A Safe and Imperceptible Approach for hiding Encrypted Text in Color Images Using LSB Steganography

Suvhodip Saha, Soumendu Banerjee

Department of Computer Science and Engineering Academy of Technology, Hooghly, West Bengal

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ABSTRACT

Steganography refers to various means of concealing a secret message from view in a digital environment by concealing its visibility so that no one sees it. There are many types of steganography; however, many prefer the use of images and the Least Significant Bit method as it is very simple to use and can hide a great deal of information within an image. In this paper, an efficient LSB-based image steganography technique is designed and implemented to securely hide sensitive information while preserving the visual quality of the original image. The secret information is placed in the least significant bit of each pixel, making the stego image indistinguishable from the original image presented as a cover image. Experimental evaluation using P. S. N. R and M. S.E ensures minimal distortion and high opacity.

Keywords- Steganography, Least Significant Bit (LSB), Image Steganography, Mean Squared Error (MSE), Peak Signal-to-Noise Ratio (PSNR), Test hiding, Cyber Security

INTRODUCTION

Digital media (photographs, videos, etc.) allows for the concealment of data through steganography. Steganography can be achieved by hiding information in a digital media file or by creating an invisible message behind a digital media file. An example of steganography is to use another image as a cover image to hide data (text, binary data, etc.) and keep the visual quality of the cover image intact. In response to the rapid development of digital and telecommunications, as well as the growing number of security threats associated with them, there has also been a marked increase in the amount of attention being paid to the use of steganography within secure communications, copyright protection, and personal privacy through the use of data encryption [1].

The use of steganography is not limited to digital text; image-based steganography techniques are used extensively. Among all of image-based techniques, the spatial domain techniques, which include the least significant bit (LSB) method, are popularly employed because of their simplicity, low computational complexity, and ability to hide large amounts of data. The LSB technique hides data by inserting bits from secret messages within the least significant bits of the pixel intensity value; as a result, there is a minimal amount of visual distortion to the cover image. To date, multiple researchers have shown that LSB-based methods are much more ambiguous than conversion domain techniques, such as Discrete Cosine Transform (DCT) or Discrete Wavelet Transform (DWT), when used to hide text data[2],[3].

Current research has focused on improving upon the traditional LSB technique by adding encryption, randomization, and hybrid approaches to improve the overall security, preserving the quality of the cover images. These improvements introduce a trade-off between robustness and opacity, which makes objective quality assessment indispensable. Min Squared Error (MSE) and peak signal-to-noise ratio (PSNR) are commonly used to measure the distortion between the original cover image and the generated stego image. Research has shown that using LSB to hide encrypted text results in lower MSE and higher PSNR values than using conversion-domain techniques; therefore, the visual quality and strength of concealability of LSB methods compared to other image steganography techniques[4].

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In response to the aforementioned needs, this paper proposes a new LSB-based image steganography method for hiding encrypted text in color images. The main purpose of this work is to ensure the correct extraction of secure embeddings and hidden text while minimizing perceptual distortion. The effectiveness of the proposed method is verified through experimental analysis using MSE and PSNR metrics, which shows that Stego images maintain high visual fidelity compared to the original cover images[5].

MAJOR CONTRIBUTION

1. We have developed an LSB-based image steganography technique to securely hide hidden text information in digital color images.

2. The goal of developing a simple, easy-to-use app with the purpose of providing a way to automate the embedding and extraction process of encrypting text as well as creating a visually identical image (the Stego Image) to its original (the Cover Image).

3. The proposed system enables the secure transmission of stego images over public or private communication networks, allowing the intended recipient to accurately extract the hidden message using the same displayed method.

4. Mean squared error (MSE) for performance evaluation and peak signal-to-noise ratio (PSNR) and objective image quality assessment metrics including have been used, with results indicating minimal distortion and high opacity.

RELATED WORK

Least Significant Bit (LSB) based image steganography has been extensively investigated due to the inherent redundancy of digital images and its ability to embed secret information with minimal perceptual distortion. One of Chan and Cheng [6] earliest and most influential works introduces simple LSB substitution to hide information, showing that the least significant bits of pixel values can effectively hide information while preserving visual quality. The success and continued growth of LSB steganography within the spatial domain has established LSB as a reliable and cost-efficient approach to a wide range of Steganographic techniques and methods Recent studies have focused on enhancing the security and robustness of traditional LSB methods.

Banoori et al.[7] research on hybrid image steganography using AES base-encrypted image data, combined with LSB embedding technique. The hybrid approach significantly enhances the security of information embedded using standard LSB techniques but still provides a very high PSNR and low MSE score. Stochastic LSB embedding methods are a significant enhancement over traditional deterministic LSB embedding methods. Wang et al. [8] demonstrated that rendering randomness in the selection of LSB replacement pixels creates an essentially random pixel in which to embed messages, significantly reducing the possibility of a successful statistical attack. Rahman et al.[9] presented further improvements in LSB-based steganography and proposed an optimized LSB substitution technique for efficient text embedding. P. S. N. R and M. S.E . Their experimental results through e-analysis demonstrate high invulnerability and robustness.

Panigrahi and Padhi [10] Some researchers extended the LSB-based methods to include the ability to hide the information in images using specific parameters. This type of embedding allows for greater control over visual artifacts associated with the process of embedding. Survey-based studies have also contributed to consolidating existing knowledge. Chaudhary et al.[11] Provides a comprehensive review of LSB-based image steganography techniques, comparing capacity, safety, and opacity metrics.

Patil and Sonaje [12] have developed a method which combines AES encryption and LSB to form a crypto-stego model that adds further robustness to the hybrid security approach. In addition to these methods, more recent research has shown a trend toward the use of intelligent machines and learning algorithms to perform steganography in a number of different ways (including but not limited to LSB embedding methods).Hitney et al.[13] Deep learning-based image steganography conducts a comparative performance evaluation of techniques, showing that neural networks can outperform conventional methods in complex attack scenarios.

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Raiyan and Kabir [14] proposed a secure LSB framework using randomized encryption and Reed-Solomon coding to increase robustness against noise and data loss. As interest grows in using Generative Adversarial Networks (GANs) and Artificial Intelligence (AI) for digital forensics, Rehman [15] proposed a method of steganography that was enhanced through use of GANs, achieving a much higher level of resistance against steganalysis. In addition, Suresh and Kamalakannan [16] have developed new ways of scanning the spatial domain for LSBs, thus allowing for greater opacity through improved pixel traversal actions. Emerging research has also addressed semantic accuracy and extraction reliability.

Lee et al. [17] reported advances in semantic accuracy and reliability of the extraction of hidden text via natural language processing models for steganographic applications. DeSalvo [18] explored steganographic embedding as a data enhancement, indicating greater applicability in the context of machine learning. Recent hybrid encryption-based solutions continue to strengthen LSB relevance.

Radivilova et al. [19] An LSB-AES-based image steganography method was proposed, with an emphasis on safe transmission and accurate extraction. In addition, Rehman [20] further demonstrated the effectiveness of GAN-based steganography for hiding high-capacity and invisible data.

In conclusion, despite the emergence of advanced methods of transforming fields of data through deep learning, the simple operation of LSBs yields good fidelity and performance, which is further enhanced by adding encryption methods, randomness and intelligent optimization, providing inspiration for the secure LSB-based steganography approach outlined here.

Steganography and Types

Steganography and cryptography are both methods to conceal information. Steganography is focused on concealing the "presence" (of a message), while cryptography conceals the "content" (of a message). As a result, steganography is used in circumstances where confidentiality and security of the message are significant concerns. There are different ways to classify the various types of steganography based on the type of media (e.g., images, videos, sound, etc.) used to conceal the secret message.In this article, we discuss a number of common types of steganography:

1. Text-Based Steganography: Text-based steganography is when secret information is placed within a text document without altering the readability of the document. Examples of text-based steganography include line-shift coding and word-shift coding, and character switching. Even though this is a straightforward process, text-based steganography does not have many capabilities and is at risk of reformatting the text or otherwise altering it.

2.Image-Based Steganography: Image-based steganography is one of the most common forms of steganography, as secret messages may be hidden within a digital photo (or other image) by changing the value of pixels in the image. Pictures are suitable for hiding information due to their large size and high redundancy. The least significant bit (LSB) method is the most popular spatial-domain technique, where hidden bits are embedded in the least significant bits of the pixel intensity, resulting in minimal visual distortion.

3.Audio Steganography: Audio Steganography is a technique that is used in order to hide information in a way that is not detectable to the human ear (Auditory Imaging Techniques). This is accomplished by adjusting samples of audio media in a fashion that is not audible by the average human being. Techniques include LSB substitution, phase coding, and echo hiding. This type of steganography is often used in voice communication systems.

4. Video-Based Steganography: It is a process of similar to video, there is a digital medium used to embed information in a video as part of the Video Steganography Method. Video File Steganography involves embedding hidden files into digital video files.It provides higher strength and robustness due to the combination of image and audio components. The information may be hidden in the spatial or frequency domain of the video frame.

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5. Network Steganography: Network-Based Steganography is the term used to describe the process of sending messages across a digital communications network. Steganography uses protocols to obfuscate data through modifications to the header, timing of packets, and ordering of packets to intelligently alter the appearance of the packets as they travel across a network.Steganography over the network is often used for securely communicating through a network.

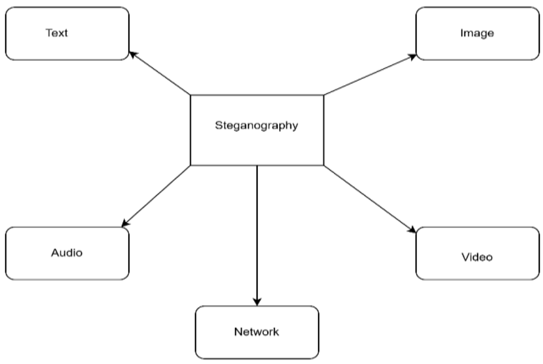

Fig.1 Steganography types

Brief Algorithm Implementation

Least Significant Bit (LSB) Steganography Technique

The least significant bit (LSB) steganography technique is one of the most widely used spatial-domain methods for hiding secret information in digital images. In this method, the least significant bit of value of each pixel of a cover image is modified to embed the secret information. When the change is made in the least significant bits (LSB), it is impossible for humans to see any difference between the original (cover) image and the new (stego) image. There are a number of advantages when using LSB-based steganography, including being easy to use, having a high data embedding capability, and having a low computational complexity. Because of this, they are ideal for applications where you want to hide text securely.

In the proposed project, the secret text is first encrypted to increase security before being embedded. The encrypted text is converted into a binary bit stream. Then a color cover image is selected and its pixel values are processed channel-wise (red, green and blue). The bits of the encrypted message are sequentially inserted into the least significant bit of the pixel value. This continues until the entire message has been embedded into the new image. The new image should look very similar to the original cover image. When you want to take out the message, you look at the new image and process it exactly the same way that you inserted the bits. You then take all the bits that you extracted from the pixel values and combine them to reconstruct the encrypted message and decrypt it to get the original text. The effectiveness of the proposed method is measured by the mean squared error (M. S. E) and peak signal-to-noise ratio (P. S. N. R) is evaluated using metrics, which ensures minimal distortion between the cover and the stego images. The functional strategy of this algorithm is shown in Figure 2.

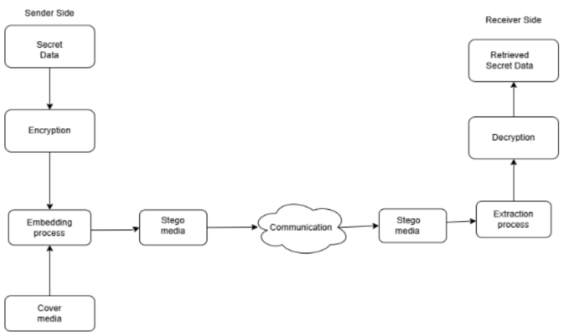

Fig 2 System architecture digram

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Table 1

Pseudocode for Encoding Process

1. Encrypt secret _ text using encryption _ key

2. Convert encrypted_text into Binary Bit Stream

3. Read cover_image and extract pixel value

4. Initialize message Index = 0

5. For each pixel of the cover _ image:

For each color channel (R, G, B):

If the message index < length of binary message:

Replace LSB of pixel value with current message bit Increase message index

6. Save modified pixels as stego _ image

7. Return stego_image

Table 2

Pseudocode for Decoding Process

1.Read Stego_images and extract pixel values

2. Initialize empty bit stream

3. For each pixel of Stego _ Image:

For each color channel (R, G, B):

Extract pixel quality LSB Append extracted bits to the bit stream

4. Convert bit stream to encrypted text

5. Decrypt encrypted text using encryption _ key

6. Return original secret_text

Fig 3 Cover Image

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The cover image refers to the original digital color image chosen to embed the hidden text. In the proposed system, the cover image acts as a carrier medium that conceals confidential information without arousing suspicion. Using a lossless image format prevents the loss of data due to compression so that the pixel data remains unchanged after embedding the secret letter within the pixel values of the cover image. Each pixel of the cover image is represented by three color components—Red, Green, and Blue (RGB)—with each component consisting of 8 bits, resulting in a total of 24 bits per pixel.

In the proposed LSB-based image steganography procedure encodes concealed information into a full-colour, RGB (Red, Green, Blue) image by altering the lowest significant bit (LSB) of the pixel's intensity value (i.e., an LSB is one of the 8 bits representing each colour channel). A single pixel in 24-bit colour RGB images consists of three colour channels (RGB), with 8-bits allocated to each colour channel for a total of 24 bits in a given pixel. Only the last bits of selected colour channels of a pixel are modified to conceal information, allowing visual distortion to be fully concealed from normal human perception.

To illustrate the process of bit-exchange, consider three consecutive pixels from the cover image presented in binary form:

(01,100,111 11,100,001 11,001,100)

(00,101,111 11,000,000 10,101,001)

(11,010,000 00,100,001 11,111,001)

All 8-bit groups represent different color elements. The secret character ‘A’ has an ASCII value of 65, which in binary is:

A = 01000001

These 8 bits are sequentially embedded in the LSB of the RGB elements of the pixel. When embedding, only the last bit of each color value is replaced with a slightly hidden message, while all higher-order bits remain unchanged. After embedding the binary sequence of 'A', the modified pixel matrix becomes:

(01,100,111 11,100,000 11,001,100)

(00,101,110 11,000,000 10,101,000)

(11,010,000 00,100,001 11,111,000)

The only bits that change are those of the Least Significant Bit (LSB), thus providing a relatively small fraction of possible bit changes; less than half of 72 bits (due to 3

pixels at 24 bits per pixel). The final LSB set to `0` in colour component 3 of the third pixel is the marker that indicates the end of the hidden message or information, allowing proper recovery to take place when decoding.

Fig 4 Stego image

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During the embedding phase, the cover image is converted into a pixel matrix and the least significant bits of the pixel intensity values are targeted for change. By changing the Least Significant Bits, the new cover image appears virtually identical to the original cover image. The LSB technique creates a cover image that cannot be seen by the human eye. Thus, it protects the confidentiality of information that is being hidden.

Use case diagram

The use case diagram represents the functional workflow of the projected LSB-based text steganography application is illustrated in the use case diagrams, detailing how end-users interact with the LSB-based text steganography to securely send hiden text using a digital image or vice versa. The end-users are typically defined as two main roles: the ability to send and receive. The process of sending text starts with selecting a cover (carrier) image for embedding. The sender then enters the secret text message that needs to be sent securely. Before embedding, the system encrypts the secret text to increase privacy and prevent unauthorized access, even if an attempt is made to extract. Once the encryption is complete, the system implements the Least Significant Bit (LSB) embedding technique, where encrypted text bits are inserted into the least significant bits of the pixel value of the cover image. The alteration from the original image to the stego captures little visual distortion. Therefore the resulting stego retains enough elements of the original image, making it indistinguishable from the original image visually. A newly created image containing the inteded hidden text will then create a new stego image, which is then sent from the sender to the such that they can then receive and enter the stego image into their own system. Thereafter, the system processes the stego image, utilizing the Least Significant Byte (LSB) of the pixel data, in the same sequence as the secret text embedded. Once the encrypted data has been extracted, the data is decrypted by the system using the appropriate key to obtain the original secret text message. The use case diagram depicts how both encryption and LSB embedding provide the means for invisible methods for transferring data securely and reliably extracting that embedded data. The image also reflects the system's ability to support secure communication over open networks while maintaining image quality, which is then validated using performance metrics such as MSE and PSNR.

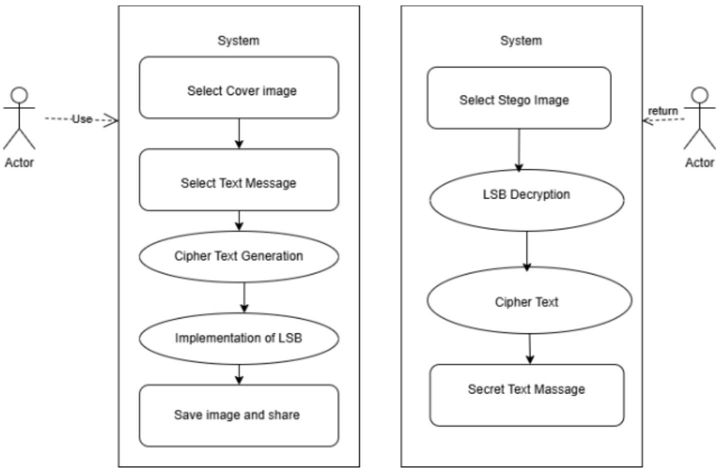

Fig5 Use Case Diagram

The decryption process is done on the side of the receiver to recover the original secret text from the stego image. Detailed steps to be able to extract a secret message will begin with the receipt of the finalized stego image.The first step in the decoding process is to retrieve the binary data from the least significant bit (LSB) of each pixel.To extract the binary data for the decoding process, each pixel's least significant bit (LSB) will be used. After encoding a secret message in encrypted format, this data was then embedded inside the photo. The binary data retrieved from the LSB of the pixel, just like the secret message, will also have to go through an appropriate decoding process before being decoded. The binary data that is decoded will become plaintext (readable) when it passes through the correct code-decoder. This ensures that regardless of whether someone obtains the encoded binary data who doesn't have access to the correct decoding key, the secret message remains secret; no one will be able to read the encoded binary data unless they possess the correct decoding key.The combination of steganography and cryptography is a more completely secure method of communicating.

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Table 3

Image Name	Image Type	MSE	PSNR (dB)	Quality Assessment
Horse.jpg	RGB image	0.0000368	92.47	Outstanding

Pseudo code for decryption

1. Load the stego image with embedded data.

2. Create an empty string for all the binary data to extract.

3. Loop through all of the pixels in the stego image sequentially.

4. Retrieve each pixel's LSB.

5. Add each retrieved LSB to the Binary Data String.

6. Break the Binary Data String into 8-bit segments.

7. For every set of 8 bits segments in binary, convert it to ASCII.

8. Store the result as encrypted text.

9. Use the decryption method that corresponds with the secret key to decrypt the message.

10. Change the decrypted data from binary back to readable text.

11. Display or store the retrieved secret message.

12. End process.

Experimental result

MSE measures the average square difference between the pixel value of the cover image and the stego image, and PSNR measures the quality of the stego image compared to the original cover image.

The formula of the Mean Squared Error (MSE) is

$$MSE=\frac{1}{MN}\sum_{i=1}^{M} \sum_{j=1}^{N} (I(i,j)-K(i,j)^2$$

The formula of the Pick signal to Noise Ratio is

$$PSNR= 10\log_{10}(\frac{(255)^2}{MAX})$$

A lower M. S. E value indicates that the distortion introduced during data embedding is minimal. The higher P. S. N. R values indicate better understanding and higher visual similarity between the images.

Table 5. Entropies of Cover and Stego images

Name of the image file	Entropy of Cover image	Entropy of Stego image
Horse	7.4711	7.4600

An MSE measure of 0.0000368 suggests that there is minimal distortion between the cover image and the stego image as this value is very low. Further, a PSNR of 92.47 dB indicates that the quality of a Stego Image is nearly equivalent to that of the original Image, which is also referred to as the Cover image. Using the LSB technology (Least Significant Bit) to hide data in text-based Steganography will produce a very high success rate with respect to securely hiding sensitive information while keeping it safe without anyone ever knowing that it was inserted into the data.

FUTURE DIRECTION

The field of image steganography continues to provide vast opportunities for innovation and practical applications in secure communications. Future research may focus on developing more powerful and intelligent algorithms that improve both the ability and ambiguity of hidden information. Advanced techniques such as adaptive LSB methods, transform domain embedding (DCT, DWT), and hybrid methods can make detection by steganalysis significantly harder, thereby increasing security. The integration of machine learning and artificial intelligence can allow for dynamic selection of optimal embedding locations, thus creating hidden data that will be better protected from common image processing activities (e.g., compression, filtering, and resizing). Furthermore, the usage of steganography with cryptographic techniques will produce an even higher level of security because the information will remain indiscernible even when detected without using the appropriate decryption key. As the volume of digital media and content on the internet continues to grow at an exponential rate, the potential applications of steganography are now being extended into web-based applications, social media sites, and cloud storage. Therefore, secure data transmission can occur instantaneously in such settings too. The authors also recommended that researchers explore the possibility of using multi-modal types of steganography, meaning embedding information in multiple formats or media (such as text, image, audio) simultaneously to provide more variety and security for transmitted messages. Furthermore, future work will be directed toward stealth optimisation that seeks to minimise the overall statistical footprint of all hidden data and therefore challenges advanced steganalysis systems. Steganography can also be embedded into IoT networks and smart devices to facilitate safe and private communication in otherwise secure environments, such as those found in defence, healthcare and critical infrastructure sectors. Therefore, the ongoing development of image steganography will provide a significant contribution to the fields of Cybersecurity, Digital Rights Management, and Exchange of Confidential Information, making it one of the most important areas being researched and developed in today's rapidly changing Digital World.

CONCLUSION

This paper demonstrates a safe and efficient technique that uses LSB-based steganography to hide messages in color images. By embedding encrypted secret text in the least significant bits of the pixel values, the proposed system successfully achieves high opacity while maintaining the visual quality of the Stego image. Experimental evaluation using objective image quality metrics, such as mean squared error (MSE) and peak signal-to-noise ratio (P. S. N. R) shows that the distortion introduced by the embedding process is minimal, which is very low M. S. E-value and similarly high P. S. N. R and defined by value. This confirms that the primary objective of this project, to create a stego image that is visually indistinguishable from its cover image, has been accomplished. Furthermore, by adding an encryption layer to the embedding process, the security of the overall system is enhanced because even if someone detects the presence of hidden data before it is placed in a cover image, they will not be able to decipher it without having the decryption key. Due to its low computational costs, uncomplicated nature and ability to create the desired effect, it is possible for this method to be used in the real world for Secure Communication Themes (eg Confidentiality & Obfuscation). Overall, the proposed method provides a balanced solution between data protection, embedding capabilities, and image quality, thereby verifying the suitability of LSB-based steganography for secure text transmission.

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