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Arnold Transform-Lifting Wavelet Transform and Singular Value Decomposition Based Alpha Blending Image Steganography for Secure Communication

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Abstract: Image steganography is an artistic approach used to conceal secret data within a cover image (CI) while maintaining its visual quality. This paper presents a strategy for image steganography by applying Arnold Transformation (AT) to Secret Image (SI), Singular Value Decomposition (SVD), and Lift Wavelet Transformation (LWT) to CI and SI. AT is enforced on the RGB plane of SI, and the LWT is engaged to decompose the image into approximations and detail coefficients, allowing for the identification of areas suitable for embedding without noticeable changes. The SVD is operating on the approximation coefficients, resulting in the U, singular value S, and V matrices. By modifying the singular values, secret data is embedded. The proposed method offers improved robustness and security as modifications are distributed across various frequency components, making it challenging for unauthorized parties to detect the confidential information. Experimental results demonstrate that the combination of LWT and SVD yields effective results, i.e., Mean Squared Error (MSE) and Peak Signal to Noise Ratio (PSNR) with minimal visual distortion. However, the embedded information may still be susceptible to specific steganalysis attacks, necessitating additional security measures for sensitive data.

Keywords: *Cover image, Payload image, Stego image, PSNR, Steganography.*

1. Introduction:

Image steganography is a technique that involves hiding secret data within an image without perceptibly altering its visual appearance [1]. This provides a covert way of transmitting sensitive information by embedding it into the pixels of CI [2]. Transmission of Electronic Medical Record (EMR) using the Internet of Things (IOT) [3] Arnold Transformation (AT), LWT and SVD techniques are used in this paper [4] [5] [6]. AT is a two-dimensional chaotic map that is enforced on a reference image to rearrange its pixel value positions; AT operates by dividing the image into cells or blocks of equal size [7]. The LWT method is based on the wavelet transform, which is a mathematical tool that measures and is used for analyzing and processing images [8]. An image is divided into several frequency bands using LWT, representing different levels of detail. By manipulating the coefficients in these frequency bands, it is possible to embed secret information [9] [10]. The common approach is to modify the Least Significant Bits (LSBs) of the wavelet coefficients to encode the hidden information [11]. The small variations in LSBs are less noticeable to the human visual system; the modifications are usually imperceptible [12]. The SVD technique utilizes the algorithm to decompose an image matrix into three matrices: U, S, and V. The S matrix contains the singular values, which represent the image's energy. By modifying these singular values, secret data is concealed within the image [13] [14]. Similar to LWT, the modifications are performed in a way that ensures minimal visual impact on the image. AT- LWT and SVD techniques provide a robust means of hiding information in images [15]. They offer different approaches for embedding data and have their advantages and limitations. The choice between the techniques depends on factors such as the application requirements, the optimum degree of security, and the susceptibility to steganalysis [16][17][18]. All the researchers in this field often explore and combine several techniques to enhance the efficiency and security of image hiding [19] [20].

Contribution: Arnold Transform (AT) – LWT, SVD, and Alpha Blending Image Steganography is proposed in this paper.

Organization: Section II is related works; Section III is the proposed steganography technique. Section IV and Section V are result analysis and conclusion.

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2. Related Works:

Saidi et al. [21] discussed the steganography system rooted on DCT. Chaotic mapping is used to select the embedding position. Rabie et al. [22] proposed a DCT domain-embedding process rooted on a global adaptive region.

Chang, C.C [23], proposed a modified quantization table that embeds enciphered data with quantized DCT coefficients. Chan et al. [24] proposed an approach, which uses Haar Discrete wavelet Transform (DWT) to convert spatial domain into frequency domain. Dai et al. [25] proposed an approach situated on DCT domain quantization-table modification and image scrambling. Ramu et al. [26] proposed a DWT- based steganography that uses singular values to embed secret information. Ghebleh et al. [27] proposed a robust chaotic strategy grounded on three-dimensional chaotic cat mapping and DWT for three-dimensional chaotic images. Li et al. [28] proposed an image steganography that uses discrete cosine transform (DCT). Miri [29] proposed an adaptive image steganography rooted on the DWT using genetic algorithms. Sharma [30] proposed a safe, high embedding capacity based on DWT. Chaudhary et al. [31] proposed an image steganography based on spectral wavelets using SVD and Arnold transform. This is the original paper by Vladimir Arnold [32], where they introduced the cat map and discussed its properties. Image enciphering approach situated on AT combined with the chaotic standard map is presumed [33]. Li, S et al [24] proposes an efficient implementation of the AT using matrix operations, which can accelerate the image scrambling process. Xu, Z [34] presents an image enciphering strategy that combines the AT with bit-level permutation to enhance the robustness and security. Nascimento et.al [35] provides an outline of chaos-based image enciphering procedure, including those that employ AT. Ding et.al [36] recommends an efficient implementation of the AT using matrix operations, which can accelerate the image scrambling function.

2.1. ARNOLD TRANSFORMATION (AT):

Two-dimensional chaotic map is utilized to an image to rearrange its pixel positions. AT operates by dividing the image into blocks, with equal size. Each block is transformed by applying a permutation operation [32] [33].

The characteristic of the AT is its ability to mix and scramble the pixels of an image while preserving its overall structure. It is important to note that the AT alone may not provide strong security or enciphering. AT is used for encryption approach or in combination with other techniques [45].

2.2. LIFTING WAVELET TRANSFORM (LWT):

LWT is a specific implementation of the DWT that provides an efficient and computationally better method for image and signal analysis. The LWT [43] operates on an image to decompose it into frequency sub bands, capturing both the high frequency and the low-frequency approximation components. The steps involved in LWT is as follows:

Step1 . **Prediction step**: Estimates the coarse approximation (low-frequency component) of the image.

Step 2. **Update step**: Computes the detail (high-frequency component) by subtracting the predicted approximation from the original image.

Step 3. **Scaling and wavelet functions**: The prediction and update steps are applied iteratively to generate multiple approximation and detail coefficients.

Step 4. **Down sampling:** Input signal is down-sampled by discarding a portion of the coefficients.

Step 5. **Inverse transform**: The inverse LWT is performed by applying the prediction and update steps in reverse order, using the stored coefficients to reconstruct the original image.

The LWT equation are represented mathematically as below:

Forward LWT: Let us consider a 1D signal x (n) of length N. LWT can be performed as follows in equation 1, 2 and 3.

Step 1**. Splitting Step**: x1(n) = x (2n);

x1(n) is even indexed samples………………………….…...(1)

x2(n) = x (2n+1); x2(n) is odd indexed samples………………..(2)

Step 2. **Prediction Step**: p (n) = x1(n) - (x2(n-1) + x2(n))/2…...(3)

Step 3. **Update Step**: u (n) = x2(n) + (p (n-1) + p (n))/4……….(4)

The output of the LWT consists of two sets of coefficients: approximation (p) and detail coefficients (u).

Step4**: Inverse LWT** (ILWT): To reconstruct the original signal from the approximation and detail coefficients, ILWT is employed using the following equation 5, 6 and 7:

1. **Update Step**: x2(n) = u (n) - (p (n-1) + p (n))/4……….….(5)
2. **Prediction Step**: x1(n) = p (n) + (x2(n-1) + x2(n))/2……..(6)
3. **Concatenation**: x (n) = [x1(0), x2(0), x1(1), x2(1) ….x1(N/2-1), x2(N/2-1)]… …………………………….(7)

The above-mentioned equations describe the basic lifting scheme for LWT.

2.3 SINGULAR VALUE DECOMPOSITION (SVD):

SVD is used for matrix factorization to decompose a matrix into three separate matrices. Given a matrix A, the SVD [45] factorizes it into three matrices as follows in equation 8,

$A = U * S * V^T$……..………………………………. (8)

Where U→ m x n matrix of the orthonormal eigenvectors of $A*A^T$

V → Transpose of n x m matrix consist of the orthonormal eigenvector of $A*A^T$

S → n x n diagonal matrix of the singular values, the square root of the eigenvalues of $A*A^T$.

The columns of U are called the left singular vectors of A. The columns of V are called the right singular vectors of A. Where diagonal elements known as the singular values of A. The non-zero singular values are sorted in descending order. V is an n × n unitary matrix, meaning V' * V = I. SVD provides a way to express any matrix as a linear combination of rank-one matrices, represented by the singular values and singular vectors [44].

3. Proposed Model:

The proposed Block diagram of AT-LWT, SVD and alpha blending image steganography for secure communication is as shown in Figure1 below.

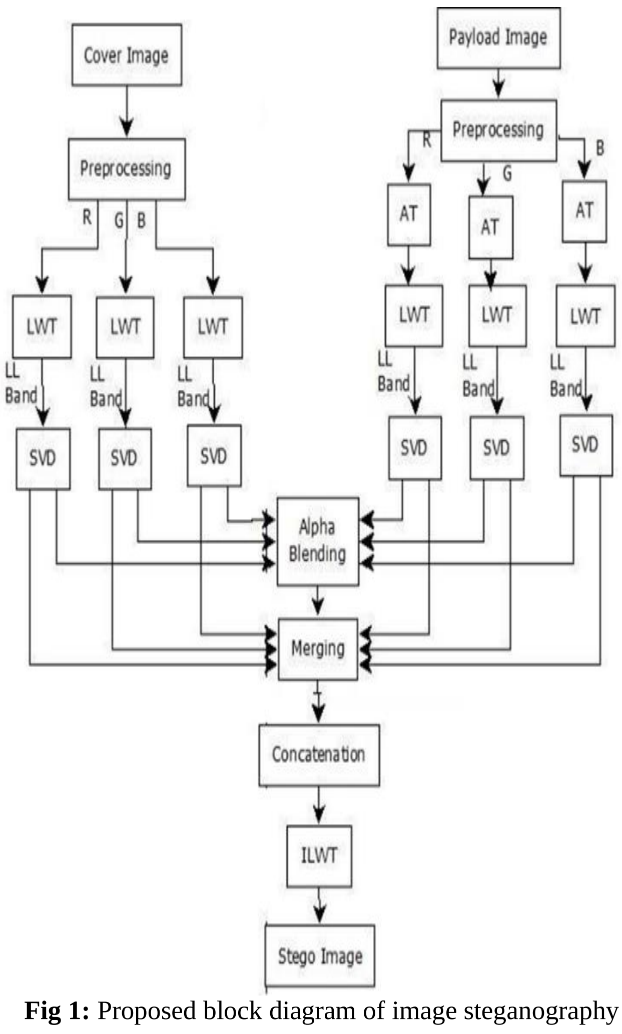

Fig 1: Proposed block diagram of image steganography

The approach of steganography as depicted in Figure 1 using AT-LWT and SVD typically involves the following **steps:**

1. CI and SI is read and preprocessed.
2. The original image is converted to RGB planes if it is a color image.
3. AT is applied on the RGB planes of secret information.
4. Image decomposition: The RGB Plane is decomposed using the LWT.
5. After applying LWT, the approximation, **LL Band** is chosen from CI and SI.
6. **SVD:** The LL Band obtained from the previous step is subjected to SVD, resulting in the U, singular value, and V matrices.
7. **Merging and concatenation** is done.
8. **Embedding:** The secret data is then embedded by modifying the singular values.
9. **Inverse LWT**: The modified approximation coefficients and the detail coefficients are combined.
10. **Inverse operation** is enforced to extract the payload information.

By using AT-LWT and SVD in combination, this steganography technique provides a high level of security and robustness to attacks, as modifications are spread across different frequency components and are not concentrated in a single region of the image.

The Figure1 is the proposed block diagram of image steganography, which comprises the preprocessing, color conversion to RGB Planes, AT, LWT, and LL Band is chosen, SVD is applied on each LL Band, Alpha Blending, Merging and concatenation, ILWT is performed to generate stego image. Figure2 is the extraction process of secret image, which includes LWT, SVD, and Inverse Arnold Transformation (IAT). The process of extraction in Figure2 is the inverse process of Figure1. Alpha deblending and IAT is employed to extract the secret data.

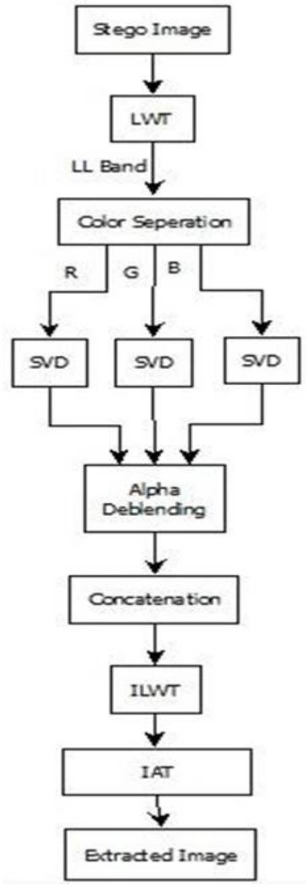

Fig 2: Extraction Process

4. Result Analysis:

The schemed algorithm is experimented with using MATLAB [35] where the MATLAB coding [30] is utilized. The performance of the approach using standard images [43] is shown in Figure 3 to Figure 6. The result parameters are MSE and PSNR. Mean Squared Error (MSE) measures the average squared difference between the pixel values of two images. The lower the MSE value, the closer the stego image is to the original image. To measure the MSE, each pixel in the CI and stego images is compared. The squared differences are averaged across all pixels [38]. PSNR [39] is a metric for measuring the quality of an image by comparing it to a reference image. The PSNR [40] is expressed in decibels (dB) is as follows in equation 10.

PSNR = 10 * log10 ((MAX^2) / MSE) ……………. (10)

Where, MAX is the maximum possible pixel value of the image (for example, 255 for an 8-bit grayscale image) [41].

The Result is as shown in table1, which comprises Test images along with their result parameters [47] [48].

Table 1: Result Analysis

COVER IMAGE	PAYLOAD IMAGE	MSE	PSNR
Airplane	Baboon	0.2051	61.8924
Baboon	Fruits	0.1816	62.9465
Peppers	Airplane	0.1641	63.8306
Cat	Girl	0.0605	72.4890
Monarch	Fruits	0.0430	75.4677
Sails	Tulips	0.3906	56.2956
Arctichare	Baboon	0.4297	55.4677
Tulips	Monarch	0.2168	61.4097
Hestain	Tissue	0.1309	65.7947
Peppers	Fruits	0.1074	67.5089
Airplane	Lena	0.1543	64.3637
Lena	Tissue	0.0332	77.7072

The sample images [42] utilized for testing i.e., cover image, payload image, stego image is as shown below in figure3 to figure6 respectively.

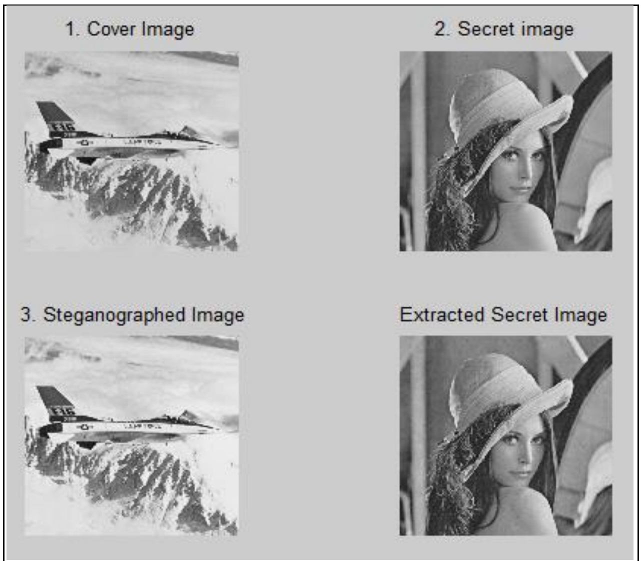

Fig 3: Result Image

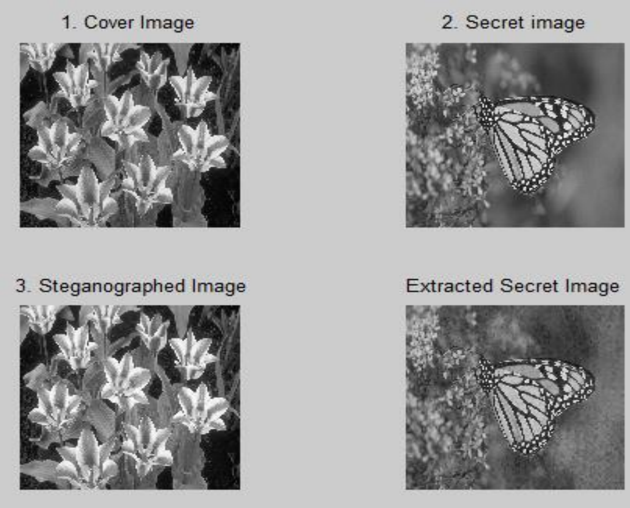

Fig 4: Result Image

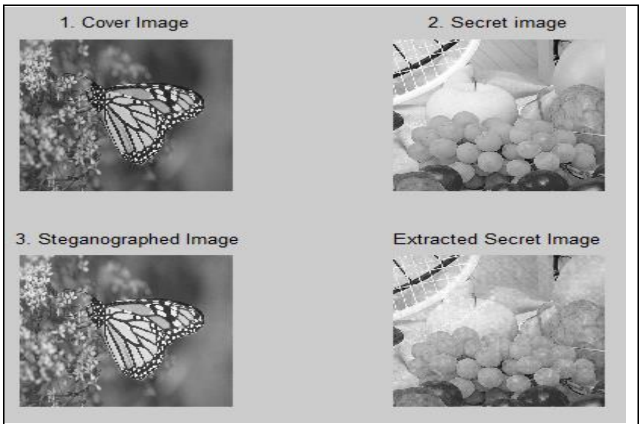

Fig 5: Result Image

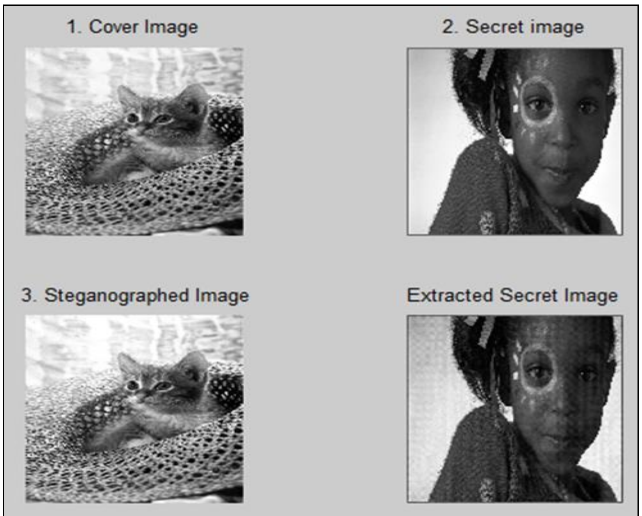

Fig 6: Result Image

The figure 3 to figure 6 as shown above represents the various test images of cover and payload along with the stego images.

A gray-scale value distribution called an image histogram displays how frequently each value at each gray-level occurs [46].

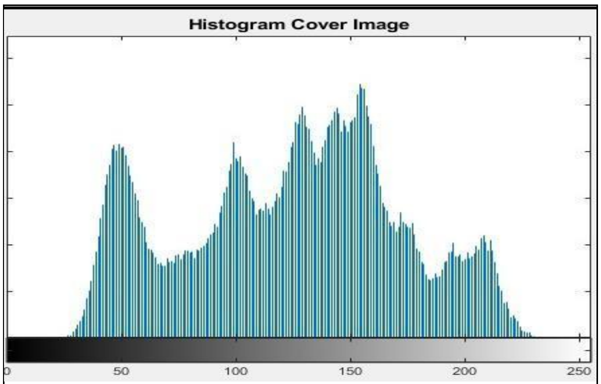

Figure 7: Histogram of Cover Image

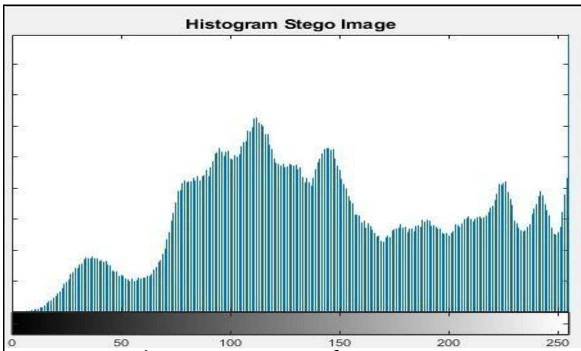

Fig 8: Histogram of stego Image

The figure 7 and figure 8 as shown above represents the histogram of cover image and stego image respectively.

4.1. COMPARISON WITH EXISTING TECHNIQUES:

The PSNR values of the schemed methodology with the current [1,2, 15, 16] are compared in table 2, from which it is evident that the proposed algorithm is able to generate better maximum PSNR values than existing ones. This proves that the presented algorithm is more effective than the existing one in retaining the CI characteristic. Result Comparison is shown below in table2.

Table 2: PSNR Comparison

Authors	Techniques	PSNR (dB)
Aya Jaradat et al. [2]	Chaotic PSO	68.51
Kapre Bhagyashri, S. et al. [15]	DWT-SVD	36.60
Ghoshal, N. et al. [16]	DFT-LSB	33.20
Hussah N et al. [1]	IWT-LSB	55.50
Proposed System	**AT-LWT and SVD**	**77.70**

5. Conclusion:

Image steganography using AT-LWT and SVD techniques offers effective and covert ways of embedding secret data within images. While minimizing visual alterations to the image the proposed techniques provide different approaches for concealing information. The AT is used to scramble the secret data and LWT technique utilizes wavelet transform to divide the image into frequency bands, allowing for modification of coefficients at different levels of detail. The SVD technique decomposes the image matrix into three matrices, including the S matrix representing the energy of image. By manipulating the singular values in the S matrix, secret information is concealed within the cover image. Image steganography using AT- LWT and SVD techniques offers powerful methods for covert communication and data concealment within images. These techniques play a crucial role in various fields by providing a means to securely transmitting sensitive information without arousing suspicion, including secure communication.

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