Usage of analytic hierarchy process for steganographic inserts detection in images

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Abstract

This article presents the method of steganography detection, which is formed by replacing the least significant bit (LSB). Detection is performed by dividing the image into layers and making an analysis of zero-layer of adjacent bits for every bit. First-layer and second-layer are analyzed too. Hierarchies analysis method is used for making decision if current bit is changed. Weighting coefficients as part of the analytic hierarchy process are formed on the values of bits. Then a matrix of corrupted pixels is generated. Visualization of matrix with corrupted pixels allows to determine size, location and presence of the embedded message. Computer experiment was performed. Message was embedded in a bounded rectangular area of the image. This method demonstrated efficiency even at low filling container, less than 10%. Widespread statistical methods are unable to detect this steganographic insert. The location and size of the embedded message can be determined with an error which is not exceeding to five pixels. Keywords: steganography, steganalysis, LSB-method, algorithm for making decision, hierarchy analysis method.

1 Introduction

The simplest and most common method of embedding steganographic inserts is a substitution of the least significant bits (LSB-substitution) \[1\]. The basic idea of the method is to replace from one to four the least significant bits in bytes of image color representation pixels. The least visible variant is the replacement of the blue component of the color, because that is associated with the peculiarities of the human eye color perception. This method is used both alone and as part of a more complex methods. Despite the simplicity of the algorithm formation steganographic insert, the problem of detection without additional information is quite complex. To date, there is no method that can determine with certainty the existence...
and the dimensions of the steganographic insert in any container. Most methods are statistical in nature and are based on the assumption that the change in the statistical properties of the image bits by placing it in the inserted information. Known to date methods are effective when steganographic container is filled not less than 50% \([2]\).

In \([3]\) detection of stenographic insertion is performed on the assumption of change in correlation between adjacent pixels. The proposed by the authors method is that nearest neighbors of each pixel are considered. From the analysis of the surrounding pixels we can make predictions about the value of the center pixel and compare with current value.

In \([4]\) an algorithm for detecting steganographic inserts with using templates for surrounding pixels. Template building is also based on the assumption of a strong correlation between pixels of the original image. Correlations between pixels is also used in \([5]\) to build the statistical method for detecting steganographic inserts. A similar statistical method based on the the value of correlation between adjacent pixels is proposed in \([6]\). In \([7]\) there is a generalized method for determining the length of the steganographic inserts by combining multiple detectors.

Using the autoregressive model for the detection of hidden messages, as well as an assessment of their relative lengths is proposed in \([7, 8]\).

Thus, the main steganalysis objectives today are the fundamental discovery of the presence of a hidden insert and, if possible, the length determination of it. The purpose of this article is a developing an algorithm for deciding whether a particular bit is spoofed. That is not simply to determine the presence of steganographic insert, and, if possible, its definition.

2 Formulation of the problem

We will analyze the images, which can have embedded information in the form of steganography inserts in the least significant bit of the blue component. In this case we start from the two assumptions. First, we assume that we don’t know if there is any steganographic. Secondly, it is not known in advance about number of embedded bits and their geometric position in the image. The problem is posed to detect steganographic insert and determining the maximum number of pixels, which have spoofed the LSB of the blue component. The second assumption significantly complicates the task, because there can be a situation when pixels are replaced in all zero-layer bits of blue components. In this case, analysis of the zero layer of image does
not give any information. At the same time it is not known in advance whether to allow the zero-layer analysis to make any conclusions. In this case the analysis requires higher layers. We will rely on the assumption that basic regularities of the image gradually changes from one layer to another. Therefore detected regularity in one layer must be repeated with high probability in the surrounding layers.

We will find pixels with substitution in zero bits with separately analyzing zero layer and next three layers. In the future, we will build a chart of the results of these two algorithms, and adopting a general solution.

Let the \( k \)-th layer of the blue component of the original image is defined as a binary color matrix \( B_{ij}^{(k)} \), and the coordinates of the embedded information are set in the form of a matrix \( R_{ij} \). In this case, \( R_{ij} = 1 \), if there is a substitution LSB blue components of the corresponding pixel and \( R_{ij} = 0 \), if there is no substitution. As a result of embedding steganographic insert, instead of the zero layer \( B_{ij}^{(0)} \) matrix will be formed \( A_{ij}^{(0)} \). The problem is reduced to the most accurate restoration of matrix \( R_{ij} = 0 \) from analysis of the matrices \( A_{ij}^{(0)}, B_{ij}^{(1)}, B_{ij}^{(2)}, B_{ij}^{(3)} \).

3 Application of the analytic hierarchy process to identify spoofed bits

Let’s apply the analytic hierarchy process [9] for a decision on the substitution of the bit. This requires to formulate alternative solutions, from which selection is performed and also criteria for analyzing alternatives. As mentioned in the statement of the problem it’s necessary to identify the pixels with LSB substitution. Therefore only one of the possible two solutions denoted hereafter or \( Y \), if there is a substitution in LSB of given pixel, or \( N \), if pixel was not changed.

First, we construct a system to identify the substitution of bits based on the analysis of the zero layer. For this we will perform sequential pass over all bits of zero layer and make an analysis of the nearest neighbors of each of them. We distinguish three criteria:

\( K_1 \) – adjacent bits on the sides have the same value as the analyzed or different from it.
\( K_2 \) – the corners adjacent bits have the same value as the analyzed or different from it.
\( K_3 \) – bit deviation from the average value of surrounding eight bits.

The first two criteria allow to detect extended regions of the same color on image. The third
criterion is needed to identify areas with a gradient. Thus, we obtain a two-level hierarchical tree of alternatives which is shown in Figure 1. The final decision is indicated by $R$.

![Hierarchical tree of criteria](image)

**Figure 1**: Hierarchy of criteria to determine the substitution bit from zero layer analysis.

For the application of the analytic hierarchy process it is required to determine the relative weights of the criteria $r_i$ ($i = 1, 2, 3$), and weight solutions within one criteria and weight solutions within one criteria $p_i$ and $q_i$ ($i = 1, 2, 3$). We will assume that the criterion $K_1$ is more important than $K_2$ in $n$ times, and criterion $K_2$ is more important than $K_3$ in $k$ times. Also, we assume the presence of transitivity, this means that $K_1$ is more important than $K_3$ in $nk$ times. Then coherent matrix of pairwise comparisons will look like:

|     | $K_1$ | $K_2$ | $K_3$ |
|-----|-------|-------|-------|
| $K_1$ | 1     | $n$   | $kn$  |
| $K_2$ | $1/n$ | 1     | $k$   |
| $K_3$ | $1/(kn)$ | $1/k$ | 1     |

From this matrix the weighting coefficients can be obtained with standard methods [9]:

$$r_1 = \frac{nk}{nk + k + 1}, \quad r_2 = \frac{k}{nk + k + 1}, \quad r_3 = \frac{1}{nk + k + 1}.$$

With classical usage of the analytic hierarchy process pairwise comparisons are determined on the basis of expert evaluations. In our approach, we use some objective indicators instead of expert evaluations, which are determined by the number. In particular, constraints on the values $n$ and $k$ we will determine from consideration trivial examples further. The most suitable values of these parameters will be obtained from computer experiment.

Let’s turn to the definition of the weighting factors in each of the criteria. We begin with $K_1$. Let four bits of contacting with $x$ have the same value, then the solution $N$ has more weight as compared with $Y$ (namely analyzed bit is not spoofed) in $x/(4-x)$ times. Writing
the matrix of pairwise comparisons and making the necessary changes, we are getting the values of the coefficients $p_1 = (4 - x)/4$, $q_1 = x/4$. Similarly for the criterion $K_2$. Let four bits in contact with current bit only at the vertices have the same value. Then, the weight coefficients will be changed to $p_2 = (4 - y)/4$, $q_2 = y/4$.

For the calculation of weight coefficients according to the criterion let’s assume that value of analyzed bit and the average value of the surrounding bits is $c_0$. The following arguments are used to find weight coefficients. Let the solution $N$ has more weight than $Y$ in $a$ times, where the value $a$ depends on the absolute value of the deviation value of the bit, $c$ depends on the average values of surrounding bits $c_0$ ($dc = |c - c_0|$). Then, the weight coefficients will have the form:

\[ p_3 = \frac{1}{a + 1}, \quad q_3 = \frac{a}{a + 1}. \]

Let’s consider extreme cases. If the current bit is equal to the average value of the surrounding bits ($dc = 0$) we will assume that this bit is not spoofed, the coefficients of this bit will have this values $p_3 = 0$, $q_3 = 1$. If bit has maximum difference from the surrounding ($dc = 1$), then we will think that it was spoofed, i.e $p_3 = 1$, $q_3 = 0$. Therefore, when $dc = 0$ there should be $a \to \infty$. So, if $dc = 1$ then $a = 0$. These conditions are satisfied the following expression:

\[ a = \frac{1}{dc} - 1. \]

Weighting coefficients will have the following values:

\[ p_3 = dc, \quad q_3 = 1 - dc. \]

For a final decision it is necessary to calculate values:

\[ P(Y) = r_1p_1 + r_2p_2 + r_3p_3, \quad P(N) = r_1q_1 + r_2q_2 + r_3q_3. \]

If $P(Y) > P(N)$, then we will make a decision that $R = Y$, this means that bit is spoofed, otherwise, if $P(Y) \leq P(N)$, then we will make a decision that $R = N$, this means that bit is not spoofed.

We will extend the proposed method of bit analysis with a comparison of three overlying layers. We will consider bits in each layer, which lies over the data and eight nearest adjacent bits. In the future, this set of bits will be called as window in the corresponding layer. Let’s introduce the criteria for making decision based on analysis of $k$-th layer ($k = 1, 2, 3$):
$K_1^{(k)}$ – adjacent bits on both sides in the window of $k$-th layer have the same value as the analyzed bits of zero-layer or different from it.

$K_2^{(k)}$ – the corners bits on both sides in the window of $k$-th layer have the same value as the analyzed bits of zero-layer or different from it.

$K_3^{(k)}$ – deviation of bit in zero-layer from the average value of bits in window of $k$-th layer.

Three-level hierarchical tree of alternatives is shown in figure 2. The final decision is denoted $R_1$.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Hierarchy of criteria to determine bit substitution from analysis of overlying layers.}
\end{figure}

We will assume that the results of the analysis of the first layer is more important than the results of the second twice, and the second layer is more important than the third twice too. Hence, we obtain the values of the weighting coefficients:

$$t_1 = \frac{4}{7}, \quad t_2 = \frac{2}{7}, \quad t_3 = \frac{1}{7}.$$ 

Within the framework of a single layer it is difficult to single out some of the criteria, so we assume that they are all equal:

$$s_1 = s_2 = s_3 = \frac{1}{3}.$$ 

For the weighting coefficients for two decisions under one criterion we apply an approach which is similar to used in the zero layer analysis. For the first criterion:

$$p_1^{(k)} = \frac{4 - x^{(k)}}{4}, \quad q_1^{(k)} = \frac{x^{(k)}}{4},$$

where $x^{(k)}$ is a number of neighbors on each side, with the same value in the window of $k$-layer.
For the second criterion:

\[ p_2^{(k)} = \frac{4 - y^{(k)}}{4}, \quad q_2^{(k)} = \frac{y^{(k)}}{4}, \]

where \( y^{(k)} \) is a number of neighbors on the diagonal, with the same value in the window of \( k \)-layer. The weighting coefficients of the third criterion:

\[ p_3^{(k)} = dc^{(k)}, \quad q_3^{(k)} = 1 - dc^{(k)}, \]

where \( dc^{(k)} \) – difference between the bit value from the average value of bits in the window of \( k \)-layer.

For making decision it is necessary to calculate values:

\[
P_1(Y) = t_1 \left( s_1p_1^{(1)} + s_2p_2^{(1)} + s_3p_3^{(1)} \right) + t_2 \left( s_1p_1^{(2)} + s_2p_2^{(2)} + s_3p_3^{(2)} \right) + t_3 \left( s_1p_1^{(3)} + s_2p_2^{(3)} + s_3p_3^{(3)} \right),
\]

\[
P_1(N) = t_1 \left( s_1q_1^{(1)} + s_2q_2^{(1)} + s_3q_3^{(1)} \right) + t_2 \left( s_1q_1^{(2)} + s_2q_2^{(2)} + s_3q_3^{(2)} \right) + t_3 \left( s_1q_1^{(3)} + s_2q_2^{(3)} + s_3q_3^{(3)} \right).
\]

If \( P_1(Y) > P_1(N) \), then we make decision \( R_1 = Y \), i.e. bit is spoofed, otherwise, if \( P_1(Y) \leq P_1(N) \), then we make decision \( R_1 = N \), i.e. bit is not spoofed.

**4 The algorithm to detect spoofed pixels**

Let us write the algorithm formally that implements the proposed method. We perform a consistent passage for all pixels in the image. For each pixel we will perform a series of steps:

Step 1. Select size of the window 3 \( \times \) 3 in the zero, first, second and third layers.

Step 2. Calculate values \( P(Y), P(N), P_1(Y), P_2(N) \).

Step 3. If at least one of the two equations is true \( R = Y \) or \( R_1 = Y \), that we assume that the bit is spoofed. Then we will add this element to matrix \( R_{ij} \) with value 1, otherwise value is 0.

The output matrix \( R_{ij} \) will have list of spoofed pixels. Since the algorithm is performed in a single pass for all pixels and each pixel is performed for a fixed number of steps, then complexity of the algorithm is linear. Also of note is the localization of the data which is needed for making decision, in a small area around the current pixel, it’s easy to make a simple parallelization algorithm with partitioning the image into regions.
5 Computer experiment and results

Computer experiment was performed to research the effectiveness of the proposed method to detect embedded information. The experiments were performed on three types of images: gradient fill, artificial image of geometric shapes and widely used image "Lena". All images had dimensions $640 \times 480$ pixels, the color depth is 256 colors. Embedded text in Russian in the form of bit-sequences in a rectangular area located randomly in the center of the image. There were 9% of changes in zero-layer of the original image. Figure 3 shows the results of the experiment with the gradient fill.

![Figure 3](image)

Figure 3: Results of the algorithm to detect spoofed pixels on the gradient fill: a) original image; b) matrix $R_{ij}$ for the original image; c) image with integrated text; d) matrix $R_{ij}$ for the image with steganography insert.

As can be clearly seen from a comparison of figures 3a and 3b we can see visible rectangle, which has embedding. Similar results for the artificial image with a geometric figures are shown in Figure 4 for the photographic image results are shown in Figure 5.

![Figure 4](image)

Figure 4: Results of the algorithm to detect spoofed pixels on the artificial image with a geometric figures: a) image with integrated text; b) matrix $R_{ij}$ for the image with steganography insert.
Figure 5: Results of the algorithm to detect steganographic insert on the photographic image:
a) image with integrated text; b) matrix $R_{ij}$ for the image with steganography insert.

Both figures have clearly visible area, which was built by inserting hidden message.

6 Conclusion

Thus, the proposed algorithm in this article allows us not only to detect the presence of steganography insertion into the image, but also it allows to determine with sufficient accuracy location and volume of steganography insertion. Unlike presently common algorithms, in this proposed method there was not any statistical approach. It should be noted that the all used images images with steganographic insertions easily pass the Chi-square test which detects embedded messages in them. This method requires further research for the development of algorithms for the analysis of the resulting matrix $R_{ij}$.

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