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Dual Parted Pairwise PEE with Adaptable IPVO for High Fidelity Images

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Abstract

In this study, we explore the practical application of Reversible Data Hiding (RDH) in digital images using Adaptive Integer Pixel-value Ordering and Verification (Adaptive IPVO) and Two-Segment Pairwise Pixel Embedding and Extraction (Two-Segment Pairwise PEE). Our project employs Python and its robust libraries, namely NumPy and Pillow, to manipulate image and data. The system successfully embeds binary data into an image, then extracts and restores the original image, demonstrating RDH's reversibility. We also evaluate the performance using key metrics such as payload capacity, embedding efficiency, and Peak Signal-to-Noise Ratio (PSNR). Future work aims at improving robustness, error handling, and user-friendliness, facilitating the use of RDH for broader audiences.

Introduction

Reversible Data Hiding (RDH) is a rapidly evolving domain within the broader sphere of information security. As digital communication continues to expand, the need to hide information within various forms of media is increasingly important. RDH offers a powerful way to conceal data within images, audio, video, or other forms of digital content. The key characteristic that sets RDH apart from other data hiding techniques is its reversibility - the ability to extract the hidden data and restore the carrier medium to its original form without any distortion.

Our project delves into this intriguing field, focusing on the development of an RDH system based on two primary methodologies - Adaptive Integer Pixel-Value Ordering and Verification (Adaptive IPVO) and Two-Segment Pairwise Pixel Embedding and Extraction (Two-Segment Pairwise PEE).

The Adaptive IPVO is a histogram-based method that selects an optimal pixel value for data embedding. It leverages the properties of the histogram of an image, using the pixel values and their frequencies to identify the best positions for embedding data. The technique adapts to each image, ensuring maximum data hiding capacity while minimizing the distortion caused by data embedding.

On the other hand, the Two-Segment Pairwise PEE technique presents an innovative way of dividing an image histogram into two segments. It identifies pairs of pixel values that can be manipulated to embed data, ensuring that the modification does not exceed the acceptable distortion level.

Python, our programming language of choice, is renowned for its ease of use and versatility. Python also offers extensive library support, which was critical in executing this project. For instance, we employed NumPy, a popular library known for its superior handling of arrays and complex mathematical functions. Pillow, a powerful image processing library, was instrumental in executing various image-related tasks.

The project code is segmented into multiple modules, each tasked with a unique function. This modular structure promotes code readability and maintainability, creating a coding environment that allows easy detection and resolution of issues and facilitates future improvements.

Our system begins by converting input data into a binary format. This binary data is then embedded into an image using our chosen RDH methodologies. Once the data is embedded, the system can extract the hidden data and restore the original image. Performance metrics such as payload capacity, embedding efficiency, and Peak Signal-to-Noise Ratio (PSNR) are measured to evaluate the efficacy of our implementation.

At present, our RDH system can successfully embed a string of data into an image and retrieve it while restoring the original image. As we move forward, we aim to improve the data extraction process, refine our error handling mechanisms, and optimize the performance of our RDH methodologies for larger datasets and higher-resolution images. Our ultimate goal is to transform this technology into a user-friendly application, making the power of RDH accessible to non-technical users.

Through this project, we hope to demonstrate the practical potential of RDH in the realm of secure digital information transmission. We believe that our work could significantly contribute to the further development of more efficient, robust, and user-friendly RDH systems, thereby advancing the field of information security.

The textual version of the architecture of the project based on the abstract, introduction, and code. Here's a simple structure:

1. Input: The user inputs an image file and the secret data they wish to embed. This can be done via a simple user interface or command-line prompt.

2. Image Preprocessing Module: The image is loaded into the system and is converted to grayscale using the Python Pillow library.

3. Data Preparation: The input data (text, for example) is converted into a binary string. This binary string is then padded as needed to match the dimensions of the image.

4. Adaptive IPVO Module: This module processes the grayscale image to create a histogram. It then finds the optimal threshold for data embedding using the Adaptive IPVO method.

5. Two-Segment Pairwise PEE Module: The Two-Segment Pairwise PEE algorithm is applied to embed the binary data into the image.
6. Data Embedding Module: This module uses the thresholds and parameters identified in the previous steps to embed the binary data into the image.
7. Output Image: The output is an image file with embedded data. This can be saved and transmitted as needed.
8. Data Extraction Module: The system can also extract embedded data from an image. This process is effectively the reverse of the data embedding steps. The output is the extracted binary data and the restored original image.
9. Performance Evaluation Module: The system calculates payload capacity, embedding efficiency, and PSNR to assess the performance of the RDH methods.

Related work

The research paper introduces a new data-hiding technique that uses dual AMBTC images to enhance security and efficiency in low-bandwidth channels. By incorporating Hamming code and LSB replacement, the method improves data reliability. It is versatile and applicable to different cover images and data formats, making it a promising solution for secure communication [1].

The research paper presents a new and original approach to reversible data hiding. It introduces a unique local contrast enhancement technique that surpasses previous methods in terms of quality and capacity performance. The proposed method achieves high hiding rates ranging from 0.1 to 2 bits per pixel while preserving luminance in both dark and bright areas. [2]

The paper builds upon previous work on video encryption and reversible data hiding, noting that while there have been many studies in these areas, few have proposed schemes for reversible data hiding in encrypted videos (RDH-EV) and those that exist use a singular framework. [3]

The paper builds upon previous work in the field of digital watermarking, image data hiding, computer vision, document image processing, authentication, video compression, and DSP. It also references advancements in visual signal processing and communications, digital multimedia data hiding, and information assurance. [4]

The paper is a continuation of research in the field of Reversible Data Hiding (RDH) in encrypted images, focusing on techniques like histogram shifting and difference expansion. It also references work on digital watermarking and steganography. [5]

The paper expands upon prior research in the domain of Reversible Data Hiding, specifically focusing on techniques involving frequency domain transformations and Reduced Difference Expansion. It acknowledges advancements in the application of Discrete Fourier, Cosine, and Wavelet Transforms. [6]

The paper advances the field of reversible data hiding in audio files, focusing on difference expansion-based schemes. It acknowledges previous work by Tian, Alattar, Liu, and Yi, who proposed various methods to reduce expansion in difference expansion schemes, and Yan and Wang, who proposed a method for reversible data hiding in digital audio based on Prediction Error Expansion. [7]

The paper builds upon prior research in Reversible Data Hiding in Encrypted Images (RDHEI), referencing work on Variable Rate Arithmetic Encoding (VRAE) based schemes, prediction-based schemes, and histogram-based schemes. It also acknowledges advancements in the application of Vector Quantization (VQ) and index mapping mechanisms. [8]

The paper presents a novel method for reversible data hiding in JPEG images using a cascaded structure. It introduces a strategy based on the Discrete Cosine Transform (DCT) domain and a fast searching method to find optimal frequency bands and DCT blocks for embedding. The method also includes a file expansion suppression scheme based on Variable Length Coding (VLC) mapping. The proposed method achieves good visual quality while significantly reducing file expansion.[9]

The paper discusses a method for secure data transfer using a Reversible Data Hiding (RDH) technique. It employs a Least Significant Bit (LSB) scheme and Differential Evolution Heuristic (DHE) to ensure data security during transmission.[10]

Proposed Work

In our ongoing pursuit of enhancing the reversible data hiding (RDH) system, we have earmarked a few crucial areas for further development. Our primary objective is to refine and improve the methodology of data extraction to ensure the seamless retrieval of hidden data. We recognize the need for user inclusivity and thus aim to design a user-friendly interface, which would allow users with no technical expertise to use our system efficiently. We're also eager to improve scalability by optimizing our code to manage larger datasets and accommodate high-resolution images. Additionally, there is an intention to incorporate advanced features and improvements into the RDH system. This would make it a comprehensive solution for secure and efficient steganographic applications, keeping it at the forefront of such technologies.

Challenges

The challenges we foresee in this ambitious project are substantial yet surmountable. The foremost technical difficulty is the delicate balance of data capacity, image quality, and computational complexity. This issue is particularly apparent as we scale our operations to handle larger datasets and images with higher resolution. Ensuring absolute reversibility, especially while using innovative methodologies like the Two-Segment Pairwise PEE, is a complex endeavor. The accurate and error-free decoding of the extracted binary data back to its original form represents another significant hurdle. Furthermore, creating a robust error handling mechanism to ensure the system's reliability is a task that demands intense focus. Lastly, the design and development of a user-friendly interface that encapsulates the complex functionalities of our RDH system is a unique challenge that requires meticulous planning, innovative design thinking, and proficient execution.

Conclusion

In conclusion, our project showcases a comprehensive implementation of reversible data hiding using Adaptive IPVO and Two-Segment Pairwise PEE methodologies. Through our research, we have successfully demonstrated the effectiveness of these techniques in embedding and extracting data while maintaining the integrity of the original media. The proposed work addresses challenges related to data capacity, performance optimization, and secure data extraction. With further improvements to the data extraction process and enhanced system robustness, our approach has the potential to make a significant impact in the fields of data security, copyright protection, and digital forensics. Overall, our project contributes to the advancement of reversible data hiding techniques and opens avenues for future research and development in this domain.

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