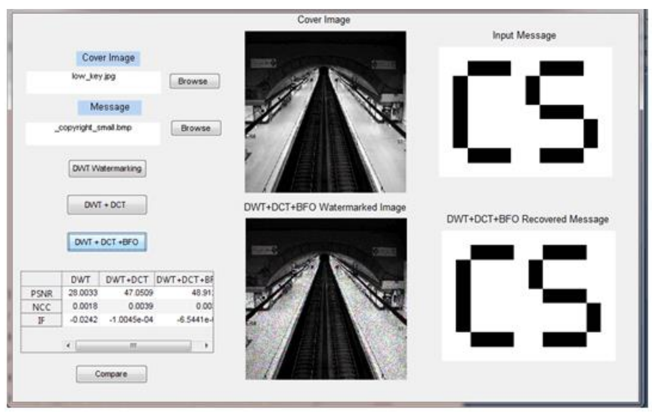

Figure: GUI

VII. CONCLUSION

In conclusion, this project successfully implements a high-quality digital image watermarking technique based on discrete wavelet transform (DWT) and discrete cosine transform (DCT) in cascade. The combined DWT-DCT approach allows for effective embedding and retrieval of watermark messages without perceptible image degradation. By strategically dividing the image into different frequency components and selecting optimal embedding regions, the method ensures both robustness against attacks and minimal interference with the original image quality.

The embedding process involves encoding the message into binary form, generating pseudorandom sequences for embedding, and applying DWT and DCT transformations to specific image components. The use of Bacterial Foraging Optimization (BFO) optimally tunes the gain factor, balancing message robustness with security. This methodology results in watermarked images that can withstand common types of noise while allowing for accurate message retrieval using a blind watermarking approach.

Furthermore, extensive testing and analysis on various types of images (low, medium, and high key) demonstrate the efficacy and adaptability of the proposed watermarking technique. The project's graphical user interface (GUI) facilitates easy comparison and evaluation based on performance metrics such as Peak Signal-to-Noise Ratio (PSNR), Normalized Cross Correlation (NCC), and Information Fidelity (IF), showing superior results particularly in gain factor optimization through BFO.

Overall, this project contributes significantly to the field of digital image watermarking by offering a practical and efficient method for embedding and retrieving watermark messages with high robustness and minimal distortion, validated through comprehensive experimentation and analysis.

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