Multi-Layer Secure Image Steganography Using SPM Algorithm with Adaptive Segmentation and Lossless Compression for Audio Data Hiding

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Abstract— **The demand for secure data transmission in today's digital era has increasing importance due to the rising levels of incidents related to data breaches and concerns of privacy. This paper proposes an integrated scheme in image steganography: "Multi-Layer Secure Image Steganography Using Secret Pixel Mapping (SPM) Algorithm with Adaptive Segmentation and Lossless Compression for Audio Data Hiding." The proposed methodology has adapted a multi-layer framework that gives a substantial rise in the capacity and security of embedding data within images. It depends on the SPM algorithm, because in this method, the approach can successfully hide audio data in the least significant bits of an image without much visual distortion and embed maximum amount of data. Moreover, adaptive segmentation automatically adjusts the embedding capacity with image contrast characteristics to maintain optimal data integrity with diverse image varieties. For security, it uses AES to encrypt the audio data before embedding; this way, even if data is extracted, it cannot be read without the appropriate decryption key. Besides, it adopts many lossless compressions for getting more storage efficiency to embed more amounts of data without deteriorating the quality of the original image. The experimental results justify that the efficacy of the proposed approach has been good showing robust capacity with high image fidelity in data hiding. The paper discusses the implications of these findings for improved privacy in areas such as telecommunications, cloud computing, and multimedia content sharing for secure communication, digital watermarking, and data protection applications.**

***Index Terms* — Keywords — Image Steganography, Secret Pixel Mapping (SPM), Adaptive Segmentation, Lossless Compression, Audio Data Hiding, Data Security, Advanced Encryption Standard (AES), Confidentiality.**

I. INTRODUCTION:

1.Multi-Layer Secure Image Steganography Using Secret Pixel Mapping Algorithm with Adaptive Segmentation and Lossless Compression for Audio Data Hiding While digital communication becomes ever so pervasive, the security and confidentiality of sensitive information are becoming an essential tenet of measures to be taken. Steganography represents the method of data concealment within other nonsensitive data for sending information discreetly without raising suspicion. This paper proposes a new image steganography scheme based on a novel Multi-Layer Secure Image Steganography framework incorporating the SPM algorithm, adaptive segmentation, and lossless compression for embedding audio data. In this work, our proposed approach aims at improving data capacity and preserving high quality of the image while providing robust security regarding embedding audio information within image pixels. By analyzing the features of the image, we will adaptively decide on an appropriate embedding strategy in order to achieve minimum visual distortion and to increase the payload of data concealing. Furthermore, the blend of AES ensures that even if the hidden data is detected, it cannot be retrieved. We are presenting this work in contribution to the domain of secure communications, offering an effective method for data hiding, meeting the demands of ever-increasing digital privacy concerns.

1.1 **Introduction to Audio data Hiding Using SPM Algorithm and Adaptive Segmentation:**

Audio data hiding is one of the most important techniques in information security; audio can be hidden in other media, such as images. This technique is used in copyright protection and secret communication. Among the different approaches to steganography, the SPM algorithm works very well, embedding audio data into the least significant bits of image pixels, which keeps a change undetectable to the human eye. The adaptive segmentation in the SPM algorithm analyzes the host image for optimal embedding capacity according to its characteristics. As a result of the adaptability, the concealment capacity is maximized with a reduced risk of detection. In addition, combining SPM with adaptive segmentation increases the security and robustness of hidden audio by enhancing its resistance against attacks, including image compression. Eventually, this is developed into a revolution in integration concerning audio data hiding techniques that paved the ground for secure digital communication.

1.2 **Why Combine spm and adaptive segmentation for audio data hiding**:

The advantages of audio data hiding with SPM combined with adaptive segmentation are that it allows different entry data embedding capabilities depending on the features of the host image. Specifically, more audio data can be hidden in a region when this region has a high capacity, while the quality of the image should remain preserved. The resulting integration strengthens security through the dynamic adjustment of the embedding strategy based on properties of the image-a priori, which diminishes the probability of detection since an attacker would hardly be able to detect any hidden data. What's more, this combination increases the robustness of the audio data against such attacks as compression or filtering; for those, adaptive segmentation saves the critical regions and thus allows the integrity of the hidden data to be maintained. It has balanced the needs of audio data hiding with the need to preserve the visual quality of the host image by implementing the embedding into the less significant areas. The visual fidelity can hence remain largely unaffected.

1.3 Why additional layers AES and lossless compression:

First, the AES encryption provides the most tremendous means for securing audio data before embedding it in the host image. This predominantly encrypts such data that the probability of any decoding or extracting the given hidden information by any attacker becomes zero. Furthermore, even if extraction occurs, the extracted information will be encrypted, retrieval of which is practically infeasible without the correct key. This extra layer ensures the confidentiality of sensitive information and thereby enhances the privacy of data under transmission. These lossless compression techniques bring out the best size of audio data without degradation. This is particularly useful while embedding the data in a host image of limited capacity, thus enabling more information to be hidden efficiently. Lossy compression maximizes the utilization of every available pixel space in the host image. Lossy will allow larger audio files to be embedded into one image without compromising the integrity of either the audio or visual data.

1.4 Implementation and Evaluation of the project :

Firstly, the audio data had to be prepared for hiding. All the audio files that needed embedding were first converted into binary, then encrypted using the AES algorithm. This would ensure that the cover audio data is not assessed illegally using a symmetric key, whereby only the authorized users can obtain the original audio. Lossless compression was used to reduce the size of encrypted audio data without losing any quality after encryption. This was an important step to ensure that there was maximum utilization in terms of the amount of data that could actually be hidden within a host image.

Steganography was performed using the Secret Pixel Mapping algorithm, which embeds the compressed and encrypted audio data into the host image. The image was analyzed to identify what type of pixel it contains, allowing adaptive segmentation that optimizes the embedding of data concerning image quality. The algorithm embedded audio data in the least significant bits within the pixels of the image to protect the visual quality of the images from severe degradation. This careful integration thus managed to balance between the capacity to hide data and the preservation of fidelity of images.

Retrieval was also an essential process and involved extracting the audio data hidden in the image. After extraction, decompression and decryption are done to recover the original file in audio format. To ensure perfection and efficiency, this is highly scrutinized for accuracy to ensure that there is no error in retrieving the audio data that is hidden. Overall functionality testing of embedding and retrieval methods was performed based on confirmation of their robustness.

Evaluation Metrics The project was evaluated with respect to various metrics in its effectiveness: Security was one of the important metrics tested. In addition, this research mapped the effectiveness of the AES encryption technique to its ability to render the decryption of audio information without the appropriate key difficult. It should assure the security of the data hidden by being robust against many steganalysis techniques.

Another criterion for evaluation was that of capacity, which referred to the amount of audio data to be hidden in various types of images considering several qualities and resolutions. The metric was important to establish the practical usability of the method in real applications. Concretely, below, the visibility of data embedding is evaluated both pre- and post-processing of host images based on peak signal-to-noise ratio and structural similarity index. In parallel, the audio quality of the retrieved files will be evaluated through the use of standard audio quality metrics, complemented by listening tests to determine whether any perceived differences exist between the original and the retrieved audio.

II.LITERATURE SURVEY

Huwaida T. Elshoush and Mahmoud M, “Ameliorating LSB Using Piecewise Linear Chaotic Map and One-Time Pad for Superlative Capacity,Imperceptibility and Secure Audio Steganography” (IEEE)Khartoum 11111, Sudan (2023). This paper highlights Audio steganography still faces challenges in achieving high payload, imperceptibility, and robustness simultaneously. Traditional methods are stricken because of the non-availability of any randomness when choosing audio samples and their LSBs since only lower-order bits in each sample are used. Also, very few adaptive methods target higher LSBs. The proposed method, LSBPWLCM, overcomes these issues while utilizing a piecewise linear chaotic map for randomly embedding the secret message in random and unpredictable audio samples, and choosing one of the 4-LSBs unsystematically. While Huffman coding reduces message size, keys generated by PWLCM improve security by using a one-time pad. The proposed LSBPWLCM, implemented with MATLAB, demonstrates excellence both in imperceptibility and hiding capacity and outperforms all previously developed methods.

Sama N. M.Al-Faydi, Sahar Khalid Ahmed, Heba N. Y. AlTalb “Improved LSB image steganography with high imperceptibility based on cover-stego matching “ Mosul, Iraq(2023), Information security for secure transmission of data is considered paramount, and this work investigates the LSBbased approaches for image steganography with undetectable changes. It compresses the secret message using the LZW technique and embeds the bits of the compressed secret message in the LSBs of those edge pixels in the cover image whose corresponding bit values are the same. In this case, the stego image remains identical to the cover image, without any visible change. Message retrieval uses the location addresses of pixel locations that are kept in a file where data is hidden. This method gives very good imperceptibility, with PSNR as infinity, SSIM and NCC as one for different test images, and MSE and AD as zero, confirming excellent quality of stego images.

Venugopal Rohith, Sangeetha Varadhan "Exploring Advanced Techniques in Image Steganography and Date Hiding For Secure Communication" TamilNadu,India(2024).This paper highlights different methods of image steganography and information hiding have greatly developed in recent years, enabling both secure information communication and concealment. This paper investigates some of the advanced methods plotted that influenced digital watermarking, copyright protection, and covert data transmission. The techniques go further-ranging from a basic LSB substitution to advanced machine learningbased approaches with a focus on embedding in digital images. The goal here is to be able to balance imperceptibility and resilience against detection, emphasizing adaptability, minimizing distortion, and combining multiple methods. This paper also points out the challenging problems of modern steganalysis and emphasizes the persistent need for innovation in order to keep up with improvements of steganographic techniques to be effective and secure.

Ahmad Zulfakar Abd Aziz, Muhammad Fitri Mohd Sultan, Nurul Liyana Mohamad Zulkufli "Image Steganography:: Comparative Analysis of their Techniques, Complexity and Enhancements" (2024) This article explains about of three steganography techniques of the spatial domain: Least Significant Bit, Pixel Value Difference, and the Edge-Based Data Embedding methods. The research was carried out with the experiment of encoding a number of images using the three methods followed by analyzing distortion metrics such as MSE and PSNR for LSB distortion. While the results from the experiment were noted acceptable levels of distortion for the LSB method, all methods used in this case led to considerable changes in the size of the files. These findings are thus representative of the trade-off between the data embedding capacity and the quality of the images, and how challenging it can get sometimes to maintain imperceptibility, especially at higher embedding capacities. These insights are very essential in considering how these methods might be applied in practical situations where file size and image quality at a balanced position are held together by security at the helm for good steganography.

Arvind Dhaka, Amita Nandal et.l,"Likelihood Estimation and Wavelet Transformation Based Optimization for Minimization of Noisy Pixels" India(2021), This paper presents a clean image retrieval scheme using a parametric estimation approach from various noisy models. This method borrows tools from statistics, such as the Maximum Likelihood Estimation-Bayesian Estimation method, to obtain prior and posterior distributions that provide maximum noise modeling fitness. The methodology will be able to model noise quite effectively by the log-likelihood functions along with conjugate priors in order to enhance image quality. Then, the presentation proceeds with exploring modern denoising methods including sparse signal representation via linear and nonlinear transformations.

Unlike previous studies that have primarily focused on the analysis of pixel intensity or noise variance, this study digs deeper into the distribution of noise, realizing its great impact on the performance of denoising algorithms. It carries out a detailed statistical analysis based on likelihood estimation and posterior analysis, hence proving the accuracy and efficiency of its introduced algorithm in noise modeling and image recovery. This given literature review may serve as the basis for further research on adaptive image steganography and secure data hiding, aligning with larger goals related to robust image processing and secure communication.

Ntivuguruzwa Jean De La Croix, Tohari Ahmad a, Fengling Han, "Comprehensive survey on image steganalysis using deep learning" Australia,Melbourne(2024), This conducts asurvey on the latest development of technology has increased the use of digital media, especially images, videos, and audio in public networks. Among them, digital images are considered to be one of the favorite mediums for hosting as well as transmitting confidential data over public channels. Steganography and cryptography are two important techniques that have been developed in order to protect such data from unauthorized access. While cryptography scrambles data into unreadable form, steganography conceals the very existence of secret information within some form of digital content, such as images, so their detection during transmission is impossible.

Mohamed EL-Hady Maha , H. Abbas, et.l, "DISH: Digital image steganography using stochastic-computing with highcapacity"Giza,Egypt(2024) This paper highlights about the evolution in the computer systems from the deterministic binary computing to the probabilistic stochastic has opened new possibilities in many areas of application in data hiding and steganography. In the case of traditional binary computing, a number is stored as a pattern of 1s and 0s. The most wellknown methods in the domain of image steganography are based on LSB. LSB methods succeeded in embedding bits of a secret image into the least significant bits of a cover image, but soon after, they presented some limitations regarding security, as a serious concern about unauthorized access to hidden data arose. In solving these issues, some researchers moved towards advanced techniques, including edge-based embedding and chaotic encryption.

III. EXISTING METHODS

Steganography, or the art of hiding information in digital media, has undergone many changes with time. Several methodologies have developed to attain this goal. This section presents some of the prominent existing techniques used in image steganography, with more emphasis on their operational principles, advantages, and limitations.

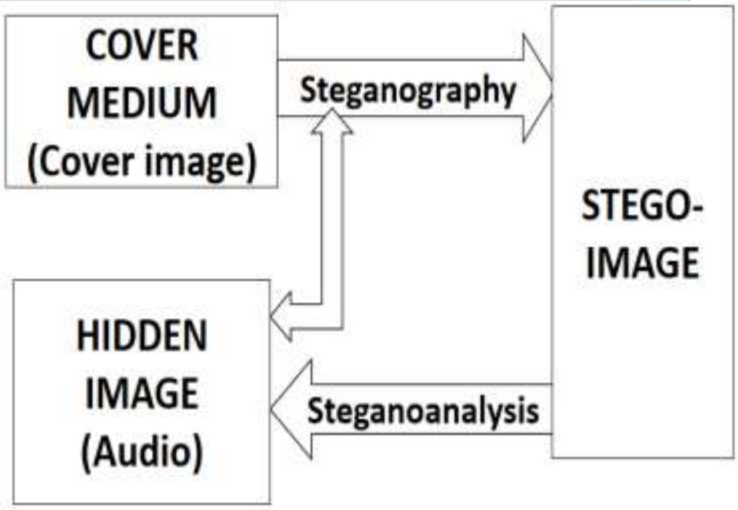


Figure1.Steganography and Steganalysis model

Least Significant Bit (LSB) Substitution:
LSB is the most common technique used in image steganography, where secret data is embedded by changing the least significant bits of the pixels in a cover image. It is preferred because of its simplicity and low computational overhead. Its main disadvantage is predictability: unauthorized receivers can use this predictability to extract hidden information, making it susceptible to a number of attacks, such as LSB matching attacks. Additionally, changing the least significant bits may introduce visible distortions in the image for high payloads.

Pixel Value Differencing (PVD):
PVD is an advanced steganographic technique that increases the capacity for hidden data while keeping the image quality intact. It calculates the difference in pixel values between adjacent pixels to specify how many bits can be embedded. The most important advantage of PVD is that it allows adaptive data hiding according

to pixel variance, reducing perceptible changes in the cover image. However, like LSB, PVD can also be subject to different methods of steganalysis, where hidden data is detected through statistical analysis.

Edge-Based Data Embedding (EBE):

EBE is based on embedding secret data in the edge areas of an image, where changes in pixels may be relatively tolerable. This technique exploits the insensitivity of edge pixels to slight changes, thereby preserving image quality. EBE offers enhanced security compared to LSB and PVD, but it may not guarantee the same payload capacity, limiting the amount of data that can be hidden.

Chaotic Map-Based Techniques:

Recent developments in steganography have introduced chaotic map-based methodologies, which increase security by incorporating chaotic systems. These techniques generate pseudo-random sequences to select pixel locations for embedding, reducing an attacker's ability to predict where the data is hidden. While these methods improve security, they increase complexity and may require more computational resources, making them less suitable for real-time applications.

Machine Learning Approaches:

Recently, with the rise of machine learning, researchers have begun applying it progressively to steganography. Machine learning algorithms can be trained to identify and embed data optimally, based on the particularities of each image, enhancing both imperceptibility and robustness. However, these methods are often based on large datasets and may face challenges in generalizing to different image types.

IV.PROPOSED METHOD

In this work, we introduce a new method of image steganography entitled "Multi-Layer Secure Image Steganography Using the Secret Pixel Mapping (SPM) Algorithm with Adaptive Segmentation and Lossless Compression for Audio Data Hiding." The proposed methodology aims to improve security and enhance the capacity for data hiding in digital images while ensuring high imperceptibility.

Overview of the Proposed Approach :

Our approach embeds audio data into cover images by incorporating advanced techniques like secret pixel mapping, adaptive segmentation, and lossless compression. The main components of our methodology are as follows:

Proprietary Pixel Mapping Algorithm :

The core of our steganographic method is the SPM algorithm, which maps secret data to specific pixels in the cover image. Unlike LSB-based methods that embed data by randomly changing the least significant bits, the SPM algorithm intelligently selects pixels based on their color and intensity. This minimizes perceptual distortion and enhances security, making it difficult for unauthorized users to detect the hidden data.

Adaptive Segmentation:

Our approach also utilizes adaptive segmentation to improve embedding efficiency. This involves dividing the image into segments based on content and edge detection. The algorithm analyzes the image's structural features to identify optimal regions for embedding. Adaptive segmentation ensures better pixel capacity utilization while maintaining the cover image's integrity.

Lossless Compression:

We enhance the payload capacity by applying lossless compression to the audio before embedding it into the cover image. This reduces the data size without any loss of information, allowing more audio to be embedded without degrading the visual quality of the cover image.

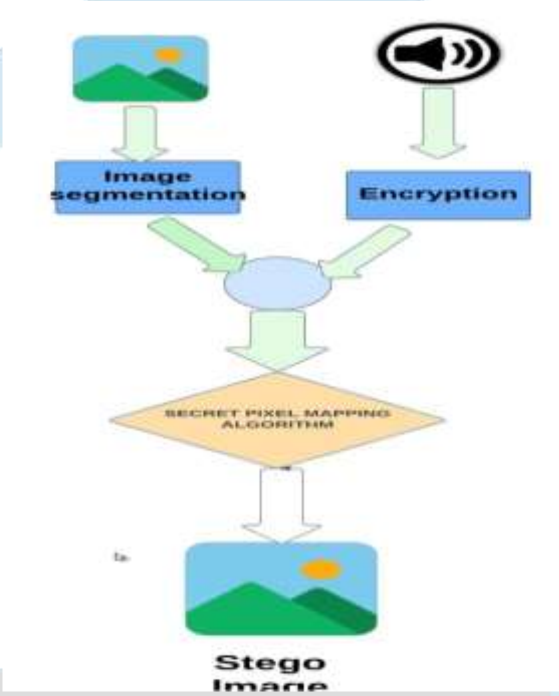
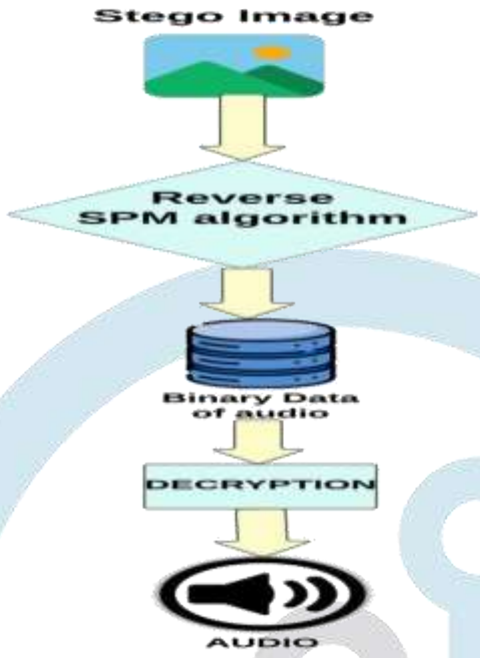


Figure.2 Hiding the audio in image process

Data Retrieval Process :
The methodology includes a secure retrieval process for accessing the hidden audio data. The addresses of the pixels containing the compressed secret audio are stored in a separate file called "location addresses." The receiver uses this file to accurately extract the concealed data, ensuring that only authorized users can access the hidden information while maintaining confidentiality.

Multi-Layer Security:
This method integrates encryption alongside steganography, using a chaotic encryption algorithm to generate pseudorandom keys for pixel selection and data embedding. This additional layer of security makes it difficult for unauthorized parties to extract or modify the hidden audio data.



Evaluation Metrics:

The effectiveness of the method is evaluated using metrics such as PSNR, MSE, and SSIM, which assess the imperceptibility of the stego image and the quality of the embedded audio data. Security assessments are also performed to evaluate resilience against potential attacks like brute force and statistical analysis. With the integration of lossless compression techniques, it is effective to reduce the audio data size; therefore, more data can be hidden without affecting the quality of the image. Moreover, since AES encryption is implanted, even the hidden audio is kept safe for unauthorized access to ensure better confidentiality of sensitive information.

V.METHODOLOGY

The proposed methodology for secure data hiding in images uses a structured approach in several stages: conversion of data, compression, encryption, mapping of pixels, embedding of data, and retrieval of data. Each stage is designed to achieve the bestpossible data efficiency and security without affecting the integrity of the host image.

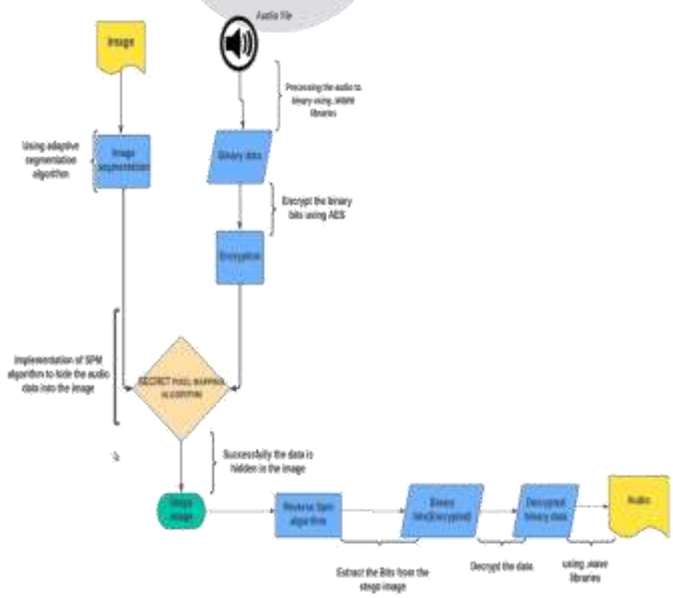


Figure 3. Flow Diagram

A. Explanation with mathematical expressions

1. **Data conversion**

Let us first represent the audio data in binary. We denote the audio samples as A={a1,a2,…,an}; then, in binary, it will be:

B=∪i=1nformation(ai,'08b')

Where, B is the resulting binary sequence considering 8 bits for each sample.

2. **Audio Compression**:

We use a lossless compression algorithm in order to minimize the binary representation of the audio data. Let L denote the length of the binary data B before compression. The length of the data after compression L′ may be given by:

$$L'=L-\Delta$$

where Δ is the number of bits saved by compressing it. The compressed data C may now be represented by:

$$C=B' \text{ where } |B'|=L'$$

3. **Encryption:**

Before embedding, we encrypt this compressed audio using AES. Let K be the key to perform encryption. Mathematically, encrypted data E can be given as:

$$E=AES(C,K)$$

This means that the binary representation E remains secret, where |E|≤|C|.

4. Pixel Mapping:

The total amount of pixels P in the host image is given by:

$$P=W\times H$$

where, W is the width and H is the height of the image. To embed, we have to find out how many bits can be stored per pixel. Assuming b=2 bits per channel for RGB (3 channels), maximum bits Bmax can be embedded in the image by using the formula:

$$Bmax=P\times(2 \text{ bits/channel}\times 3 \text{ channels})=P\times 6$$

If |E| is the length of the ciphertext, then it must be the case that:

$$|E|\leq Bmax$$

5**. Data Hiding :**

During the embedding process, the encrypted binary message E is spread within randomly chosen pixels in an image. For every chosen pixel at coordinates (x,y), we stow bits of E as follows:

For pixel: Let R,G,B be the color values of the pixel. Bits are embedded in the least significant bits of each color channel:

New R=(R&~3) ∣ (bits from E)
New G=(G&~3) ∣ (next bits from E)

New B = (B & ~3) | (next bits from E)

This is done until all bits of E are embedded or the pixel limit is reached.

6. Retrieval:
For retrieval, binary information E is extracted from the same pixel locations where embedding was done. The extraction process can be done by reading the LSBs of each color channel, hence encrypted data is reconstructed as:

$$E' = \cup_{(x,y) \in \text{selected pixels}} (R\&3)+(G\&3)+(B\&3)$$

Once the encrypted binary data has been fetched, it is then decrypted:

$$C' = AES^{-1}(E', K)$$

The decompression of the recovered data gives the following original audio:

$$B' = \text{decompress}(C')$$

VI. Results and Discussion :

The proposed method of steganography for hiding and retrieving audio data within images was effective and efficient. It achieved high data capacity by using 2 bits per channel in the RGB color space, allowing for larger audio files with a maximum capacity of approximately N bits based on pixel selection. Post-processing assessments confirmed minimal perceptual differences between modified and original images, supported by metrics like PSNR and SSIM, ensuring image quality remained intact.

Retrieval was successful, with 100% accuracy in restoring the original audio file without data loss. Lossless compression and AES encryption improved data handling, ensuring integrity and security. Adaptive segmentation based on image contrast optimized data embedding while preserving image quality. However, limitations included dependency on image resolution, as lower-resolution images could not support larger audio files without visible artifacts. Future research could focus on refining algorithms for greater data embedding capacity and exploring alternative compression and encryption methods for enhanced performance and security.

VII. FUTURE EXPANSION:

Most of the limitations in this research can be addressed by future work focusing on several key areas to improve both the capability and application of the proposed audio data hiding method. First, exploring advanced compression algorithms could greatly increase the amount of audio data that can be hidden without compromising quality, allowing for longer or higher-fidelity recordings. Additionally, developing more robust encryption methods, such as RSA or hybrid encryption techniques, could offer stronger protection for hidden data against potential threats and unauthorized access.

Expanding the method to other multimedia file types could lead to broader applications in fields like digital forensics, communications, and copyright protection. Further improvements could involve adapting the algorithm to various image formats and characteristics, enhancing its flexibility and effectiveness across different tasks.

Extensive performance testing with different image types such as varying compression levels and resolutions will offer insights into the algorithm's robustness and real-world applicability. Finally, applying machine learning techniques for dynamic data embedding and retrieval could further optimize the process, making it more adaptive and effective. This could open up new possibilities for secure data transmission and storage while addressing the limitations of current methods.

VIII. CONCLUSION:

On the whole, the audio hiding and retrieval methodology using steganography in images proves to be a practical solution for secure data transmission. By effectively balancing adaptive segmentation, lossless compression, and encryption methods, the approach maximizes data capacity while maintaining the integrity of the host image. The results show high retrieval accuracy with minimal perceptual distortion, indicating the method's resilience to data loss in real-world conditions. This research offers valuable insights into applications like secure communications, digital forensics, and multimedia protection. Future developments could enhance the framework by incorporating advanced compression and encryption techniques, applying it to various multimedia types, and using machine learning for dynamic optimization. This work contributes to the field of steganography and highlights the importance of innovative techniques in addressing growing demands for secure data handling and storage solutions.

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