Enhanced Steganography using Dynamic Compression and Encryption Algorithms

[1]P. Shashank Reddy, [2]T. Sathvik Reddy, [3]Md. K. Khaled

[1]UG Student, Department of CSE, Anurag University, Hyderabad, India
[2]UG Student, Department of CSE, Anurag University, Hyderabad, India
[3]UG Student, Department of CSE, Anurag University, Hyderabad, India

[1]21eg105b42@anurag.edu.in
[2]21eg105b50@anurag.edu.in
[3]21eg105b64@anurag.edu.in

Abstract. Traditional steganography systems suffer from outdated compression and encryption methods, leading to large key sizes, high computational complexity, and increased vulnerability to steganalysis attacks. These limitations make conventional steganography inefficient and less secure. Additionally, advancements in AI-driven image analysis have made image steganography increasingly ineffective, as modern algorithms can easily detect hidden data within images. In contrast, audio steganography remains an underexplored field with significant potential, though existing solutions are often underdeveloped and lack robust security measures. To address these challenges, we propose an Enhanced Audio Steganography System that integrates modern lossless compression algorithms (e.g., Zstandard, Brotli) with state-of-the-art encryption techniques (e.g., AES-256, ChaCha20). Our system employs Least Significant Bit (LSB) steganography, enhanced with dynamic algorithm selection and randomization, to maximize security and efficiency. By intelligently combining compression, encryption, and adaptive embedding techniques, our approach significantly improves imperceptibility, robustness, and adaptability, making it ideal for secure communication and covert data transfer. By leveraging advanced cryptographic and compression techniques, our system achieves high security with minimal computational overhead, effectively overcoming the limitations of traditional methods while ensuring efficient and secure audio-based data concealment.

Keywords. Audio Steganography, Lossless Compression, Encryption Algorithms, Least Significant Bit (LSB) Steganography, Covert Communication, Secure Data Transfer

INTRODUCTION

With the growing demand for secure digital communication, audio steganography has become a vital tool for covert data transmission. However, traditional systems face significant limitations, including fixed encryption algorithms, outdated compression methods, high computational complexity, and vulnerability to steganalysis attacks. Many existing approaches still rely on basic encryption techniques such as Blowfish, or lack encryption entirely, leaving them exposed to unauthorized access. Additionally, older compression methods like Huffman coding introduce inefficiencies, limiting adaptability in dynamic environments.

To overcome these challenges, we propose an Enhanced Audio Steganography System that integrates Least Significant Bit (LSB) steganography with modern lossless compression techniques (e.g., Zstandard, Brotli) and robust encryption algorithms (e.g., AES-256, ChaCha20). The system dynamically selects and randomizes encryption and compression methods, enhancing security, imperceptibility, and efficiency. This adaptive approach ensures that hidden data remains undetectable while maintaining low computational overhead.

The proposed system is highly relevant in fields such as secure communication and confidential data transfer, where robust security and adaptability are crucial. By leveraging advanced cryptographic and compression techniques, our work aims to overcome the limitations of traditional methods, providing a more efficient, secure, and flexible solution for audio-based steganography.

LITERATURE SURVEY

TABLE 1. Review papers

Title	Description	Limitation
A novel audio steganography technique integrated with a symmetric cryptography: a protection mechanism for secure data outsourcing	Securing audio steganography with variable sample selection and Blowfish encryption for improved imperceptibility and security	Complexity increased and higher performance overhead due to advanced techniques like variable sample selection.
Ameliorating LSB Using Piecewise Linear Chaotic Map and One-Time Pad for Superlative Capacity, Imperceptibility and Secure Audio Steganography	Enhancing audio steganography with chaotic mapping, adaptive LSB selection, and dual-layer security for high payload, imperceptibility, and robustness.	Increased computational overhead due to Piecewise Linear Chaotic Map, increased vulnerability due to lack of encryption.
Enhancing LSB Using Binary Message Size Encoding for High Capacity, Transparent and Secure Audio Steganography–An Innovative Approach	Enhancing LSB audio steganography with BMSE, adaptive embedding, and AES-128 encryption for high security and imperceptibility	Vulnerable to noise-based and LSB attacks despite robustness against resampling.
A Novel n-Rightmost Bit Replacement Image Steganography Technique	A novel n-right most bit replacement technique for image steganography, enhancing PSNR, embedding capacity, and robustness against attacks.	Trade-off between peak signal to noise ratio and embedding capacity based on the value of n.

PROPOSED SYSTEM

The proposed system consists of an Enhanced Audio Steganography module, where users can securely embed and extract hidden messages within digital audio files using a python-based interface. The system employs advanced encryption algorithms and dynamic compression techniques to ensure high security, imperceptibility, and efficient data concealment. The steganography embedding process utilizes a Least Significant Bit (LSB) modification technique to minimize distortions and maintain the original audio quality. To ensure message confidentiality, the hidden data undergoes encryption before embedding, preventing unauthorized access.

For message extraction, the system accurately retrieves the hidden data using a robust decoding mechanism that considers the original signal properties. Users can access the system through a user-friendly python-based interface, enabling them to easily upload, encode, and decode messages. The system also integrates authentication and access control mechanisms to prevent unauthorized data extraction.

Advantages Over the Previous System:

- Improved Security: Uses encryption before embedding, preventing unauthorized access.
- High Imperceptibility: Dynamic encoding ensures the message remains undetectable in the audio.
- Efficient Compression: Reduces data size without loss of quality, allowing larger messages.
- User-Friendly Interface: Simplifies steganography for non-technical users.
- Scalability: Suitable for various applications, including confidential communication and watermarking.

MODEL IMPLEMENTATION

1. Python Tkinter Interface

The system is built with a Tkinter-based GUI that provides two main functionalities: Encoding and Decoding. Users can either record audio in real-time or upload an audio file for message embedding in the encode interface.

2. Encode Interface

This interface accepts an audio recording (via built-in microphone) or an existing audio file (WAV) along with the secret message that is to be hidden within the audio. Upon clicking "Start Encoding", the system follows the encoding process. The secret message is first compressed using lossless algorithms like Zstandard, Brotli, LZMA, bzip2 to reduce data size. Then it encrypts the compressed message using either AES-256 or ChaCha20 encryption algorithm, randomly selected for added security and data confidentiality. The key used for the encryption process is generated randomly every time to maintain security. Then the system embeds the encrypted message within the Least Significant Bits (LSB) of the audio file. It then generates the secret key which contains the compression code, encryption code and the encryption key combined for recognising the algorithms used in the process so that decoding is possible. It stores the key in a text file. It stores the embedded audio file in the user's system. Then the system prompts the user if they want to send the key in a mail to the receiver. If the user gives the email of the receiver the key is sent to the receiver via email.

3. Decode Interface

This interface accepts two inputs from the user. It takes the embedded audio file that the user received and it also accepts the secret key of the embedded audio file. The system then starts the decoding process when the user clicks "Start Decoding". First the system extracts the message from the embedded audio file. This is an encrypted message. Then the system extracts the compression code, encryption code and encryption key from the secret key given to it. Then the system uses the encryption code to identify the encryption algorithm used and uses the decryption key to decrypt the message which gives a compressed message. Then the system uses the compression code to identify the compression algorithm used and decompresses the message. We can then see the secret message embedded in the audio file displayed in the GUI. The also gives an option for the user to save the secret message in a text file.

4. Compression and Encryption Module

Compression Module: This module contains the implementation of the compression algorithms used in the system. It contains the implementation for Zstandard, Brotli, LZMA and Bzip2 algorithms. It randomly selects an algorithm for compression and compresses the data. The compression algorithms are assigned compression codes so they can be used to identify which compression algorithm was used. This compression algorithm is combined with the key before exchange.
Encryption Module: This module contains the implementation of the encryption algorithms used in the system. It contains the implementation for AES-256 and ChaCha20 algorithm. It also contains function to generate a random 256-bit key for encryption used in these algorithms and a new key is generated every time for security. This key is later encoded in base64 encoding so it easy for exchange and readable. The algorithms are assigned codes so that we can identify which algorithm is used for decoding. This code is combined with the key before exchange. The key exchange can be done via email from the system or the user can send it themselves in another way.

RESULTS

Data Embedding Capacity

The embedding capacity of the Enhanced Audio Steganography System depends on the number of audio samples, with 1 bit embedded per sample using LSB steganography.

- 7-sec audio: 345,600 samples → 43,200 bytes (~42.2 KB) capacity
- 14-sec audio: 627,710 samples → 78,463 bytes (~76.6 KB) capacity

To maintain audio quality and imperceptibility, it's recommended to use 50–60% of the total capacity:

- 7-sec audio: ~21 KB (50% of 42.2 KB)
- 14-sec audio: ~38 KB (50% of 76.6 KB)

Compression Efficiency

The system utilizes modern lossless compression algorithms to optimize embedding efficiency and improve upon traditional methods. In the previous system Huffman coding was used for data compression, but it has limitations in achieving higher compression ratios. This research explores the use of advanced algorithms like Zstandard, Brotli, LZMA, and Bzip2, which provide better compression while maintaining lossless decompression.

Message Size (bytes)	**Huffman Coding**	**Zstandard**	**Brotli**	**LZMA**	**Bzip2**
1493	789	717	511	808	723

2946	1578	726	516	820	890

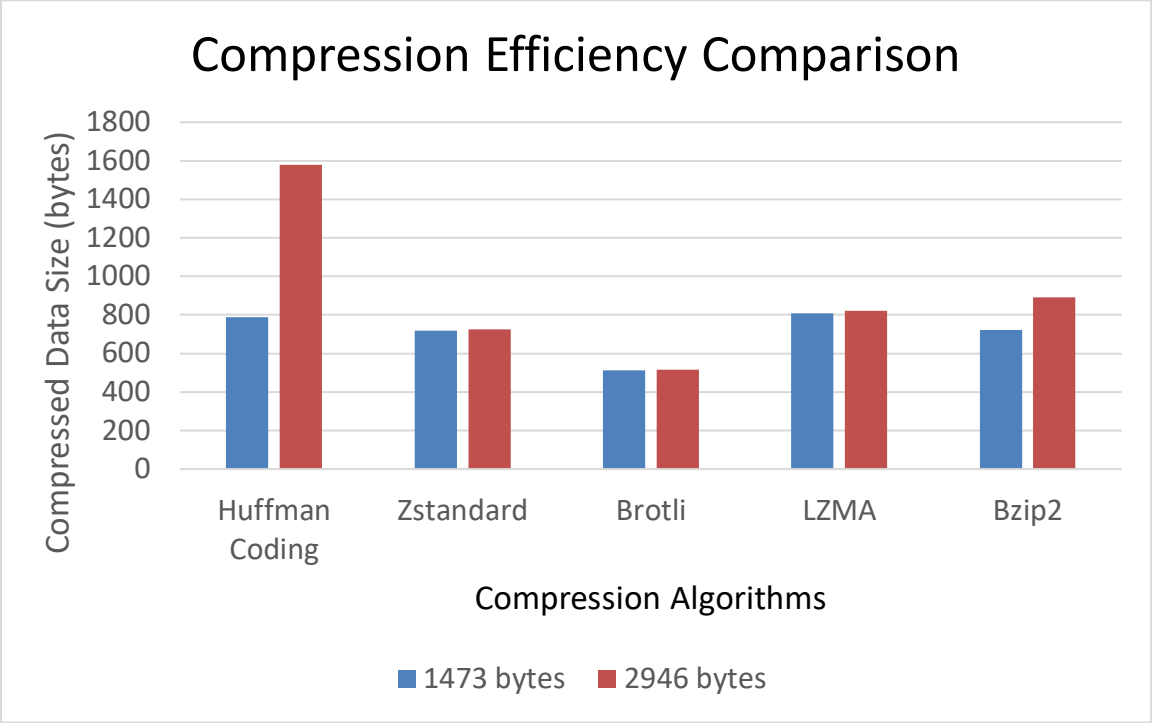

FIGURE 1. Compression Efficiency Comparision

For a larger message (2,946 bytes), Brotli demonstrated the highest compression efficiency, reducing the size to 516 bytes (0.17 ratio, ~83% reduction), whereas Huffman coding was the least efficient, compressing only to 1,578 bytes (0.53 ratio, ~47% reduction).

Comparison with Huffman Coding:

- Higher Compression Ratios: The new system achieves up to 65–83% compression, while Huffman coding provides only 46–53% reduction.
- Optimized for Steganography: A smaller compressed size allows more secret data to be embedded without noticeable distortion in the audio.
- Faster and More Efficient: Brotli and Zstandard provide faster decompression than Huffman coding, making the system more practical for real-time applications.

Observation**:** All modern algorithms outperform Huffman coding in terms of compression ratio and efficiency while ensuring lossless decompression. Brotli emerges as the best option, making the proposed system more suitable for steganographic applications where minimizing the hidden message size is crucial to maintaining imperceptibility.

Key Insights

- Higher Compression Efficiency = More Data Embedded without compromising audio quality.
- Optimal embedding at 50–60% capacity ensures imperceptibility and audio integrity.
- The combination of compression and optimized embedding enhances security, capacity, and robustness in steganography.

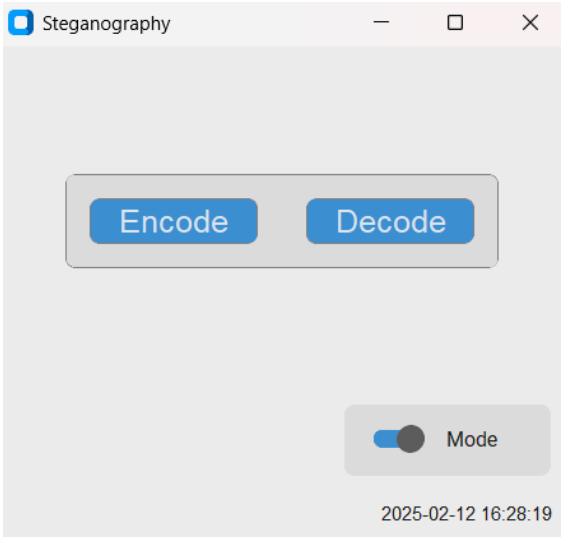

FIGURE 2. Starting Interface

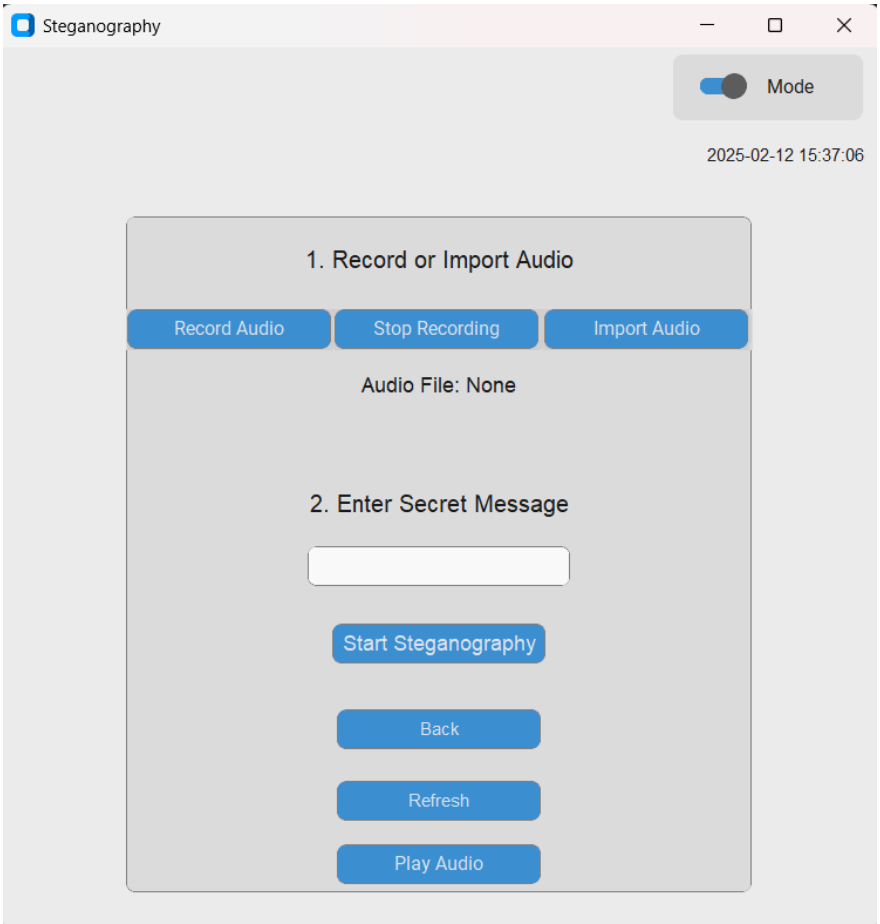

FIGURE 3. Encode Interface

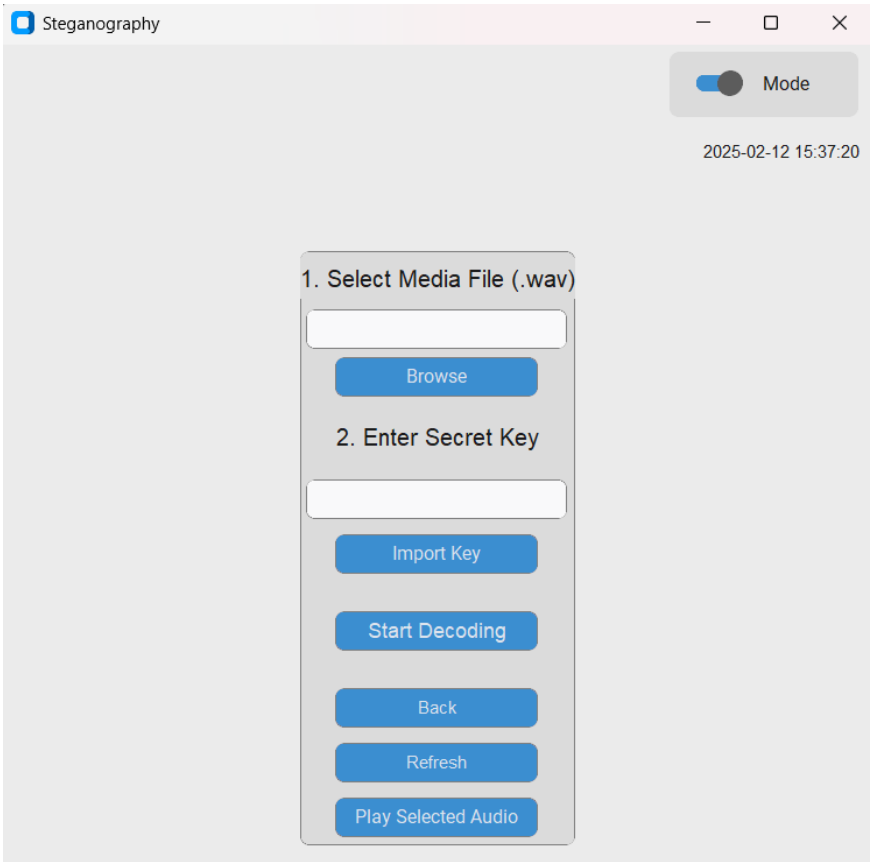

FIGURE 4. Decode Interface

FUTURE SCOPE AND IMPROVEMENT

The Enhanced Audio Steganography System introduces a secure and efficient approach to covert data communication. However, there is significant potential for further research and improvements. The following areas outline future enhancements and applications:

AI-Driven Adaptive Steganography

- Implementing machine learning models to analyze audio characteristics and dynamically optimize compression, encryption, and embedding strategies**.**
- AI can enhance imperceptibility and security by predicting the most effective hiding techniques based on the audio signal.

Cross-Format Steganography

- Enhancing compatibility with multiple audio formats (MP3, WAV, FLAC, AAC) while preserving data security and imperceptibility.
- Investigating novel embedding techniques for lossy audio formats, where traditional LSB methods may not be effective.

Blockchain Integration for Secure Key Exchange

- Using blockchain technology to securely distribute encryption keys, ensuring tamper-proof and decentralized key management**.**
- This would prevent man-in-the-middle attack**s** and unauthorized key access.

Multi-Layered Security Approaches

- Introducing multi-stage encryption **or** hybrid steganography where audio, image, and text steganography are combined for higher security.
- Exploring quantum cryptography for next-generation secure communication methods.

Forensic and Cybersecurity Applications

- Utilizing the system for forensic watermarking in legal and copyright-sensitive environments.
- Applying the method to secure critical communications in military, intelligence, and corporate sectors where confidentiality is paramount.

CONCLUSION

In conclusion, the Enhanced Audio Steganography System effectively combines dynamic algorithm selection with compression and robust encryption techniques with LSB steganography, enhancing both data security and embedding efficiency. By utilizing modern lossless compression algorithms like Zstandard, Brotli, LZMA, bzip2 along with strong encryption methods such as AES-256 and ChaCha20, the system ensures high data concealment capacity while maintaining audio quality. The dynamic selection of algorithms adds an extra layer of security, making the system adaptable for diverse applications like secure communication and covert data transfer.

This approach addresses the shortcomings of traditional steganography methods, particularly in terms of security vulnerabilities and outdated compression techniques. Overall, the system proves to be a promising solution for cybersecurity and confidential data exchange. Moving forward, future enhancements could focus on supporting additional audio formats, incorporating advanced encryption strategies, and leveraging AI-driven optimizations for even greater performance and security.

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