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Steganalysis of a PVD-based content adaptive image steganography

Xiaolong Li [a], Bin Li [b], Xiangyang Luo [c,d], Bin Yang [a,*], Ruihui Zhu [a]

[a] Institute of Computer Science and Technology, Peking University, Beijing 100871, China
[b] Shenzhen Key Lab of Advanced Communications and Information Processing, Shenzhen University, Shenzhen 518060, Guangdong, China
[c] Zhengzhou Information Science and Technology Institute, Zhengzhou 450002, China
[d] State Key Laboratory of Information Security, Institute of Information Engineering, Chinese Academy of Sciences, Beijing 100093, China

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ABSTRACT

Pixel-value-differencing (PVD) is a well-known technique for content adaptive steganography. By this technique, secret data are embedded into the differences of adjacent pixels. Recently, a new PVD-based steganographic method is proposed by Luo et al. Besides realizing adaptive embedding using PVD, the new method also exploits a pairwise modification mechanism to reduce the distortion. In this work, a targeted detector is devised to detect the new PVD-based steganography. We show that although content adaptive approach may enhance the stego-security, Luo et al.'s PVD-based scheme is not a good choice for realizing adaptive embedding since it contains a serious design flaw in data embedding procedure and this flaw can lead to possible attacks. More specifically, by counting the differences of adjacent pixels in both vertical and horizontal directions, a folded difference-histogram is generated and we show that Luo et al.'s PVD-based method may arise significant artifact to this histogram which can be exploited for reliable detection. Experimental results verify that Luo et al.'s PVD-based method can be detected by the proposed detector even at a low embedding rate of 0.05 bits per pixel.

1. Introduction

Steganalysis algorithms can be generally classified into two categories: targeted and universal [1–4]. Targeted algorithms aim to identify the existence of hidden data embedded by a specific steganographic method, whereas universal algorithms intend to detect a wide range of steganography. We consider digital image as cover data and study the technique of targeted steganalysis in this work.

It is widely accepted that taking the characteristics of natural image into account may enhance stego-security. For example, it is obvious that embedding modifications operated in rough regions of a natural image are less perceptible than that in flat regions. Besides, the slight modifications to rough regions cannot be easily perceived by analyzing usual image statistics since the embedding noise is covered by the inherent noise. Thus the content adaptive approach for steganography has the potential to provide a higher level of security. Based on this consideration, Wu et al. proposed the so-called pixel-value-differencing (PVD) steganography [5], in which the difference value of a pixel pair is considered as a smoothness measurement and more data bits will be embedded into the pair if its difference is relatively large. Thereafter, numerous PVD-based methods are proposed [6–9] and their security are also discussed [10–13].

Recently, a new PVD-based method is proposed by Luo et al. [14]. By incorporating PVD with the pairwise embedding algorithm of Mielikainen [15], this method can realize content adaptive embedding and meanwhile provide a better PSNR compared with some previously proposed PVD-based methods. The experimental results reported in [14] show that this method is secure in resisting state-of-the-art steganalyzers.

* Corresponding author. Tel.: +86 10 82529693; fax: +86 10 82529207.
E-mail addresses: lixiaolong@pku.edu.cn (X. Li), libin@szu.edu.cn (B. Li), xiangyangluo@126.com (X. Luo), yang_bin@pku.edu.cn, yangbin.pku@gmail.com (B. Yang), 8910182001@sina.com (R. Zhu).

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In this work, we propose a targeted detector to detect Luo et al.'s PVD-based method. We show that although content adaptive embedding is a way to enhance stego-security, Luo et al.'s PVD-based scheme is not a good choice for realizing adaptive embedding since it contains a serious design flaw in data embedding procedure and this flaw can lead to possible attacks. More specifically, by counting the differences of adjacent pixels in both vertical and horizontal directions, a folded difference-histogram is generated and we show that Luo et al.'s PVD-based method may arise significant artifact to this histogram which can be exploited for reliable detection. By our detector, Luo et al.'s PVD-based method can be detected even at a low embedding rate (secret data bits embedded per pixel, ER for short) of 0.05 bits per pixel (bpp).

The rest of this paper is organized as follows. First, the embedding procedure of Luo et al.'s method is described in Section 2. Then, to better present our idea, we consider to detect a simple case of Luo et al.'s method in Section 3.1. A theoretical analysis of our method for this simple case is also provided. Next, the proposed detector for the general case of Luo et al.'s method is introduced in Section 3.2. Finally, experimental results are reported and conclusions are drawn in Sections 4 and 5, respectively.

2. Embedding procedure of Luo et al.'s method

The data embedding procedure of Luo et al.'s method is described step by step as follows. Some remarks are also included in the description.

Step 1 (pixel pair partition): First, for a pre-selected integer $Bz \in \{1,4,8,12\}$, divide the cover image into non-overlapped blocks of $Bz \times Bz$ pixels. Then, for each pixel block, rotate it by a pseudo-random degree chosen from $\{0^\circ, 90^\circ, 180^\circ, 270^\circ\}$. Next, rearrange the resulting image as a row vector V by raster scanning. Finally, divide V into non-overlapped pairs consisting of every two consecutive pixels.

Step 2 (threshold selection): For every integer $t \ge 0$, define a set $EU(t) \subseteq V$ as

$$EU(t) = \{(x,y) \in V : |x-y| \ge t\}. \tag{1}$$

Then take a threshold T as the largest $t \in \{0,\dots,31\}$ satisfying $2|EU(t)| \ge M$, where $|\cdot|$ means the cardinal number of a set and M is the message length.

Step 3 (PVD-based embedding): Permute pixel pairs of $EU(T)$ in a pseudo-random order, and sequentially, embed 2 bits into each pair using Mielikainen's algorithm [15] until the message is embedded. We remark that Mielikainen's algorithm is a special case of the method proposed in [16]. Then, for a pixel pair $(x,y) \in EU(T)$ and 2 bits (b_1,b_2) to be embedded, the stego pixel pair (x',y') is in fact determined as follows:

$$(x',y') = \arg\min_{(u,v)\in S_1} |u-x| + |v-y| \tag{2}$$

where

$$S_1 = \{(u,v) : -1 \le u-x, v-y \le 1;\ u+2v \equiv b_1+2b_2 \pmod 4\}. \tag{3}$$

By this means, the stego pixel pair (x',y') can be given in a concise way

$$(x',y') = \begin{cases} (x,y) & \text{if } m=0 \\ (x+1,y) & \text{if } m=1 \\ (x,y\pm 1) & \text{if } m=2 \\ (x-1,y) & \text{if } m=3 \end{cases} \tag{4}$$

where

$$m = b_1 + 2b_2 - x - 2y \pmod 4. \tag{5}$$

Particularly, when $m=2$, there are two solutions $(x,y+1)$ and $(x,y-1)$, and one of them will be selected randomly.

Step 4 (adjustment): After Step 3, x' or y' may be out of the range of $[0,255]$ (i.e., overflow/underflow may occur) or the new difference $|x'-y'|$ may be less than T. In such cases, to avoid overflow/underflow and remain the set EU (T) unchanged, (x',y') is adjusted to (x'',y'')

$$(x'',y'') = \arg\min_{(u,v)\in S_2} |u-x| + |v-y| \tag{6}$$

where

$$S_2 = \{(u,v) : u \equiv x' \pmod 4;\ v \equiv y' \pmod 2;\ |u-v| \ge T;\ 0 \le u,v \le 255\}. \tag{7}$$

Here we give some remarks:

- Neglecting the rare cases of overflow/underflow, the solution to (6) for $T \ge 1$ can also be given in a concise way (see Table 1).
- When $T=0$, the adjustment step is unnecessary and the stego pixel pair is just (x',y') determined by Step 3. It is essentially degraded to Mielikainen's algorithm [15] in this case. So the adaptive embedding can only be realized when $T \ge 1$.

Step 5 (rotation restoration): Finally, rotate back the blocks and the stego image is obtained.

Take the Lena image for an example (see Fig. 1(a)), the positions of modified pixels due to the above embedding procedure are shown in Fig. 1(b), for an ER of 0.1 bpp with block size $Bz=1$. One can see that the modifications are located in rough regions, and thus content adaptive embedding is realized by this PVD-based algorithm.

Table 1
Solution (x'',y'') to (6) for $T \ge 1$.

	$\|x-y\|>T$	$x-y=T$	$x-y=-T$
$m=0$	(x,y)	(x,y)	(x,y)
$m=1$	$(x+1,y)$	$(x+1,y)$	$\begin{cases}(x+1,y\pm 2) & \text{if } T=1 \\ (x+1,y+2) & \text{if } T>1\end{cases}$
$m=2$	$(x,y\pm 1)$	$(x,y-1)$	$(x,y+1)$
$m=3$	$(x-1,y)$	$\begin{cases}(x-1,y\pm 2) & \text{if } T=1 \\ (x-1,y-2) & \text{if } T>1\end{cases}$	$(x-1,y)$