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Varied PVD + LSB evading detection programs to spatial domain in data embedding systems

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ABSTRACT

Image steganographic schemes based on the least-significant-bit (LSB) replacement method own the character of high capacity and good quality, but they are detected easily by some programs. Pixel-value differencing (PVD) approaches are one kind of methods to pass some program detections, but PVD approaches usually provide lower capacities and larger distortion. Accordingly, the combined method of PVD and LSB replacement was proposed to raise the capacity and the quality of PVD approaches over the past literatures. In this paper, not only we contribute a new exploration in spatial domain to benefiting both the capacity and the fidelity on the basis of varied LSB + PVD approaches, but also the risk of the RS-steganalysis detection program is evaded. Furthermore, proof works are conducted to proclaim the correctness of the general LSB + PVD method. Following up, the varied LSB + PVD approach is therefore applied to our scheme.

1. Introduction

Steganography means 'covert writing'. It embeds secret data into digital media such as images, texts, and audio. The purpose of steganography is to prevent malicious plunders or attacks from the existence of secret data hidden in the stego-image (Artz, 2001; Katzenbeisser and Petitcolas, 2000; Chang et al., 2002). The embedding capacity and the quality of the stego-image are two main goals for the techniques of steganography. The qualities of the stego-images are usually evaluated by the peak signal-to-noise ratio (PSNR).

One of well-known steganographic techniques is least-significant-bit (LSB) substitution, which replaces the least significant bits of the cover image with secret bits (Lee and Chen, 2000; Wang et al., 2000; Chang et al., 2003; Wang, 2005; Yang and Wang, 2006; Yang, 2008; Chan and Chen, 2004; Yang et al., 2008). LSB approaches usually receive a considerably high capacity and remain a good quality.

Because the simple LSB substitution method degrades the stego-image significantly when a large data are embedded, some methods have been proposed to improve the simple LSB substitution method. Wang et al. (2000) proposed a LSB substitution scheme based on the secret data transformation to improve the PSNR values of the stego-images and they proposed a genetic algorithm to find an approximate solution in their scheme. For searching an optimal solution exactly and efficiently, Chang et al. (2003) proposed a dynamic programming strategy and Yang and Wang (2006) proposed a matching approach. Besides, an inverted pattern LSB substitution approach was proposed by Yang (2008). To improve the quality of the stego-image more efficiently, most-significant-bits (MSBs) are modified in some of LSB approaches (Lee and Chen, 2000; Wang, 2005; Chan and Chen, 2004). Moreover, to consider the characteristic of the human visual system, the approaches with variable sizes of LSBs have been proposed (Lee and Chen, 2000; Wang, 2005; Yang et al., 2008).

Although LSB approaches are efficient for the capacity and image quality, the existence of embedding data can be easily detected by the bit-plane analysis method or some detection programs (Lee and Chen, 2000; Fridrich et al., 2001; Ker, 2005, 2007). Therefore, some hiding approaches were based on the concept of human visual system and were different to the LSB approach (Wu and Tsai, 2003; Chang and Tseng, 2004; Yang and Weng, 2006; Wu et al., 2005; Liu and Shih, 2008). Wu and Tsai (2003) proposed a "pixel-value differencing" steganographic method that uses the difference value between two pixels in a block to determine how many secret bits should be embedded. Chang and Tseng (2004) proposed a side match approach to embed secret data. The number of bits embedded into a pixel is decided by the difference between the pixel and the averaged value of its upper and left side pixels. We also proposed a multi-pixel differencing approach that used three dif-

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ference values in a four-pixel block to determine how many secret bits should be embedded (Yang and Weng, 2006). Those steganographic methods obeyed the principle that blocks in edge areas can tolerate larger changing than that in smooth areas.

Wu et al. (2005) proposed an LSB + PVD approach, which combined the PVD method with the LSB method, for the purpose of improving the capacity and the PSNR value of the PVD method. In their LSB + PVD method, the PVD approach is applied if the 2-pixel blocks have larger differencing values and the LSB approach is applied if the 2-pixel blocks have smaller differencing values. In this paper, we look into the strategies of combining PVD and LSB replacement methods and provide some views that were not mentioned in Wu et al.'s paper. In their paper, they emphasized that their method made the capacity and the PSNR value of the PVD method better than ever studies. However, we point out that Wu et al.'s LSB + PVD approach is too conformable to LSB approach. In our analysis, the blocks with smaller differencing values occupy the major part of a cover image. Therefore, most of their embedding operations belong to LSB approach. Also, according to their approach, smooth areas are embedded with more secret data than edged areas. This fact seems to be opposite to the concept of human visual system. We show that their results can be detected by the program of Fridrich et al. (2001), but Wu and Tasi's PVD and Liu and Shih's generalization of PVD approaches cannot be detected (Wu and Tsai, 2003; Liu and Shih, 2008).

The fact shown in our experimental results is that LSB replacement methods display both higher capacity and higher PSNR values than that of Wu et al.'s LSB + PVD approach. Does it mean that the LSB + PVD approach is not worth? We point out a concept to support the idea of the LSB + PVD approach. Because lots of detection methods (Lee and Chen, 2000; Fridrich et al., 2001; Ker, 2005, 2007) are developed to attack one certain kind of hiding approaches, it is a good idea to develop hiding approaches which harmoniously combine multiple hiding strategies. Combining both PVD and LSB replacement methods maybe confuse the attacks of some detection programs. In this paper, the sophisticated skills are provided to significantly promote Wu et al.'s LSB + PVD approach. Also, a proof about the correctness of the general LSB + PVD method is provided. Experimental results show that our proposed LSB + PVD approach has better PSNR values and can get rid of the detection of Fridrich et al.'s program.

The rest of the paper is organized as follows. Section 2 briefly describes Wu and Tsai's PVD (Wu and Tsai, 2003) and Wu et al.'s LSB + PVD approach (Wu et al., 2005). In Section 3, we provide experimental results to demonstrate the different views of Wu et al.'s approach. Our scheme is then presented in Section 4. Finally, the conclusions are provided in Section 5.

2. Review of literature

In this section, Wu and Tsai's PVD method (Wu and Tsai, 2003) and Wu et al.'s LSB + PVD method are introduced (Wu et al., 2005).

2.1. Wu and Tsai's pixel-value differencing

Wu and Tsai's PVD method uses pixel-value differencing of two pixels to embed secret data. The gray-valued host image is partitioned into non-overlapping blocks of two consecutive pixels by running through all the rows of the host image in a zigzag manner. The block difference value d_i is calculated by $|p_i - p_{i+1}|$, where p_i and p_{i+1} are two pixels in the block. All possible values of d_i (0–255) are considered and they are classified into a range table with n contiguous ranges, say R_k, where $k = 1, 2, 3, \ldots, n$. The width w_k of R_k is $u_k - l_k + 1$, where u_k is the upper bound of R_k and l_k is the lower bound of R_k. The number of embedded bits is determined by the

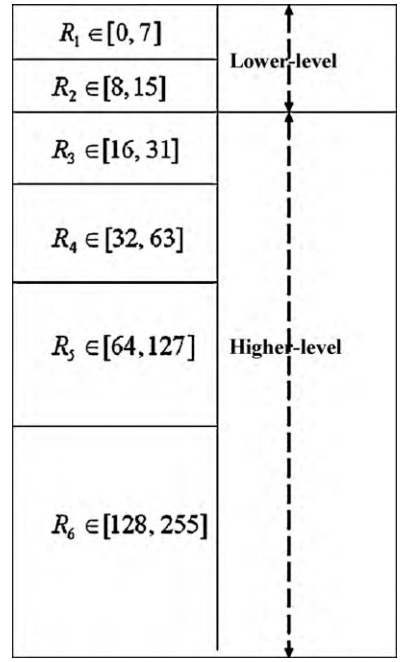

Fig. 1. A division of 'lower-level' and 'higher-level' (*Div* = 15).

width of R_i, which d_i falls into, and is equal to $\lfloor \log_2 w_i \rfloor$. Let b be the decimal value of embedded bits. Then, the embedding operation is to replace d_i with a new difference value d'_i, where $d'_i = l_i + b$. Finally, an inverse calculation of d'_i is performed to yield the new gray values of the two pixels in the block. For instance, assume $(p_i, p_{i+1}) = (110, 124)$, $R_2 = [8,15]$, and secret bits are $010_{(2)}$. So, we have $d_i = 14$, $R_i = R_2$, $w_i = 8$, $b = 010_{(2)} = 2_{(10)}$, and $d'_i = 10$. An inverse calculation of d'_i gets new gray values $(p'_i, p'_{i+1}) = (112, 122)$, so as to hide 3-bit secret data into the cover image. Note that it must avoid the condition that the new gray values of the two pixels fall outside the boundaries of the range [0, 255]. Therefore, the falling-off-boundary checking, which performs the inverse calculation of u_i to produce gray values (p^*_i, p^*_{i+1}) and checks whether these two values fall out the range [0, 255] or not, is executed. If one or two values of (p^*_i, p^*_{i+1}) fall outside the range [0, 255], the block must be abandoned for embedding data.

In the extracting phase, it is necessary to get the original range table. The secret data are extracted from the blocks of the stego-image in the same order as the embedding phase. The number of secret bits embedded in a two-pixel block is determined by the range R_i which the difference value between the two pixels belongs to. In addition, the value of the embedded data in the block is calculated by subtracting the lower bound of R_i from the difference value of the block. Therefore, the embedded bits in the block can be reconstructed. Continuing the previous instance, we have $(p'_i, p'_{i+1}) = (112, 122)$ and $d'_i = 10$. Because d'_i falls into R_2, there are $\lfloor \log_2 8 \rfloor = 3$ embedded bits and these bits can be extracted by $d'_i - l_i = 10 - 8 = 010_{(2)}$.

2.2. Wu et al.'s LSB + PVD approach

In Wu et al.'s approach, it embeds data into smooth areas by the LSB method and edged areas by the PVD method. The range table is divided by a value *Div* into the lower-level (i.e. smooth areas) and the higher-level (i.e. edge areas). For example, let *Div* = 15, the lower-level contains R_1 and R_2, and the higher-level contains R_3, R_4, R_5, and R_6 as shown in Fig. 1. The gray-valued host image is partitioned into non-overlapping blocks of two consecutive pixels by running through all rows of the host image in a zigzag manner.