Reversible Steganographic Scheme with High Embedding Capacity using Dual Cover Images

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Abstract: The advances in Internet technology and digital image representation helped the user to easily exchange the secret message. On Internet the transmission of the secret message is conducted using digital images which created new needs, issues and opportunities to the researcher. The basic objective of secret message communication is to transmit a message securely by embedding it into a cover-image such that unintended observers are unable to detect it. The image steganographic schemes are used in secret message communication. In this paper, we have proposed reversible steganographic scheme for gray-scale images. This scheme uses dual cover images to hide secret image and generates the perceptually similar dual stegoimages. Further, to extract the secret image the knowledge of dual stegoimages and stego-key are necessary which improved the security of this scheme. The experimental results show that the scheme provides a higher embedding capacity and robustness with un-noticeable distortions in the stegoimages. The performance of the scheme is analyzed for various types of image processing attacks on stegoimage. The proposed scheme was found rigid to the image processing attacks.

1 INTRODUCTION

In many countries of the world the political dissent is not tolerable and illegal. Hence, to exchange the secret messages the dissident organization must exercise extreme caution (Nagaraj V. Dharwadkar, 2010). The dissidents always use the Internet to exchange secret messages and face the security threats (Zou et al., 2003). To conceal secret communications the dissidents may use *encryption* or *steganography* methods. Using encryption the dissidents will ensure the privacy of their communications. Unfortunately, the very important fact is that two people are exchanging encrypted messages indicates that they have something to conceal. An alternate solution to this problem is the use of steganography for secret communication(Lee and Chen, 2000a; Katzenbesser and Petitcolas, 2004; Artz, 2001). Steganography is the art of hidden writing. First documented example of steganography was found in the Histories of Herodotus, where the father of history relates several stories from the times of ancient Greece (Kahn, 1967). There are stories of secret messages written in invisible ink or hidden in letters such that the first character of each sentence is used to spell a secret message (Cox et al., 2008). In recent days, digital steganographic schemes are widely used by prisoners, spies, terrorists and soldiers. Most of the recent secret communications occurs electronically, where the digital multimedia representations techniques are used as the carrier for secret communication (W et al., 1996). The Internet is increasingly becoming the popular communication channel for secret communication. The image Steganographic schemes are widely used in the transmission of secret messages via the Internet to provide secured communication (Artz., 2001; Lee and Chen, 2000b).

In 2001, T. Sharp (Sharp, 2001) proposed one bit LSB *substitution* scheme. In this scheme the secret message is embedded into cover image by substituting the LSB of each pixel with encrypted secret bit stream. Only the authorised receiver will extract the secret bits by decrypting every LSB of pixel of the cover image using a *shared key*. The embedding capacity of this scheme is 1 bit/pixel. This scheme generates visually imperceptible stegoimage which can be statistically analyzed by unauthorised entity without knowledge of the shared key. The random LSB bit jumbling attack on stegoimage makes it difficult to extract the secret message. To address this prob-

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lem, A. Ker (Ker, 2005) proposed the LSB matching scheme, but this scheme is vulnerable to detection algorithms. In order to minimize the effect of detectability Rehab H. (Alwan et al., 2006) proposed a novel scheme of image embedding which detects the edge of the image using Sobel mask filters. On the LSB of each edge pixels, a gray level connectivity is applied using fuzzy logic and the ASCII code information is embedded into the edge pixels. The well known steganographic scheme is Least Significant Bit (LSB) substitution scheme. This scheme divides the secret message into n bit blocks and embeds each of these n bits by directly replacing the n LSBs of a pixel of the cover image (Wang et al., 2001; Thien and Lin, 2003). Using LSB substitution schemes, more number of secret bits can be hidden into cover image with low computational complexity (Chan and Chen, 2004; Nagaraj V. Dharwadkar, 2010). Based on the ability of the steganographic schemes to recover the cover images during extraction, the schemes are classified as reversible (Honsinger et al., 2001; Fridrich et al., 2002; Tian, 2003) and irreversible (Chan and Cheng, 2004; Mielikainen, 2006). The reversible steganographic schemes are able to recover the original cover image during extraction of the secret message; where as in the irreversible steganographic scheme the secret message is extracted from the stegoimages with no capability of recovering the cover image into its original state.

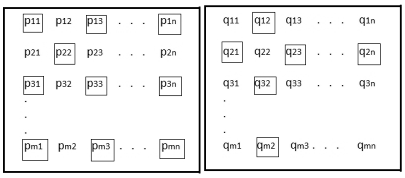
The embedding capacity, visual quality and security are three important issues concerned to a successful steganographic schemes (Wang et al., 2001). The crucial issue of the steganographic scheme is rigidity of scheme to different types of attacks. To address issues like embedding capacity, visual quality and security of stegoimage, Chin-Feng et.al.(Lee et al., 2009). In 2010, to address similar issues we have proposed a scheme (Nagaraj V.Dharwadkar, 2010) which is an improved reversible steganographic scheme based on dual stegoimages. In Chin-Feng et.al. scheme, a maximum of two secret bits are embedded into a pair of pixels which are originated from one original cover image and its copy. This scheme achieves an embedding capacity of 0.75 bpp. Where as the earlier proposed our scheme embeds the three secret bits into pair of pixels (Nagaraj V.Dharwadkar, 2010). This scheme achieves an embedding capacity of 1.21 bpp. This scheme is purely blind scheme and it will not use any auxiliary array in extraction algorithm.

After analysing these schemes it was found that the embedding capacity of these scheme can be possible to further increase using auxiliary array. To achieve the high embedding capacity, in this paper we propose an improved reversible steganographic scheme using two cover images. In this scheme, five bits of secret image are embedded into a pixel pair which are alternatively selected from the original cover image and its copy. We have used auxiliary array known as stego-key which increases the embedding capacity and security of the scheme. This scheme provides reversibility and high security with less distortion in stegoimage. We have analyzed the proposed scheme for its embedding capacity and its robustness to different types of image processing attacks.

The rest of the paper is organized as follows. The proposed steganographic scheme is explained in Section 2. Section 3 gives details of the experimental results. Section 4 gives the comparison of the proposed scheme with the Chin-Feng Lee $et.\ al$ and our own earlier proposed scheme. The effect of image processing attacks on dual stegoimages is discussed in Section 5. Section 6 concludes the paper.

2 PROPOSED SCHEME

In the gray-scale image the intensity value of pixel is represented by 8 bits value. The proposed scheme relies on binary stream of intensity of pixel to define space for embedding the secret bits. We consider two identical cover images P and Q each of size $m \times n$. In Figure 1, the cover images P and Q are represented as a matrices $(P_{i,j})_{1\leq i\leq m;1\leq j\leq n}$ and $(Q_{i,j})_{1\leq i\leq m;1\leq j\leq n}$. For embedding data we choose a pair of pixels $(P_{i,j}, Q_{i,j})$ each from P and Q. If $P_{i,j}$ is used for embedding secret, then $P_{i,j}$ is referred as the $Embed\_pixel$ and $Q_{i,j}$ is referred as the Ref_pixel. For the next pair $(P_{i+1,j}, Q_{i+1,j})$, $P_{i+1,j}$ is Ref_pixel and $Q_{i+1,j}$ is $Embed\_pixel$. Likewise, pair of pixels are chosen row-wise from each cover image P and Q. The proposed scheme embeds five bits into a pair of pixels by maintaining the negligible difference between the original pixel and modified pixel. To achieve negligible difference the modified pixel is scaled up or down. The scale factors which are used to preserve the difference narrow is encoded in a location-map which is known as stego-key. The hidden message is encoded in two places : the image and the location-map. The secret bits S_k are selected and embedded into $Embed\_pix_k$ for $0 \leq k \leq 4$ using look-up table as shown in Figure 2 to generate resultant *Res_pix*.Later, the difference $d = Embed\_pix - Res\_pix$ is computed. If the difference $|d| > 3$ and $d > 0$ and to make *Res_pix* equal to $Embed\_pix$ 4 is added *count* number of times and stored in *Res_pix*. Otherwise if $d < 0$ to make *Res_pix* equal to $Embed\_pix$ 4 is subtracted *count* number of times and stored into *Res_pix*. Store the *count* in to $Stego - key$ element such that the LSB of $Stego - key$ element represents addition or subtraction operation. The remaining bits represents the *count* value. The embedding algorithm is given in Algorithm : 1 and continued in Algorithm : 2.



(a) Cover image P.
(b) Cover image Q.

Figure 1: Selection of alternate pixels from dual cover images P and Q where $P = Q$.

In extraction algorithm consider two embedded images P' and Q' each of size $m \times n$. From the embedded image P' and Q' we choose a pair of pixels $(P'_{i,j}, Q'_{i,j})$ each from P' and Q'. If $P'_{i,j}$ is used for extracting secret, then $P'_{i,j}$ is assigned to the *Embed_pix* and $Q'_{i,j}$ is assigned to the *Ref_pixel*. For the next pair $(P'_{i+1,j}, Q'_{i+1,j})$, $P'_{i+1,j}$ is *Embed_pixel* and $Q'_{i+1,j}$ is *Ref_pixel*. Likewise, pair of pixels are chosen row-wise from each stegoimage image P' and Q'. This scheme extracts five bits from pair of pixels using the location-map known as the stego-key. The stego-key content is used to decide the scale factor by which the embedded pixel values to be increased or decreased. The altered embedded pixel and reference are used to recover the hidden data.The original cover pixel is recovered from the reference pixel. The extraction algorithm is given in Algorithm: 3 and 4.

2.1 Illustration with Example

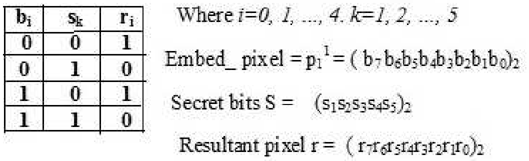
Let's explain the scheme with a simple example. Assume that we have two cover images I_1, I_2 of size 3×3, where $I_1 = I_2$ and secret image S of size 4×4

$$I_1 = I_2 = \begin{pmatrix} 20 & 5 & 9 \\ 1 & 7 & 15 \\ 37 & 2 & 52 \end{pmatrix}$$

$$S = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

The execution of embedding steps for cover image I_1, I_2 and secret image S will generate the following output: Select the pixel $p_1^1 = 20 = (00010100)_2$ of cover image I_1 and 00001 the first 5 bits of S. Using look-up table as given in Figure 2 we get $r = (00011110) = 30$ as modified pixel. The difference $|d| = |p_1^1 - r| = |20 - 30| = 10$ is calculated. As $|d| > 3$ $r = r - 4 = 26$ and set $c_0 = 1$. Iteratively we calculate $|d| = |p_1^1 - r| = |20 - 26| = 6$ until $|d| > 3$ therefore we get $r = 26 - 4 = 22$. Then, we calculate $|d| = |p_1^1 - r| = |20 - 22| = 2$, $|d| < 3$ therefore $q_1^1 = r = 22$. Thus, in this complete iterations as 4 is subtracted 2 times we get $(c_3, c_2, c_1) = (0, 1, 0)$ as the first element of stego-key. Consider next pixel $p_2^2 = 5 = (00000101)_2$ from I_2 and next 5 bits $(11010)_2$ of S. Using look-up table we get $r = (00000101)_2 = 5$, $|d| = |p_2^2 - r| = |5 - 5| = 0$ and $|d| < 3$ therefore $c0 = 0$ and (c_3, c_2, c_1)=(0,0,0) as the next element of stego-key. Then the pixel $p_3^1 = 9 = (00001001)_2$ is selected from I_1, next 5 secret bits $(11001)_2$ from S. We get $r = (00000110)_2 = 6$. Compute the difference $|d| = |p_3^1 - r| = |9 - 6| = 3$ therefore $c_0 = 0$ and $(c_3, c_2, c_1) = (0, 0, 0)$ will be the next element of stego-key. The remaining secret bit in S is 0 and pixel $p_4^2 = 1 = (00000001)_2$, using look-up table we get $r = (00000001)_2 = 1$ and $|d| = |p_4^2 - r| = |1 - 1| = 0$. As $|d| < 3$ therefore append 0 to stego-key. The resultant stegoimages are $I'_1 = \begin{pmatrix} 22 & 5 & 6 \\ 1 & 7 & 15 \\ 37 & 2 & 52 \end{pmatrix}$,

$I'_2 = \begin{pmatrix} 20 & 5 & 9 \\ 1 & 7 & 15 \\ 37 & 2 & 52 \end{pmatrix}$ and Stego-key=$(0101, 0000, 0000, 0)_2$



b_i	s_k	r_i
0	0	1
0	1	0
1	0	1
1	1	0

Where $i=0, 1, ..., 4$. $k=1, 2, ..., 5$

Embed_ pixel = $p_1{}^1 = (b_7 b_6 b_5 b_4 b_3 b_2 b_1 b_0)_2$

Secret bits S = $(s_1 s_2 s_3 s_4 s_5)_2$

Resultant pixel r = $(r_7 r_6 r_5 r_4 r_3 r_2 r_1 r_0)_2$

Figure 2: Look-up table used to map the cover image pixels into stegoimages.

The execution of extraction steps on dual stegoimages I'_1, I'_2 using Stego-key will generate the following output: $I'_1 = \begin{pmatrix} 22 & 5 & 6 \\ 1 & 7 & 15 \\ 37 & 2 & 52 \end{pmatrix}$,

$I'_2 = \begin{pmatrix} 20 & 5 & 9 \\ 1 & 7 & 15 \\ 37 & 2 & 52 \end{pmatrix}$ and Stego-key=$(0101, 0000, 0000, 0)_2$ Select the first pixel from cover image $p_1^1 = 22$ from I'_1 and first 4 bits of Stego-key $(c_3, c_2, c_1, c_0) = (0, 1, 0, 1)$. From the bits of first stego-key element we separate c_0 bit to get $(c_3, c_2, c_1) = (0, 1, 0) = 2$ & $c_0 = 1$. As $c_0 = 1$ hence we need to add 4 twice to p_1^1. Thus, we get $r' = 22 + 4 + 4 = 30 = (00011110)_2$.

Matching the 5 LSB bits of the reference pixel $p_1^2 = 20 = (00010100)_2$ and look-up table we get $(00001)_2$ as the first five secret bits. Select the next pixel $p_2^2 = 5 = (00000101)$ from I_2' and next 4 bits of Stego-key element $(c_3, c_2, c_1, c_0) = (0,0,0,0)$. We get $(c_3, c_2, c_1) = (0,0,0) = 0$ & $c_0 = 0$. Using reference pixel $p_2^1 = 5 = (00000101)_2$ and look-up table we get secret bits $(11010)_2$. Select the next pixel $p_3^1 = 6 = (00000110)_2$ from I_1' and 4 bits of Stego-key element. Using the reference pixel $p_3^2 = 9 = (00001001)_2$ we get secret bits $(11001)_2$. Select the last pixel $p_4^2 = 1 = (00000001)_2$ from I_2' and stego-key element value is $c_0 = 0$. using the reference pixel $p_4^1 = 1 = (00000001)_2$ and look-up table we get 0 as the secret bit.

Algorithm 1: Embedding Algorithm.

```
Input  : Grayscale image $I_1$ of size $m \times n$ and its
         copy $I_2$, where $I_1 = \{p_1^1, p_2^1, ..., p_{m\times n}^1\}$,
         $I_2 = \{p_1^2, p_2^2, ..., p_{m\times n}^2\}$, $I_1 = I_2$ and secret
         image $S$ of size $h \times w$, where
         $S = \{s_1, s_2, ..., s_{h\times w}\}$ and $s_k \in \{0,1\}$
Output: Dual stegoimages, $I_1' = \{q_1^1, q_2^1, ..., q_{m\times n}^1\}$
         and $I_2' = \{q_1^2, q_2^2, ..., q_{m\times n}^2\}$ such that $I_1' \neq I_2'$
         and stegokey of size $(4 \times h \times w)/5$, where
         $C = \{C_0, C_1, ..., C_{(4\times h\times w)/5} - 1\}$,
         $C_t = \{c_3, c_2, c_1, c_0\}$ and $c_k \in \{0,1\}$
1. Set i=1; k=1; $x = h \times w$; t=0; ;
2. Set $Embed\_pixel = p_i^1$; $Ref\_pixel = p_i^2$ ;
3. if $(x < 5)$ then goto step 8
   else Set x=x-5; Count=0; $r = Embed\_pixel$;
   $\{b_7, b_6, b_5, b_4, b_3, b_2, b_1, b_0\} = (Embed\_pixel)_2$.
   Secret bits $\{s_k, s_{k+1}, s_{k+2}, s_{k+3}, s_{k+4}\} \in S$ are embed
   into $r$ using the following steps ;
4. for $j \leftarrow 0$ to 4 do
       $Switch(b_j, s_{k+4-j})$
       $Case(0,0) : r_j = 1; break;$
       $Case(0,1) : r_j = 0; break;$
       $Case(1,0) : r_j = 1; break;$
       $Case(1,1) : r_j = 0; break;$
5. Compute $d = Ref\_pixel - r$
6. if $(|d| \leq 3)$ then $q_1^1 = r$ goto step 7
   if $(|d| > 3$ & $d > 0)$ then $r = r + 4$;
   $Count = Count + 1$; $flag = 1$; goto step 5
   if $(|d| > 3$ & $d < 0)$ then $r = r - 4$;
   $Count = Count + 1$; $flag = 0$; goto step 5
7. Indicate the modification of $r$ into stego-key
   $C_t = \{c_3, c_2, c_1, c_0\}$ using following steps.
   (a) if $(flag == 1)$ then $c_0 = 0$
   (b) if $(flag == 0)$ then $c_0 = 1$
   (c) The remaining bits $c_3, c_2, c_1$ are assigned using
       following cases: $Switch(Count)$
       $Case0 : (c_3, c_2, c_1) = (0,0,0)$ break;
       $Case1 : (c_3, c_2, c_1) = (0,0,1)$ break;
       $Case2 : (c_3, c_2, c_1) = (0,1,0)$ break;
       $Case3 : (c_3, c_2, c_1) = (0,1,1)$ break;
       $Case4 : (c_3, c_2, c_1) = (1,0,0)$ break;
       $Case5 : (c_3, c_2, c_1) = (1,0,1)$ break;
       $Case6 : (c_3, c_2, c_1) = (1,1,0)$ break;
       $Case7 : (c3, c2, c1) = (1,1,1)$ break;
8. Set $i = i + 1$; $k = k + 5$ $x = x - 5$; $t = t + 1$;
9. if $(i\%2 == 1)$ then goto step 3;
   else Set $Embed\_pixel = p_i^2$ and $Ref\_pixel = p_i^1$,
   Select next five secret bits $(s_k, s_{k+1}, s_{k+2}, s_{k+3}, s_{k+4})$
   from $S$ and repeat step 3 to step 7.
```

3 RESULTS AND DISCUSSION

For the experimental analysis, we implemented the proposed scheme using JAVA package. In the series of experiments, the perceptual quality of stegoimage is measured using Peak Signal to Noise (*PSNR*) and Mean Square Error (*MSE*) between the two stegoimages and cover image respectively. The experimental values of *PSNR* and *MSE* between stegoimages and cover image shows that both stegoimage are perceptually similar to cover image. In order to analyze the embedding capacity of the proposed scheme, we considered different secret images for embedding on different cover images. The experimental setup used in measuring perceptual quality and embedding capacity are explained in the following sections. For the experimental determination of the embedding capacity, we considered the Lena, Peppers, Baboon and Chessboard images of size 300 × 420, 225 × 225, 250 × 250 and 256 × 256 respectively as shown in Figure 3. Four different monochrome secret images of different sizes are used in the embedding algorithm. Figure 4 and Figure 5 show the dual stegoimages generated by proposed scheme. Figure 6 to Figure 9 show the original monochrome secret image and extracted secret images from Lena, Peppers, Baboon and Chessboard cover images.

3.1 Perceptual Quality of Stegoimages

Table 1 shows the perceptual quality measures between cover image and the stegoimages. For each cover image, the amount of noise added into the stegoimage is calculated by using *PSNR* and *MSE* between cover image and both stegoimages using following equation.

$$MSE = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} (C[i,j] - I[i,j])^2}{MN} \qquad (1)$$

Here, M and N are the height and width of image respectively. $C(i,j)$ is the $(i,j)^{th}$ pixel value of the

Algorithm 2: Embedding Algorithm continued.

```
10 if $(x < 5)$ then $Embed\_pixel = p_i^2$ convert it into
   binary stream $\{b_7, b_6, b_5, b_4, b_3, b_2, b_1, b_0\}$ and
   select $x$ secret bits from $S$ and Count1=0;
   a for $j \leftarrow 0$ to $x - 1$ do
       $Switch(b_j, s_{k+4-j})$
        $Case(0,0) : r_j = 1; break;$
       $Case(0,1) : r_j = 0; break;$
       $Case(1,0) : r_j = 1; break;$
       $Case(1,1) : r_j = 0; break;$
   b Compute $d' = Ref\_pixel - r$;
       if $(|d'| \leq 3)$ then $q_1^1 = r$ goto step c
       if $(|d'| > 3\ \&\ d' > 0)$ then $r = r + 4$;
       $Count1 = Count1 + 1$; $flag = 1$; goto step b
       if $(|d'| > 3\ \&\ d' < 0)$ then $r = r - 4$;
       $Count1 = Count1 + 1$; $flag = 0$; goto step b
   c Indicate the modification of $r$ into stegokey using
       following steps.
       if $(x == 1)$ then $C_t = \{c_0\}; c_0 = 0$;
       if $(x == 2)$ then $C_t = \{c_0\}; c_0 = 1$;
       if $(x == 3)\&(flag == 1)$ then
       $C_t = \{c_1, c_0\}; c_0 = 0; c_1 = 1$;
       if $(x == 3)\&(flag == 0)$ then
       $C_t = \{c_1, c_0\}; c_0 = 1; c_1 = 1$;
       if $(x == 4)\&(flag == 0)$ then $c_0 = 1$; if
       $(x == 4)\&(flag == 1)$ then $c_0 = 0$;
       $Switch(Count1)\ Case0 : (c_2, c_1) = (0,0)$
       $Case1 : (c2, c1) = (0,1)\ Case2 : (c2, c1) = (1,0)$
       $Case3 : (c2, c1) = (1,1)$
```

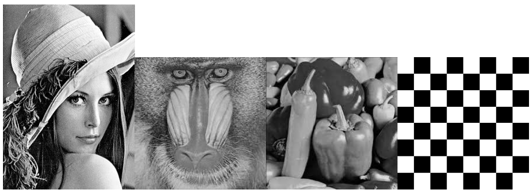

(a) Lena. (b) Baboon. (c) Peppers. (d) Chessboard.

Figure 3: Cover Images.

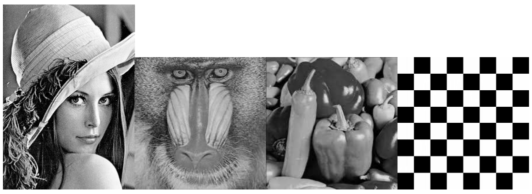

(a) Lena. (b) Baboon. (c) Peppers. (d) Chessboard.

Figure 4: Stegoimage1 generated by proposed scheme.

cover image and $I(i,j)$ is the $(i,j)^{th}$ pixel value of stegoimage.

$$PSNR = 10 \log \frac{(2^n - 1)^2}{MSE} \tag{2}$$

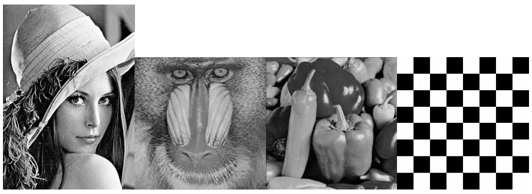
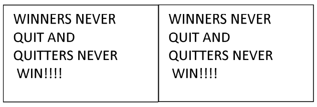

(a) Lena. (b) Baboon. (c) Peppers. (d) Chessboard.

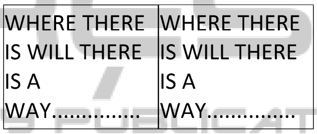
Figure 5: Stegoimage2 generated by proposed scheme.


WINNERS NEVER
QUIT AND
QUITTERS NEVER
WIN!!!!

WINNERS NEVER
QUIT AND
QUITTERS NEVER
WIN!!!!

(a) Original Secret image. (b) Extracted Secret image.

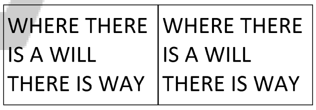
Figure 6: Secret image used in Lena cover image.


WHERE THERE
IS WILL THERE
IS A
WAY..............

WHERE THERE
IS WILL THERE
IS A
WAY..............

(a) Original Secret image. (b) Extracted Secret image.

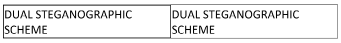
Figure 7: Secret image used in Baboon cover image.


WHERE THERE
IS A WILL
THERE IS WAY

WHERE THERE
IS A WILL
THERE IS WAY

(a) Original Secret image. (b) Extracted Secret image.

Figure 8: Secret image used in peppers cover image.


DUAL STEGANOGRAPHIC
SCHEME

DUAL STEGANOGRAPHIC
SCHEME

(a) Original Secret image. (b) Extracted Secret image.

Figure 9: Secret image used in chessboard cover image.

Where *n* is the number of bits used for color representation. From these experimental results it was found that the *PSNR* between the stegoimage and cover image is in the range of 44 to 46 *dB*, which is the nearest to the PSNR value of the perceptual images considering the Human Visual System.

The quality of extracted secret image is measured by taking four different cover images. The quality measures like Normalized Cross Correlation (*NC*) and Standard Correlation (*SC*) are calculated between extracted image and secret image using following equations.

$$SC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(I[i,j] - I')(J[i,j] - J')}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}(I[i,j] - I')}\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}(J[i,j] - J')}} \tag{3}$$

Table 1: The *PSNR* and *MSE* between the cover image and stegoimage.

Properties	**Lena**	**Baboon**	**Peppers**	**Chessboard**
Size of cover image	300×420	250×250	225×225	256×256
Size of secret image	1000×630	625×500	625×405	1280×256
MSE between cover & stegoimage1	1.65	1.74	1.74	2.24
PSNR between cover & stegoimage1 (dB)	45.93	45.72	45.70	44.62
MSE between cover & stegoimage2	1.67	1.75	1.73	2.24
PSNR between cover & stegoimage2 (dB)	45.88	45.69	45.74	44.62

Here, $I(i,j)$ is original secret image, $J(i,j)$ is extracted secret image, I' is the mean of original secret image and J' is mean of extracted secret image.

$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(I[i,j]I'[i,j])}{\sum_{i=1}^{M}\sum_{j=1}^{N}(I[i,j])^2} \tag{4}$$

Where $I(i,j)$ is original secret image and $I'(i,j)$ is extracted secret image, M is height of image and N is width of image. Table 2 shows the *NC* and *SC* between extracted and original secret images for different cover images. The experimental results show that the *NC* and *SC* for all images are equal to 1 which show that the extracted secret image is completely correlated to the original secret image.

3.2 Embedding Capacity

In steganography the most important issue is achieving higher embedding capacity. The embedding capacity of the cover image is the number of secret bits that can be embedded into a cover image (Nagaraj V.Dharwadkar, 2010). The embedding capacity is measured as bits per pixel (bpp). The embedding capacity of image of size $m \times n$ is calculated as

$$C = \frac{|T|}{mn} \tag{5}$$

where $|T|$ is the total number of secret bits embedded into cover image of size $m \times n$. Equation (5) is used when the scheme uses only one cover image. Since our proposed scheme uses dual cover images, each of size $m \times n$, we calculate the embedding capacity as

$$C = \frac{|T|}{2mn} \tag{6}$$

To estimate the embedding capacity of proposed scheme, consider two cover images C_1 and C_2 each of size $m \times n$ such that C_2 is copy of C_1. Assume hat all distinct consecutive pairs of pixels are *embeddable*. Under these assumptions we estimate the embedding capacity achieved by proposed scheme. There are $(mn)/2$ embeddable pairs of pixels in each cover image C_1 and C_2. So there are mn pairs of pixels among two cover images. The proposed scheme embeds 5 secret bits into pair of pixels. Thus, the total number of secret bits that can be embedded is $5mn$. According to (5), the embedding capacity is

$$C = \frac{5mn}{2mn} = \frac{5}{2} = 2.5 \tag{7}$$

From the experimental results we found all pairs of pixels are embeddable and proposed scheme achieves on average an embedding capacity of 2.5 bpp.

4 COMPARISON

We can compare our proposed scheme with T Sharp, Chin-Feng steganographic schemes and our own earlier proposed scheme (Nagaraj V.Dharwadkar, 2010). The steganographic schemes proposed by T. Sharp and Chin-Feng achieve an embedding capacity of 1 bpp and 0.75 bpp respectively. Where as our earlier proposed improved reversible steganographic scheme using dual images can able to achieve an embedding capacity of 1.12 bpp. The earlier proposed scheme is entirely different scheme which will not use any auxiliary array information in embedding and extraction. The earlier scheme is purely blind scheme. Where as to achieve high embedding capacity the current proposed scheme use an auxiliary array known as the stego-key. Thus, the secret message is encoded in both auxiliary array and stegoimage. Using stego-key we can able to achieve an embedding capacity of 2.5 bpp. Thus, compared to T. Sharp scheme, proposed scheme achieved 150 % increase in the embedding capacity and compared to Chin-Feng scheme proposed scheme achieves 233 % increase in embedding capacity with high perceptible stegoimages. Table 3 shows the comparisons of embedding capacity of proposed scheme with references.

5 EFFECT OF IMAGE PROCESSING ATTACKS

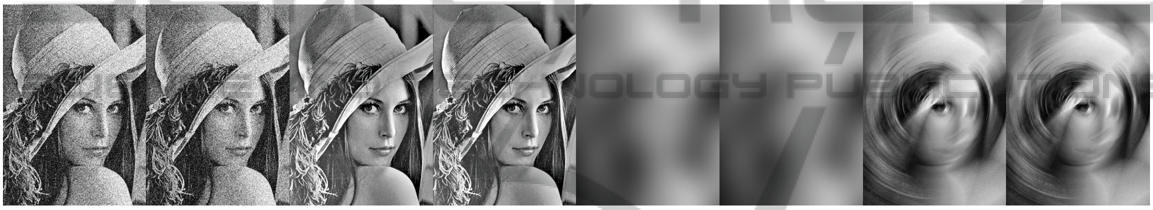
Secret image communication over insecure channel may lead to intentional or unintentional tampering of steganoimages. The alterations of steganoimage content is considered to be the attack on steganoimages.

Table 2: The *NC* and *SC* between the extracted and original secret images.

Properties	Lena	Baboon	Peppers	Chessboard
NC	1.00	1.00	1.00	1.00
SC	1.00	1.00	1.00	1.00

Table 3: Comparison of proposed scheme with Chin-Feng scheme (Lee et al., 2009) and our earlier scheme (Nagaraj V.Dharwadkar, 2010) in terms of embedding capacity (bpp).

	Lena	Peppers	Baboon	Chessboard /Barbara	Security
Proposed scheme	2.5	2.5	2.5	2.5	Dual stegoimages & stegokey
Our earlier scheme	1	1.12	1.1	1.20	Dual stegoimages
Chin-Feng scheme	0.75	0.75	0.749	0.749	Dual stegoimages



(a) Gaussian Noise density 30% on stegoimage1.

(b) Gaussian Noise density 30% on stegoimage2.

(c) Gaussian filter with 30 % stegoimage1.

(d) Gaussian filter with 30 % on stegoimage2.

(e) Gaussian Blurr radius of 30 pixels on stegoimage1.

(f) Gaussian Blurr radius of 30 pixels on stegoimage2.

(g) Radial Blurr radius of 30 pixels on stegoimage1.

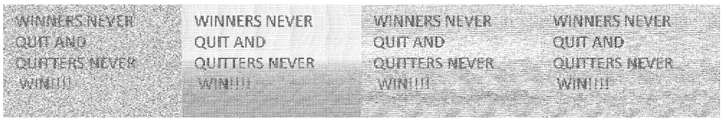
(h) Radial Blurr radius of 30 pixels on stegoimage2.

Figure 10: Effect of image processing attacks on Lena image.

In this section, we discuss the reasons for hostile and coincidental attack on a steganoimage. The hostile attack is an attempt to weaken, remove or alter the hidden image. Where as the coincidental attack can occur during common image processing and communication process. These attacks are not aimed at tampering the secret image. In hostile or malicious attack, the goal is to distort or add noise to the steganoimage in order to render the secret image unreadable (W et al., 1996). The attack is successful if the secret image cannot be extracted anymore. In coincidental attacks, while transmission of image via Internet the image is noise is added and filtered which leads to failure in the extraction of secret image. We discuss the effect of attacks on steganoimages. For experimental analysis we have considered the image processing attacks like filtration, adding noise and blurring. Figure 10 shows the effect of filtration, adding noise and blurring attacks on Lena image. Figure 11 shows the extracted secret image from attacked Lena stegoimage with the *NC* between the extracted and original secret image.

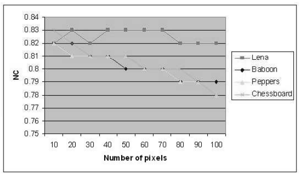
5.1 Effect of Gaussian Filter

The effect of filtering attacks on steganoimage is analyzed by applying Gaussian filter on steganoimage. The two dimensional Gaussian filter is applied on both stegoimage with standard deviation sigma (positive) varied from 10 to 100 %. The effect of Gaussian filter is analyzed by calculating *NC* between extracted and original secret image. Figure 12 shows the effect of Gaussian filter on extraction algorithm. The results show that the extraction of secret image from all images produce *NC* between extracted and secret original images in the range of 0.8 to 0.7 for Gaussian filtered stegoimage with 100 % standard deviation. From the results it was found that as the filtration factor increases, the normalized correlation between extracted and original secret image decreases. To design a robust steganography scheme against known group of filters, the secret image should be hidden into high energy components of the cover image for which filters change the least.



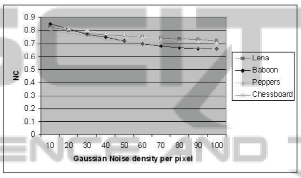
(a) Gaussian Noise with NC= 0.68. (b) Gaussian filter with NC= 0.70. (c) Gaussian Blurr with NC=0.68. (d) Radial Blurr with NC= 0.70.

Figure 11: Extracted secret image from attacked Lena image.



(a) NC.

Figure 12: Effect of Gaussian filters on steganoimages.

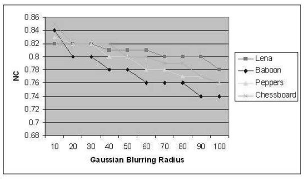


(a) NC.

Figure 13: Effect of Gaussian noise on steganoimages.

5.2 Effect of Gaussian Noise

To analyze the effect of adding noise to stegoiamge, a random signal with a given distribution (eg Gaussian, uniform, Poisson, Bernoulli) is added to the image. In certain applications the additive noise may originate from Digital-to Analog (D/A) and A/D converters, or as a consequence of transmission errors. However, an attacker may introduce perceptually shaped noise (image-dependent mask) with maximum unnoticeable power. This will typically force the increase of threshold at which the correlation of the detector operates. The Gaussian noise is added to the stegoimages with noise density d which affects approximately $d \times (size(I))$ pixels. The performance of extraction algorithm is analyzed by increasing noise density starting from 10 up to 100 pixels. The quality of extracted secret image is measured in terms of NC between original and extracted secret image. Figure 13 shows the effect of adding noise on both Stegoimage by varying the noise density from 10 to 100 pixels. In this experiment it is found that extraction of secret image from stegoimages produces NC between the extracted and the secret image is nearly equal to 0.80. These results show that the proposed scheme is robust against the addition of noise.



(a) NC.

Figure 14: Effect of Gaussian blurring on steganoimages.

5.3 Effect of Gaussian Blurring

To analyze the effect of blurring on stegoiamges, a Gaussian blurring is applied with varying blurring radius from 10 to 100 pixels. The disk radius is varied from 10 to 100 pixels. The effect of blurring on extraction algorithm is analyzed by calculating NC between secret image and extracted secret image. Figure 14 shows the effect of blurring on stegoimage in terms of NC between secret image and extracted secret image. Experimental results shows that extraction algorithm produces an image which is highly correlated to the secret image.

5.4 Effect of Radial Blurring

A Special type of circular averaging filter (pillbox filter) is applied on the both stegoimage to analyze the effect of blurring. This filter filters the stegoimage within the square matrix of size $2 \times (DiskRadius) + 1$. The disk radius is varied from 10 to 100 pixels. The effect of blurring on extraction algorithm is analyzed by calculating NC between secret image and extracted secret image. Figure 15 shows the effect of blurring on stegoimage in terms of NC between secret image and extracted secret image. Experimental results shows that even at $DiskRadius = 100$ pixels the extraction algorithm produces an image which is highly correlated to the secret image. Thus, the proposed scheme is robust against the blurring attack.

6 CONCLUSIONS

We have proposed a reversible dual cover image based steganographic scheme. The proposed scheme produ-

Algorithm 3: Extraction Algorithm.

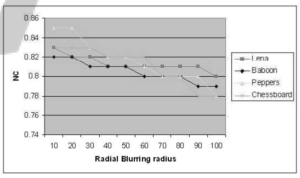
```
input  : Dual stegoimages, $I'_1 = \{q^1_1, q^1_2, ..., q^1_{m\times n}\}$
         and $I'_2 = \{q^2_1, q^2_2, ..., q^2_{m\times n}\}$ such that $I'_1 \neq I'_2$
         and stego-key of size $(4\times h\times w)/5$, where
         $C = \{C_0, C_1, ..., C_{(4\times h\times w)/5}\}$,
         $C_o = \{c_3, c_2, c_1, c_0\}$ and $c_k \in \{0,1\}$
output: Secret image $S$ of size $h\times w$ where
         $S = \{s_1, s_2, ..., s_{h\times w)}\}$ and two identical
         grayscale images $I_1$ and $I_2$ of size $m\times n$

1. Set i=1; l=0; k=1; $x = h\times w$ ;
2. if $(numbe\_of\_bits(stego - key) < 4)$ then
   goto step 7.
3. if $(i\%2 == 1)$ then $Embedd\_pexel = p^1_i$ and
   $Ref\_pixel = p^2_i$ else $Embedd\_pexel = p^2_i$ and
   $Ref\_pixel = p^1_i$
4. select two pixels $Ref\_pixel$ and $Embedd\_pexel$
   and four bits of key $\{c_k, c_{k+1}, c_{k+2}, c_{k+3}\}$.
   $Switch(c_k, c_{k+1}, c_{k+2})$
   $Case(0,0,0) : count = 0; break;$
   $Case(0,0,1) : count = 1; break;$
   $Case(0,1,0) : count = 2; break;$
   $Case(0,1,1) : count = 3; break;$
   $Case(1,0,0) : count = 4; break;$
   $Case(1,0,1) : count = 5; break;$
   $Case(1,1,0) : count = 6; break;$
   $Case(1,1,1) : count = 7; break;$
   if $(c_{k+3} == 1)$ then $p^1_i = p^1_i + 4\times count$. else
   $p^1_i = p^1_i - 4\times count$
5. Select $Ref\_pixel = (b^1_7, b^1_6, ..., b0^1)$ and
   $Embedd\_pexel = (b^2_7, b^2_6, ..., b0^2)$ respectively and
   apply the following operations.
6. for $j \leftarrow 0$ to $4$ do
       $Switch(b^1_j, b^2_j)$ $Case(0,0) : s_j = 1; break;$
       $Case(0,1) : s_j = 0; break;$
       $Case(1,0) : s_j = 1; break;$
       $Case(1,1) : s_j = 0; break;$
   Thus, the extracted secret bits are
   $(s_{j-4}, s_{j-3}, s_{j-2}, s_{j-1}, s_j)$ $x = x - 5$.
7. set $i = i+1; k = k+4$;
   Repeat step 3 to step 6 until $x < 4$.
8. if $(x == 1)$ then if $(c_k == 0)$ then $p = 0$;
   goto step 12 if $(x == 2)\&(c_k == 1)$ then $p = 0$;
   goto step 12
   if $(x == 3)$ then $p = 1$ goto step 9 else $p = 2$
```

ces perceptual good quality stegoimages with an embedding capacity of 2.5 bpp. The usage of dual stegaoimages and stego-key enhances the security of the secret image. Without complete knowledge of both stegoimages and stego-key it is difficult to determine the secret image. From the experimental results it was found that proposed scheme preserves the perceptual quality of stegoimages. The proposed scheme has the advantage of higher embedding capacity and good visual quality of stegoimages. The performance of the steganography scheme is analyzed by considering various types of image processing attacks and the scheme was found robust to various types of image processing attacks.

Algorithm 4: Extraction Algorithm continued.

```
9  Select two pixels $p^1_i$ and $p^2_i$ and bits of stegokey
   $(c_k, c_{k+1}, c_{k+2})$. $l = c_{k+2}$; $Switch(c_k, c_{k+1})$
   $Case(0,0) : count = 0; break;$
   $Case(0,1) : count = 1; break;$
   $Case(1,0) : count = 2; break;$
   $Case(1,1) : count = 3; break;$
10 select two pixels $p^1_i$ and $p^2_i$ and stegokey bits
   $(c_k, c_{k+1})$ if $(c_k == 1)$ then $count = 1; l = c_{k+1}$
   else $count = 0$;
 if $(l == 1)$ then $p^2_i = p^2_i + 4\times count$ else
   $p^2_i = p^2_i - 4\times count$
11 Select $p^1_i = (b^1_7, b^1_6, ..., b^1_0)$ and $p^2_i = (b^2_7, b^2_6, ..., b^2_0)$
   apply the following operations.
   for $j \leftarrow 0$ to $p$ do
       $Switch(b^1_j, b^2_j)$ $Case(0,0) : s_j = 1; break;$
       $Case(0,1) : s_j = 0; break;$
       $Case(1,0) : s_j = 1; break;$
       $Case(1,1) : s_j = 0; break;$
   The secret bits $\{s_0, s_1, ..., s_p\}$ are extracted.
12 set i=1;
13 if $(i\%2 == 1)$ then $p^1_i = p^2_i$; else $p^2_i = p^1_i$;
14 $i = i+1$; Repeat step 12 to step 13
   until $i == m\times n$
```

aaa



(a) NC.

Figure 15: Effect of radial blurring on steganoimages.

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