Optimal Grayscale Visual Cryptography using Error Diffusion to Secure Image Communication

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Abstract: With the emergence of networks, accessing the multimedia information over the network is increased. Hence securing such information is the most important issue in communications. The traditional cryptography techniques encrypt the image, which was more difficult, time-consuming and tedious process. Visual cryptography (VC) is a special type of secret sharing scheme which hides secret images in shares such that, when the shares are superimposed, a hidden secret image is revealed. It does not require complex computational method to decode the secret information. The scope of proposed Optimal Grayscale Visual Cryptography (OGVC) affords a friendly situation to deal with images. OGVC uses two techniques, namely Error Diffusion and inverse halftoning to covert grayscale to binary and vice versa. While sharing the share images, the chance of guessing for an intruder is considerably reducing. Thus it provides an extra layer of security to the images while transferring. The experimental result shows that the proposed OGVC scheme provides robustness, high quality and less computational complexity.

1. INTRODUCTION
Multimedia information sharing over the internet increases vastly. This implies the pressure on securing such information. While securing the information the factors such as size of the information, type of the data and computational complexity are to be considered. Generally images are bigger in size and quantity of data in it. Visual cryptography is the new method to encrypt the image data in a better way. Naor and Shamir [1] scheme describes the principles of Visual Secret Sharing (VSS), as shown in Table 1., to generate two share images by the combinations of black and white pixels according to the secret image. G. Ateniese et al [2] designed a novel technique to bring k out of n visual cryptography schemes but unable to get any secret information by stacking a less number of favorable shares. Wu et al [3] scheme is to share more than one secret image in two random shadows. Ito et al [4] minimized the size of share images, by invariant visual secret sharing scheme. The schemes [1-4] are applied to binary images, which applies to carry out the work of generating shares with higher efficiency.

<table>
<thead>
<tr>
<th>Images</th>
<th>White Pixel</th>
<th>Black Pixel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Share 1</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
<tr>
<td>Share 2</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
<tr>
<td>Share 1 x Share 2</td>
<td>[ ]</td>
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Wang et al[5] found that the configuration of binary values in the halftone images, which resulted better quality of reconstructed images. Self-verifying visual secret sharing method [6] verifies the reliability of the secret image by halftone logos. Wang et al [7] applied the technique of error diffusion[12] to perform the halftone operation on
secret images by deriving the error values and distributed to their adjacent pixels, which increases the reconstructed image clarity. Shyong Jian Shyu [8], proposed minimizing the pixel expansion for a \((k, n)\)-VCS into an integer linear program (ILP), to ensure that the constraints for GVCS can be satisfied. Hodeish [9], proposed a \((2,2)\) VCS where two adjacent pixels are taken together as the one time input for generation of shares. Fatahbeigy [10], explains a master share that is constructed according to the block classification results and then owner share is generated by comparing master share together with binary watermark.

2. MATERIALS AND METHODS

The phases of the proposed system are explained in this section. The proposed system consists of two phases; Firstly, Share construction phase in which two shares \(S_1\) and \(S_2\) are generated from the given input image and two cover images. Secondly, in Revealing phase, the two share images \(SH_1\) and \(SH_2\) are generated from the shares \(S_1\) and \(S_2\) respectively. A reconstructed image is revealed by stacking the two share images using XOR operation.

The share images look like natural images, individual share image does not reveal any information about the secret pixels. To create this confusion to the intruder, share images will show that one cover image hides the other cover image. The chances of guessing the presence of secret image will be significantly reduced. In the proposed system, Halftoning process is done by Floyd Steinberg error diffusion technique [12] to convert the gray scale image into halftone image \(HI\). The \(HI\) is given to the share construction phase to generate shares. In the revealing phase, reconstructed gray scale image \(GI'\) is obtained by inverse halftoning technique [11]. Block diagram of the proposed system is shown in Fig. 1.

![Block diagram of proposed scheme](image)

Figure 1: Block diagram of proposed scheme

3. SHARE CONSTRUCTION PHASE

*Step 1.* Consider an \(m \times n\) secret grayscale image \((GI)\) and two natural grayscale images as cover images (1); then

\[
GI_{i,j} \in \{0,1,2,3,\ldots,255\} \\
CI1_{i,j} \in \{0,1,2,3,\ldots,255\} \\
CI2_{i,j} \in \{0,1,2,3,\ldots,255\}
\]

(1)

where \(i\) and \(j\) are varying from 1 to \(m \times n\).

*Step 2.* Generate a halftone image \(HI\) by applying the Error Diffusion (ED) technique on \(GI\) (2);

\[
HI_{i,j} \in \{0,255\} \quad \leftarrow \quad ED(GI_{i,j})
\]

(2)
Step 3. Construct the shares $S_{1_{ij}} \in \{0, 1, 2, 3 ..., 255\}$ and $S_{2_{ij}} \in \{0, 1, 2, 3 ..., 255\}$ from HI by using SHARE_CONST algorithm; now, shares $S1$ and $S2$ will have the pixel expansion of 3 and also assures that the secret information can be completely restored after stacking from the shares. Shares are delivered to the receiver. Fig. 2 explains the share construction phase.

![Share Construction Phase](image)

**Figure 2: Share Construction Phase**

**Algorithm:**

For given matrices $C1^i$, $C2^i$ and HIof size $(m \times n)$.
Let shares $S^1$ and $S^2$ be empty as size of $m \times 3n$.

**procedure** SHARE_CONST (HI, CI$^1$, CI$^2$)

for $i = 1$ to $m$

for $j = 1$ to $n$

\[
PA_{ij} \leftarrow \text{AVG} (CI_{1_{ij}} + CI_{2_{ij}})
\]

if $HI_{ij} = 255$ then

\[
Wa \leftarrow [PA_{ij}, PA_{ij-1}, PA_{ij}, PA_{ij-1}]
\]

\[
Wb \leftarrow [PA_{ij-1}, PA_{ij}, PA_{ij-1}, PA_{ij}]
\]

\[
Pi \leftarrow \text{RANDOM}(Wa,Wb)
\]

end if

if $HI_{ij} = 0$ then

\[
Ba \leftarrow [PA_{ij}, PA_{ij-1}, PA_{ij-1}, PA_{ij}]
\]

\[
Bb \leftarrow [PA_{ij-1}, PA_{ij}, PA_{ij-1}, PA_{ij}]
\]

\[
Pi \leftarrow \text{RANDOM}(Ba,Bb)
\]

end if
end if

\[ S_{1}^{(i,3j-2)} \leftarrow C_{1ij} \]
\[ S_{1}^{(i,3j-1)} \leftarrow P_{i}(1) \]
\[ S_{1}^{(i,3j)} \leftarrow P_{i}(2) \]
\[ S_{2}^{(i,3j-2)} \leftarrow C_{2ij} \]
\[ S_{2}^{(i,3j-1)} \leftarrow P_{i}(3) \]
\[ S_{2}^{(i,3j)} \leftarrow P_{i}(4) \]

end for

end procedure

4. REVEALING PHASE

Step 1. Let the share images \( S_{1ij} \in \{0, 1, 2, 3 \ldots, 255\} \) and \( S_{2ij} \in \{0, 1, 2, 3 \ldots, 255\} \)

Step 2. The share images \( SH_{1ij} \in \{0, 1, 2, 3 \ldots, 255\} \) and \( SH_{2ij} \in \{0, 1, 2, 3 \ldots, 255\} \) can be derived from \( S_{1ij}, S_{2ij} \) using SHARE_REVEAL algorithm. Now, \( SH_{1} \) and \( SH_{2} \) have the pixel expansion of 2 as of GI.

Step 3. To generate the reconstructed Halftone Image \( HI' \), digitally stacking the share images \( SH_{1}, SH_{2} \) by XOR operation.

Step 4. The inverse halftoning technique is applied to \( HI' \) to generate the reconstructed Gray scale Image \( GI' \).

However, HI extracted during the revealing phase could be either an original image or a noise-like image depending on whether the received shared images are original or fake.

Let \( d \) is the difference between the GI and GI’, \( d=GI-GI' \). If the value of \( d \) is equal to zero, it implies that the GI is completely restored from \( HI' \) by inverse halftoning technique [11].

This method can be expanded to color images. First, divide the color image (RGB) into three individual images: Red(R), Green (G) and Blue(B). Then, the method is applied separately to each individual image, independently. Finally, the reconstructed secret color is generated by stacking the three reconstructed channels together.

Algorithm:

For given matrices \( S^{1}, S^{2} \) of size \((m \times n)\).

Let shares \( SH^{1} \) and \( SH^{2} \) be empty as size of \( m \times n/3 \).

procedure SHARE_REVEAL \((S^{1}, S^{2})\)

for \( i = 1 \) to \( m \) do

for \( j = 1 \) to \( n \) do

\[ R_{1} = S_{(i,3j+1)}^{1} - S_{(i,3j)}^{1} \]
\[ R_{2} = S_{(i,3j+1)}^{2} - S_{(i,3j)}^{2} \]

If \((R_{1}==1 \text{ and } R_{2}==1)\)

\[ SH_{i,(2j-1)}^{1} = 255 \]
\[ SH_{i,(2j)}^{1} = 0 \]
\[ SH_{i,(2j-1)}^{2} = 255 \]
else if (R1 == -1 and R2 == -1)
    \(SH^2_{i,(2j)} = 0\)
    \(SH^1_{i,(2j+1)} = 0\)
    \(SH^1_{i,(2j)} = 255\)
    \(SH^2_{i,(2j+1)} = 255\)
else if (R1 == -1 and R2 == 1)
    \(SH^1_{i,(2j+1)} = 0\)
    \(SH^1_{i,(2j)} = 255\)
    \(SH^2_{i,(2j+1)} = 0\)
    \(SH^2_{i,(2j)} = 255\)
else if (R1 == 1 and R2 == -1)
    \(SH^1_{i,(2j+1)} = 255\)
    \(SH^1_{i,(2j)} = 0\)
    \(SH^2_{i,(2j+1)} = 0\)
    \(SH^2_{i,(2j)} = 255\)
else if (R1 == 1 and R2 == 1)
    \(SH^1_{i,(2j+1)} = 0\)
    \(SH^1_{i,(2j)} = 255\)
    \(SH^2_{i,(2j+1)} = 255\)
    \(SH^2_{i,(2j)} = 0\)
end for
end for
RI = BITXOR(SH^1, SH^2)
end procedure

EXPERIMENTAL RESULTS

Experimental results demonstrate on three objectives. First, robustness of the algorithm; secondly, construct the original secret image with high quality and lastly, less computational time. The proposed OGVC allows no limitation on the size of the secret images. The set of test images shown in Fig. 3 illustrates that OGVC can perform well on grayscale images. The set contains eight 512 × 512 grayscale images: Apple, Batman, BMW, Motorola, Number, SRM, Twitter and YouTube. The efficiency of the proposed method outlined in this paper is tested by coding and running the algorithm in MATLAB 7.10 Tool. The image quality measures [13] such as Peak Signal to Noise Ratio (PSNR), Mean Absolute Error (MAE) Structural Similarity Index (SSIM) and Normalized Correlation (NC) are evaluated between reconstructed images and original secret images using following equations;

**Peak Signal to Noise Ratio (PSNR):** It is the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. PSNR is expressed in terms of the logarithmic decibel is given by (3),

\[
PSNR = \log_2 \left( \frac{2^n - 1}{MSE} \right)
\]  

**Mean Absolute Error (MAE):** It is a capacity used to measure how nearby predictions are to the eventual consequences. The mean absolute error is given by (4),
Here, mean absolute error is an average of the absolute errors $e_i = |f_i - y_i|$, where $f_i$ is the prediction and $y_i$ the true value.

\[
MAE = \frac{1}{n} \sum_{i=1}^{n} |f_i - y_i| = \frac{1}{n} \sum_{i=1}^{n} |e_i| \tag{4}
\]

Structural Similarity Index (SSIM): It measures the similarity of two images, based on an initial uncompressed or distortion-free image (5).

\[
SSIM(x, y) = \frac{2m_1(P) \times m_2(P) + C_1}{m_1(P)^2 + m_2(P)^2 + C_1} \times \frac{2s_1(P) \times s_2(P) + C_2}{s_1(P)^2 + s_2(P)^2 + C_2} \tag{5}
\]

Where $m_1(P)$ and $m_2(P)$ are mean values, $s_1(P)$ and $s_2(P)$ are standard deviations of seq1 and seq2, $c(P)$ is the covariance between seq1 and seq2 computed over the same window, $C_1 = (K1*L)^2$: regularization constants, $C_2 = (K2*L)^2$, $K1$, $K2$: regularization parameters, $L = 255$ and the default window is a Gaussian window with standard deviation 1.5 along both the X and the Y axis.

Normalized Correlation (NC): It measures the similarity representation between the original image and decrypted image (6).

\[
NC = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} (I[i, j]I'[i, j])}{\sum_{i=1}^{M} \sum_{j=1}^{N} (I[i, j])^2} \tag{6}
\]

Where $I(i, j)$ is original image and $I'(i, j)$ is decrypted image, $M$ is height of image and $N$ is width of the image.
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Table 2
Statistical analysis

<table>
<thead>
<tr>
<th>Image</th>
<th>PSNR</th>
<th>MAE</th>
<th>SSIM</th>
<th>NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>+32.45</td>
<td>0.25</td>
<td>0.92</td>
<td>0.98</td>
</tr>
<tr>
<td>Batman</td>
<td>+29.84</td>
<td>0.41</td>
<td>0.87</td>
<td>0.97</td>
</tr>
<tr>
<td>BMW</td>
<td>+24.57</td>
<td>1.28</td>
<td>0.756</td>
<td>0.91</td>
</tr>
<tr>
<td>Motorola</td>
<td>+24.54</td>
<td>1.27</td>
<td>0.73</td>
<td>0.92</td>
</tr>
<tr>
<td>Number</td>
<td>+25.09</td>
<td>0.94</td>
<td>0.87</td>
<td>0.82</td>
</tr>
<tr>
<td>SRM</td>
<td>+23.88</td>
<td>1.40</td>
<td>0.79</td>
<td>0.84</td>
</tr>
<tr>
<td>Twitter</td>
<td>+30.92</td>
<td>0.34</td>
<td>0.89</td>
<td>0.98</td>
</tr>
<tr>
<td>YouTube</td>
<td>+27.90</td>
<td>0.61</td>
<td>0.83</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Fig. 4(a), 4(b), 4(c), 4(d), 4(e) and 4(f) shows secret image Number, cover images Lena and Baboon, Share1, Share2 and reconstructed secret image number. Share images are looking completely different from secret image; therefore, this method can show the robustness.

The graph representation of the various image quality measures shown in Fig. 5. The PSNR values of the reconstructed secret images and the original images range from 23.88 to 32.45 dB. From the obtained PSNR, MAE, SSIM and NC values [13], the quality of the reconstructed grayscale image is maintained as original secret image.
The Table 3 shows the time taken to execute the algorithm on different images and the result shows that the method is less computational and efficient.

**CONCLUSION**

The Proposed OGVC, which uses the error diffusion. The use of error diffusion technique improves the quality of encrypted image and decrypted image. The proposed method helps to generate high quality share images. An individual shares does not show the secret information. Future studies should therefore investigate on 3D visual secret sharing with higher visual quality of the reconstructed secret images.
References


