A High Capacity Data and Image Hiding Technique in Stereo Audio Signals Using Chaotic Maps and Wavelet Transforms

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Abstract. Information security domain has witnessed a great development in recent years to meet the rapid growth in multimedia communication technology. Audio Steganography is one of the challenging security techniques which refers to the art of hiding information into a cover audio signal. Stereo audio signals are very tempting for this goal as they provide double the capacity of data hiding as compared to mono audio signals. This paper introduces a novel high capacity and secure image hiding technique in stereo audio signals using chaotic maps and wavelet transforms. Two different types of wavelet transform, namely, the Discrete Wavelet Transform (DWT) and the Integer Wavelet Transform (IWT) are considered as the data embedding technique. The embedding of secret data (or image) is in two sub-bands of stereo audio signals to increase the hiding capacity without affecting the integrity of the cover sound. Hénon map is one of the simplest two-dimensional maps with chaotic behaviour. Its use is proposed to provide a strong, though simple, and highly secure data encryption as well as adaptive embedding through pixel positions permutation. The experimental results show that using the IWT allows lossless reconstruction of the hidden data with less complexity and minimal time. On the other hand, using the DWT gives higher peak signal-to-noise ratio (PSNR) of the stego-audio file which leads to a better quality of the cover audio signals.

1. Introduction

Ensuring individual's privacy nowadays has become a challenging issue. Steganography has been used in various forms for thousands of years, and the development of internet, digital signal processing and coding theory has created a wide development and made steganography involved in various useful applications [1-3]. Steganography has a distinctive properties over cryptography because it doesn't draw attention to its existence and the data may be encrypted before the embedding process, so it comprises the advantages of cryptography with an added benefit of undetectable communication[4]. Hiding schemes in audio files are characterized by three integral properties, which are: robustness against distortions or modifications, security against steganalysis and the capacity of hidden data [5]. A variety of techniques have been used by researchers during last few years. Some commonly used audio Steganography methods are: Least Significant bit (LSB) coding, Parity Coding. Phase Encoding. Spread Spectrum, Echo data hiding and transform domain techniques.
The remainder of the paper is organized as follows: In section 2 some of the related work are discussed. Section 3 specifies the steps for the proposed techniques. In section 4 simulation analysis and results are introduced, and a comparison between the proposed method and other previous methods is presented. And finally, in section 5 the conclusion of paper is deduced.

2. Related Work

Some of the researches performed in this field are as follows: In [7], this study presents a high-performance audio hiding scheme using spread spectrum modulation. It exploits the perceptual characteristic of audio before correlation. In [14], Fallahpour. M. and Megias. M have proposed an audio hiding technique in frequency domain using interpolated FFT samples to generate imperceptible marks. In [15], Kumar. P has presented a new hiding scheme in fast Fourier transform (FFT) domain based on

singular value decomposition (SVD) and Cartesian-polar transformation (CPT). SVD is applied to the selected FFT coefficients of each frame represented in a matrix form, and the highest singular values of each frame are selected and are decomposed into two components using (CPT). The Watermark information is embedded into each of these CPT components. In [16], a high payload audio hiding is proposed by M.W. Fakhr, based on the compressed sensing and sparse coding framework, with robustness to MP3 compression attacks. The signal to embedding noise ratio is kept in the range of 27-30 dB. In [19], A.Al-haj has proposed a semi-blind, imperceptible, and robust digital hiding algorithm. The proposed algorithm is based on cascading two well-known transforms: the discrete wavelet transforms and the singular value decomposition. In [22], a novel hiding algorithm is proposed using Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT). Furthermore, the Arnold transform and error correction technique are utilized to improve the performance of proposed algorithm in [23], A.R. Elshazly, M. E. Nasr, M. M. Fuad and F. E. A. El-Samie, have proposed a new audio hiding scheme based on Discrete Wavelet Transform (DWT), Singular Value Decomposition (SVD), and Quantization Index Modulation (QIM) with synchronization code embedded within double encrypted watermark images or logos into stereo audio signal. In [37], a multi-layer steganographic method based on the collaboration of them (MLS-ATDSS&NS) is proposed. MLS-ATDSS&NS is realized in two covert layers (audio steganography layer and network steganography layer) by two steps. A new audio time domain segmented steganography (ATDSS) method is proposed in step 1, and the collaboration method of ATDSS and NS is proposed in step 2. In [38], Dhar, P. K. and Shimamura, T have proposed a blind singular value decomposition (SVD) based audio hiding scheme using entropy and log-polar transformation (LPT) for copyright protection of audio signal.
The main aim of this paper is to come up with a technique to hide the data in audio file in such a way there are no perceivable changes in the audio file after the message insertion. Also, if the message that is to be hidden is also encrypted for further increasing the level of security to a more satisfactory level. A new chaos-based audio steganography method is proposed to increase the embedding capacity while maintaining high imperceptibility and robustness. The paper also, simulates and evaluates the performance of audio steganography scheme using DWT and IWT on stereo audio signals, and compares between the two schemes corresponding to time and robustness towards various attacks to illustrate the suitable applications for each technique. A powerful encryption method for secret image was also proposed, with adaptive embedding positions using 2-D Hénon maps.

3. Proposed Algorithm

This paper provides a unique platform to hide the secret information in stereo audio files using wavelet transform and henon maps. It also studies the performance of two wavelet transforms in audio steganography: the discrete wavelet (DWT) with two decomposed levels, and the two level (Int2Int) lifting wavelet transform (IWT). The paper compares the results and discusses the suitable applications for each technique. For more security, steganography is usually mixed up with cryptography to change the form of image before concealing its existence. The technique consists of two security levels: Secret image Encryption using 2-D Chaotic maps diffusion, and Steganography using threshold comparison and efficient choosing of hiding positions using Hénon chaotic maps.

3.1. Encryption process

In the proposed encryption scheme, the Hénon map is employed to implement the pixel positions permutation process.

- 2-D Hénon map is generated with parameters a=1.4 and b=0.3 and using initial values (0.1, 0) for example.
- Divide the resulted 2-D map into two maps, each of size 128*128.
- The two maps values are adapted to be between 0 and 255 and the values are XORed sequentially with the values of image pixels to obtain a twofold cipher image.

3.2. Steps for data embedding

1. Read the cover audio and secret image files
2. Encrypt image as previously discussed using 2-D Hénon map.
3. Divide Cipher image into two smaller matrices, one has the odd rows of encrypted image pixels and the other has the even rows, and convert each matrix elements into one-dimension binary bits.
4. Apply two levels wavelet transform to each of the two channels of the audio file and the second detail sub-band coefficients of first approximation for each channel is chosen for hiding process to maintain audio quality and increase the robustness of hidden data.
5. Generate 2-D Hénon map using suitable initial state conditions and split it into two maps, adjust the values of each map to choose the index of hiding positions, and the odd rows of image matrix are hidden using the first map random sequence and the even rows with the other map.
6. The method for embedding image bits depends on a predetermined threshold:

- If image bit equal 1, then the coefficient value is modified to be greater than or equal to threshold value.
- If image bit equal 0, then the coefficient value is modified to be less than threshold value.

The threshold value is chosen to equal to the mean value of details coefficients.

7. Apply inverse wavelet transform to get final stego audio output.

3.3. Steps for data extraction

In the extraction phase, the previous steps are reversed to obtain final image. The following steps are used:

1. Read stego audio file
2. Apply two levels wavelet transform on the two audio channels.
3. Generate the same 2D- Hénon map and extract the odd rows and even rows of encrypted image bits, as if the details coefficients of each channel are greater than or equal to threshold, so image bit =1, otherwise, image bit= 0.
4. Convert image bits to decimal and decrypt it using the same parameters of 2-D Hénon map used in encryption process. The proposed technique is described on figures 1and 2.

4. EXPERIMENTAL RESULTS

This section discusses the experimental results. The algorithm is tested by hiding two secret color images of128*128 sizes in eight cover audio samples of lengths between (ten) seconds up to five minutes. The program code is generated using MATLAB R2014a, Intel core i5@2.4 GHz CPU. The proposed algorithm employs 2-Level lifting decomposition of each channel of the stereo cover audio which increases the total embedding capacity depending on the number of embedding detail coefficients, that are changed based on the threshold value.

4.1. Performance evaluation parameters

There are two types of methods to evaluate the sound quality of audio steganography. There is subjective evaluation to listen to the sound and objective evaluation such as using Peak-Signal-To-Noise Ratio (PSNR) and Mean Square Error (MSE) tests.

4.1.1 Subjective test evaluation. The subjective difference grade (SDG) is one of the most widely used subjective methods for evaluating the quality of a stego – audio signal. The (SDG) ranges from 5.0 to 1.0 (imperceptible to very annoying). The results of subjective test are shown in figure 3, and from figure we can notice that the sound quality is better when using DWT. The mean of subjective test for DWT is 4.18, and for IWT is 3.7.

4.1.2 Objective test evaluation. The performance evaluation metrics for stego audio signal and extracted image with the two wavelet transform types are shown in table 1. From table results we notice that the algorithm has high stego audio signal quality with both kinds of wavelet transform but it is better when using DWT, whereas using IWT ensures full recovery of hidden image without losses. Figure 4 shows the execution time for embedding and extracting data in DWT and IWT. From figure it's obvious that IWT has less embedding and extracting time than DWT.

4.2. Problems and Attacks on Audio Signals

Some of the common types of processes on audio signal undergoes when transmitted through a medium [39-40], so, it's necessary to test the performance of algorithm against different types of attacks. It should be possible to retrieve the hidden data even if the stego audio is subjected to certain attacks. The results of algorithm performance against Attacks are all shown in table 2.

4.3. Comparison between the Proposed Technique and Some Other Related Works

The proposed technique is compared with some previous methods that use either DWT or IWT like [11], [14], [15], [17], [19], [23] and [38]. The comparison is based on mean of PSNR values and hiding capacity. From table 3, we notice that proposed method gives better results in both transform domains. Also, in the robustness test, the bit error rate (BER) was measured and compared with some other methods like in [7], [15], [19], [22] and [37] for various attacks as shown in table 4 and the proposed scheme achieves good performance.

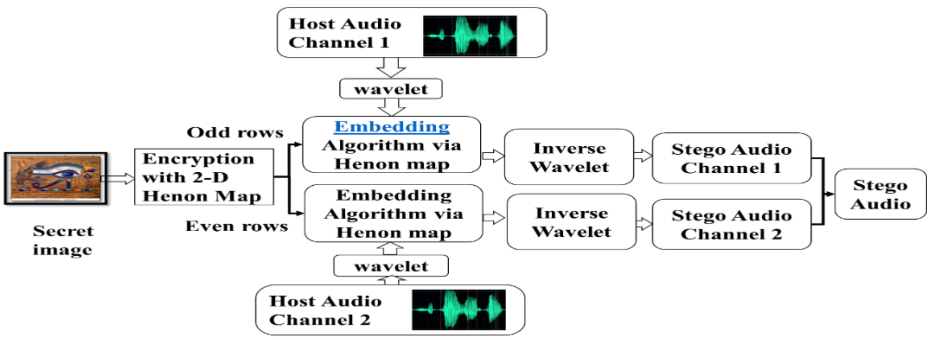

Figure 1. The Proposed Steps for Embedding Process

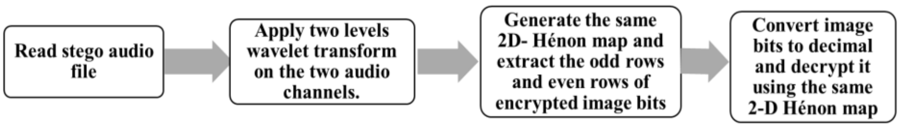

Figure 2. The Proposed Steps for Extracting Process

Table 1. MSE, PSNR and MSSIM for different audio signals with two hidden images

Cover Audio	Secret Image	DWT			IWT		
		MSE	PSNR	MSSIM	MSE	PSNR	MSSIM
Sample 1(sampling frequency =22050 Hz)	Image 1	6.46e-06	50.70	0.99	8.43e-06	49.55	1
	Image 2	6.52e-06	50.66	0.99	8.49e-06	49.52	1
Sample 2(sampling frequency =22050 Hz)	Image 1	1.73e-06	47.53	0.99	2.86e-05	35.38	0.99
	Image 2	1.75e-06	47.51	0.99	2.90e-05	35.30	1
Sample 3((sampling frequency =48000 Hz)	Image 1	4.43e-07	58.77	0.99	2.45e-05	41.34	1
	Image 2	4.48e-07	58.73	0.99	2.48e-05	41.29	1
Sample4 ((sampling frequency =44100 Hz)	Image 1	1.63e-04	38.36	0.99	1.35e-04	38.42	1
	Image 2	1.63e-04	38.36	0.99	1.36e-04	38.38	0.99
Sample5 ((sampling frequency =44100 Hz)	Image 1	2.36e-05	46.26	0.99	1.13e-05	49.46	1
	Image 2	2.36e-05	46.26	0.99	1.13e-05	49.44	1

Sample6 ((sampling frequency =44100 Hz)	Image 1	1.09e-05	49.50	0.99	1.47e-05	48.21	1
	Image 2	1.09e-05	49.51	0.99	1.48e-05	48.18	0.99
Sample7((sampling frequency =44100 Hz)	Image 1	7.88e-06	48.61	0.97	3.02e-05	42.78	0.99
	Image 2	7.88e-06	48.62	0.95	3.05e-05	42.73	1
Sample8((sampling frequency=44100 Hz)	Image 1	2.46e-05	43.14	1	2.67e-05	42.79	1
	Image 2	2.48e-05	43.11	1	2.70e-05	42.7452	1

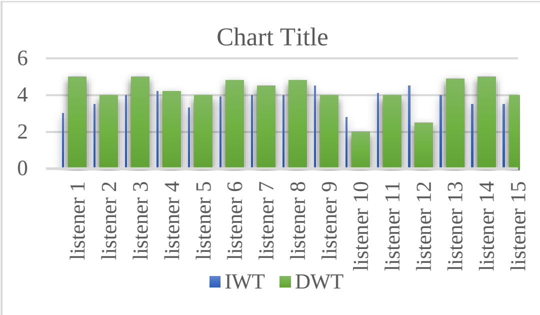

Figure 3. The results of subjective test with DWT and IWT

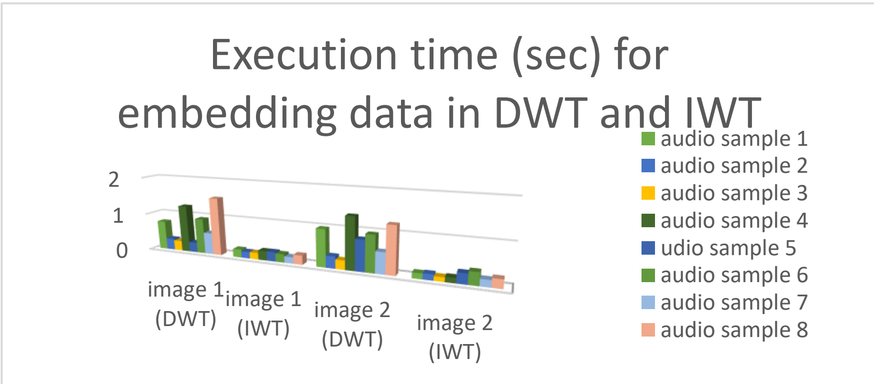

Figure 4. Embedding time for Different Audio Signals in DWT and IWT

Table 2. Tests of Robustness Against Attacks

Attack		DWT		IWT	
		PSNR (dB)	MSSIM	PSNR (dB)	MSSIM
AWGN	SNR=40	36.28	0.950	31.20	0.77
	SNR=30	35.90	0.873	31.08	0.60
	SNR=20	33.27	0.754	30.00	0.46
MP3 COMPRESSION	320kbps	36.03	0.924	36.12	0.81
	128kbps	31.79	0.831	29.99	0.69
	64 kbps	22.04	0.804	21.99	0.56
RESAMPLING	48,000 Hz	36.32	0.996	49.52	0.96
	96,000 Hz	36.32	0.996	49.52	0.96
	32,000 Hz	36.50	0.796	49.64	0.74
CROPPING	2 million samples	40.84	0.78	33.75	0.61
JITTERING	Jittering parameter=0.3	36.32	0.997	37.20 9	0.98

AMPLITUDE SCALING	Scale 0.8	36.33	1	49.59	1
	Scale 1.2	36.23	1	49.52	1
ECHOADDITION	decay rate10%	33.31	0.826	19.65	0.53

Table 3. Comparison between Hiding Capacity and mean PSNR of the proposed algorithm and some other related works

Method	**Hiding Capacity(bps)**	**Mean PSNR (dB)**
Proposed Method (DWT)	11016	52.21
Proposed Method (IWT)	11016	43.03
[14]	2996	30.55
[15]	489.56	36.86
[16]	2756	27
[19]	1032	38.17
[23]	1648.8	50.81
[38]	172.39	37.20

Table 4. Comparison between BER of the proposed algorithm and some other related works

Attack Type	**BER**						
	(DWT)	**(IWT)**	**[22]**	**[7]**	**[37]**	**[15]**	**[19]**
Gaussian Noise	0.23	0.45	0.13	0.53	0.33	0.24	0
Crop	0.21	0.33	0.16	-	--	0.04	-
Resample	0.01	0.02	0.45	0.03	0.32	--	0.01
MP3 Comp.	0.18	0.34	-	0.45	--	0.27	0.29

5. CONCLUSION

The main aim behind this paper is to provide a security for our confidential data using chaos-based steganography method for audio signals and wavelet transform. A new hiding technique was proposed using chaotic Henon map. This algorithm is simple, fast, and efficient and has high imperceptivity. The chaotic Henon map has been used in encrypting and embedding with wavelet transform which increases the security and imperceptivity because the sensitivity of chaotic maps to initial condition leads to generate different sequence with different initial value. Unlike the existing audio steganography methods, the proposed method can embed large number of bits into each audio channel, which increases embedding capacity dramatically. The performance of data hiding using different wavelet transforms in audio is also analyzed. The basic idea of embedding algorithm depends on comparing wavelet coefficients with a predetermined threshold value and selecting position of embedding with adaptive method using 2-D chaotic maps. It was found from experimental results that using DWT in audio signals helps in maintaining better quality and less MSE than in integer wavelet, so it's more suitable for some applications where high-fidelity cover sound is the most important thing like in audio watermarking for copyright protection purposes. While using IWT has many other advantages as it helps in full recovery of hidden data with good cover audio quality. It also consumes less embedding time than in DWT and with more robustness to attacks, so it has many uses in medical applications, defense organizations and intelligence agencies. The proposed algorithm has considerable advantages: first, the using of wavelet transform helps to increase the complexity of hiding technique and makes the embedded data more robust to the geometric attacks., Also using a distinctive encryption scheme via 2-D Hénon maps helps the algorithm in resisting many attacks. Besides, the efficient choice of embedding positions in the proposed scheme makes the algorithm have larger hiding capacity than many other methods and increases robustness. The submitted method also has an acceptable running time for embedding and extracting in both DWT and IWT, and achieves a good trade-off between imperceptibility, robustness, and payload.

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