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A magic cube based information hiding scheme of large payload

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ARTICLE INFO

Article history:
Available online 7 December 2015

Keywords:
Grayscale image
Information hiding
LSB
Magic cube

ABSTRACT

Hiding information on grayscale images has been drawing much attention in recent years. In pervious techniques, many schemes like Zhang and Wang's method or Sudoku method use magic matrix as a plane reference to modify the LSBs of cover images. To further improve the hiding capacity and visual quality, we propose the so-called magic cube based (MCB) information hiding scheme. MCB is an early attempt to use three-dimensional reference to achieve information hiding in grayscale image. Secret data are embedded in the cover pixel LSBs by utilizing spatial coordinates. MCB has a larger probability to modify fewer pixels in the whole image. The comparison experiments show that MCB achieves higher hiding capacity and better visual quality with impressive undetectability. Moreover, our method can easily avoid the overflow problem in the embedding process and the hiding capacity is flexible by operating on magic cubes with different scales.

1. Introduction

Information hiding on grayscale images (Chan and Cheng, 2004; Kim et al., 2010; Lan and Tewk, 2006; Lee et al., 2007; Tai et al., 2009) is a technique of concealing secret messages within cover images to obtain stego-images. It is difficult for humans to distinguish the difference between cover images and stego-images. As a result, image data hiding is an efficient way to hide secret messages (Chakraborty et al., 2013; Salehi and Balafar, 2014).

In image data hiding, the hiding capacity (the number of bits embedded into one cover pixel), visual quality (the quality of stego-image) and undetectability (the ability to against steganalysis) are the basic factors. In general, it is quite challenging to achieve high hiding capacity with good visual quality and undetectability.

In 1989, Turner proposed a famous image data hiding scheme called the least significant bit (LSB) replacement (Turner, 1989). This method embeds secret data into the LSBs of cover pixels. However, embedding data in the LSBs can be vulnerable to the steganalysis detectors.

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http://dx.doi.org/10.1016/j.jisa.2015.08.003

To make a better resistance for steganalysis, several plane references are applied in the information hiding schemes. In 2006, Zhang and Wang proposed a new exploiting modification direction (EMD) method using magic matrix as a reference to modify the LSBs of cover pixels (Zhang and Wang, 2006). In 2008, a novel steganography scheme using a 9×9-Sudoku was proposed by Chang et al. (2008). Compared to the EMD method, because the possible solutions of Sudoku are large, the security is better. Moreover, the hiding capacity of Sudoku scheme is 1.5 times higher than the EMD method. In 2009, an improved method inspired by the Sudoku method was proposed by Lin et al. (2009). In this method, a similar secret reference matrix (SRM) is constructed. Chang and Wu (2014) proposed a two-level EMD scheme. Its maximum embedding rate is 2.32 bpp, which is double that of the EMD method.

With the purpose of achieving higher hiding capacity and better visual quality and undetectability, we propose a new and simple model (MCB). MCB applies magic cube as a three-dimensional reference. Every three pixels are divided into a group to embed at least three secret bits. The cover pixels are modified according to the secret data and the magic cube. Experimental result shows that the proposed method has superior embedding rate with impressive visual quality. The main contributions of MCB are listed as follows:

- MCB is an early attempt to use magic cube as a three dimensional reference.
- The hiding capacity and the quality of stego-image outperform many existing methods. The hiding capacity can be 1 bpp, 2 bpp, 3 bpp and even higher. Moreover, the PSNR is more than 38 even when the hiding capacity is 3 bpp.
- The overflow problem in EMD can be easily avoided in MCB.
- The undetectability is quite impressive in MCB.

The rest of the paper is organized as follows. The review of previous methods is presented in Section 2. Section 3 describes the proposed scheme in details. In Section 4, we analyze the experimental results. Conclusions are finally drawn in Section 5.

2. Related work

In this section, since recent methods are mainly based on EMD or Sudoku, we will briefly introduce the EMD method and Sudoku scheme in subsections 2.1 and 2.2. Assume a cover image $X = \{x_i | 0 \le x_i \le 255, 0 \le i < (H \times W)\}$, where H and W represent the height and width of the cover image.

2.1. Zhang and Wang's method

The embedding process of the EMD method is summarized as follows: Firstly, the binary secret data S is partitioned into the k-sized segments. Secondly, each segment is converted into h secret digits in the base-$(2n+1)$ numeral system. k is computed by Equation (1):

$$k = \lfloor h \times \log_2(2n+1) \rfloor \tag{1}$$

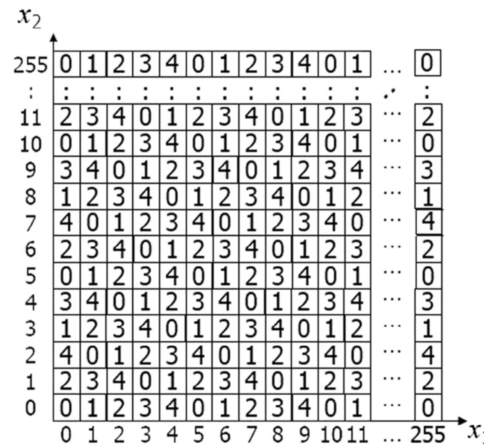

Fig. 1 – A simple demonstration when $n = 2$.

Thirdly, the cover image X is divided into a series of n-sized consecutive pixel groups. An extraction function f is defined to embed one secret digit β into a pixel group $(x_1, x_2, \ldots, x_n)$. Equation (2) is the extraction function.

$$\alpha = f(x_1, x_x, \ldots, x_n) = \sum_{i=1}^{n} (x \times i) \, mod(2n+1) \tag{2}$$

Fig. 1 is a simple demonstration for $n = 2$. Three rules based on the secret digit β and the values of α are shown as follows.

Step 1. If $\beta = \alpha$, then keep $(x_1, x_x, \ldots, x_n)$ unmodified.
Step 2. If $\beta \ne \alpha$ and $m \le n$, where $m = (\beta - \alpha) mod(2n+1)$, then increase the value of x_m by 1.
Step 3. If $\beta \ne \alpha$ and $m > n$, then decrease the value of x_{2n+1-m} by 1.

2.2. Sudoku method

In Sudoku method (Chang et al., 2008), a 9×9-Sudoku grid is expanded to a 256×256 reference matrix M. An example of M is showed in Fig. 2.

The original binary secret stream is converted into 9-base numeral stream B and $B = b_1, b_2, \ldots, b_n$, where n is the total number of converted secret digits $b_j \in [0,8]$, and $1 \le j \le n$. The cover pixels are divided into consecutive pixel pairs. For each pixel pair (x_i, x_{i+1}), where $0 \le i < H \times W$, it locates its value $M(x_i, x_{i+1}) = v$ on M with the row x_i and column x_{i+1}.

Assume a secret digit to embed is b_j. If $b_j = v$, then keep the pixel group (x_i, x_{i+1}) unchanged. Otherwise, generate three areas on M according to the located value v: the row (CE_H), the column (CE_V) and sub-block (CE_B). These three areas are also shown in Fig. 2. Find three elements $M(x_H, y_H), M(x_V, y_V)$ and $M(x_B, y_B)$ taken from CE_H, CE_V and CE_B, where $M(x_H, y_H) = M(x_v, y_H) = M(x_H, y_H) = b_j$.

Furthermore, the Manhattan distance between (x_i, x_{i+1}) and the three candidate elements $(M(x_H, y_H), M(x_V, y_V))$ and $(M(x_B, y_B))$ are computed. Assume (x'_i, x'_{i+1}), where $(x'_i, x'_{i+1}) \in (x_H, y_H), (x_V, y_V), (x_B, y_B)$, has the minimum Manhattan distance. Then the cover pixel group (x_i, x_{i+1}) is modified as (x'_i, x'_{i+1}).