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Image hiding in audio file using chaotic method

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ABSTRACT

In this paper, we propose an efficient image hiding method that combines image encryption and chaotic mapping to introduce adaptive data hiding for improving the security and robustness of image data hiding in cover audio. The feasibility of using chaotic maps to hide encrypted image in the high frequency band of the audio is investigated. The proposed method was based on hiding the image data in the noisiest part of the audio, which is the high frequency band that was extracted by the zero crossing filter. Six types of digital images were used, each of size fit the length of used audio, this to facilitate the process of hiding them among the audio samples. The input image was encrypted by a one-time pad method, then its bits were hidden in the audio by the chaotic map. The process of retrieving the image from the audio was in the opposite way, where the image data was extracted from the high frequency band of the audio file, and then the extracted image was decrypted to produce the retrieved image. Four qualitative metrics were used to evaluate the hiding method in two paths: the first depends on comparing the retrieved image with the original image, while the second depends on comparing the audio containing the image data with the original audio once, and another time by comparing the cover audio with the original audio. The results of the quality metrics proved the efficiency of the proposed method, and it showed a slight and unnoticed effect between the research materials, which indicates the success of the hiding process and the validity of the research path.

Keywords: Image hiding, Audio signal, Chaotic map, zero crossing filter.

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1. Introduction

Data hiding is the process of embedding information, such as text, image, or audio, into a cover media without causing any noticeable changes to it. Data hiding techniques have become increasingly popular due to their potential applications in areas such as security, copyright protection, and data authentication [1][2]. One of the most used types of data hiding is image steganography, which involves the hiding of secret information within an image. In recent years, researchers have been exploring the use of chaotic systems to improve the security and robustness of image steganography [3][4]. Chaotic systems are a type of dynamic system that exhibit complex, unpredictable behavior. They have been found to be effective for generating random sequences that can be used as encryption keys or to scramble data. Researchers have proposed several chaotic-based image steganography schemes, including those based on chaotic maps and chaotic oscillators [3][4][5]. Chaotic maps are mathematical functions that can generate unpredictable and complex behavior, which makes chaotic map is appropriate to achieve better security in the field of data hiding in digital media. The continued interest and innovation in the field of chaotic maps and their potential for enhancing the security and processing of digital data were demonstrated in recent studies. Such studies focused on developing new chaotic maps for image encryption and then hiding it in a cover media [6]. However, these techniques are not without their limitations. One of the main challenges in data hiding is to ensure that the hidden information is robust to various attacks, such as compression and noise. Therefore, researchers have been developing adaptive data hiding techniques that can adjust their parameters based on the characteristics of the cover media to enhance their robustness and security [7][8].

2. Related work and contribution

There are many papers devoted to image hiding, they are different in the used approaches and materials. It is appropriate to first define the research problem, then review the related works, and then clarify the scientific contribution of the present research.

2.1 Problem statement

Despite a lot of research having resulted in the field of hiding information in digital media, most of it had limitations related to used approaches. These limitations have contributed to reducing the amount of security of the hidden data, as well as preventing the application of that approach to be applied in a wide range of digital data. With the multiplicity of digital media applications on the Internet, the search for effective methods to hide data in a way that guarantees high confidentiality has become the focus of scientific research these days.

2.2 Related works

Much scientific research has been prepared within the field of interest, they achieve good security and performance in terms of embedding capacity, imperceptibility, and hidden image extraction. The most interesting ones are given in the following:

Zhang et al. proposed a new chaotic system for image encryption based on a 3D quadratic polynomial map, which is relevant to image encryption and uses a 3D quadratic polynomial map [9]. Chen et al. introduced a new chaotic image encryption scheme based on a fractional-order Lorenz system, which is relevant to image encryption and uses a fractional-order Lorenz system [10]. Luo and Zhang proposed a new chaotic system for color image encryption, highlighting the potential of chaotic maps for enhancing the security of digital data [11]. Additionally, Lin et al. proposed a new chaotic image encryption scheme based on a 3D chaotic Henon map and a hyperchaotic Chen system, which is relevant to data hiding and compression [12]. S. Chen et al. proposed an image hiding scheme that uses a chaotic map and discrete wavelet transform in an audio signal. Their scheme achieves high embedding capacity, good imperceptibility, and strong robustness against various attacks [13]. Z. H. Lian et al. proposed a scheme that uses a chaotic map and secret sharing to hide an image in an audio file [14]. Jia, S. et al. propose a new image hiding scheme that uses the fractional-order Chen system and the Hilbert-Huang transform in audio signals [15]. Yu, H. et al. proposed an improved image hiding algorithm based on the logistic chaotic map in audio. Their algorithm enhances the security of the image hiding process by using a secret key to encrypt the image and introduces a new embedding method based on the correlation between adjacent samples in the audio signal [16][17]. Q. Yang et al. proposed an efficient image hiding scheme in audio based on chaotic encryption and modulation, in which the chaotic map is combined with an amplitude modulation technique to embed the image in the audio signal [18][19].

2.3 Our Contribution

This research adopts the idea that state the information can be hidden in the noisy media well, so the contribution included that the image data was hidden in the high frequency band of the audio, which is a band of noisy behavior because it contains more noise samples. Also, the contribution included the employment of the chaotic system to select hiding sites in the high frequency band of the audio after encrypting the fine elements of the image want to be hidden.

3. Materials and method

In the current work, the used material images were with different types of concepts for the data to be hidden in order to study the interaction of the nature of that image type to the proposed method. Likewise, a method with sequential stages was adopted to achieve intermediate goals related to formulating the data in a way that is useful in achieving greater security when hiding it in the audio. The following subsections describe in more detail the nature of the image and audio materials used and the proposed method.

3.1 Used materials

The used materials are an audio file used as cover media for image hiding, and an image used as a secrete message to be hidden in the audio. The audio used are short audio recordings of about 5 seconds, in which the speaker says four words at normal pronouncing speed. The characteristics of the audio file are wave file format, mono, resolution of 8 bits per sample, and sampling rate of 22 kilo samples per second. Figure (1) shows the used audio recording of the aforementioned specifications that were used in current research as a cover media to hide the image data. Whereas the used images are a set of images that included different concepts of imaging techniques, natural, artificial, and satellite images. The chosen material images include all types that can be found in the field of digital image processing. The images set contains 12 images with fine details of different spectral distribution and colours, in order to examine the performance of the proposed method and its suitability with the nature of the image for the purpose of achieving the highest security for data hiding. The resolution of all the images used was 256×256 pixels. Figure (2) shows the this used images set. The two images (1-a and b) represent a bi-level image (monochrome), in which the pixel value is 0 or 1, which is useful for evaluating the results of the hiding process and noting the retrieved edges in the image. The two images (1-c and d) are grayscale images with a pixel value between 0-255 and contain grayscale stretches according to normal tone with significant contrast in the edge regions, such images are useful in evaluating the hiding process that deals with closely gray levels in adjacent image regions. The two images (1-e and f) represent natural scenes and are useful in testing the hiding process applied on images of sharp colour lustre. While the two images (1-g and h) are colour satellite images that contain fine details and are useful in verifying the sensitivity of the hiding process of fine details of the image. Images (1-i and j) are artificial cartoon images with discontinuous gradations and extended areas of colour and may contain few colours but do not contain noise or distortion like a natural image. This type of image contains regions of uniform colour, each region having one colour, but the adjacent region may have completely different colours which is useful in estimating the hiding performance of images of extended colour regions. Later, the two images (1-k and l) are continuous colour tone TV images, this type of image can contain many similar colours. The neighbouring pixels in TV images may differ by only one colour level, and it is difficult or even impossible for the eye to distinguish their colours. This type of image is useful in evaluating the performance of the hiding process applied on facial details and blurred background.

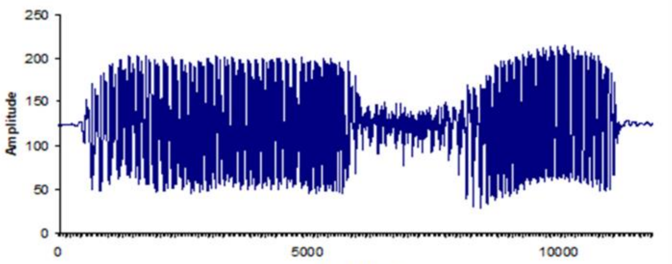


Figure 1. Material audio samples used to contain the hidden image

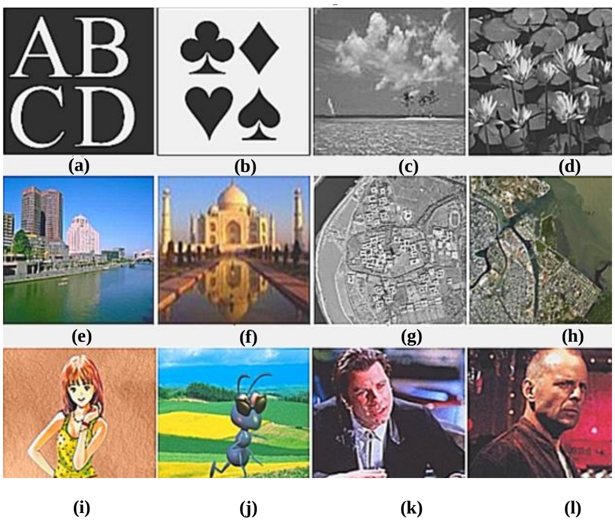


Figure 2. Material images used for testing the proposed method.

3.2 Proposed method

The proposed method depends on hiding the image data in a part of the audio that is the noisiest part, and this requires first extracting this part of the audio, which is the high frequency band (HFB). The zero crossing filter is used to extract HFB to be ready to hide the encrypted image data. The remainder of the audio is only the low frequency band (LFB), which is a part that we will not benefit from during processing. On the other hand, the image is encrypted by the one-time pad method. Later, a search for suitable locations in the HFB audio part is carried out for hiding the encoded data of the image. This search is done by the chaotic map method. This map will later help in deducing the locations of hidden data in the audio. Then, the HFB part is then merged with the LFB according to extraction map, so that the new cover audio will be like the original audio and contain hidden image codes inside it. Figure (3) shows the proposed method of image hiding inside an audio. The following subsections explain more details about each stage of the proposed method:

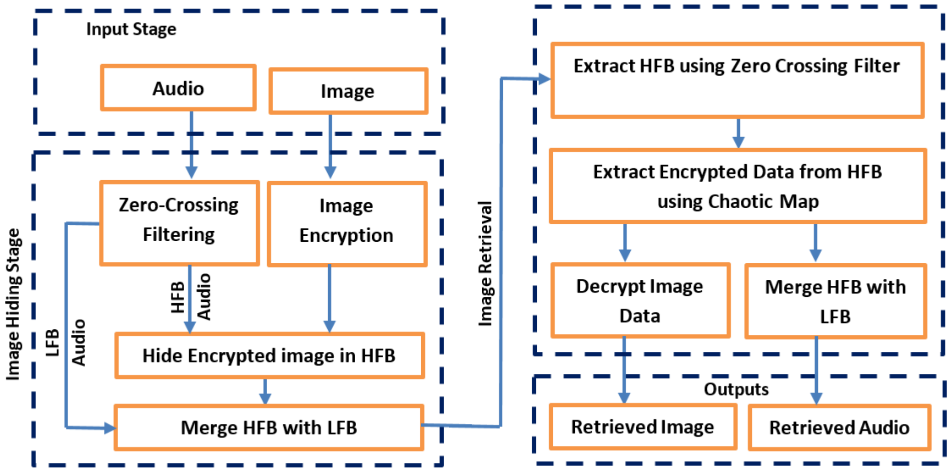


Figure 3. Block diagram of the proposed image hiding in audio file.

The zero cross filter was used to extract the HFB from the sound wave. Where the audio signal was divided into a successive window, each of length of 100 samples, then the number (C) of consecutive samples located above and below the offset was calculated. The offset is the average value of the wave samples. If C is greater than 40% of the size of the window, then this window belongs to the HFB, otherwise the window belongs to the LFB. Both LFB and HFB are saved in a specific two vectors, and the positions of each window in the original sound wave are also stored for later retrieval.

The process of encrypting the image was done using the one-time pad, where a random password was first generated and converted into characters by UTF-8 to be saved in a binary array (R_{sa}). Then, to extend the size (L) of this array (i=0,1,2, …, L-1) was stretched into 64 bytes (B_o, B_1, B_2, …, B_{63}). The hash function was applied on R_{sa} to generate 64 pseudo keys (k_o, k_1, k_2, …, k_{63}). Later, apply the following equation to each pixel in the input original image (I_o) to obtain an encrypted image (I_e):

$$I_e = \left(I_o + R_{sa}(i\ Mod\ L_r)\right) Mod\ 256 \qquad \dots (1)$$

It is necessary first to check if the size of the used audio fits the size of encrypted image data. Then, the process of embedding the encrypted data in the audio using the chaotic map method. The chaotic map is used to select random hiding locations (P_n) in the audio through the following relationship:

$$P_n = R \times P_o \times (1 - P_o) \qquad \dots (2)$$

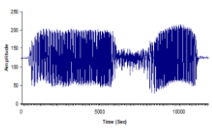
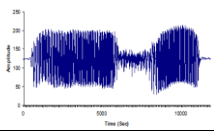
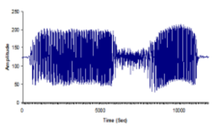
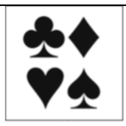
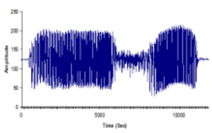
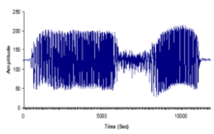
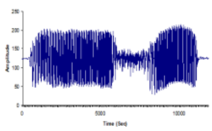
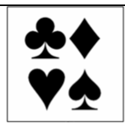
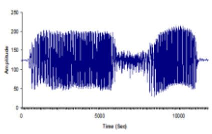
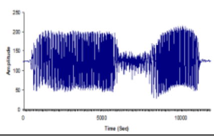
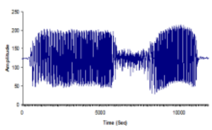
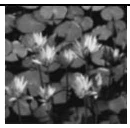
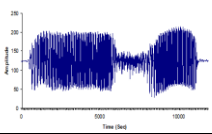
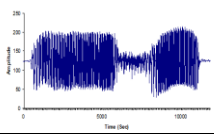
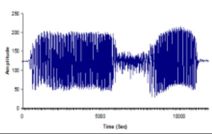
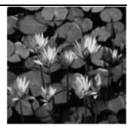
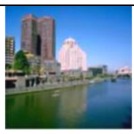
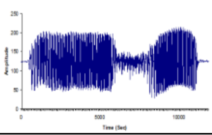
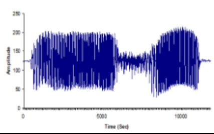
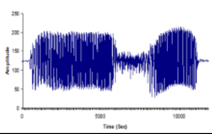
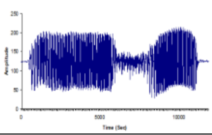
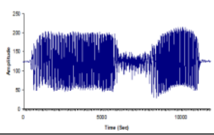
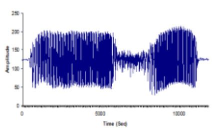
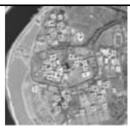
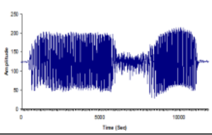
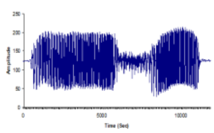
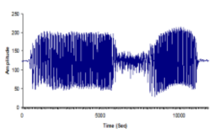
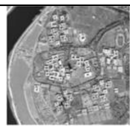
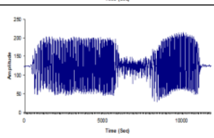
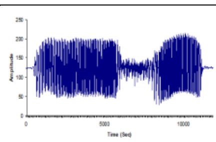
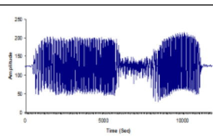
Where R is constant equal to 3.6, P_o is the last hiding position in audio that has initial value of 0.7, P_n is current hiding position in the audio representing an integer sequence of one byte of the audio. Thus, one can denote the chosen position P_n with a Boolean variable (*Flag*) to avoid selecting it in a later step. The initial values of *Flag* sign are true, and it becomes false when choosing its corresponding byte in the audio for hiding current encrypted image bit. Therefore, the current encrypted image bit is stored in the LSB location of the chosen audio byte at position P_n unless the *Flag* sign is true. The process of the hiding continues by choosing a hiding location from the audio bytes that was not previously chosen (*Flag*=True), then storing the current bit of the image at LSB, and so the process is repeated until all the bits of the encrypted image are finished. The chaotic map is stored in a specific array to be used in the image retrieval during the decryption stage.

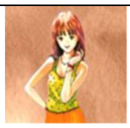
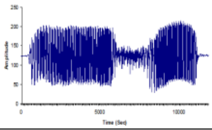
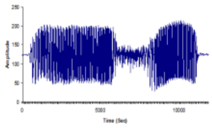
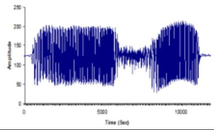
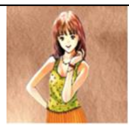
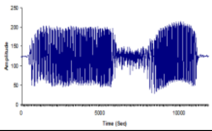
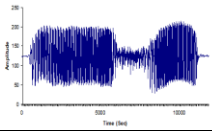
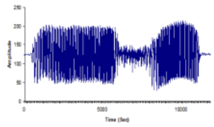
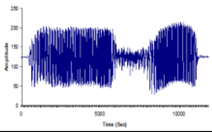
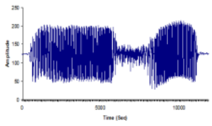
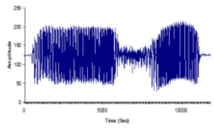
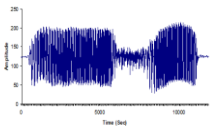
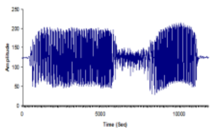
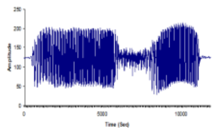
The process of retrieving the encrypted image data from the audio is a reverse process. First, the chaotic map is used to deduce the hidden locations in the audio. Then, an empty number image array is created, all bits are collected and arranged within the array sequentially. After completing the process of retrieving all the bits of the encrypted image in the array, the array is decrypted using encryption keys to produce numerical bit values of image either 0 or 1, and these bits are arranged so that each 8 bit represents the value of one byte of retrieved image.

4. Results and Discussions

The proposed method was applied to hide one of the 12 used images in the used audio. It is important to mention that the size of the image was large compared to the size of the audio, which necessitated reducing the size of the image to 100×100 *pixels*. Thus, the total number of image pixels was 10,000 *pixels*, and the audio sample was 112,640 (5*sec*×22528*sample/sec*) *samples*. Table (1) shows the input images that were used in the process of hiding in the audio, as well as the outputs, in addition to the audio that contained the hidden information. It was noticed that there are no visually distinguishable differences between the original and retrieved images, also there are no noticeable visual differences between the input and output audio waves, as well as the audio that contained the hidden image information. Therefore, the adoption of quantitative rather than qualitative measures may indicate the possibility of measuring the performance of the proposed method.

Table 1. Input-output of image hiding in the audio.

Ser.	Input image	Input audio	Audio carried image	Cover audio	Retrieved image
1					
2					
3					
4					
5					
6					
7					
8					

9					
10					
11					
12					

The embedded capacity (C_e) measured in bit per sample (*bps*) of all hiding tests are as follows:

$$C_e = \frac{Number\ of\ safe\ hidden\ bits}{Audio\ Size}(bps) = \frac{Image\ Size}{Audio\ Size} = \frac{10000}{112640} = 0.089\ bps$$

This indicates that the audio can accommodate the image size when the image bits are hidden in the LSB of the audio. Whereas the use of the commonly used normalized qualitative measures to evaluate the process of image hiding in the audio were estimated twice: one between the input audio and the audio carried the hidden image within as shown in Table (2) and Figures (4 and 5), and another time between the input audio and the cover one as shown in Table (3) and Figures (6 and 7). Whereas Table (4) indicates the results of the quality metrics of the retrieved image compared with the input image, which is clearly shown in Figures (8 and 9).
From observing the results presented in Table (2) that indicated in Figures (4 and 5), it is found that the behavior of all qualitative metrics curves took an almost similar indication. Although the correlation values are high, there is clear fluctuations in the behavior of the correlation scale between the different images, with a remarkable similarity in the behavior of the correlation belonging to the different types of images. Also, it is noticeable that there are clear variations in the values of the quality measures of the different images, and significant differences between the average values of these measures. In comparison with the data of Table (3) that indicated in Figures (6 and 7), it can be seen that the behavior of the quality metrics was close and that the differences are few between the values of each metric dependent on a different image. This indicates that the amount of randomness in the audio has increased slightly after hiding the image data in it, but this randomness did not exceed the limits of the regularity of the sound and did not impact its quality. As the SNR rate for the audio has become slightly lower after hiding the image, but in both cases, this measure was within the limits that indicate the quality of the sound and the clarity of its hearing.

Table 2. Resulted quality metrics of audio carried hidden data versus input audio

Ser.	Variance	Correlation	MSE	Entropy	SNR
1	1.34	0.863	0.024	0.215	33.826
2	1.75	0.826	0.047	0.313	33.752
3	2.65	0.824	0.087	0.398	32.725
4	2.73	0.879	0.093	0.427	33.192
5	2.96	0.925	0.102	0.461	31.825
6	3.15	0.884	0.117	0.474	32.025
7	3.72	0.837	0.162	0.469	31.926
8	3.69	0.826	0.153	0.472	31.873
9	1.64	0.935	0.007	0.379	34.524
10	2.27	0.962	0.014	0.381	33.726
11	3.84	0.672	0.174	0.392	33.261
12	3.59	0.717	0.138	0.368	33.826
Average	2.77	0.845	0.093	0.395	33.040

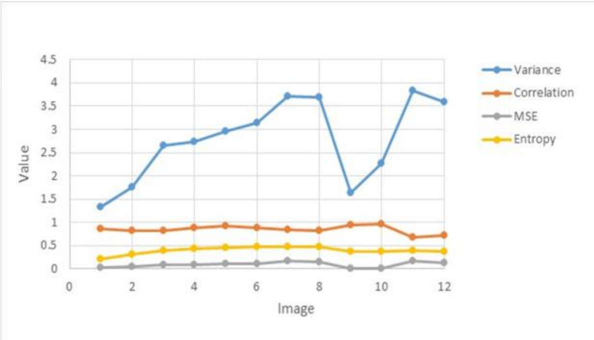


Figure 4. Evaluation metrics of audio carried hidden data versus input audio.

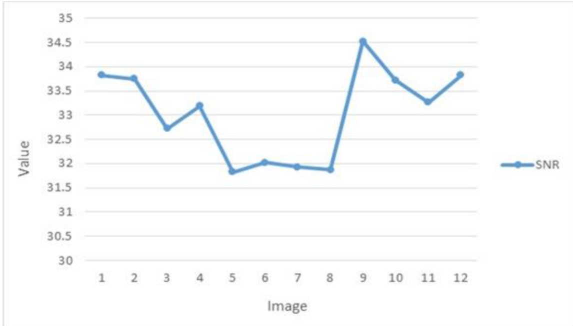


Figure 5. SNR behavior of audio carried hidden data versus input audio.

Table 3. Resulted quality metrics of cover audio versus input audio

Ser.	Variance	Correlation	MSE	Entropy	SNR
1	0.16	0.927	0.003	0.016	35.783
2	0.03	0.953	0.003	0.019	35.725
3	0.16	0.936	0.004	0.017	34.702
4	0.72	0.962	0.004	0.015	34.791
5	0.71	0.985	0.007	0.016	34.835
6	0.68	0.968	0.005	0.017	34.726
7	0.04	0.974	0.103	0.003	34.683
8	0.77	0.938	0.106	0.102	34.039
9	0.65	0.997	0.001	0.017	35.682
10	0.81	0.992	0.008	0.006	35.698
11	0.85	0.892	0.003	0.073	35.387
12	0.68	0.907	0.004	0.058	35.478
Average	0.52	0.953	0.021	0.029	35.127

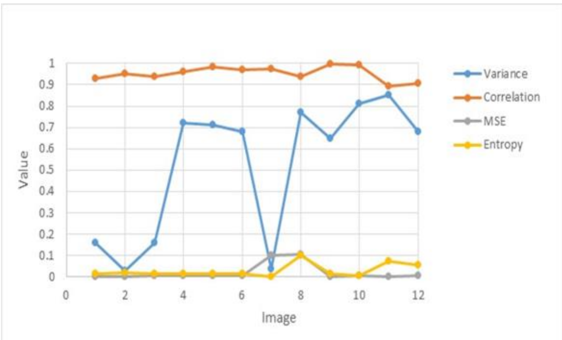


Figure 6. Evaluation metrics of cover audio versus input audio

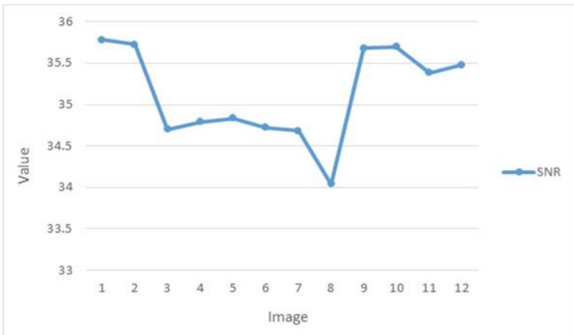


Figure 7. SNR behavior of cover audio versus input audio

The analytical comparison of the two images: the retrieved one versus the input image using the quality metrics indicated in Figures (8 and 9), one can found that the differences that were calculated between the pixels of the two images were in very small amounts, as the rate of color variation of 0.066 average and the amount of correlation was relatively large of 0.945, while the MSE and entropy were very small with average of 0.00158% and 0.069 % respectively. Whereas, the SNR values were relatively higher, with an average of 39.111, for all the images used, which indicates the great similarity between the retrieved image and the input image. Figures (10-14) show the behavior of each qualitative metric separately from others, in which the behavior of each is appeared monotonic for all images, which confirms the validity of its computation, and reflects the amount of its interaction with the type of image and its ability to express its content. Furthermore, it is found that the edges of the image were not affected much when it was retrieved after the hiding process, as one did not notice any visible deviation in the edges of the retrieved images, which clearly shown in retrieved binary and grey images. Likewise, no change was observed in the color tone of the images that contain extended color areas, which can be seen clearly in the results of natural scenes and cartoon-like images, where the calculated error metrics were very few and not exceeding the color difference that observed by the human eye. The same results are noticed for the details of the image cues, in which the retrieved images are shown without changing in color or location, which can be noticed by watching retrieved satellite images and TV images relative to the original. In general, the evaluation of the results of the qualitative measures indicated the efficiency of the proposed method and proved the validity of the research path followed to accomplish the process of image hiding in the audio.

Table 4. Resulted quality metrics of retrieved image versus input image

Ser.	Variance	Correlation	MSE	Entropy	SNR
1	0.041	0.986	0.00021	0.053	39.726
2	0.037	0.962	0.00023	0.062	39.683
3	0.089	0.953	0.00155	0.072	38.638
4	0.093	0.961	0.00171	0.081	38.827
5	0.058	0.968	0.00203	0.072	38.793
6	0.062	0.921	0.00259	0.053	38.073
7	0.076	0.963	0.00283	0.086	38.725
8	0.079	0.958	0.00302	0.081	38.026
9	0.002	0.989	0.00007	0.016	39.759
10	0.007	0.974	0.00009	0.024	39.758
11	0.146	0.826	0.00284	0.148	39.736
12	0.096	0.877	0.00179	0.091	39.584
Average	0.066	0.945	0.00158	0.069	39.111

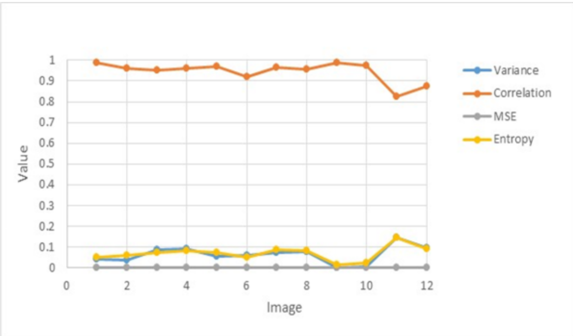


Figure 8. Evaluation metrics of retrieved image versus input image.

Figure 9. SNR behavior of retrieved image versus input image.

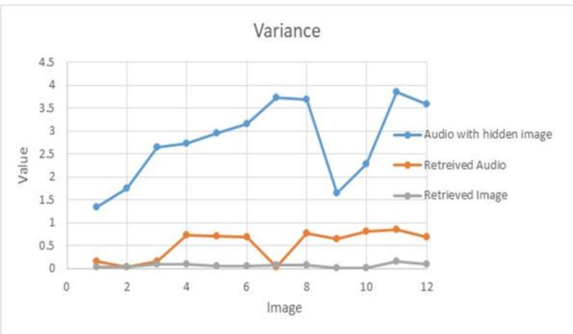


Figure 10. Variance behaviors of retrieved images versus input ones.

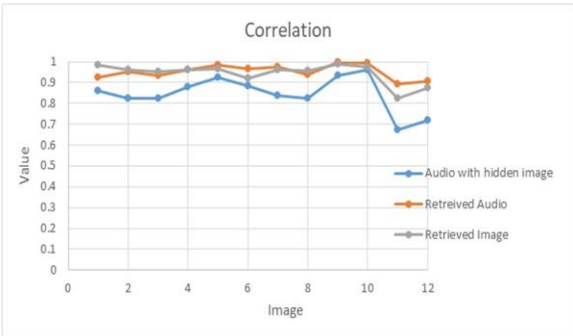


Figure 11. Correlation behaviors of retrieved images versus input ones.

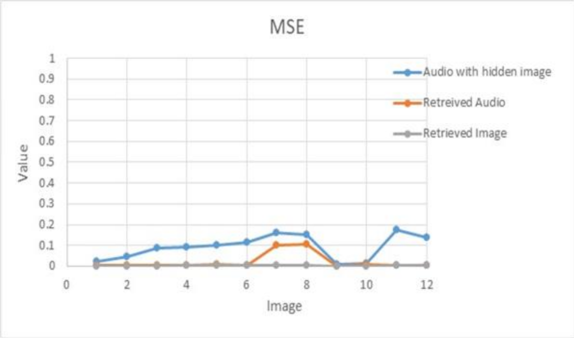


Figure 12. MSE behaviors of retrieved images versus input ones.

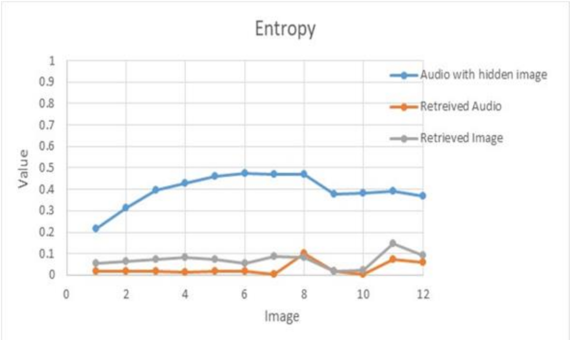


Figure 13. Entropy behaviors of retrieved images versus input ones.

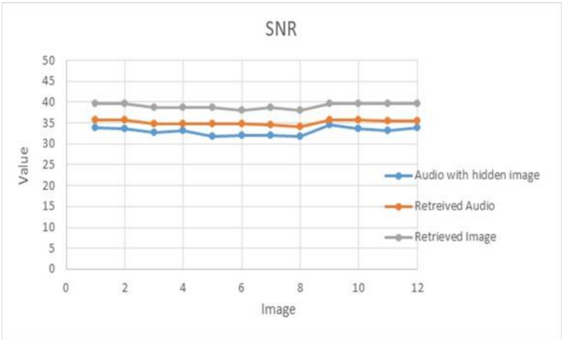


Figure 14. SNR behaviors of retrieved images versus input ones.

5. Conclusions

The analysis of the results led to the conclusion that the proposed method of hiding an image in an audio file by the chaotic map was successful and did not affect the quality of the retrieved image or the quality of the sound during hiding. The quality measures used proved that adopting the process of image encryption before hiding it helped to convert the image into a format that is compatible with the use of the chaotic map, as no in-kind errors were noticed in the retrieved image, while the quality measures indicated a high level performance of the hiding method, which is indicating the efficiency of proposed method.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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References

[1] H. Liu, X. Sun, Y. Zhang, and Y. Wang, "An adaptive color image steganography scheme based on nonsubsampled contourlet transform and chaotic mapping," Journal of Ambient Intelligence and Humanized Computing, vol. 12, no. 4, pp. 3471-3485, Apr. 2021.

[2] P. Kaur and H. Kundra, "A robust and secure image steganography using adaptive genetic algorithm-based key generation," Multimedia Tools and Applications, vol. 80, no. 17, pp. 24945-24968, Oct. 2021.

[3] Y. F. Huang, T. C. Lin, and H. S. Wu, "Chaos-based image steganography: A review," IEEE Access, vol. 8, pp. 33519-33537, Jan. 2020.

[4] Y. Gao, L. Liu, and L. Deng, "A review of chaos-based image encryption and steganography," Nonlinear Dynamics, vol. 99, no. 2, pp. 1215-1237, Jul. 2020.

[5] Z. Xu, Q. Zhou, and L. Sun, "Chaotic oscillator-based image encryption: A review," Nonlinear Dynamics, vol. 94, no. 1, pp. 1-21, Jul. 2018.

[6] R. M. May, "Simple mathematical models with very complicated dynamics," Nature, vol. 261, no. 5560, pp. 459-467, Jun. 1976.

[7] Z. Li, S. Li, S. Li, and Y. Guo, "Adaptive data hiding in encrypted images based on pixel-value differencing and LSB matching revisited," Signal Processing: Image Communication, vol. 63, pp. 81-91, Apr. 2018.

[8] W. Xu, Y. Wang, and X. Wu, "Adaptive image steganography based on differential evolution and multi-level decomposition," Journal of Ambient Intelligence and Humanized Computing, vol. 12, no. 8, pp. 8021-8032, Aug. 2021.

[9] Y. Zhang, H. Tang, and C. Huang, "A New Chaotic System for Image Encryption," Entropy, vol. 23, no. 3, pp. 329, Mar. 2021.

[10] S. Chen, J. Xie, and Y. Zhang, "A New Chaotic Image Encryption Scheme based on Fractional-Order Lorenz System," Nonlinear Dynamics, vol. 104, no. 3, pp. 1563-1575, Nov. 2020.

[11] J. Luo and J. Zhang, "A New Chaotic System for Color Image Encryption," Symmetry, vol. 13, no. 6, pp. 922, Jun. 2021.

[12] M. Lin, X. Li, and H. Qin, "A New Chaotic Image Encryption Scheme based on 3D Chaotic Henon Map and Hyperchaotic Chen System," Multimedia Tools, pp. 1-15, Mar. 2021.

[13] S. Chen, Z. Gong, and J. Liu, "A Secure Image Hiding Scheme Based on Chaotic Map and Discrete Wavelet Transform in Audio Signal," IEEE Access, vol. 10, pp. 15707-15716, 2022.

[14] Z. H. Lian and W. Hu, "A Novel Image Hiding Scheme in Audio Based on Chaotic Map and Secret Sharing," Journal of Systems Engineering and Electronics, vol. 32, no. 4, pp. 874-884, 2021.

[15] Jia, S., Liu, J., & Wang, L. A novel image hiding scheme based on the fractional-order Chen system and the Hilbert–Huang transform in audio signals. Signal Processing: Image Communication, 94, 117992, (2021).

[16] Yu, H., Zhang, X., & Jiao, R. An improved image hiding algorithm based on logistic chaotic map in audio. Journal of Ambient Intelligence and Humanized Computing. https://doi.org/10.1007/s12652-021-03355-6T5, (2021).

[17] George, L.E., Kadim, A.M.,"Color image compression using fast VQ with DCT based block indexing method",Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 2011, 6754 LNCS(PART 2), pp. 253–263.

[18] Q. Yang and F. Zhang, "An Efficient Image Hiding Scheme in Audio Based on Chaotic Encryption and Modulation," in IEEE Transactions on Circuits and Systems for Video Technology, vol. 30, no. 10, pp. 3263-3273, Oct. 2020, doi: 10.1109/TCSVT.2019.2969577.

[19] B. Alnajjar, A., M. Kadim, A., Jaber, R., Hasan, N., Ahmed, E., Altaei, M., & L. Khalaf, A. (2023). "Wireless Sensor Network Optimization Using Genetic Algorithm". Journal of Robotics and Control (JRC), 3(6), 827-835. doi:https://doi.org/10.18196/jrc.v3i6.16526.

[20] Hassan, N.A., Al-Mukhtar, F.S., Ali, E.H.,"Encrypt Audio File using Speech Audio File As a key",IOP Conference Series: Materials Science and Engineering, 2020, 928(3), 032066

[21] H. Thary Al-Ghrairi, A. Abdulwahhab Mohammed, and E. Z. Sameen, "Face detection and recognition with 180 degree rotation based on principal component analysis algorithm," IAES International Journal of Artificial Intelligence (IJ-AI), vol. 11, no2, pp. 593–602, Jun. 2022, doi: 10.11591/ijai.v11.i2.pp593-602.

[22] A. M. Al Sayed, A. M. Kadim, A. B. Alnajjar and H. M. Gheni, "Survey on Handwritten Recognition," 2022 International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), Ankara, Turkey, 2022, pp. 273-281, doi: 10.1109/ISMSIT56059.2022.9932793.