Reversible Data Hiding for Medical Images in Cloud Computing Environments Based on Chaotic Hénon Map

Li-Chin Huang, Min-Shiang Hwang, and Lin-Yu Tseng

Abstract—Reversible data hiding techniques are capable of reconstructing the original cover image from stego-images. Recently, many researchers have focused on reversible data hiding to protect intellectual property rights. In this paper, we combine reversible data hiding with the chaotic Hénon map as an encryption technique to achieve an acceptable level of confidentiality in cloud computing environments. And, Haar digital wavelet transformation (HDWT) is also applied to convert an image from a spatial domain into a frequency domain. And then the decimal of coefficients and integer of high frequency band are modified for hiding secret bits. Finally, the modified coefficients are inversely transformed to stego-images.

Index Terms—Cloud computing environments, encryption, Haar digital wavelet transformation, Hénon map, reversible data embedding.

1. Introduction

With the development of Internet, cloud computing is going to be applied in large data centers. Considering security issues, it is important to manage the data and services in cloud computing environments safely. Techniques of reversible data hiding [1]-[3] are more efficient and cheaper than intrusion detection system (IDS) [4] solutions in image security. To improve security in clinical information such as medical history, radiology images, and personal states, many reversible schemes are getting more and more important via Internet and cloud computing environments. After the process of embedding secrets, data hiding schemes [5]-[7] which can restore the original image and extract secrets from stego-images without distortion are known as reversible schemes [8],[9]. The applications of reversible techniques have already been adopted by variety of high precision systems such as the health care system, artwork, and science.

In the transform domain schemes [1],[10], the cover image will be transformed to a set of coefficients modified for embedding secrets and then the modified coefficients perform the inverse transformation to construct stego-images. An integer discrete wavelet transformation (IDWT) reversible data hiding scheme was presented by Yang et al. [11]. Based on the compressed domain [12], reversible data hiding schemes have already developed by joint photographic experts group (JPEG) [13], vector quantization [14], and block truncation coding [15]. In spatial domains, there are three schemes: difference expansion (DE), histogram shifting, and cryptography base schemes [16]. DE techniques [17] are based on checking the redundancy between the two neighboring pixels to obtain a high capacity and low distortion data hiding. In 2009, Lou et al. [18] developed a reduction DE method to adjust the expansion difference and embed data into multiple layers in medical images to increase capacity. The histogram shifting techniques [19] are adopted to search the peak and zero points in the cover image histogram. Then, the bins between the peak and zero points will be shifted with one level to empty the peak point for hiding secrets. Cryptography-based reversible data hiding techniques [20] consider steganography as a cryptography. Therefore, a variety of secret communications messages can be embedded in stego-images.

Reversible data hiding techniques play a critical role in medical images. To provide some preliminary diagnosis for health care [21],[22] without the restoration of the original medical images, some data hiding schemes [19] embedded secrets into the region of non-interest (RONI) and less secret bits are embedded into the region of interest (ROI). In mobile healthcare applications, Rochan et al. [23] adopted an arithmetic coding and cryptography to embed data in medical images.

Haar digital wavelet transformation (HDWT) is an important technique to transform an image from a spatial domain to a frequency domain composed of different frequency bands. Since human eyes are less sensitive to change the image of the high-frequency coefficients, Chang et al. [1] adopted this property to conceal secret data.
With the advent of cloud computing environments, confidentiality of data becomes more and more important. In 2011, Abbasy et al. [24] presented a data hiding based on deoxyribonucleic acid (DNA) sequences to encrypt in cloud computing environments. Conventional cryptography utilizes a long bit strings encryption key. However, it is hard to be applied in high resolution images and huge amount of data. Patidar et al. [25] adopted an efficient substitution-diffusion image cipher using chaotic standard and logistic maps. In this paper, we apply the Hénon map [26] and chaotic-based cryptosystems to data hiding.

This paper is organized as follows. Section 2 demonstrates our method. Section 3 presents the experimental results. And conclusions are drawn in Section 4.

2. Proposed Method

HDWT-based reversible image hiding is applied to embed n bits secret messages for each block in this paper. In the application of compression and data hiding, two-dimensional discrete wavelet transform (DWT) is often adopted to transform the spatial domain to the frequency domain. We apply also HDWT to transform an image in the frequency domain for data hiding described as follows.

2.1 Embedding Secret Phase

Let a one-level HDWT decomposition transform a spatial domain cover image into a frequency domain cover image. Further, each coefficient of the image is divided two parts: integer and decimal. In Fig. 1 and Fig. 2, there are 4 types of decimal fractions: 0, 0.25, 0.5, and 0.75. In this paper, we adopt decimal 0 and 0.5 to embed secret.

At preliminary process, we select four decimal fractions \((D_1, D_2, D_3, D_4)\) where \(D_1, D_2, D_3, D_4 \in [0, 0.5]\). And four decimal fractions satisfy the relation \(R\) described as follow.

\[
R = (D_1 + D_2 + D_3 + D_4) \times 10 \mod 2 = 0. \tag{1}
\]

Let \((D_1, D_2, D_3, D_4)\) be a set of candidate decimal fractions. Candidate decimal fractions will be generated as \(((0, 0, 0, 0), (0, 0, 0.5, 0.5), (0, 0.5, 0.5, 0.5), (0, 0.5, 0.5, 0.5))\). Thus, decimal secret code provides 2 bits embedding shown in Table 1.

**Step 1:** Image partition with non-overlapping image blocks.

Assume \(H\) be a 16-bit depth gray scale medical HDWT images with size \(m \times n\) where \(m\) is the image width and \(n\) is the image height. We partition image \(H\) into a set of 4×4 blocks. Thus, many blocks will be generated in image \(H\).

**Step 2:** Embed secret bits to the decimal part.

1) Apply one-level HDWT operation.

We apply one-level HDWT to the original image demonstrated in Fig. 3. The cover image \(H\) is transformed to

\[
\begin{align*}
&H_1 = \begin{bmatrix}
582 & 585 & 0 & 0 \\
582 & 585 & 0 & 0 \\
1 & 0 & 0 & 0 \\
1 & 0 & 1 & 1 \\
\end{bmatrix}, \\
&H_2 = \begin{bmatrix}
-1.75 & 0 & 0.25 & 0 \\
-1.50 & -0.5 & -1.50 & 1 \\
0.75 & 0.50 & 0.25 & 0 \\
0.50 & 0.50 & 0.50 & 0 \\
\end{bmatrix}, \\
&H_3 = \begin{bmatrix}
0.75 & 0.75 & 0.5 & 0.5 \\
0.5 & 0.5 & 0.25 & 0 \\
0.50 & 0.50 & 0.50 & 0 \\
\end{bmatrix}.
\end{align*}
\]

**Fig. 1.** Results of two dimensional image transform, (a) original image (b) values of the ROI in the medical image, and (c) coefficients of the ROI after one-level HDWT operation.

**Fig. 2.** Division of HDWT images into three matrices: \(H_1\), \(H_2\), and \(H_3\).

**Fig. 3.** Flowcharts of the data embedding.

values with decimal shown in Fig. 1 (c).

2) Retrieve decimal codes according to secret bits.

For each secret bits, we retrieve decimal codes \((D_1, D_2, D_3, D_4)\) from decimal codes table shown in Table 1. For instance, we will get the decimal codes \((0, 0, 0.5, 0.5)\) if the embed bit is 01.
3) Alter decimal value in the HDWT images to embed data.

In our method, we partition the HDWT coefficients into three parts: integer, sign, and decimal. Then, integer matrix \( H_I \), sign matrix \( H_S \), and decimal matrix \( H_D \) will be generated, as shown in Fig. 4. We merge decimal codes with integer matrix \( H_I \) and sign matrix \( S_I \) described as follows.

- Select four sets of integers from integer matrix \( H_I \) by
  \[
  H_I(i, j) = \begin{cases} 
  H_I(i, j) + D_I(i, j) & i, j \in \{1, 2\} \\
  H_I(i, j) + 2D_I(i, j) & i, j \in \{3, 4\} \\
  H_I(i, j) + D_I(i, j) & i, j \in \{5, 6\} \\
  H_I(i, j) + 2D_I(i, j) & i, j \in \{7, 8\} 
  \end{cases}
  \]
  where \( i, j \in \{1, 2\} \). Therefore, each pixel of new HDWT images combines decimal codes of secret bits and \( H_I \).

Suppose the case \( i=1, j=2 \) will retrieve \( H_I = (585, 0, 0, 0) \), we combine \( H_I \) and the set of the decimal codes \( 0.5, 0, 0.5 \) shown in Fig. 4 and Table 1. New HDWT images are obtained as follows.

- Record HD matrix.

The HD matrix will be recorded in order to restore original image at the extraction stage shown in Fig. 4. We also utilize the arithmetic coding method to compress the HD matrix and embed them to cover images.

Step 3: Embed secret bits to integer part of high-frequency band.

The coefficients of high-frequency band which are presented in Fig. 4 (c), HH area, will influence the subtle texture after applying one-level HDWT decomposition. Further, most coefficients are utilized in the data compression method. In our scheme, the secret bits are embedded to the integer part.

### Table 1: Decimal codes with 2 bits coding

<table>
<thead>
<tr>
<th>Code</th>
<th>( D_0 )</th>
<th>( D_1 )</th>
<th>( D_2 )</th>
<th>( D_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>01</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>11</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

### Table 2: New HDWT images combines decimal codes and \( H_I \) with \( H_S \)

<table>
<thead>
<tr>
<th>( i, j )</th>
<th>( H_{new}(i, j) )</th>
<th>( H_{new}(i, 1) )</th>
<th>( H_{new}(i, 2) )</th>
<th>( H_{new}(i, 3) )</th>
<th>( H_{new}(i, 4) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2</td>
<td>585</td>
<td>582</td>
<td>585</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>1, 4</td>
<td>585</td>
<td>582</td>
<td>585</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>3, 2</td>
<td>585</td>
<td>582</td>
<td>585</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>3, 4</td>
<td>585</td>
<td>582</td>
<td>585</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

### Table 3: Invert transform of new HDWT images

<table>
<thead>
<tr>
<th>( i, j )</th>
<th>( H_{invert}(i, 1) )</th>
<th>( H_{invert}(i, 2) )</th>
<th>( H_{invert}(i, 3) )</th>
<th>( H_{invert}(i, 4) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2</td>
<td>585</td>
<td>582</td>
<td>585</td>
<td>0.5</td>
</tr>
<tr>
<td>1, 4</td>
<td>585</td>
<td>582</td>
<td>585</td>
<td>0.5</td>
</tr>
<tr>
<td>3, 2</td>
<td>585</td>
<td>582</td>
<td>585</td>
<td>0.5</td>
</tr>
<tr>
<td>3, 4</td>
<td>585</td>
<td>582</td>
<td>585</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Fig. 4. Two dimensional HDWT: (a) original image, (b) horizontal operation of (a) in 4 x 4 block image, (c) vertical operation of (b), and (d) invert two dimensional HDWT.
Step 4: Invert one-level HDWT.
Two dimensional Haar discrete wavelet invert high-frequency band will be chosen to $\theta^{(1)}$. Transformation is applied to HDWT images after the embedding process in decimal and high-frequency band described in Step 2, Step 3, Fig. 4 (d), and Table 3.

Step 5: Construct invert one-level HDWT images blocks.
In order to get the stego-images, the invert one-level HDWT images blocks are constructed.

Step 6: Process the underflow/overflow problem.
In this scheme, there are two kinds of medical image formats: signed bit and unsigned bit. We adjust image histograms to prevent overflow/underflow problems. At first, we compute intensity rate by the range of intensity and bit-depth of image. The range of intensity is the difference of maximum and minimum intensity in the whole image. Bit-depth is the number of bits utilized to indicate the gray of a single pixel. In the next step, the underflow rate (or overflow rate) is calculated by the value of underflow (or overflow) and bit-depth. The value of underflow (or overflow) is the minimum (or maximum) value in the whole image. Finally, the utilization rate is the sum of the absolute values of intensity rate and underflow (or overflow) rate. The formulas are demonstrated as follows.

\[
\text{Intensity rate} = \frac{\text{The range of intensity}}{2^{\text{bit-depth}}}
\]

\[
\text{Underflow/Overflow rate} = \frac{\text{Value of underflow/overflow}}{2^{\text{bit-depth}}}
\]

The utilization rate = |Intensity rate| + |Underflow/Overflow rate|.

On low underflow/overflow rates of high bit-depth medical images, unsigned bit images will produce underflow problems. And it is hard to find the underflow/overflow problem in the signed bit images.

Step 7: Generate chaotic image.
This step is to disarrange the stego-images for cloud computing environments. We adopt chaotic Hénon map to construct a cryptographic application scheme. At first, pseudo-random sequence is generated by Hénon map\(^{(26)}\), as shown in Fig. 5.

2.2 Data Extraction Phase
In order to extract secret bits, many parameters from embedding phase are needed such as decimal codes table, block size, and shift distance for underflow/overflow. The data extraction is able to extract secrets correctly and obtain the original image without any distortions. The details are described below. At the first step, chaotic images are downloaded from cloud computing environments and perform the invert chaotic Hénon map procedure to obtain stego-images. Then, the invert underflow/overflow process is performed by shifting back histogram. The whole image is partitioned into 4×4 non-overlaying block size like the data embedding process. The next step is one-level Haar discrete wavelet transformation for each block as shown in Fig. 4. Then, the digit of integer part in high-frequency band (HH) is extracted as secret bits. As the similar way in data embedding, secrets are extracted from the decimal and restore the decimal by the original decimal. At the final step, the block image performs the invert transform of the one-level HDWT to obtain the original image.

3. Experimental Results
Our scheme is performed at two kinds of high quality computer tomography (CT) and magnetic resonance imaging (MRI) medical images with digital imaging and communications in medicine (DICOM) from the National Cancer Imaging Archive\(^{(15)}\). This method is implemented by MATLAB and experimented on Notebook with 2.67 GHz processor and 4.0 GB RAM. In general, the quality of stego-images is measured by peak signal to noise ratio (PSNR) and mean square error (MSE). The definition of MSE is described as follows.

\[
\text{MSE} = \frac{1}{mn} \sum_{i=1}^{m} \sum_{j=1}^{n} (c_{i,j} - \bar{c}_{i,j})^2
\]

\[
\text{PSNR} = 10 \log_{10} \left( \frac{(\text{Image bit depth})^2}{\text{MSE}} \right)
\]

where an image bit depth may be set to 16 (or 12). The parameters of $m$ and $n$ are the width and height of the image. Both $c_{i,j}$ and $\bar{c}_{i,j}$ are intensities of the pixels located in cover and stego-images, respectively. We experiment on
CT and MRI medical images with 16-bit depth. The capacity and bpp (bit per pixel) will depend on PSNR. In Table 4 and Table 5, the embedded bits in integer and decimal part are 7 and 2, respectively. Because the $H_D$ matrix and decimal code tale are stored in the embedding phase, the overload of capacity will reduce capacity as shown in Table 4, Table 5, and Step 2. For example, slice 1.3.6.1.4.1.9328.50.14.1141.dcm can embed 294725 bits to cover image with overload of capacity 169703. In Table 5, there are underflow problems with distance_O about intensity value 126 to 128. In order to process underflow/overflow problems, the histogram shifts to rightward with distance_O.

### 4. Conclusions

In this paper, we present a reversible image data hiding method by modifying the decimal and integer of coefficients of HDWT, and a Hénon map is adopted to transform stego-images into chaotic image to achieve an acceptable level of confidentiality in cloud computing environments.

#### Table 4: Results for sign 16-bit grayscale medical image with secret decimal 4-bit

<table>
<thead>
<tr>
<th>Image name from the National Cancer Imaging Archive</th>
<th>Image size</th>
<th>bpp</th>
<th>PSNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3.6.1.4.1.9328.50.14.1141.dcm</td>
<td>458×512</td>
<td>0.5331520</td>
<td>62.638953</td>
</tr>
<tr>
<td>1.3.6.1.4.1.9328.50.14.1207.dcm</td>
<td>429×512</td>
<td>0.9661049</td>
<td>61.005768</td>
</tr>
<tr>
<td>1.3.6.1.4.1.9328.50.14.1210.dcm</td>
<td>429×512</td>
<td>0.4901615</td>
<td>62.896981</td>
</tr>
<tr>
<td>1.3.6.1.4.1.9328.50.14.1278.dcm</td>
<td>444×512</td>
<td>0.5036335</td>
<td>62.819597</td>
</tr>
<tr>
<td>1.3.6.1.4.1.9328.50.14.1280.dcm</td>
<td>444×512</td>
<td>0.9400118</td>
<td>61.07852</td>
</tr>
<tr>
<td>1.3.6.1.4.1.9328.50.14.157 .dcm</td>
<td>395×512</td>
<td>0.4500445</td>
<td>63.25194</td>
</tr>
<tr>
<td>1.3.6.1.4.1.9328.50.14.159 .dcm</td>
<td>395×512</td>
<td>0.7965635</td>
<td>61.620651</td>
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<tr>
<td>1.3.6.1.4.1.9328.50.14.1141.dcm</td>
<td>547×512</td>
<td>0.9639082</td>
<td>60.96576</td>
</tr>
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<td>1.3.6.1.4.1.9328.50.14.1911.dcm</td>
<td>547×512</td>
<td>0.5982633</td>
<td>62.252136</td>
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<tr>
<td>1.3.6.1.4.1.9328.50.14.2 .dcm</td>
<td>424×512</td>
<td>0.4213637</td>
<td>63.388013</td>
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<tr>
<td>1.3.6.1.4.1.9328.50.14.2084.dcm</td>
<td>424×512</td>
<td>0.7626170</td>
<td>61.768315</td>
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<tr>
<td>1.3.6.1.4.1.9328.50.14.2087.dcm</td>
<td>454×512</td>
<td>0.7943454</td>
<td>61.642575</td>
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<tr>
<td>1.3.6.1.4.1.9328.50.14.2143.dcm</td>
<td>454×512</td>
<td>0.4357620</td>
<td>63.346303</td>
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<td>1.3.6.1.4.1.9328.50.14.216 .dcm</td>
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<td>0.4483299</td>
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<tr>
<td>1.3.6.1.4.1.9328.50.14.219 .dcm</td>
<td>523×512</td>
<td>0.7757529</td>
<td>61.715509</td>
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</table>

#### Table 5: Results for sign 16-bit grayscale medical image

<table>
<thead>
<tr>
<th>Image name from the National Cancer Imaging Archive</th>
<th>Image size</th>
<th>bpp</th>
<th>PSNR</th>
<th>Overflow/ Underflow</th>
<th>Distance_O</th>
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</thead>
<tbody>
<tr>
<td>000000.dcm</td>
<td>256 × 256</td>
<td>0.48335</td>
<td>53.762265</td>
<td>Yes</td>
<td>126</td>
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<tr>
<td>000001.dcm</td>
<td></td>
<td>0.43300</td>
<td>53.73705</td>
<td>Yes</td>
<td>127</td>
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<tr>
<td>000002.dcm</td>
<td></td>
<td>0.40025</td>
<td>53.736887</td>
<td>Yes</td>
<td>128</td>
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<tr>
<td>000003.dcm</td>
<td></td>
<td>0.38234</td>
<td>53.785076</td>
<td>Yes</td>
<td>127</td>
</tr>
<tr>
<td>000004.dcm</td>
<td></td>
<td>0.37482</td>
<td>53.787826</td>
<td>Yes</td>
<td>127</td>
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<tr>
<td>000005.dcm</td>
<td></td>
<td>0.37950</td>
<td>53.756697</td>
<td>Yes</td>
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<tr>
<td>000006.dcm</td>
<td></td>
<td>0.37048</td>
<td>53.765285</td>
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<tr>
<td>000007.dcm</td>
<td></td>
<td>0.35817</td>
<td>53.775588</td>
<td>Yes</td>
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<tr>
<td>000008.dcm</td>
<td></td>
<td>0.34732</td>
<td>53.785244</td>
<td>Yes</td>
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<tr>
<td>000009.dcm</td>
<td></td>
<td>0.30473</td>
<td>53.818609</td>
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<td>128</td>
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<tr>
<td>000010.dcm</td>
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<td>0.36018</td>
<td>53.775254</td>
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<tr>
<td>000011.dcm</td>
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<td>0.37294</td>
<td>53.886029</td>
<td>Yes</td>
<td>126</td>
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<tr>
<td>000012.dcm</td>
<td></td>
<td>0.38667</td>
<td>53.935396</td>
<td>Yes</td>
<td>125</td>
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<tr>
<td>000013.dcm</td>
<td></td>
<td>0.38055</td>
<td>53.879266</td>
<td>Yes</td>
<td>126</td>
</tr>
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</table>
Generally, HDWT is a popular method to convert an image from spatial domain to frequency domain which is composed of different frequency bands as LL, LH, HL, and HH. The HH bands will be embedded with secret bits.

Chang et al.[1] adopted HH bands to embed secret bits in zeros of Integer part. In our scheme, we embed secret bits to both decimal part and integer part in HH bands. The result of capacity and the quality of image are demonstrated on Table 4 and Table 5. Although the overhead of the recording $H_2$ matrix will reduce capacity, the best capacity is still reach 0.96 bpp (bit per pixel) as shown in Table 4. In cloud computing environments, the most of important problem is data confidentiality. The Hénon map is a simple and efficiency method to disarrange stego-images.

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**References**


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