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Image Hiding in an Audio File Using Chaotic Method via Genetic Algorithm

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Abstract

Information security is one of the most important parts of information technology and communication in the modern world. Information security has gained a lot of attention recently due to the need to transmit information through global communication channels and through the Internet. In this research, the genetic algorithm is used to develop the chaotic maps that are randomly generated by the chaotic system to find the best map by which the locations of image data are inferred to be hidden in the audio. An average image size of 64×64 pixels is used to be hidden in an audio recording of 7 seconds duration at average resolution specifications. The results show that one of the chaotic maps created at the 739 generations is the best in determining image byte hiding locations in the high-frequency band of the audio. The quality measures show the cover audio that includes the hidden image is not much different from the original input one. This confirms the validity of the proposed method and the good selection of hiding locations in accordance with information security concepts.

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1. Introduction

The popularity of the network and the wide application of information technology have made us more aware of the importance of safe data transmission. Digital images are a significant carrier of information transfer. Information hiding and encryption can be grouped into two categories to secure information security [1,2]. Information hiding is a fundamental concept in computer programming and software design. It refers to the practice of encapsulating data and restricting access to it from the outside world, thereby preventing direct data manipulation by external entities or parts of the program. It plays a crucial role in designing robust and secure software by providing controlled access to data and implementation details, resulting in more maintainable and scalable applications. Due to their potential uses in fields including security, copyright protection, and data authentication, data-hiding techniques have grown in popularity [3]. Image steganography, which includes hiding confidential information within an image, is one of the most popular methods of data hiding. It is the practice of hiding sensitive information within a carrier medium, such as an image, audio file, video, or text, without attracting any suspicion that the hidden data exists. In the context of image steganography, the goal is to embed confidential or secret data into the pixels of an image in such a way that the changes are imperceptible to the human eye. It is used to cover up the existence of secret communication [4,5]. The secret data is inserted to achieve the desired result without causing the cover image to be significantly altered and minimizing the disparity between the stego and cover image [6,7]. Traditional encryption techniques like DES and RSA are no longer useful since digital images and texts have alternative storage methods and their own unique properties, such as high correlation, high redundancy, and a huge amount of data between neighbouring pixels [8]. As a result, numerous academics have put forth numerous encryption algorithms [9]. These technologies primarily rely on wavelet compression, chaotic systems, cellular automata, DNA computing and other techniques [10]. Dynamic systems that exhibit complicated, erratic behaviour are known as chaotic systems. They have proven useful for producing random sequences that can be used as encryption keys or to mix up data [11]. Numerous areas of chaos research have advanced significantly. It satisfies the criteria for image encryption because of its properties, including great sensitivity to initial conditions and control settings and inherent randomness [10]. Researchers, including ones based on chaotic maps and chaotic oscillators, have developed several chaotic-based image steganography techniques [12,13]. Finding the most suitable chaotic map for optimal image-hiding locations in the audio can be a challenging task due to the vast parameter space of chaotic systems. This is where the evolutionary algorithms come into play. One of these algorithms is the genetic algorithms which are powerful optimization techniques inspired by the process of natural selection, allowing for the search of the best chaotic map parameters to achieve efficient and secure hiding.

Recently, studies on the chaos embedded in evolutionary algorithms have been reported. Lifang et al. proposed a steganography method that combines chaos theory, genetic algorithms, and image-based LSB embedding [14]. The method shuffles the secret message using a logistic map and genetic algorithm to minimize image degradation. The shuffled message is then embedded into the cover image using LSB embedding. Experimental results demonstrate high embedding capacity, good image quality, and high security. Aya Jaradat et al. proposed a steganography technique that conceals secret data within a cover image while maintaining image quality [15]. It combines particle swarm optimization (PSO) with chaos theory. The method identifies optimal pixel locations in the cover image for effective data embedding. The cover and secret images are divided into blocks to maximize the embedding capacity. Experimental results show that the proposed method outperforms existing approaches regarding image quality, measured by metrics like PSNR and SSIM. Al-Dabbagh examined a novel knapsack cipher cryptanalysis method known as the compact genetic algorithm (cGA), representing the population as a probability distribution over the set of solutions [16]. The findings demonstrate that cGA successfully cracked the ciphertext. A comparison of the Spillman, simple GA (sGA), and results was included. The results show that cGA is worth considering for the attack of trapdoor 0-1 knapsack cipher.

N. J. Kadhim proposed Population Based Incremental Learning (PBIL) for breaking knapsack cipher [17]. The effectiveness of the genetic algorithm attack on the knapsack cipher proposed by Spillman in 1993 was improved by Poonam Grag, Aditya Shastri, and D.C. Agarwal (2006), whose results are compared with those of this implementation. The comparison's findings demonstrate that population-based incremental learning is less complex and faster than genetic algorithms (i.e., accurate results can be produced with fewer generations than genetic algorithms). Additionally, population-based incremental learning has a significantly lower overhead than genetic algorithms. Xiaowei Gu et al. presented a study that examines genetic algorithm-based image information concealment technology, simulates images using various types of moms, and presents the findings [18]. No matter how the size varies, the mother image may achieve effective information concealing for the images that need to be hidden. The parent image only slightly changes. This method has a higher peak signal-to-noise ratio as compared to the Least Significant Bit (LSB) methodology. Pratik et al. described a genetic algorithm (GA)-based technique for high-capacity image steganography that uses secret data alteration [19]. The hidden data is embedded using this novel technology, which replaces the least significant bit (LSB) with steganography. However, before being inserted into the LSBs of the cover image, the hidden data is reorganized and altered. GA controls the parameters that are used to organize and change the secret data. Flexible chromosome, a novel idea, is presented, allowing GA to interpret the chromosome value in several ways.GA seeks to identify the optimal parameter value that produces stego images with great visual quality. The stego pictures created by the suggested method have average PSNR values of 46.41 dB and 40.83 dB for data hiding capacities of 2 bit per pixel (bpp) and 3 bpp, respectively.

Hasan et al. suggested an effective image hiding technique that combines image encryption and chaotic mapping to increase the security and resilience of picture data hiding in cover audio [20]. The image data was concealed in the audio's high frequency range using six different kinds of digital images. The procedure was evaluated using four qualitative metrics, and the findings indicated a very little, barely perceptible relationship between the research materials. Al-Kateeb et al. proposed a new method for encrypting important data based on the circular shapes information extracted from the cover image [21]. The encryption process uses simple calculations, while the hiding process is done in pixels and three forms of concealment. Experiments showed excellent encryption and hiding, with a data recovery ratio of Bit Error Rate BER=0. Hassan et al. adopted a novel encryption technique with two secret key applications. A random modification was also proposed for audio (.WAV) files. The suggested method delivered effective audio files with a very high-frequency band that are also very secure audio.WAV files. The suggested system converts voice audio files into text, which then uses the hash function to build a password seed with two keys. The first key is encrypted using the proposed algorithm, and the second key and key pair are then used to encrypt the original audio (.WAV) file using the Rijndael algorithm.

This paper aims to use the genetic algorithm to find the best chaotic map that can determine image information hiding locations within the audio. Also, the noise integrated with the audio in the high frequency band (HFB) makes it possible to switch the value of one sample in the long audio with one image pixel (pixel hiding) from time to time, which gives the possibility for the audio to bear all the pixels of the image without harming the accuracy of hearing the sound. Thus, the contribution is based on improving the performance of the Genetic Algorithm (GA) by using the chaotic behavior obtained from the chaotic system to introduce the first generation used in GA. This enables rapid development with the advancement of generations to reach a better chaotic map that produces the best image hiding in the audio.

2. Theoretical Aspects

2.1 Chaos Embedded GA

Chaos was employed to enhance and prevent local solutions in search for optimal solutions to optimization problems. In the creation of evolutionary algorithms, chaotic maps include chaotic sequences that can be used to build individuals. The logistic map, first described by May in 2004 and frequently used to explain the evolution of complicated behavior from a straightforward nonlinear dynamic equation, is one of the most significant techniques for producing chaotic maps. According to the following equation, the logistic map generates chaotic sequences in the interval 0–1. [23]:

$$x_{k+1} = a x_k \, (1 - x_k) \qquad \ldots (1)$$

where a is a parameter almost set to 4 in the simulation. Initialization, crossover, and mutation are the three important phases that are chosen to be integrated with chaos when considering genetic algorithms (GA) as the commonly used method of evolutionary algorithms [24,25].

i. Initialization

Iterations begin with the initial population. The initial population's variety is essential to ensure that the population is distributed as uniformly as feasible over the search spaces. Instead of using a random population, chaotic maps are used to create the initial population in this case. The characteristics of randomness during initialization can provide an appropriate solution space with good distribution, speeding up convergence and improving the ability of global search. Consequently, those individuals can be described as $x_s = \{x_1\, s, x_2\, s, \ldots x_i\, s, \ldots x_n\, s\}$, where $s = 1, 2, \ldots N$, $i = 1, 2, \ldots N$. For the logistic map initialization, $x_{i+1}\, s = 4 x_i\, s\,(1 - x_i\, s)$.

ii. Crossover Operator

For GA, the crossover operator is essential. The crossover operator produces the majority of the offspring. It significantly affects how quickly convergence occurs. Rapid convergence might be avoided by an effective crossover operator. Ergodicity of chaos aids in searching for all potential solutions, preventing them from achieving a local optimum, and achieving the global optimum. The crossover operators substitute chaotic sequences at random. Binary crossover (SBX) operator is adopted in simulated problems., where a two child individuals: $xc_1 = \{x_1\, c_1, \ldots, x_i\, c_1, \ldots, x_n\, c_1\}$ and $xc_2 = \{x_1\, c_2, \ldots, x_i\, c_2, \ldots, x_n\, c_2\}$ are generated by a pair of parents $xp_1 = \{x_1\, p_1, \ldots, x_i\, p_1, \ldots, x_n\, p_1\}$ and $xp_2 = \{x_1\, p_2, \ldots, x_i\, p_2, \ldots, x_n\, p_2\}$ as follows:

$$x_{c1}^{i} = \frac{1}{2}\left[\,(1-\beta)x_{P1}^{i} + (1+\beta)x_{P2}^{i}\right] \quad \ldots (2)$$

$$x_{c2}^{i} = \frac{1}{2}\left[(1-\beta)x_{P1}^{i} + (1+\beta)x_{P2}^{i}\right] \quad \ldots (3)$$

where, β is generated in the following manner:

$$\beta = \begin{cases} (2u)^{\frac{1}{\eta_c+1}} & if\ u \leq 0.5, \\ \left(\frac{1}{2(1-u)}\right)^{\frac{1}{\eta_c+1}} & otherwise \end{cases} \quad \dots (4)$$

where u is an arbitrary number between [0, 1]. The crossover operator's distribution index is given by η_c. Since u is a random number, it can be generated by chaotic map in the ith iteration (u_i), then in the $(i + 1)^{th}$ iteration as follows: $u_s = u_{i+1} = 4 \times u_i(1 - u_i)$.

iii. Mutation Operator

The mutation operator is important to the GA because it increases its chances of reaching the global optimum and prevents solutions from settling into local optimums. Solutions are prevented from being locked in local optimums by the characteristics of chaos, such as randomness and sensitivity to beginning conditions. In mutation operators, chaotic sequences take the place of random parameters. The mutation is defined as follows for a solution:

$$x_s^* = x_s + (x_s^u - x_s^l) \times \delta_s \quad \dots (5)$$

where x_s^l and x_s^u are the lower and upper bounds of x_s, and

$$\delta_s = \begin{cases} (2u)^{\frac{1}{\eta_m+1}} & if\ u < 0.5 \\ 1 - \left(2 \times (1 - u_s)\right)^{\frac{1}{\eta_m+1}} & otherwise \end{cases} \quad \dots (6)$$

where u_s is a random number between 0 and 1. η_m is the mutation operator's distribution index. The phase for mutation is that u_s is calculated by chaotic maps in the i^{th} iteration: $u_s = u_i$, then in the $(i + 1)^{th}$ iteration, $u_s = u_i+1 = 4 \times u_i(1 - u_i)$.

3. Materials and Method

The materials used in this paper are 6 images of different concepts and one audio recording of appropriate length. The six different concept images are shown in Figure (1). The first image is a binary image that is useful for examining the effect of sharp color edges when used in the proposed method. The second image is a grayscale image with bigger contents that is useful for examining the effect of grey-level variation when data is hidden and retrieved. The third image is a color image with relatively large contents that is used to examine the effect of color extensions along extended regions after the hiding and retrieval. The fourth image is a color satellite image with fine details that can tell us the extent to which the fine details in the image are affected after being retrieved by the proposed method. The fifth image is a cartoon image that contains a few colors extending over large areas of the image and can give a clear perception of how affected the narrow quantum range is after image retrieval. The sixth image is a television image with a distinctive color lustre that can tell about the extent of the effect of color saturation after retrieving the image by the proposed method. The used audio is a medium-resolution audio recording with a time length of 7 seconds, single-channel, with a resolution of 1 byte per sample, and a sampling rate of 22 kilo samples per second, as shown in Figure (2). Thus, the number of samples in all audio recordings is 157,696 bytes, while the number of image pixels to be hidden in the audio is 4096, which represents 2.5% of the total size of the audio. This also represents the containment capacity of the audio calculated as follows: The embedded capacity (Ce) measured in bit per sample (bps) of all hiding tests are as follows:

$$C_e = \frac{Number\ of\ safe\ hidden\ bits}{Audio\ Size}(bps)$$
$$= \frac{Image\ Size}{Audio\ Size} = \frac{4096}{157696} = 0.025\ bps$$

This indicates that the audio can accommodate the image size when the image bytes are hidden in the audio. The following subsections explain more details about each stage of the proposed method:

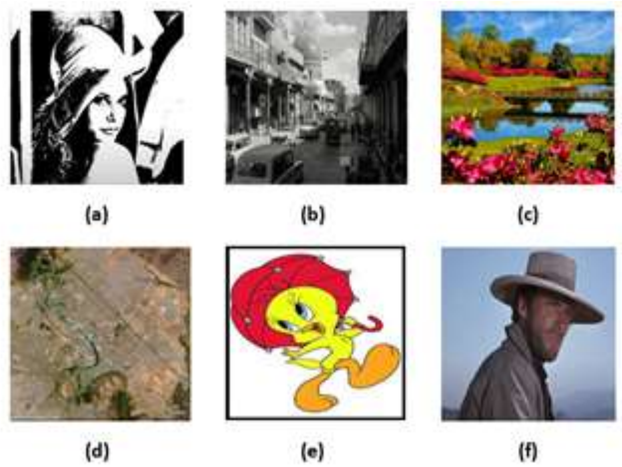


Figure 1. Material images used for test the proposed

The proposed method shown in Figure (3) consists of two phases: image hiding and image retrieval. The image hiding phase contains three stages within, while the image retrieval phase contains only one stage. The three stages of the hiding were sequenced to find the best hiding sites by generating chaotic maps, then applying the optimization to find the best one by GA that refers to the optimal map of hiding the pixels of the image in the audio. The GA depends on repeating the generation of chaotic map to create the populations of the first generation, which consists of 10 individuals, as shown in Figure (4). Then the genetic algorithm is used to generate the individuals of the second generation depending on the parents of the first generation, and so the generations are successively continued until the generation that includes the best individuals is achieved, which represents the optimal chaotic map to hide the pixels of the image in the audio without effects that may affect the accuracy of hearing the sound. The following subsections explain more details about the stages of the proposed method:

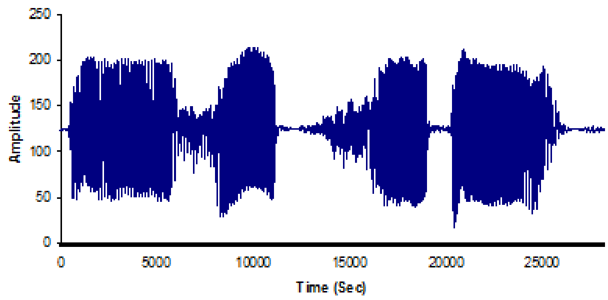


Figure 2. Material audio samples used to contain the hidden image data.

The chaotic map (P_n) is a guide for pixel hiding locations in the audio, which can be deduced from the following equation:

$$P_n = R \times P_o \times (1 - P_o) \quad ...(7)$$

where R is a numerical constant, P_o is the location of the previous hiding and has an initial value of P_i. The values of the variables R and P_i were exploited in order to produce a number of chaotic maps indicating the locations of image pixels in the audio by randomly changing the values of R within the range 3-4 and changing the values of P_i within the range 0.1-0.9 randomly. Then, a ten chaotic maps were produced by randomly choosing both R and P_i within the specified ranges and saved in the vector P_n, where n=10 represents the number of individual population for the first generation of chaotic maps.

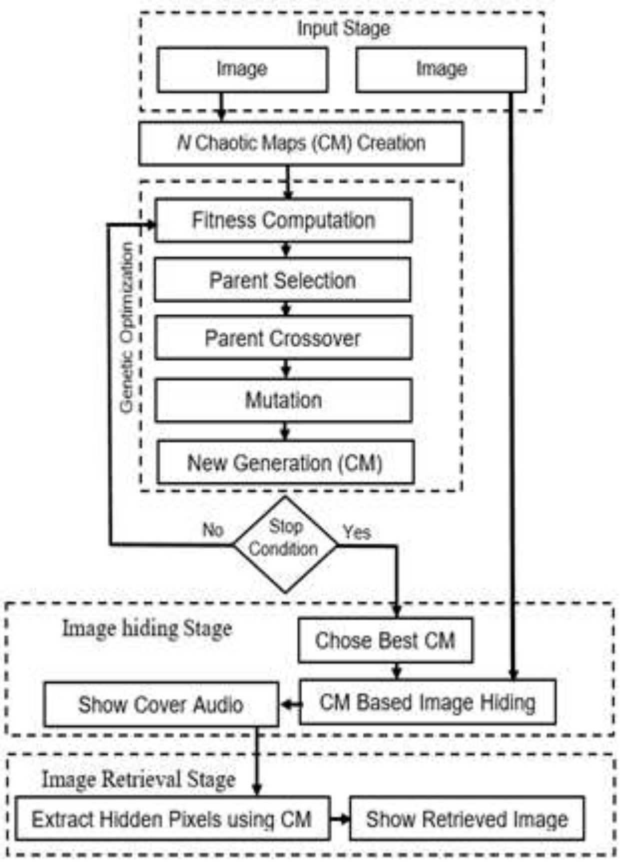


Figure 3. Block diagram of the proposed image hiding in audio file.

Figure 4. Sample ten individuals, each with 4096 chromosomes (Chr).

The behavior of genetic optimization depends on the modeling of the objective function (J), and in order for the objective function to be effective, it was found preferable to contain three terms as given in equation (8), in which each term represents a fitness function that has control over directing the calculations towards achieving optimal solutions.

$$J = 0.5 \times F_1 + 0.3 \times F_2 + 0.2 \times F_3 \qquad \dots(8)$$

where F_1 is the value of P_n for an individual in sequence n of the current generation. This fitness function was given a weight of 0.5 due to its importance and ability to influence the calculations to the correct side. Whereas the second fitness function F_2 represents the inverse of the average number of the hiding sites in each audio window (as a preparatory step, the audio wave is divided into sequential windows, each of 100 samples length) . The solutions improve when F_2 is relatively larger, which indicates the number of sites in the audio window is less. Also, the third fitness function F_3 represents the average spacing distance between the hiding sites in the audio windows, which can be at its best when these sites are far apart from each other, which means that this fitness function is greater. In general, using the relationship in equation (2) to be the objective function that controls the generation calculations towards optimization will enable to obtain optimal solutions when the objective function is as large as possible. Practically, three pairs of individuals that have a high fitness function value were selected for mating and generated three new pairs of individuals in the new generation. Then the remaining two pairs were selected to generate two more pairs of individuals in the new generation. Thus, there are ten new individuals are produced from the parental generation. Considering that each individual consists of 4096 chromosomes representing hiding sites in the chaotic map, the mating process relied on replacing half of these chromosomes between the parental couple to generate the chromosomes of the new two individuals in the new generation, as shown in Figure (5). The mutation step was applied to a small number of new individuals with a chance ratio not exceeding 0.1. It is worth noting that both dead and dead require the absence of any duplicate chromosome. In case of a duplication, the first chromosome takes its original value before the change.

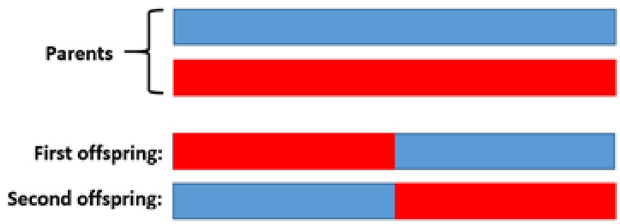


Figure 5. Adopted crossover method for producing the two new offspring.

The optimal solution provided by the genetic algorithm is a set of individuals. The optimal generation is the last generation that fulfills the condition of stopping the generation process. The condition for stopping the generation process is to reach the largest value of the objective function or not to achieve a significant difference in the objective function with generations. The best members of the last generation can be selected to be the perfect chaotic map for hiding pixels in the audio. The optimal chaotic map used to hide the image pixels represents the master key through which the image pixels can be inferred to extract it from the audio. This key is kept from the audio and stored in an external file. After inferring the hiding location of each pixel, it is saved in a two-dimensional array representing the image pixels, whereas the audio sample of that location is compensated by the average value of the neighboring samples before and after that sample. Thus, we have an encoder that extracts the optimal chaotic map for hiding an image in the audio, and there is a decoder that uses the master key (chaotic map) to retrieve the image information from the audio.

5. Results and Discussions

Ten chaotic maps were created to be the first generation population. Random values were assigned to each chromosome with adopting a condition that no chromosome is duplicated in one individual is met. Then the genetic algorithm was applied to the first generation individuals to produce subsequent generations; the developed individuals were obtained in generation 739. When observing the behavior of the objective function, a significant development occurred with the progression of generations, as shown in Figure (6). To prove this development, the behavior of the objective function was pictured for 1000 successive generations after neglecting the stopping condition at generation 739. It is noticeable that the behavior of the objective function started upward until the 739th generation, then it began to decrease until the last generation gradually. This confirms that the 739th generation is the best and that the quality of the characteristics of the subsequent generations has declined.

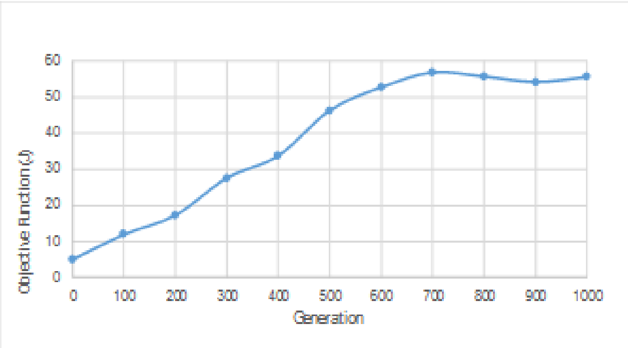


Figure 6. Resulted objective function behavior along 1000 generations.

The best individual of the 739 generation was used to make a chaotic map to hide one of the six images in the audio. Table (1) represents the results of using the proposed method by hiding any one of the six images in the audio; the first and second columns represent the input image and the cover audio, the third column represents the sound waveform of the audio after hiding the image within, the fourth column represents the audio waveform after extracting information image from it, and the fifth column represents the image retrieved from the audio using the optimal chaotic map. In general, there is no noticeable visual difference between the information entering the hiding system and the output information. The retrieved image appeared the same without a noticeable visual change, and also the audio was seen the same without a noticeable visual change. The qualitative measures may refer to the general behavior without delving into the details of the accurate information, and therefore it is better to access the quantitative measures to sense the variation that occurred in the information through the close scope.

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

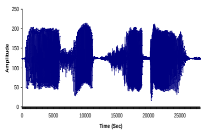
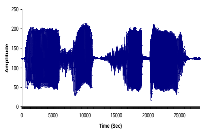
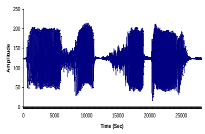
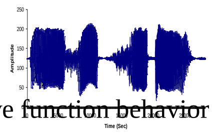
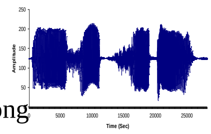
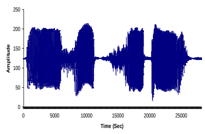
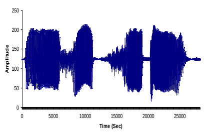
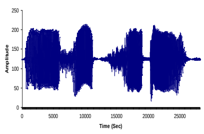
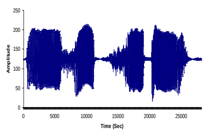
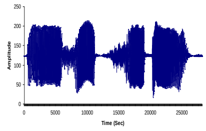
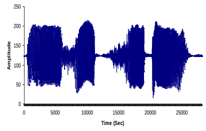
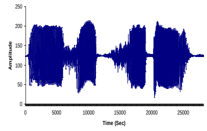
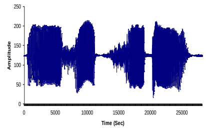
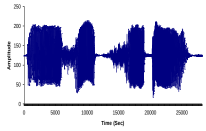
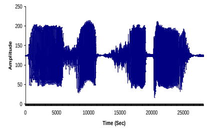
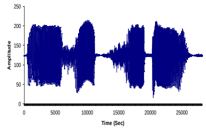
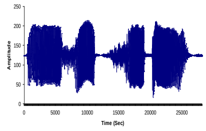
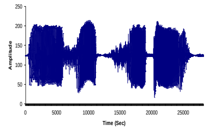
Ser.	Input image	Input audio	Audi carried image	Retrieved audio	Retrieved image
1					
2					
3					

Figure 6. Resulted objective function behavior along

4					
5					
6					

The quantitative measures adopted to test the proposed method for hiding one of the six images used in the audio recording are: variance (σ^2), mean square error (*MSE*), Entropy (ε), correlation (*C*), and signal to noise ratio (*SNR*). Figures (7 and 8) show the behaviour of quantitative measures between the retrieved image and the original image for the cases of using these six images. It can be seen that the values of both the σ^2 and *MSE* were very few. While the behaviours of ε and *SNR* were within the acceptable minimum limits, which indicates that the retrieved image is free of any noise resulting from the hiding process. The behaviour of the *C* measure was high values indicating the amount of identical correspondence between the two retrieved and original images. In general, the behaviour of all quantitative meters was monotonic and balanced without sudden fluctuations.

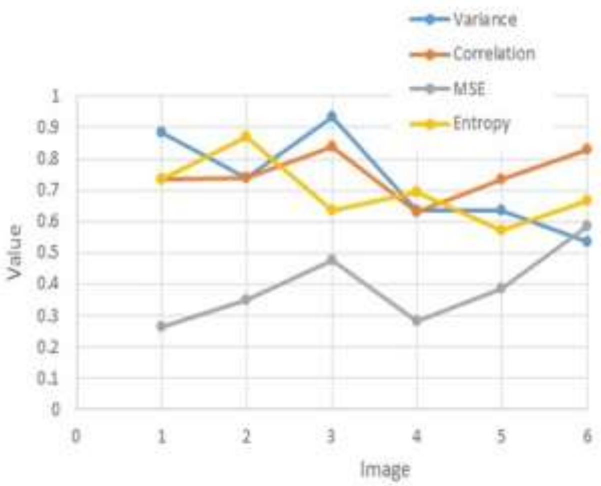


Figure 7. Resulted from quality measures behaviors of the retrieved image with respect to the original input image.

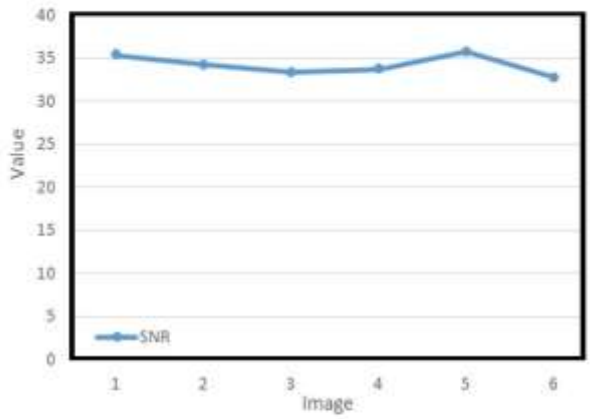


Figure 8. Resulted from SNR behavior of the retrieved image with respect to the original input image.

Furthermore, Figures (9 and 10) show the behavior of the quantitative measures of the audio that carries the hidden image relative to the original audio for the six cases of the six used images. It can be seen that there is a slight difference in the audio resulting from the hiding process compared to the original cover audio. It was noticeable that these behaviors differed slightly from those related to the retrieved image shown in Figures (7 and 8), which can be considered as a source of comparison due to the similarity of the retrieved image and the original image. It was found that both the σ^2 and *MSE* were observed slightly more, which indicates that there is a slight difference between the audio carried the hidden image and the original audio.

Likewise, there was no clear or noticeable change in both ε and *MSE*, and this indicates that the presence of the image inside the audio did not affect the audio information and that the hiding process did not affect it in general, and its hearing remained clear and with the same accuracy. Also, it was noted that the *C* behavior was almost similar to that shown in Figure (8), which indicates that the fine details of the sample audio were not affected by the presence of the hidden image among them. This confirms the efficiency of the proposed method and the validity of the used procedures.

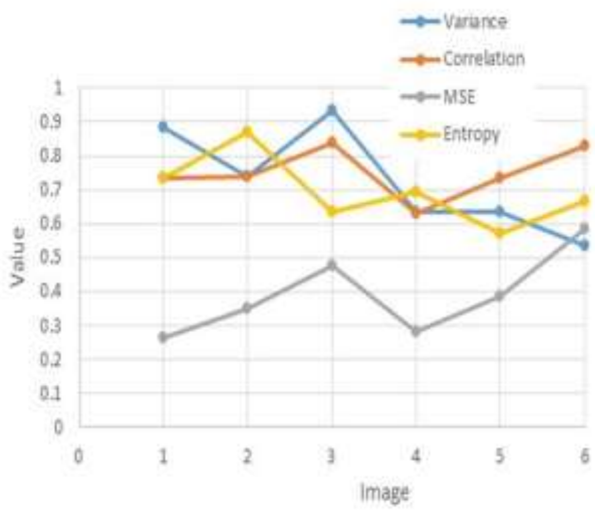


Figure 9. Resulted quality measures behaviors of audio carried hidden image with respect to input cover audio.

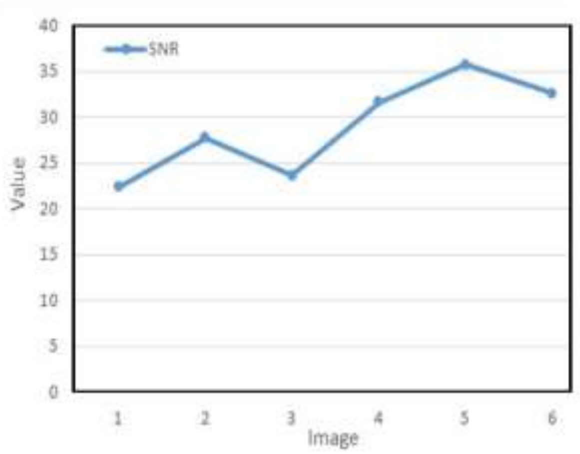


Figure 10. Resulted SNR behaviors of audio carried hidden image with respect to input cover audio.

6. Conclusions

The results analysis indicated the quality of the proposed method to hide an image in audio of a suitable length. One of the strengths of the proposed method is that the image data is hidden byte-wise in the HFB of the audio, which did not show a clear effect on the quality of the audio after the hiding process. The genetic algorithm served to obtain the best chaotic map to infer the hiding locations of the image bytes in the audio, which produced consistency between the image and audio information, and the hiding process was successful and imperceptible. The proposed approach integrates chaotic behavior with the genetic algorithm, focusing on pixel hiding in the high-frequency band of audio, and aiming for efficient development of generations to find the best chaotic map. These aspects distinguish this research from other studies in the field of image hiding in audio files and may lead to potential advancements in steganography techniques. To further improve the effectiveness of the method, we intend to research the effects of additional varieties of chaotic maps on pixel selection in future work. The suggested technique could be improved by running additional tests with images larger than 64x64 pixels, and also applying a combination of another EA with GA on the proposed method.

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