Speech Steganography System Using Lifting Wavelet Transform

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Abstract
This paper presents a new lossless speech steganography approach based on Integer-to-Integer Lifting Wavelet Transform (Int2Int LWT) and Least Significant Bits (LSBs) substitution. In order to increase the security level a simple encryption with chaotic key has been proposed. The proposed system has a high sensitivity in choosing keys because a small change in CKG causes a new secret key for transmitting. Speech steganography algorithm that based on (Int2IntLWT) can satisfy full recovery for the embedded secret messages in the receiver side.

Keywords: Speech steganography, information hiding, Int2Int LWT, (LSB) technique, XOR operation.

1 Introduction
Discrete wavelet transform (DWT) is widely used for analyzing signals, steganography art, compression and noise reducing. DWT implements multi resolution analysis for the signals that have an adjustable location in each of space (time) and frequency domains. Because of large amount of calculations required, and there have been many research efforts to improve DWT and give a new fast algorithms that are used for performance DWT. The major challenges in the buildings devices for 1-D DWT and 2-D DWT is the speed processing and the number of multiples, where the memory issue which dominate the hardware cost and complexity of the architecture[1].

2 Lifting Wavelet Transform (LWT)
Llifting scheme is introduced to fast DWT, this easily achieved by the computer due to the great reduction in calculations. LWT scheme usually requires less mathematical operations compared with traditional approach convolution. LWT achievement does not require additional memory because of the in-place calculation features of the lifting. This is particularly suitable for the devices implementation of with a limited memory. LWT scheme submitted integer to integer transformation appropriate for lossless processing signal[2]. This approach is totally based on the spatial performance of the DWT. Basic concept of LWT is to exploit the correlation infrastructure that present in most real life signals to build a dispersed approximation. Correlation infrastructure is normally localization into space (time) and frequency; neighboring samples and frequencies are much more interconnected from that are in distant from. Figure (1) represents the forward transform scheme of three levels of three levels LWT with the three stages (split, production and update)[3, 4].

![Figure (1) forward transforms operation for three levels of LWT](image)

2.1 Split stage
This stage divides the set of signal into two frames;[4, 5]

1. The first frame consists of even index samples such as (λ₀₀, λ₀₂, λ₀₄, ..., λ₀₂k). We will call this frame coarser resolution signal or approximation.
   \[ \text{even} = \lambda_{0,2k} \ldots (1) \]

2. The second frame consists of odd index samples such as (λ₁, λ₃, λ₅, ..., λ₀₂k₊₁). We will call this frame as smoother resolution signal or detail.
   \[ \text{odd} = \lambda_{(0,2k+1)} \ldots (2) \]
Each signal in first and second frames consists of \( N \) samples from the original signal samples. In split stage any mathematical operations are not performed. Splitting signal into two parts is called lazy wavelets.

2.2 Prediction stage (Dual lifting)
Predicting the odd coefficient basis of the linear combination of even samples and odd samples, this predicted stage is also referred to as the dual lifting step; the lost data are simply incorporated in odd coefficient \([4, 6]\). Predict the odd samples by using linear interpolation predict the odd coefficient based on a linear combination of even samples and odd samples (replace \( \lambda_{0,2k+1} \) with \( \gamma_{-1,k} \)) as follow:

\[
\gamma_{-1,k} = \lambda_{0,2k+1} - P(\lambda_{-1,k}) \quad \ldots \quad (3)
\]

Odd value Predicted value

\[
P(\lambda_{-1,k}) = \frac{1}{2} (\lambda_{0,2k} + \lambda_{0,2k+2}) \quad \ldots \quad (4)
\]

Substitute’s equation (2) in (1) getting equation (3):

\[
\gamma_{-1,k} = \lambda_{0,2k+1} - \frac{1}{2} (\lambda_{0,2k} + \lambda_{0,2k+2}) \quad \ldots \quad (5)
\]

2.3 Update stage (Primal lifting)
Update the even samples based on a linear combination of difference samples obtained from the predict stage. We require constructing update operator \( U \) for this lifting process \([4, 6]\).

\[
\lambda_{-1,k} = \lambda_{0,2k} + U(\gamma_{-1,k}) \quad \ldots \quad \ldots \quad (6)
\]

\[
U(\gamma_{-1}) = \frac{1}{2} (\gamma_{-1,k-1} + \gamma_{-1,k}) \quad \ldots \quad \ldots \quad (7)
\]

\[
\lambda_{-1,k} = \lambda_{0,2k} + \frac{1}{2} (\gamma_{-1,k-1} + \gamma_{-1,k}) \quad \ldots \quad (8)
\]

3 Chaotic Key Generation (CKG)
An important feature of chaos systems is their ability to produce very complicated patterns of behavior. This quality has made them especially advantageous for the application in a wide variety of disciplines, such as biology, economics, engineering, signal processing, secure communications, and compression the information and data encryption. In such applications, chaotic systems are used to produce the chaos, simulation, help or control of the various processes and improving their performance or provide more convenient output \([7]\).

One of the simplest chaotic functions that have been studied recently for cryptography applications is the logistic map. The logistic map function is expressed as follows \([8]\):

\[
x_{n+1} = r \cdot x_n \cdot (1 - x_n) \quad \ldots \quad (9)
\]

Where \( x_n \) takes value in the interval \((0, 1)\), the parameter \( r \) is a positive constant taking values up to 4. Its value determines and explores the behavior of the logistic map.

4 The Proposed System Design
The basic design of the proposed steganography system consists of two phases embedding and extraction. In embedding Phase the sender side hide secret message inside a speech signal (male speaker, female speaker) each signal represented with bit resolution and frequency rate 16 bits/sample, 8000 Hz/sec respectively. The choice of speech signal should be suitable size and enough to embedding the message. The proposed system allows to choosing any speech cover and any secret message, there is no limitation for the cover size and message size. The proposed steganography system allows the user to hide any kind of electronic signals after converting the value of secret message data to binary digital system numbers. The user can hide a small message or large message under after comparing size cover with size message And make sure that the speech is enough to hide all message data within. The embedding phase contains two stages, they are as follows:

1. **Preprocessing stage**
   The preprocessing stage is depicted in figure (2). The figure illustrates the steps of preprocessing stage.
The inputs are secret message and CKG1 generated from algorithm (1).

Algorithm (1): Preprocessing stage

**Input:**
- Message // Secret message
- Cover // Cover sound file
- X // Number LSB replaced for each coefficient of LWT
- W // Length each frame
- CKG1 // First chaotic Key Generation

**Output:** Scrambled message, Capacity (CP), Length message (Len)

**Began:**

**Step 1:** Read secret message and calculate its size

\[ c1 \times c2 \times c3 \rightarrow \text{size(msg)} \]

**Step 2:** Read sound cover and finding its bits resolution (nbits) and rate samples \( F_s \) and its size

\[ [Y,F_s,\text{nbits}] \leftarrow \text{waivered(Cover)} // \text{Store sound cover in matrix Y} \]

\[ [c4, c5] \leftarrow \text{size(Y)} \]

**Step 3:** Calculate size secret message and size of cover file

\[ \text{Len} \leftarrow c1 \times c2 \times c3 \times 8 \quad L \leftarrow c4 \times c6 \times \text{nbits} \]

**Step 4:** Calculate total number of frames in sound cover \( (\text{Frm}_{\text{cov}}) \) and total frames that will be needed to hide message \( (\text{Frm}_{\text{msg}}) \) and residue set bits \( (Q1) \)

\[ \text{Frm}_{\text{cov}} \leftarrow \frac{L}{W} \]

\[ \text{Frm}_{\text{msg}} \leftarrow \text{fix}[\frac{\text{Len}}{X \times (\frac{W}{2} + W/4)}] \]

\[ Q \leftarrow \text{mod}[\frac{\text{Len}}{X \times (\frac{W}{2} + W/4)}] \]

**Step 5:** Comparing the cover size with message size

If \( \text{Frm}_{\text{msg}} > \text{Frm}_{\text{cov}} \)

Error \leftarrow Message Box (Cover is small to hide this message)

Break

End if

**Step 6:** Calculating capacity of cover and comparing the size cover with size message in bits

\[ \text{Capacity} \leftarrow \frac{\text{Len} \times 100}{L} \]

**Step 7:** Scrambling secret message data in random locations

\[ \text{msg2} \leftarrow \text{msg1}(\text{CKG1}) \]

**Step 8:** Save Scrambled message

\[ \text{msg22} \leftarrow \text{reshape(msg2,c1,c2,c3)} \]

**Step 9:** Converted \( \text{msg2} \) from decimal to binary with 8 bites to get data values

\[ \text{msg3} \leftarrow \text{decimal to binary(msg2)} \]

**Step 10:** Reshaping \( \text{msg3} \) from matrix 8 column to matrix 1 column and calculate its length

\[ \text{Len} \leftarrow \text{length(msg3)} \]
2. Embedding stage
The speech signal is framed to the number of frames, each frame contain 512 samples. Int2IntLWT has been used to convert speech signal to the frequency domain. First and second levels of Int2IntLWT were implemented for each frame where the results were four sub bands matrices. High frequency for sub-band1 and sub-band2 were used for embedding operation. The secret message data were scrambled by using first chaotic key generation (CKG1), and then the message was divided in a number of blocks bits. The block of the message was divided into two bits sets. The two sets were embedded within each frame of cover by replacing LSBs method for each coefficient of two high frequency sub-band. The embedding stage is depicted in figure (3).

![Figure (3) Block diagram for embedding stage](image)

Two chaotic keys (CKG1, CKG2) also were used to select the chaotic indexes of coefficients that their LSBs are replaced with message bits. XOR operation was performed between the block message and the chaotic numbers resulted from CKG1. The embedding stage algorithm is listed in algorithm (2):

**Algorithm (2): Embedding secret message**

**Input:**
- \( y \): Matrix of Cover sound file
- \( \text{msg3} \): Binary matrix of secret message
- \( X \): Number LSBs replaced for each coefficient of Int2IntLWT
- \( W \): Length each frame
- \( \text{Frmmsg} \): Number frames that needed to embed secret message
- \( U \): Index bit of the real number of CKG2 for the purpose of XOR operation
- CKG2, CKG3: Chaotic keys using to select coefficients positions.

**Output:**
- Stego: Stego speech signal

**Began:**
**Step1:** Beginning the hiding process within all frames of cover signal that are needed to hide message
- \( F1 \leftarrow 0 \)
- \( F2 \leftarrow 1 \)
**For i ← 1 to Frmmsg**
- \( \text{Frm} \leftarrow Y(F1 * W; F2 * W) \)
**Step2:** implemented 2 levels Int2IntLWT for each frame
- \([\text{low1}(1 : \frac{W}{2}), \text{high1}(1 : \frac{W}{2})]\) ← Int2Int LWT (Frm)
- \([\text{low2}(1 : \frac{W}{4}), \text{high2}(1 : \frac{W}{4})]\) ← Int2Int LWT (low1)
**Step3:** Cutting set of bit from real number of CKG2 and put it in new matrix
- \( V1 \leftarrow \text{gettingbits}(\text{CKG2}(1 : \frac{W}{2}), U) \)
- \( V2 \leftarrow V1(1 : \frac{W}{4}) \)
**Step4:** Implemented XOR operation and replace LSB of matrices coefficients high sub-band1
- \( a1 \leftarrow 0 \)
- \( a2 \leftarrow 1 \)
**For j ← 2 to X**
msg4(a1 + 1/2:a2 + 1/2) ← XOR(msg3(a1 + 1/2:a2 + 1/2), V1)
high11(CKG2(a1 + 1/2:a2 + 1/2)) ← replace(high1(CKG2(a1 + 1/2:a2 + 1/2)), j, msg4(a1 + 1/2:a2 + 1/2))
[V, j] ← msg4(a1 + 1/2:a2 + 1/2)
[a1 ← a1 + 1]
[a2 ← a2 + 1]
End for // j

Step5: Implemented XOR operation and replace LSB of matrices coefficients high sub-band2
b1 ← 0
b2 ← 1
For k ← 2 to X
msg4(0:1/4) ← XOR(msg3(0:1/4), V2)
high22(CKG3(b1 + 1/4:b2 + 1/4)) ← replace(high2(CKG3(b1 + 1/4:b2 + 1/4)), k, msg4(0:1/4))
[V, k] ← msg4(0:1/4)
b1 ← b1 + 1
b2 ← b2 + 1
End for // k

Step5: Implemented invers Int2IntLWT for two levels
high11 ← InversInt2IntLWT(low2, high22)
D1 ← InversInt2IntLWT(low1, high11)
Stego(F1 * 2:F2 * 2) ← D1

Step6: Ending hiding process for one frame
F1 ← F1 + 1
F2 ← F2 + 1
End for // i
End

Figure (4) shows the steps of extraction stage. It is implemented as the same way of embedding stage but in reverse form.

5 Experimental results
The proposed algorithm show efficiency of hiding in terms of security level, stego signal properties are unchanged as a result of hiding secret message. The experimental result points to that the stego file is undetectable and imperceptible by the HAS. Figure (5) shows waveform of stego speech file and it’s original.

Several testing measurements for the quality of stego signals are presented, and three types of secret messages have been embedded within speech signals:
- Color image message of size (512*512).
- Sound speech message of time (2 minutes) with bit resolution (8 bits/sample) and frequency (8000
Text message with length 15206 character.

Figures (6, 7 and 8) show the three type of message in three cases of original, encrypted and extracted message. Tables (1, 2 and 3) illustrate the objective quality measurements using four files of speech covers. The tables pointing that the quality measurements signal to noise ratio (SNR), signal to noise ratio segmental (SNRseg) and signal to noise ratio spectral (SNRspec) are decreasing with increasing the replaced LSBs numbers. The measure MSE increased with increasing the replaced LSBs numbers, because of increasing error in host signal. Finally the parameter runtime and correlation test (Rxy) are decreasing with increasing the replaced LSBs numbers.

![Figure (5) Waveform for the original and stego speech signal](image)

![Figure (6) Histogram of components (RGB) (a) original image (b) scrambled image(c) Extracted image](image)

![Figure (7) the waveform of secret speech message before and after embedding operation.](image)
Figure (8) the form of a text message (a) original text, (b) scrambled text and (c) extracted text

Table (1) objective measurements of hiding Baboon image (256*256) within speech file (4 minutes)

<table>
<thead>
<tr>
<th>cover name</th>
<th>LSB replaced</th>
<th>Run time sec</th>
<th>SNR db</th>
<th>SNRseg db</th>
<th>SNRspc db</th>
<th>MSE</th>
<th>( R_{xy} )</th>
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<td>36.327394</td>
<td>59.4319</td>
<td>57.0692</td>
<td>60.1042</td>
<td>2.5397e-09</td>
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<tr>
<td></td>
<td>4</td>
<td>24.230065</td>
<td>50.1294</td>
<td>45.1449</td>
<td>48.1344</td>
<td>2.1629e-08</td>
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<td>8</td>
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It is possible to hide more than one secret message inside the same speech cover under the condition of suitable size cover with the required number messages that hiding in it. It is possible to use speech signal as a channel to send any secret message between two persons for the purpose of secret communication with good security.

Table (2) objective measurements of hiding speech message (1 minute) within speech file (4 minutes)

<table>
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<tr>
<th>cover name</th>
<th>LSB replaced</th>
<th>Run time sec</th>
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<th>SNRseg db</th>
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<th>MSE</th>
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Table (3) objective measurements of hiding text1 (letters) within speech file (4 minutes)

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