Analysis of Parity Assignment Steganography in Palette Images

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Abstract. In parity assignment-based steganography for palette images, all colors in a host image are divided into two subsets, and each pixel is used to carry one secret bit. This paper describes an analytic method against the parity assignment-based steganographic techniques. By finding the rule of color modifications, a steganalyst can attempt to recover the original histogram in a way that is a reverse of data embedding. Because of the abnormal colors in the original image, an excessive operation will cause some negative values in the recovered histogram. This provides a clue for revealing the presence of secret message and estimating the length of embedded bit sequence.

1 Introduction

The objective of steganography is to send secret message under cover of a carrier signal [1]. It is generally accepted that any steganographic technique must possess two important properties: good imperceptibility and sufficient data capacity. The first property ensures that the embedded message is undetectable, and the second means efficiency in hidden communication. Despite that steganographic techniques only alter the most insignificant components of the host media, they inevitably leave detectable traces so that successful analysis, i.e., revelation of the presence of embedded data [2], is often possible. Many steganalytic techniques have been developed [3].

Various types of multimedia data can be used as carriers in steganography, among which palette images are popular since they are widely available and convenient to transmit via the Internet. Palette image uses a few, generally no more than 256, colors to provide acceptable visual quality. Each pixel possesses an index value mapped to a displayed color according to a palette, which includes all colors in the image. In the steganographic techniques for palette images proposed by Fridrich [4, 5], all colors in the palette are divided into two subsets representing respectively the secret bits 0 and 1. For a pixel into which one secret bit is embedded, no modification is needed if the original color belongs to the subset corresponding to the secret bit, otherwise the closest color in another subset is chosen to replace the original color. In [4], assignment of colors to the subsets is done according to the parity of the sum of red, green, and blue components.

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In [5], a smarter optimal parity assignment (OPA) method is used as described below:

1. Calculate the Euclidean distances between all pairs of colors $d_{ij} = |c_i - c_j|$, and arrange them in an ascending order to produce a sequence of distances, $\{d\}$. Set $C = \emptyset$. Iteratively repeat the next step until C contains all colors.
2. Orderly choose the distance d_{kl} from $\{d\}$ such that either $c_k \notin C$ or $c_l \notin C$. No such d_{kl} can be found if C already contains all colors. If neither c_k nor c_l belongs to C, pseudo-randomly assign c_k and c_l to the two different subsets according to a key. In case $c_k \notin C$ and $c_l \in C$, assign c_k into the subset that does not contain c_l. Update $C = C \cup \{c_k\} \cup \{c_l\}$.

In the OPA method, a color in the palette and its closest neighbor must belong to two different subsets [5]. Thus, the original color of any pixel is either kept unchanged or modified into its closest neighbor. The distortion introduced is therefore very small.

It is shown in this paper that both parity assignment steganographic techniques as mentioned in the above are not secure. A steganalyst can derive the rule of color modifications and try to recover the original histogram, and the negative value in recovered histogram provides a clue for revealing the presence of secret message and estimating the length of embedded bit sequence.

2 Steganalytic Method

Let us first study the effect of data embedding on a palette image. Denote colors in the image as $c_1, c_2, \ldots, c_N$, and divide them into two subsets using a parity assignment method. In OPA, a color and its closest neighbor must belong to two different subsets. But this cannot be guaranteed by using the method described in [4]. Figure 1 sketches a case of parity assignment when the palette contains 6 colors, in which the white and gray circles are used to represent colors in the two different subsets. In this figure, there are 6 arrows from c_j to c_i if c_i is the closest neighbor of c_j among all colors in the subset that does not include c_j. This means that the color c_j may be changed into c_i in data embedding. An $N \times N$ matrix, $\mathbf{A}$, is also used to indicate the rule of color modifications, in which an element $A(i, j)$ equals 1 if an arrow from c_j to c_i exists. Otherwise $A(i, j) = 0$. Clearly, there is only one element having a value 1 in each column, and the other $N-1$ elements are all 0. In the case of Figure 1,

$$\mathbf{A} = \begin{bmatrix} 0\,0\,0\,0\,0\,0 \\ 1\,0\,1\,0\,0\,0 \\ 0\,1\,0\,1\,0\,0 \\ 0\,0\,0\,0\,1\,0 \\ 0\,0\,0\,0\,0\,1 \\ 0\,0\,0\,0\,0\,0 \end{bmatrix} \tag{1}$$

Denote the numbers of color occurrences of the original image as $h_1, h_2, \ldots, h_N$, and those of the stego-image as $h'_1, h'_2, \ldots, h'_N$. Let α be the ratio between the number of embedded bits and the total pixel number of the cover image . Since the rate of color changes due to data embedding is approximately $\alpha/2$, h_ns and h'_ns are related by a matrix $\mathbf{T}(\alpha)$:

$$\begin{bmatrix} h'_1 \\ h'_2 \\ \vdots \\ h'_N \end{bmatrix} \approx \mathbf{T}(\alpha) \begin{bmatrix} h_1 \\ h_2 \\ \vdots \\ h_N \end{bmatrix} \tag{2}$$

where

$$\mathbf{T}(\alpha) = \mathbf{A} \cdot \alpha/2 + \mathbf{I} \cdot (1 - \alpha/2) \tag{3}$$

$\mathbf{I}$ is an identity matrix.

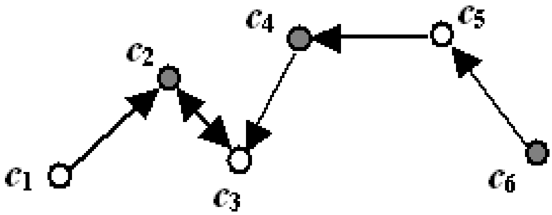

Fig. 1. A case of parity assignment when the palette contains 6 colors

If a steganalyst knows the parity assignment scheme used for data embedding, he can always derive the matrix $\mathbf{A}$. When the OPA method is used, although the steganalyst cannot find the particular division of two subsets due to the pseudo-random assignment in Step 2, he does know that a color may only be modified into its closest neighboring color in the embedding and the pseudo-random mechanism does not affect $\mathbf{A}$. Therefore the analyst can always work out the matrix. If the color assignment is determined by the sum of red, green, and blue components [4], it is even easier to obtain the matrix $\mathbf{A}$ since the steganalyst can find the exact subset division.

If a color c_s in the palette satisfies the following two conditions simultaneously: 1) occurrence of c_s in original image is very rare, i.e., $h_s \approx 0$, and 2) sum of occurrences of all c_r satisfying $A(s, r) = 1$ is significantly greater than h_s, we call c_s an *abnormal color*, which will provide a clue for detecting the presence of hidden data. As a simple example, when the original histogram is given in Table 1 and the color assignment in Figure 1, the color c_4 is an abnormal color. After data hiding with an embedding rate $\alpha = 0.5$, the histogram of the stego-image is also listed in Table 1. In fact, the procedure of data embedding is to change c_j to c_i in many pixels when $A(i, j) = 1$. Define

$$\mathbf{H}''(t) = \begin{bmatrix} h''_1(t) \\ h''_2(t) \\ \vdots \\ h''_N(t) \end{bmatrix} = [\mathbf{T}(t)]^{-1} \begin{bmatrix} h'_1 \\ h'_2 \\ \vdots \\ h'_N \end{bmatrix} \tag{4}$$

so,

$$\mathbf{H}''(\alpha) = \begin{bmatrix} h''_1(\alpha) \\ h''_2(\alpha) \\ \vdots \\ h''_N(\alpha) \end{bmatrix} \approx \begin{bmatrix} h_1 \\ h_2 \\ \vdots \\ h_N \end{bmatrix} \tag{5}$$

Equation (5) indicates that $\mathbf{H}''(\alpha)$ is similar to the original histogram. It can be viewed as a procedure of changing c_i back to c_j when $A(i, j) = 1$. Thus, $h''_s(\alpha)$ approximately equals zero if c_s is an abnormal color. Considering $\mathbf{H}''(\alpha + \Delta t)$, where Δt is a small positive number, the value of $h''_s(\alpha+\Delta t)$ should be less than zero, since more pixels are subsequently departed from the abnormal color c_s. Figure 2 gives the value of $h''_4(t)$ as a function of t, which is derived from the stego-histogram in Table 1 and the matrix $\mathbf{A}$ in Equation (1). It is also shown that the curve of $h''_4(t)$ intersects the t-axis at $t = 0.53$, very close to the embedding rate 0.5.

Table 1. A sample of original and stego histograms

Colors c_i	c_1	c_2	c_3	c_4	c_5	c_6
Occurrence number h_i	52	186	467	9	742	144
Occurrence number h'_i	40	275	392	197	586	110

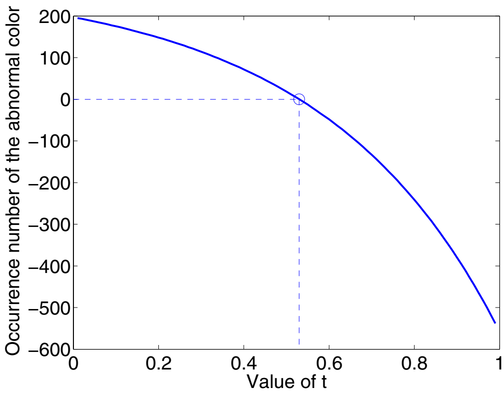

Fig. 2. Value of $h''_4(t)$ with different t

In natural palette images, there always exist some abnormal colors or semi-abnormal colors, where *semi-abnormal* means the two conditions in definition of *abnormal color* are roughly satisfied. Although a steganalyst does not know which color is abnormal or semi-abnormal since he does not have the original image, he can calculate the histogram of a suspicious image, obtain the matrix $\mathbf{A}$, and attempt to recover the original histogram in a manner that is the reversal of data embedding. Because of the presence of abnormal colors in the original image, an excessive operation will produce some negative values in the recovered histogram. This fact can be used for revealing the presence of secret message and estimating length of the embedded bit sequence. The detailed steganalytic method is as follows:

1. Get the histogram $[h'_1 \quad h'_2 \quad \ldots \quad h'_N]$ from a suspicious palette image.
2. Compute $\mathbf{H}''(t)$ with different t using Equation (4), and find the minimum value in $\mathbf{H}''(t)$,
$$y(t) = \min_{n=1,2,\ldots,N} [h''_n(t)] \tag{6}$$
3. Find the maximum value of t at which $y(t)$ changes from positive to negative as an estimate of embedding rate α_{E}. A small α_{E} implies a clear palette image, and a large α_{E} indicates the presence of hidden message.

While $y(\alpha)$ is always little greater than 0 as $\mathbf{H}''(\alpha)$ is similar to the original histogram, it is possible that $y(t) < 0$ when $t < \alpha$ for some special stego-images. So, in the steganalytic method, the last t at which $y(t)$ changes sign is taken as an estimate of embedding rate. Thus, from the stego-histogram in Table 1 and the matrix $\mathbf{A}$, one can obtain the estimated embedding rate = 0.53 (see Figure 3), which is close to the actual rate 0.50.

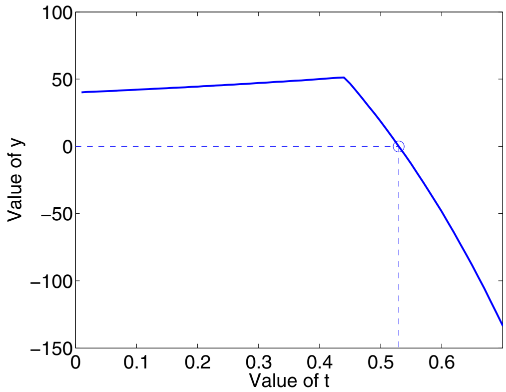

Fig. 3. Value of $y(t)$ with different t

3 Experiment and Discussion

Figure 4 is a stego-image with 256 colors and a size of 426×568, in which 80% pixels were used to carry secret bits embedded by OPA method, and its y-t curve is shown in Figure 5. The last intersection between the curve and the t-axis indicates $\alpha_{\mathrm{E}} = 0.82$, although one section of this curve on the left is below the t-axis.

In another experiment, a total of 80 palette images were used as covers, among which 40 were downloaded from the Internet and the others acquired using a digital camera in an uncompressed form and then converted to the gif

Fig. 4. Stego-image obtained by OPA steganography with $\alpha = 0.8$

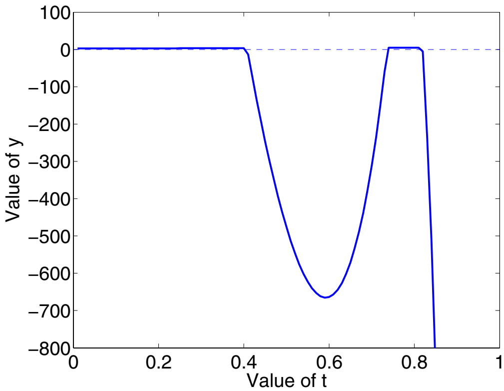

Fig. 5. y-t curve of the stego-image in Figure 4

format with a commercial tool. Both the OPA method [5] and the color assignment method based on the RGB sum [4] were performed to hide data with $\alpha = 0.5, 0.8$. Using the steganalytic technique described in the previous section, the estimated embedding rates of the original and stego images are illustrated in Figures 6 and 7. The two figures show that the more the embedding rate, the more accurate the estimation. Performance of analysis for the assignment steganography based on RGB sum is better than that for the OPA technique. For some images the estimates are considerably higher than the actual embedding rate. This is because that the colors in the covers do not exactly satisfy the abnormality conditions. In general, nonetheless, the proposed steganalytic method is effective.

Acknowledgments

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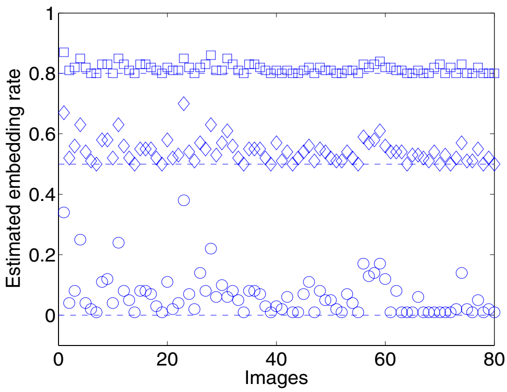

Fig. 6. Estimated embedding rates for OPA steganography (Circles: originals; Dimonds: stego-images with $\alpha = 0.5$; Squares: stego-images with $\alpha = 0.8$)

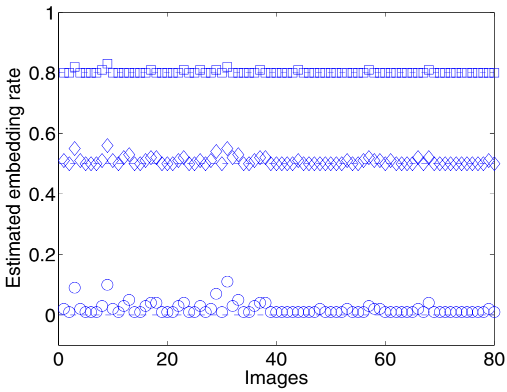

Fig. 7. Estimated embedding rates for the assignment steganography based on component sum (Circles: originals; Dimonds: stego-images with $\alpha = 0.5$; Squares: stego-images with $\alpha = 0.8$)

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