AN APPROACH FOR HIDING VOICE NOTES IN IMAGE COVER MEDIA USING DISCRETE WAVELET TRANSFORM

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Abstract
The secret communications of information can be performed through diverse approaches including the spatial domain and transform domain. There is still the problem of insecurity of undercover communications due to vulnerable channels such as high imperceptibility, large embedding size, and low robustness. Image steganography has significantly been researched in the two decades as means for embedding secret messages of all kinds of media (text, sound, and image) into image carriers. Least Significant Bits (LSBs) and Most Significant Bits (MSBs) substitutions embedding approaches enable secret message bits superimpositions into the bits of image carriers. This paper proposes DWT decomposition of voice notes bits into two components; then, each component is hidden in either LSB or MSB position. The outcomes revealed that the mean, PSNR, and CR for MSB substitution at 7.45, 39.06 dB, and 11.12 outperformed the LSB substitution at 9.81, 38.25 dB, and 10.55 respectively. This implies the suitability of LSB and MSB for protecting secret communication through image cover medium. However, future works can consider the audio and image formats to measure the efficacy of the proposed image steganography.

Keywords: LSB, Image, MSB, Steganography, Secret Message, Imperceptibility.

Introduction

The advancements of Internet technology have altered different industries, humans, and the ways newsletters are enjoyed. The concept of Steganography is derived from the two Greek words *stegos* and *grafia* meaning *cover* and *writing* (Tevaramani & Ravi, 2022). It is simply the art and science of invisible information exchanges. Steganography is termed cover writing is hiding information in other information to conceal the presence of the former. One method of Steganography is called image steganography, in that information hiding is performed exclusively using images or pictures. It is a covert technology (Gong, Yi, & Zhao, 2019).

Presently, digital communication offers several benefits such as high speed, compression, and better quality. Security is a major concern of digital data/information because of the fear of theft during transmission (Sarosh, Parah, & Bhat, 2021). In effect, Steganography offers protection to the information before transmission. The steganography field is concerned with ways of concealing secret messages in a cover message. The cover message includes text, video, audio, and image (Alfa et al., 2019). Cryptography is another field of information security that encrypts secret message prior to their transmission in order to evade unauthorized users from intercepting sensitive/valuable information in the communication channel (Adewale, Boyinbode, & Salako, 2021). Again, Cryptography scrambles a message in a manner that cannot be understood, but, Steganography conceals the presence of such secret message. However, most information hiding approaches make use of Steganography and Cryptography to increase security for data/information (Ghasemzadeh, 2018).

The applications of information hiding (such as Steganography and Cryptography) (Abd El-latif, Abd-El-Atty, & Venegas-Andraca, 2019; Alsabhany, Ali, Ridzuan, & Azni, 2020) have deployed in digital Computers, Military, Telecommunications Industry, Banking, and data centres. Steganography is categorized into Spatial and Transform domains. Spatial domain Steganography is widely deployed because information hidden offer high capability and ease of realization. LSB and Bit Plane Complexity Slicing algorithm fall into the spatial domain Steganography. Similarly, Transform Domain Steganography involves embedding transform coefficient of cover image. Discrete Cosine Transform, Discrete Fourier Transform and Discrete Wavelet Transform are instances of Transform domain Steganography (Xue et al., 2019).

The growth of multimedia content and secret communications has evolved rapidly over the past 10 years. There is need to protect and secure sensitive information/data in form of sound/audio files across the Internet and communication channels. Steganography has been deployed on a number of occasions to deal with these issues. However, the obvious problem with voice notes is large size, which smaller than most image files used for cover. There is need to compress large sizes speech/voice notes into appropriate size before concealing them in cover images. The biggest challenge is to maintain perceptual transparency, robustness and hiding capacity of secret message as well as message cover image (Yassin & EL Houby, 2022). This paper attempts to hide is to hide secret message (speech/voice notes) into image cover medium using Most and Least Significant Bits substitution using Discrete Wavelet Transform (DWT) steganography method.

Related Works

Abd El-latif, Abd-El-Atty, & Venegas-Andraca (2019) introduced quantum walks for data hiding in image steganography. The QWs S-box regulated the embedding and extraction procedures. The inclusion of cryptographic QWs S-box increases the security of both embedding and extraction phases. At the extraction phase, only the stego image and the secret values are needed for constructing the secret data. Experimental results revealed that, the approach presented has a high-security, high embedding capacity and good visual quality. The more optimisation techniques can be included in subsequent studies.

A new image steganography scheme based on a U-Net structure was formulated by (Duan et al., 2019). Firstly, the trained deep neural network comprised a hiding network and an extraction network; then, the sender uses the hiding network to embed the secret image into another full-size image without any modification and sends it to the receiver. Thereafter, the receiver uses the extraction network to reconstruct the secret image and original cover image correctly. The outcomes revealed that, the proposed scheme compresses and distributes the information of the embedded secret image into all available bits in the cover image, which not only solves the obvious visual cues problem, but, increases the embedding capacity. More optimisations can be performed for better performance. Igantius & Setiadi (2020) adopted Peak signal to noise ratio (PSNR) and structural index similarity (SSIM) to assess quality on three spatial domain image steganography techniques (that is, LSB, PVD, and CRT). Color images were chosen as container images because human vision is more sensitive to color changes than grayscale changes. The test results showed that, where LSB has the most superior value based on PSNR and PVD get the most superior value based on SSIM. Also, the changes in the histogram representations are more noticeable in LSB and CRT than in PVD. Other forms of images and optimizations can be considered in future works.

Yassin & EL Houby (2022) proposed an Integer Wavelet Transform (IWT) based image steganography. The cover image is transformed using IWT to suppress the secret message into the high frequency bands HH, LH, and HL of the cover image. The coefficients of these bands are labelled into six categories according to their most significant bits (MSBs). The embedding process starts from the highest category and continues to the next category by controlling the number of coefficients to match the size of the secret message. The outcomes revealed that, an average PSNR of 54 dB is obtained with a message size of 67.7 kb against comparable techniques. Up to 70% embedding rate can be provided with average PSNR of 47 dB with full reversibility and perfect reconstruction of data. Other forms of transformations can be experimented. Hassaballah, Hameed, Awad, & Muhammad (2021) introduced HHOIWT method for covert communication and secure data in the IoT environment using digital image steganography. It conceals secret data in the cover images using a metaheuristic optimization algorithm (Harris Hawks Optimization (HHO)) to efficiently select image pixels that can be used to hide bits of secret data within integer wavelet transforms. HHO-IWT method achieves higher levels of security than the state-of-the-art methods and that it resists various forms of steganalysis. But, integrating discrete wavelet transform with pixel value differencing schemes, and working with color images are interesting future directions.

Images constitute a large proportion of the multimedia transmitted; the concept of secret sharing is being applied to them. Image Secret Sharing techniques have been considered by (Sarosh et al., 2021). Secret sharing or secret splitting is a method by which a secret is divided among a set of participants. Each participant receives a part or share of the secret. During the secret recovery phase, a subset of a predefined number of participants can collaborate and reveal the secret information. The various application areas of secret sharing include distributed storage of data onto multiple servers as protection against single-point failures. Other application areas include key management, e-banking, data hiding, law enforcement, military, and control systems. Zear & Singh (2022) proposed for digital image watermarking in which Lifting wavelet transform (LWT), Discrete Cosine Transform (DCT) and Singular Value Decomposition (SVD). The host color image is decomposed using LWT and LH3, LL3 sub bands of the third level LWT are transformed by DCT and then SVD. Security of logo (image watermark) is enhanced by using message-digest (MD5) hash algorithm and then DCT-SVD are applied to it before embedding it into LH3 sub band. The robustness of Info (Text watermark) is increased by encoding it using Hamming error correcting code. Error correcting code increases the length of watermark therefore arithmetic coding is applied that provides lossless compression. Though, the effectiveness of the algorithm can be improved by using various optimization methods.

A watermarking optimization method based on matrix decomposition and discrete wavelet transform (DWT) for multi-size images was proposed by (Wang & Ji, 2022). The DWT, Hessenberg matrix decomposition (HMD), singular value decomposition (SVD), particle swarm optimization (PSO), Arnold transform and logistic mapping are combined for the first time to achieve an image watermarking optimization algorithm. The multi-level decomposition of DWT is used to be adapted to multi-size host images, the Arnold transform, logistic mapping, HMD and SVD are used to enhance the security and robustness, and the PSO optimized scaling factor to balance invisibility and robustness. The outcomes show that, the PSNRs are higher than 44.9 dB without attacks and the NCs are higher than 0.98 under various attacks. But, colour host images and other applications can be considered. Xu, Mou, Hu, Xie, & Zhang (2022) presented a novel flow-based framework for robust invertible image steganography, dubbed as RIIS. A conditional normalizing flow is introduced to model the distribution of the redundant high-frequency component with the condition of the container image. Moreover, a well-designed container enhancement module (CEM) also contributes to the robust reconstruction. To regulate the network parameters for different distortion levels, a distortion-guided modulation (DGM) is implemented over flow-based blocks to make it a one-size-fits-all model. The outcomes showed that, the proposed RIIS efficiently improves the robustness while retaining imperceptibility and capacity. The guarantee of steganography robustness significantly broadens the application of steganography in real-world applications. The deep learning computing framework and optimizations are future works.

Singh & Singla (2022) developed the digital media steganographic method based on Discrete Wavelet Transform (DWT) and Singular Value Decomposition (SVD). The DWT is a frequency-domain technique comprising DWT which comparatively offers better robustness and high PSNR value of stego image over other techniques. The proposed method works well for information hiding against AWGN (additive white Gaussian noise) attack and fulfills the objective to achieve high robustness and high PSNR. Tevaramani & Ravi (2022) proposed an alpha, is a scaling parameter, Cover and payload images of different types and dimensions, live images from a webcam, and predefined images of other formats have been normalized and preprocessed. A Haar Discrete Wavelet Transformation (DWT) was applied to both the cover and payload images. To generate a stego image, the payload image is encrypted and fused with the cover image. The result parameters such as PSNR, MSE, and Entropy are measured with satisfactory values. In future, different mother wavelets, capacities, alpha values, and format for grayscale and color images can be experimented.

Rustad, Ignatius, Setiadi, Syukur, & Andono (2022) proposed an adaptive method capable of selecting the most optimal pattern for message embedding to minimize the error ratio. This adaptive pattern can optimize the performance of the inverted LSB substitution method, based on the two-bit + least-significant-bit (LSB) pattern in the container image. Before embedding, the message and container image bits are tested and the error ratio is calculated using the inverted LSB substitution method for various possible patterns. The test outcomes showed that, the PSNR value ranges from 52.49 to 57.45, and the SSIM ranges from 0.9991 to 0.9999 with 1 BPP capacity, with improved LSB imperceptibility. Idakwo, Mu, Adedokun, & Sadiq (2022) developed a high payload and imperceptible digital image steganography system using a non-separable integer wavelet transform and diamond encoding. This non-separable integer-to-integer transform decomposes the digital image into the frequency domain to leverage on resiliency to attacks. The results showed the system attained a high payload and imperceptibility with an average PSNR of 65.46 dB and MSE of 0.0244 which are 25.88% and 94.73% improvements over comparable works. However, different attacks can be investigated to ascertain the performance effectiveness.

Pan, Wu, Yang, & Zhao (2022) proposed a double-matrix decomposition image steganography scheme with multi-region coverage, to solve the problem of poor extraction ability of steganographic images under attack or interference. The cover image is transformed by multi-wavelet transform, and the hidden region covering multiple wavelet sub-bands is selected in the wavelet domain of the cover image to embed the secret information. Arnold transform, Hessenberg decomposition, and singular-value decomposition were used to determine hidden regions based on embedding intensity factor. Experimental results show that the proposed method has excellent performance in concealment and quality of extracted secret images, and secret information is extracted from steganographic images. But, colour image steganography can be investigated for the proposed scheme.

Research Methodology

This section provides the description of the proposed steganography including the structure, experimental setup, system flowchart, and performance evaluation parameters.

The proposed steganography

This study proposed a method for hiding information based on image carrier for voice note secret message. The proposed steganography method uses two components-media such as image and sound, to provide security for communication between parties without risks of destroying the media and theft of secret information during transmission. This method hides the existence of secret message (voice notes) embedded in digital images (cover medium) because of their popularity in social media communications and general Internet connectivity. The choice of image cover medium is taking advantage of bits replacements features such Least Significant Bits (LSBs) and Most Significant Bits (MSBs) available to several format of pictures used for communication today. On the other hand, speech/voice notes accounted for majority of communication medium because of the ease and capacity of conveying large secret messages when compared to other media. The steganography method makes use of specials tools called Discrete Wavelet Transform (DWT) in order to preprocess, compress and transform both the secret message and the cover image for better protection from third party and data/information quality retention. The entire structure of the proposed steganography method is composed of frontend and backend units as illustrated in Figure 1.

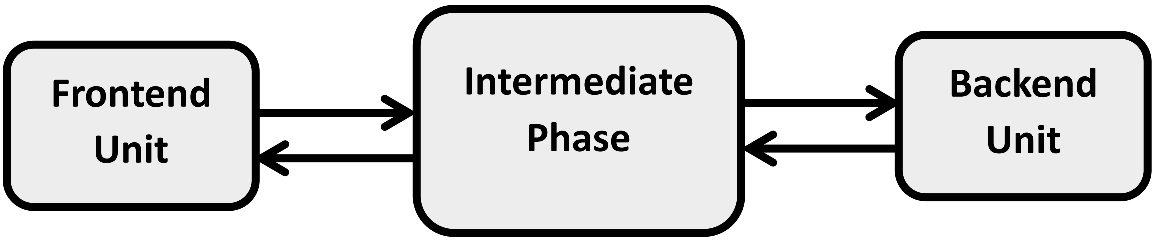

Figure 1. The structure of the proposed steganography method.

In Figure 2, the frontend is available to the sender of audio message which is concealed under image cover to produce a stego-object at the intermediate phase. The intermediate provides the communication medium such as local and Internet connectivity for the purpose of transmitting the stego-object after several preprocessing, compression of media files and transformation processes using DWT. The intended receiver of the secret message retrieves the stego-object; and performs decoding and extracting operations to recover the original message by decryption and decompression with Inverse Discrete Wavelet Transform (IDWT) tool. The details of activities and tasks undertaken by these units and phase are discussed in the next subsection.

Most and Least Significant Bits Substitution

Secret Message or sound note bits calculation: The starting point is the extraction of the sound note signal vector which is real numbers composed of negative and positive parts. Thereafter, the sound note signal is decomposed into mutually orthogonal collection of wavelets first portion and second portion using single level discrete wavelet transform (1D DWT) for the approximate coefficient and detail coefficient. The frequencies are generated for each wavelet signal for the sound notes using scaling function to produce different scaling characteristics through low pass filer impulse and high pass filter. Then, the wavelets vectors are binarized in order to generate 8-bit binary representation of the wavelets before embedding them into grayscale image cover.

Cover image embedding bits calculation: The cover image is converted into the binary form. Thereafter, the MSB and LSB pixel values for grayscale image (or cover image) are calculated which correspond to the sound notes signal (secret message) bits of the length of the sound notes wavelets to be embedded. The sound wavelets bits are simultaneously encoded into MSB and LSB position in the cover image known as the hybrid bits substitution method generated. The MLSB stego-object must remain unchanged after embedding. The first bits to be encoded are first portion of secret message which is at the MSB position of the cover image. Whereas, the second bits to be encoded are second portion of secret message which is at the LSB position of the cover image.

Experimental Setup

The minimum constraints for implementing steganography method proposed are contained in Table 1.

Table 1. The minimal hardware and software parameters

Parameters	Specification
Operating System	Microsoft Windows 8
RAM	2 GB
HDD	120 GB
GUI	MatLab R2013a, MLSB, 1D DWT
CPU Processor	671 GB
HD Graphics	2.4 GHz
System type	64-bit OS, x64-based processor
Compiler Machine	MatLab R2013a, C##
Native Browser	IE 10
Image type	GIF, TIFF
Image dimension	512x512
Voice notes format	Wave (.wav)

The Proposed Steganography Flowchart

The flowchart depicting the processes of the proposed steganography, which is image carrier for audio secret message is illustrated in Figure 2.

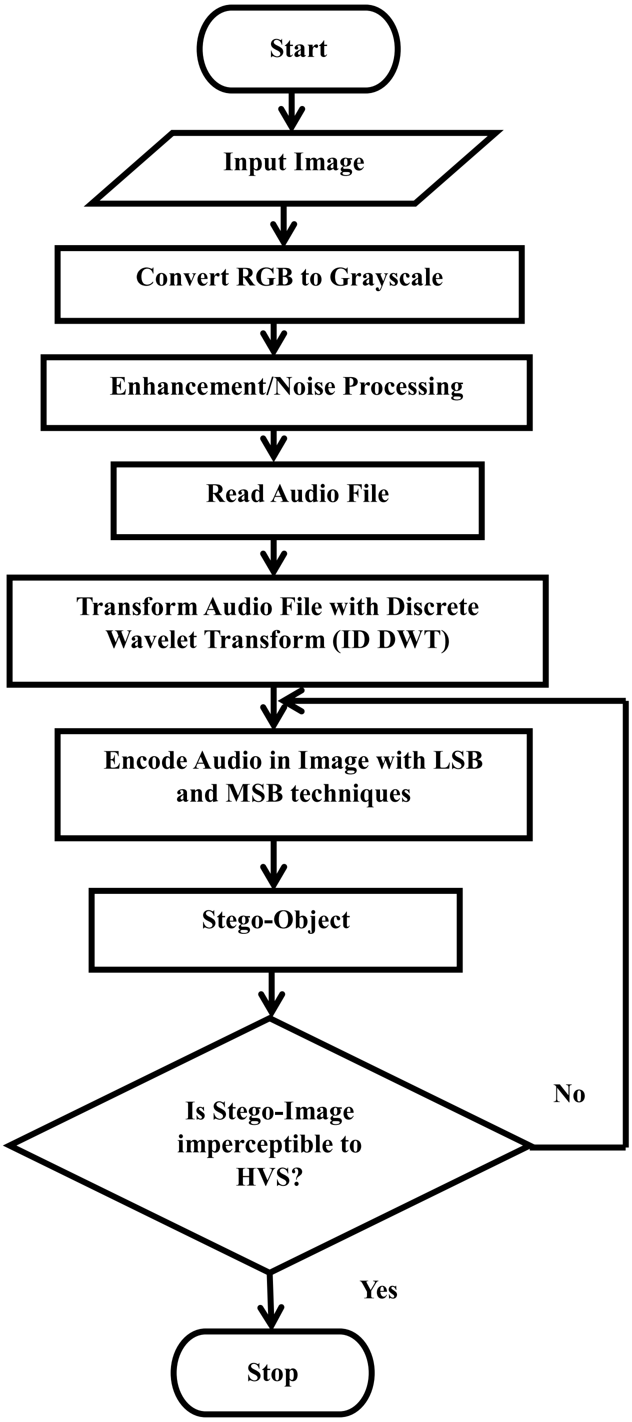

Figure 2. The flowchart of the proposed steganography.

Performance Evaluation Parameters

The key metrics for estimating the strength and effectiveness of proposed steganography method spans image and sound components is attained with two parameters MSE and PSNR. Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR): These are selected because of image cover medium selected, which calculates the rate of deviation of stego image and original image. The cumulative square error between encoded image and original image is the mean square error (MSE), while peak signal to noise ratio denotes the peak error of quality.

The values of MSE and PNSR are expected to be lower and higher respectively whenever stego image quality outperforms the original image as expressed in Equation 1.

$$MSE = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}(C(x,y) - S(x,y))^2 \quad (1)$$

where,
(x, y) are image's two coordinates,
(M, N) are image's two dimensions,
$C(x, y)$ is stego image generation function, and
$S(x, y)$ is the cover image generation function.

In other words, PSNR is used to determine the quality of image, which reveals regenerated image with higher value of PSNR possesses high quality. However, PSNR-HSV requires a lower value for more noise. The unit of PSNR is decibels (dBs) or 8 bits per pixel between two images given by Equation 2:

$$PSNR = 10\log_{10}\left[\frac{MAX^2}{MSE}\right] \quad (2)$$

where,
MAX^2 is the maximum value of pixel in original image, and MSE is Mean Square Error risk function of cumulative square error between original image and stego image.

4.0 Results and Discussion

Secret Message Encoding

The Discrete Wavelet Transform (DWT) is applied on the sound data generated from previous subsection in order to roll out the secret code. The DWT decomposes the sound data into two partitions corresponding to approximate coefficient vector (cA), and detail coefficients vector (cD). The decomposed partitions are passed to scaling low-pass filter (Lo_D) and high-pass filter (Hi_D) in order to refine the sound data. The parameters for the DWT decomposition are presented in Table 2.

Table 2. DWT sound data decomposition parameters.

Parameter	Value
dwt type	Single-level 1-D
Wave name	db1
Mode	Sym
Data type	Uint8
Partitioning style	Continuous Fixed-length

The resultant sound data produced from DWT decomposition procedure is converted into binary format. Thereafter it is divided into two portions (1000 x 8 = 8000 bits each) and used to replace the most significant bits (MSB), least significant bits (LSB) and most and least significant bits (MLSB) experimented in this work for the purpose of secret communication. The structures of the experimentation are represented in Figure 3.

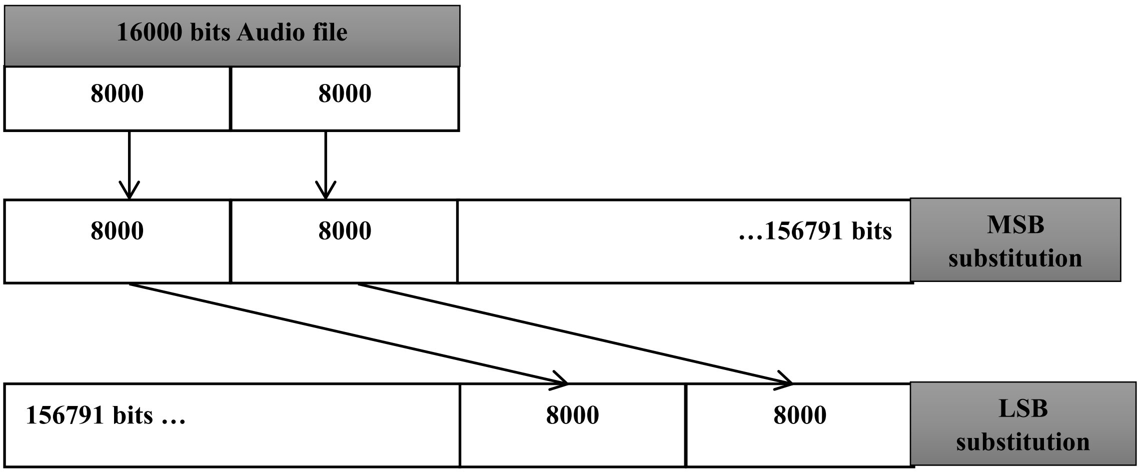

Figure 3. The bits substitutions methods of LSB and MSB compared.

Grayscale Stego-Object Encoding

The outcomes of the audio embedding process into Grayscale image cover carrier using different image bits substitution schemes are illustrated in Figures 4, 5, and 6.

Figure 4. Original grayscale cover image.

Figure 5. The MSB grayscale stego-object.

Figure 6. The LSB grayscale stego-object.

In Figures 5 and 6, the bits change for cover images are easily recognizable to the HVS because of conspicuous white borders to the right and left respectively. Analogous to RGB converted to grayscale outcomes, the use of MSB and LSB substitution schemes for encoding audio signals are ineffective and possibly detected for visible largescale noise on the stego-object. Nevertheless, the proposed MLSB substitution shows two white borders to both right and left of the stego-object which could be taken for border/frame design. This is less susceptible to third party attacks except when the structure of stego-key is found. The histogram plot for the original grayscale image and stego images is depicted in Figure 7.

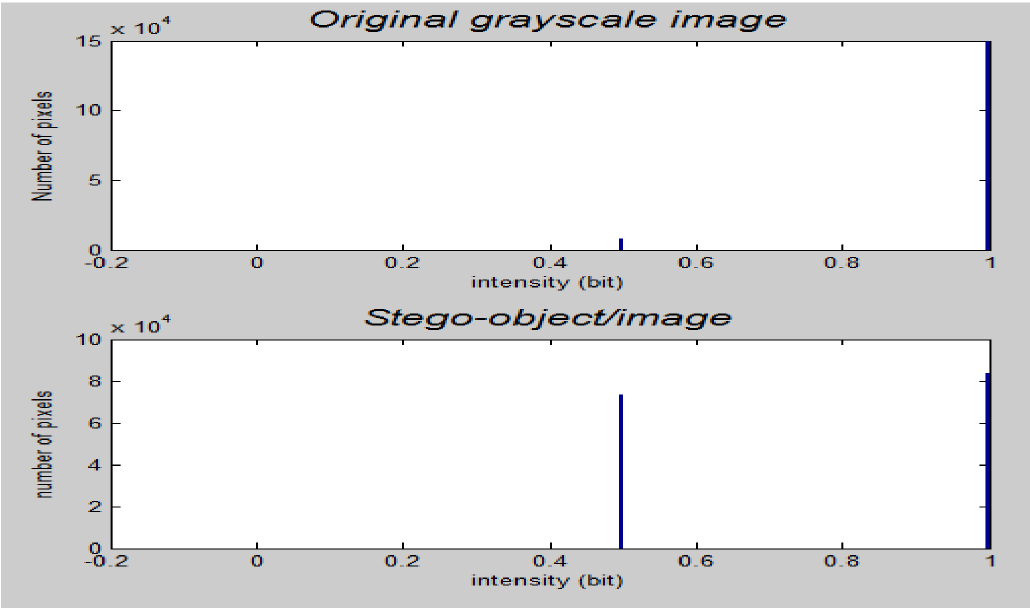

Figure 7. Distribution of bits in original grayscale image and stego image.

From Figure 7, the difference between the quality of the images is negligible to HVS, which cannot detect the alteration in distribution of pixels. The number of full intensity bits in original image is higher than stego-image (that is, 150000 to 850,000 pixels). However, the number of pixels for half-intensity for stego image is more than original image (that is, 720,000 to 100,000 pixels). This implies that, the quality of stego image is retained, which increases imperceptibility and security for voice notes transmitted through the image cover (or stego image). The measure of effectiveness of proposed cover image bits substitution methods for hiding information such as audio signal is carried out in these subsequent subsections.

MSB and LSB Substitution Outcomes

The parameters and values of metrics calculated for grayscale cover image and stego-objected generated are presented in Table 3.

Table 3: Image performance computed.

	Mean	PSNR (db)	CR
MSB substitution method	7.45	39.06	11.12
LSB substitution method	9.81	38.25	10.55

In Table 3, there is no significant differences between the two images experimented. However, the mean and PNSR of the stego-object images in case of the MSB and LSB substitutions offered better quality and indistinguishable features to individual's HSV. Again, the imperceptibility of MSB outperformed LSB because it has the highest value of 39.06 db which is the standards for standard quality image.

Conclusion and Recommendations

The secret communications between parties involving image pixel at MSBs and LSBs are common practices, which make possible to decrease risks associated highly susceptible channels. Majority of recent works in image steganography take advantage of HVS deficiencies in recognizing small variations in the pixels of cover picture medium to hide secret media such as audio without being discovered by unintended recipients. This paper observed that, grayscale images can effectively conceal the presence of secret messages communication of voice notes (audio) with small chances of being detected by HVS of unauthorised users on the channel through preprocessing approaches.

The process of hiding the preprocessed voice notes involved bits substitution method, which replaced the MSBs and LSBs of image cover medium with those of voice notes. The values of Mean and PSNR for MSB were the highest as against LSB method, which are 7.45 and 39.06 due to high compression ratio (11.12). The reason being that pixels' values distribution of stego-object is distorted by half which make it smooth and brighter. In both cases, original grayscale images and stego images are indistinguishable even with noise signal encoding to the HVS of an individual. In further works, the portions of secret message can be effectively deployed for other types of media such as images, videos and texts. Also, the steganography method can be combined with other security algorithms such as AES and cryptographic schemes to further protect secret communication between users.

References

Abd El-latif, A. A., Abd-El-Atty, B., & Venegas-Andraca, S. E. (2019). A novel image steganography technique based on quantum substitution boxes. *Optics and Laser Technology*, *116*, 92–102. https://doi.org/10.1016/j.optlastec.2019.03.005

Adewale, O. S., Boyinbode, O. K., & Salako, E. A. (2021). An Innovative Approach in Electronic Voting System Based on Fingerprint and Visual Semagram. *Int. Journal of Information Engineering and Electronic Business*, *5*, 24–37.

Alfa, A. A., Ahmed, K. B., Misra, S., Adewumi, A., Ahuja, R., Ayeni, F., & Damasevicius, R. (2019). A Comparative Study of Methods for Hiding Large Size Audio File in Smaller Image Carriers. In *Communications in Computer and Information Science*.

Alsabhany, A. A., Ali, A. H., Ridzuan, F., & Azni, A. H. (2020). Digital audio steganography: Systematic review, classification, and analysis ofthe current state ofthe art. *Computer Science Review*, *38*, 100316. https://doi.org/10.1016/j.cosrev.2020.100316

Duan, X., Jia, K. A. I., Li, B., Guo, D., Zhang, E. N., & Qin, C. (2019). Reversible Image Steganography Scheme Based on a U-Net Structure. *IEEE Access*, *7*, 9314–9323.

Ghasemzadeh, H. (2018). Multi-layer architecture for efficient steganalysis of UnderMp3Cover in multi- encoder scenario. *IEEE Transactions on Information Forensics* *and Security,* https://doi.org/10.1109/TIFS.2018.2847678

Gong, C., Yi, X., & Zhao, X. (2019). Pitch Delay Based Adaptive Steganography for AMR Speech Stream. In C. D. Y. et Al. (Ed.), *IWDW 2018, LNCS 11378,* (Vol. 11378, pp. 275–289).

Hassaballah, M., Hameed, M. A., Awad, A. I., & Muhammad, K. (2021). A Novel Image Steganography Method for Industrial Internet of Things Security. *IEEE Transactions on Industrial Informatics*, *3021*, 1–9. https://doi.org/10.1109/TII.2021.3053595

Idakwo, M. A., Mu, M. B., Adedokun, E. A., & Sadiq, B. O. (2022). Development of a Non-Separable Integer-to-Integer Wavelet Transform-Based Digital Image Steganography System. *Applications of Modelling and Simulation*, *6*, 20–27.

Igantius, D. R., & Setiadi, M. (2020). PSNR vs SSIM: imperceptibility quality assessment for image steganography. *Multimedia Tools and Applications*, https://doi.org/https://doi.org/10.1007/s11042-020-10035-z

Pan, P., Wu, Z., Yang, C., & Zhao, B. (2022). Double-Matrix Decomposition Image Steganography Scheme based on Wavelet Transform with Multi-Region Coverage. *Entropy*, *24*(246), 1–21.

Rustad, S., Ignatius, D. R., Setiadi, M., Syukur, A., & Andono, P. N. (2022). Inverted LSB image steganography using adaptive pattern to improve imperceptibility. *Journal of King Saud University - Computer and Information Sciences*, *34*, 3559–3568.

Sarosh, P., Parah, S. A., & Bhat, G. M. (2021). Utilization of secret sharing technology for secure communication: a state-of-the-art review. *Multimedia Tools and Applications*, *80*(1), 517–541. https://doi.org/10.1007/s11042-020-09723-7

Singh, J., & Singla, M. (2022). Image Steganography Technique based on Singular Value Decomposition and Discrete Wavelet Transform. *International Journal of Electrical and Electronics Research*, *10*(2), 122–125.

Tevaramani, S. S., & Ravi, J. (2022). Image steganography performance analysis using discrete wavelet transform and alpha blending for secure communication. *Global Transitions Proceedings*, *3*, 208–214. https://doi.org/10.1016/j.gltp.2022.03.024

Wang, L., & Ji, H. (2022). A Watermarking Optimization Method Based on Matrix Decomposition and DWT for Multi-Size Images. *Electronics*, *11*(2027), 1–16.

Xu, Y., Mou, C., Hu, Y., Xie, J., & Zhang, J. (2022). *Robust Invertible Image Steganography*. 7875–7884.

Xue, Y., Mu, K. A. I., Wang, Y., Chen, Y., Zhong, P., & Wen, J. (2019). Robust Speech Steganography Using Differential SVD. *IEEE Access*, *7*, 153724–153733.

Yassin, N. I. R., & EL Houby, E. M. F. (2022). Image Steganography Technique Based on Integer Wavelet Transform Using Most Significant Bit Categories. *International Journal of Intelligent Engineering & Systems*, *15*(1), 499–508.

Zear, A., & Singh, P. K. (2022). Secure and robust color image dual watermarking based on LWT-DCT-SVD. *Multimedia Tools and Applications*, *81*(19), 26721–26738.