# Preprocessing Cover Images for More Secure LSB Steganography

Shreelekshmi R, M Wilscy and M Wilscy

***Abstract*—We propose a simple method for preprocessing cover images to increase the reliability of random LSB replacement steganography in digital images in spatial domain. After the proposed transformation of cover images, most reliable steganalysis methods in the literature such as RS steganalysis, Sample pair method, Least Square method estimate embedding ratio as almost $100\%$ for any amount of hidden data. Thus it causes inaccurate estimation results by the most reliable LSB steganalysis methods thereby increasing the reliability of LSB replacement steganography. The transformation is based on the count of different types of sample pairs in the image and their subsequent change with embedding.**

## I. INTRODUCTION

Steganography hides the secret message in cover objects to obtain stego objects. Digital images, videos, sound files and other computer files that contain perceptually irrelevant or redundant information are used as cover objects to hide secret messages. The goal of steganalysis is to detect/ estimate /retrieve potentially hidden information from observed data with little or no knowledge about the steganographic algorithm or its parameters. The purpose of steganography is to hide the presence of communication, as opposed to cryptography, which aims to make communication unintelligible to those who do not possess the right keys [4].

In this paper we concentrate on LSB steganography on digital images stored in uncompressed raw format. Many methods[1], [2], [3], [5], [6], [7], [8], [12] have been proposed in the literature for steganalysis of digital images. These methods give very accurate results on most of the images.

All steganalysis methods are subject to error. Attempts were made in estimating the error in various steganalysis methods. Ker derived error distribution in Least Square steganalysis[9] on images with zero payload. It shows that LSM, one of the most reliable steganalysis methods, gives very accurate results on most of the images, but shows large estimation errors on some images due to image specific properties.

Based on the theoretical error model, Ker suggested improvements [12] to the steganalysis method by reducing bias and variance in the case of moderate payloads. However analysis of error distribution in the case of general payloads is technically difficult and hence in such cases improvements suggested can not be used for estimation [12].

With the development of very accurate steganalysis techniques, methods have been proposed for increasing reliability of LSB steganography also. Fridrich et. al developed a general coding method called matrix embedding[10] that can be applied to most steganographic schemes for improving their steganographic security.

Luo et.al [11] developed a method for increasing security of LSB steganography based on chaos system and dynamic compensation. The dynamic compensation is done after hiding the data in the image. After doing dynamic compensation the most accurate methods like RS, SPM and LSM and their improved versions detect stego images with very high payload as cover images. However dynamic compensation causes the cover images to be detected as cover images only.

In this paper we present a simple transformation on cover images to cause larger estimation errors for the most reliable steganalysis techniques such as RS steganalysis, Least Square method and Sample pair method. The method we propose involves a very simple operation of flipping for preprocessing a cover image in such a way that it gives inaccurate estimation results with/ without hidden data.

The rest of this paper is organized as follows: Section 2 explains the notations we use in this paper. Section 3 briefs RS steganalyisis, Sample Pair Method and Least Square Method. Section 4 introduces the new method for cover image transformation. Section 5 shows the experimental results we obtained. Section 6 is the conclusion and future work.

## II. NOTATIONS

*$P$ : Multiset of sample pairs $(u, v)$ drawn from digital image*
*$X_n$ : Sub multiset of $P$ that consists of sample pairs drawn from cover signal and whose values differ by $n$ and in which*

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*even value is larger*
$Y_n$ *: Sub multiset of* $P$ *that consists of sample pairs drawn from cover signal and whose values differ by* $n$ *and in which odd value is larger*
$C_m$ *: Sub multiset of* $P$ *that consists of sample pairs drawn from cover signal and whose values differ by* $m$ *in the first (b-1) bits (i.e., by right shifting one bit and then measuring the difference of* $m$*)*
$D_0$ *: Sub multiset of* $P$ *that consists of sample pairs drawn from cover signal and whose values differ by* $0$
$p$ *: Estimated message length in percent*

## III. REVIEW OF RS STEGANALYSIS, SAMPLE PAIR METHOD AND LEAST SQUARE METHOD

### A. RS STEGANALYSIS

RS steganalysis[1] divides the image into three disjoint groups viz. regular, singular and unusable groups depending on the behaviour of a discrimination function. The relative counts of all these groups under a mask M, an n-tuple with values -1, 0, and 1, are taken.

Let the relative number of regular groups for a non-negative mask M be $R_M$ (in percents of all groups) and let $S_M$ be the relative number of singular groups. This steganalytic method works based on the hypothesis that for typical cover images

$$R_M \approx R_{-M} \; and \; S_M \approx S_{-M} \tag{1}$$

.
With embedding $R_M$ and $S_M$ change quadratically and $R_{-M}$ and $S_{-M}$ change linearly. At $100\%$ embedding, $R_M$ and $S_M$ become equal. If we have a stego-image with a message of an unknown length $p$ embedded in the LSBs of randomly scattered pixels, initial measurements of the number of R and S groups correspond to the points $R_M(p/2)$, $S_M(p/2)$, $R_{-M}(p/2)$, and $S_{-M}(p/2)$. If we flip the LSBs of all pixels in the image and calculate the number of R and S groups, we will obtain the four points $R_M(1-p/2)$, $S_M(1-p/2)$, $R_{-M}(1-p/2)$, and $S_{-M}(1-p/2)$.

After rescaling the x axis so that $p/2$ becomes $0$ and $100 - p/2$ becomes 1, which is obtained by the linear substitution $z = (x - p/2)/(1 - p)$, Fridrich et.al calculated the message length $p$ from the root z of the following quadratic equation

$$2(d_1 + d_0)z^2 + (d_{-0} - d_{-1} - d_1 - 3d_0)z + d_0 - d_{-0} = 0 \tag{2}$$

where

$$d_0 = R_M(p/2) - S_M(p/2), \tag{3}$$
$$d_1 = R_M(1-p/2) - S_M(1-p/2), \tag{4}$$
$$d_{-0} = R_{-M}(p/2) - S_{-M}(p/2), \tag{5}$$
$$and \; d_{-1} = R_{-M}(1-p/2) - S_{-M}(1-p/2) \tag{6}$$

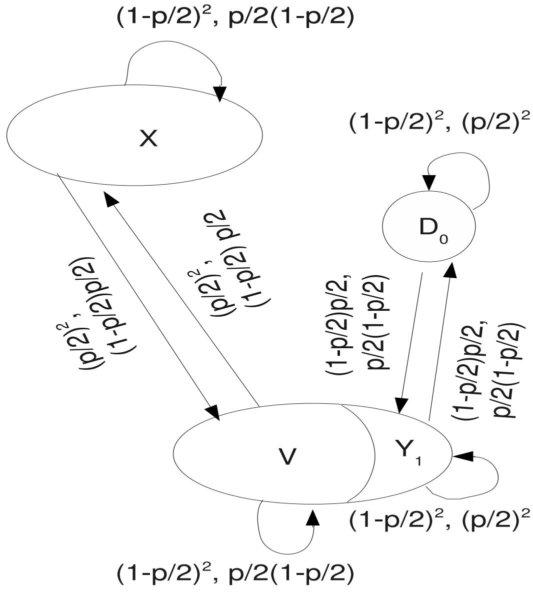


Fig. 1. Finite State Machine to verify RS method

Dumitrescu[2] et. al showed that the transitions analysed in RS method can be depicted by a finite state machine shown in Figure 1. In fact

$$X = \bigcup_{i=1}^{2^b-1} X_i \tag{7}$$
$$Y = \bigcup_{i=1}^{2^b-1} Y_i \tag{8}$$
$$R_M = XUD_0, \; S_M = Y \tag{9}$$
$$R_{-M} = YUD_0, \; S_{-M} = X \tag{10}$$
$$V = Y - Y_1 \tag{11}$$

### B. SAMPLE PAIR ANALYSIS

Sample Pair Analysis[2] is based on probabilities of transitions between sample pairs due to LSB embedding operations. $P$ is partitioned into $C_m, 0 \le m \le 2^{b-1} - 1$. The multi sets $C_m, 1 \le m \le 2^{b-1} - 1$, is partitioned into four trace sub multi sets $X_{2m-1}$, $X_{2m}$, $Y_{2m}$, $Y_{2m+1}$ and $C_0$ is partitioned into $D_0$ and $Y_1$. Clearly $C_m, 0 \le m \le 2^{b-1} - 1$ is closed, but its trace sub multi sets are not but convert reciprocally under the LSB embedding operations.

The transitions within $C_0$ are illustrated in Figure 2. The transitions between four trace sub multi sets in $C_m, 1 \le m \le 2^{b-1} - 1$, are as shown in the finite-state machine in Figure 3. The probability of transition from trace sub multi set $A$ to $B$ is same as that from $B$ to $A$. The transitions are labeled with probability of transition. For natural images, the literature [2]

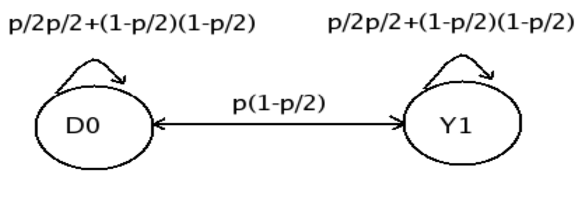


Fig. 2. Finite state machine associated with $C_0$

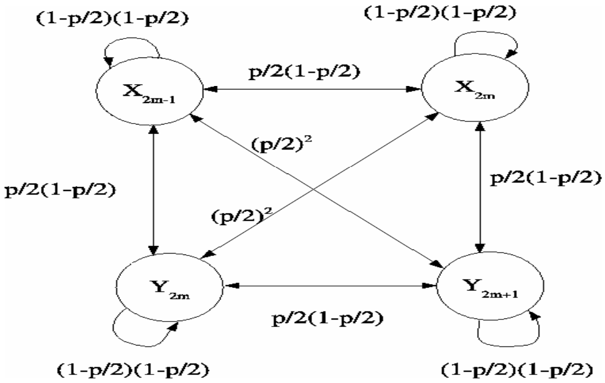


Fig. 3. Finite state machine associated with $C_m$

presented the hypotheses:

$$E\{| X_{2m+1} |\} = E\{| Y_{2m+1} |\} \tag{12}$$

According to the transitions within the finite-state machines in the Figures 2 and 3, Sorina Dumitrscu et al. derived the following quadratic equations for estimating $p$ if LSB steganography is done via random embedding. For $m \geq 1$

$$\frac{(| C_m | - | C_{m+1} |)p^2}{4} - \frac{(| D'_{2m} | - | D'_{2m+2} | + 2 | Y'_{2m+1} | - 2 | X'_{2m+1} |)p}{2} + | Y'_{2m+1} | - | X'_{2m+1} | = 0 \tag{13}$$

and for m = 0

$$\frac{(2 | C_0 | - | C_1 |)p^2}{4} - \frac{(2 | D'_0 | - | D'_2 | + 2 | Y'_1 | - 2 | X'_1 |)p}{2} + | Y'_1 | - | X'_1 | = 0 \tag{14}$$

The smaller root of quadratic equation (13) [or ( 14)] is the estimated value of p. Considering the estimating precision, the literature [2] used the hypotheses

$$E\{| \bigcup_{m=i}^{j} X_{2m+1} |\} = E\{| \bigcup_{m=i}^{j} Y_{2m+1} |\} \tag{15}$$

instead of (12) and derived the following more robust quadratic equations to estimate the value of p.

$$\frac{(| C_i | - | C_{j+1} |)p^2}{4} - \frac{(| D'_{2i} | - | D'_{2j+2} | + 2\sum_{m=i}^{j}(| Y'_{2m+1} | - | X'_{2m+1} |))p}{2} + \sum_{m=i}^{j}(| Y'_{2m+1} | - | X'_{2m+1} |) = 0, i > 0 \tag{16}$$

$$\frac{(2 | C_0 | - | C_{j+1} |)p^2}{4} - \frac{(2 | D'_0 | - | D'_{2j+2} | + 2\sum_{m=0}^{j}(| Y'_{2m+1} | - | X'_{2m+1} |))p}{2} + \sum_{m=0}^{j}(| Y'_{2m+1} | - | X'_{2m+1} |) = 0, i = 0 \tag{17}$$

The results are optimum when $i = 0, j = 30$ [2].

### C. LEAST SQUARE METHOD

The precision of SPA is based on the hypotheses (12) or (15). Actually, $E\{| X_{2m+1} |\}$ is not absolutely equal to $E\{| Y_{2m+1} |\}$ , and neither is $E\{| \bigcup_{m=i}^{j} X_{2m+1} |\}$ equal to $E\{| \bigcup_{m=i}^{j} Y_{2m+1} |\}$. Once the hypotheses do not hold, the quadratic equations above will not hold. Hence, when the embedding ratio is small, the errors of those hypotheses will lead the decision error. Thus when there are no messages embedded in images, the false alarm rate is high[3]. In fact, the false alarm rate presented by the literature [2] is $13.79\%$.

Least Square Method[3] makes the hypothesis that there is a small parity difference occur in natural signals for each $m$ . Let
$\varepsilon_m = | Y_{2m+1} | - | X_{2m+1} |$ $(0 \leq m \leq 2^{b-1} - 2)$. Equations ( 13) and ( 14) become

$$\frac{(| C_m | - | C_{m+1} |)p^2}{4} - \frac{(| D'_{2m} | - | D'_{2m+2} | + 2 | Y'_{2m+1} | - 2 | X'_{2m+1} |)p}{2} + | Y'_{2m+1} | - | X'_{2m+1} | = \varepsilon_m(1 - p^2), m \geq 0 \tag{18}$$

and

$$\frac{(2 | C_0 | - | C_1 |)p^2}{4} - \frac{(2 | D'_0 | - | D'_2 | + 2 | Y'_1 | - 2 | X'_1 |)p}{2} + | Y'_1 | - | X'_1 | = \varepsilon_m(1 - p^2), m = 0 \tag{19}$$

Considering the perfect accuracy and robustness of least square method for parameters estimate, Luo et.al used least square method to estimate the embedding ratio for the different $2^{b-1}-1$ equations. Substituting $A_m, B_m$ and $E_m$, the left of equation (19) is changed into $A_m p^2 + B_m p + E_m$. Let

$$S(i,j,p) = \sum_{m=1}^{j} (A_m p^2 + B_m p + E_m)^2, 0 \le i < j \le 2^{b-1} - 2 \tag{20}$$

Differentiating (20) yields, the following equation:

$$2\sum_{m=i}^{j} A_m^2 p^3 + 3\sum_{m=i}^{j} A_m B_m p^2 + \sum_{m=i}^{j} (2A_m E_m + B_m^2)p + \sum_{m=i}^{j} B_m E_m = 0 \tag{21}$$

By solving equation (21), a $p$ value is estimated such that the $S(i,j,p)$ is minimal. In conclusion, LSM algorithm estimates the length of embedding message by solving a third order equation. The algorithm needs the following hypothesis that for each $m$

$$(\mid Y_{2m+1} \mid - \mid X_{2m+1} \mid)(1-p)^2 \tag{22}$$

is small. The conditions of hypothesis in [3] are more relaxed than that in [2]. Experimental results[3] show that, it is precise and robust enough for LSM algorithm to take $i = 0$ and $j = 5$.

## IV. TRANSFORMATION OF COVER IMAGES

RS steganalysis, Sample pair method, and Least Square method accurately estimate length of data hidden using random LSB embedding in images in spatial domain. These methods are based on probabilities of transitions between sample pairs due to LSB embedding operations.

RS steganalysis, Sample pair method, and Least Square method make certain assumptions about cover images to produce accurate results. RS steganalysis assumes[1], [2]

$$E\{\mid \bigcup_{i=1}^{2^b-1} X_i \mid\} = E\{\mid \bigcup_{i=1}^{2^b-1} Y_i \mid\} \tag{23}$$

Sample pair method [2] assumes

$$E\{\mid X_{2m+1} \mid\} = E\{\mid Y_{2m+1} \mid\} \tag{24}$$

or a more relaxed condition

$$E\{\mid \bigcup_{m=i}^{j} X_{2m+1} \mid\} = E\{\mid \bigcup_{m=i}^{j} Y_{2m+1} \mid\} \tag{25}$$

to give correct results and Least Square method [3] assumes

$$(\mid Y_{2m+1} \mid - \mid X_{2m+1} \mid)(1-p^2) \tag{26}$$

as very small for each $m$.

The change in cardinalities of sub multi sets of $C_m$ due to embedding are shown in Figure 4. In fact cardinalities of sub multi sets in each $C_m, 0 \le m \le 2^{b-1}-1$ increase /decrease monotonically with ratio of embedding and at 100% embedding these cardinalities become equal. Typical change in cardinalities of sub multi sets in a $C_m, 0 \le m \le 2^{b-1}-1$ are shown in Figure 4.

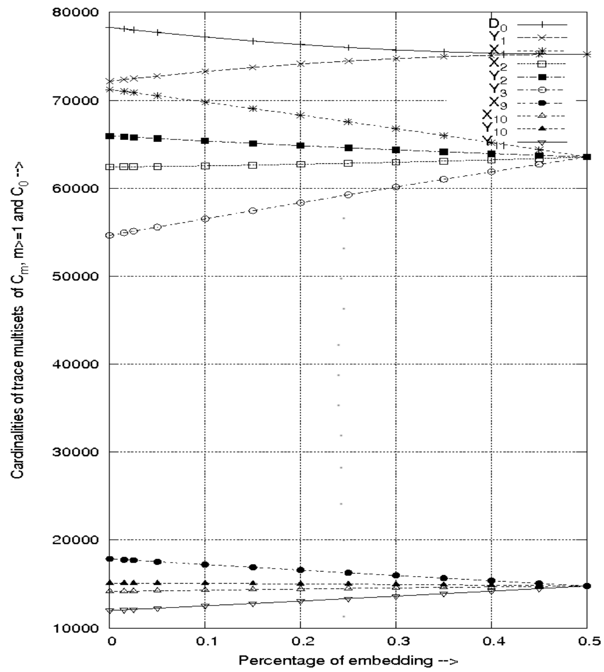


Fig. 4. Change in cardinalities of sub multi sets of $C_m$ due to embedding in general

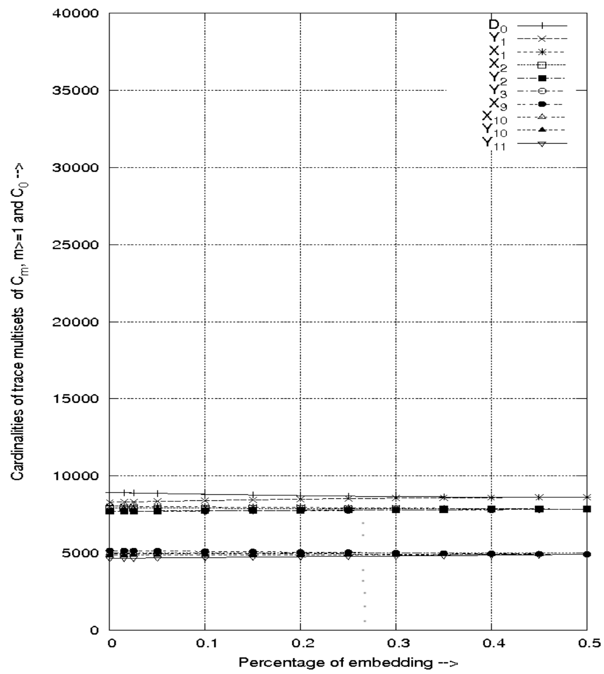


Fig. 5. Change in cardinalities of sub multi sets of $C_m$ due to embedding when their cardinalities are almost equal

In most of the images,
$\mid X_{2m-1} \mid > \mid X_{2m} \mid \approx \mid Y_{2m} \mid > \mid Y_{2m+1} \mid$ and $\mid D_0 \mid > \mid Y_1 \mid$. Hence due to embedding $\mid X_{2m-1} \mid$ and $D_0$ decreases and that of $\mid Y_{2m+1} \mid$ increases. $\mid X_{2m} \mid$ and $\mid Y_{2m} \mid$ increase or decrease depending on their initial values. At $100\%$ embedding, all these cardinalities become equal. From the monotonic increase or decrease in cardinalities of sub multi sets the $p$ value, estimated length in percent, is calculated.

The probability of transition from trace multi set $A$ to multi set $B$ and that from $B$ to $A$ are same. Therefore when

$$\mid X_{2m-1} \mid \approx \mid Y_{2m+1} \mid \approx \mid X_{2m} \mid \approx \mid Y_{2m} \mid, m > 0 \quad (27)$$

$$\mid D_0 \mid \approx \mid Y_1 \mid, m = 0 \quad (28)$$

cardinalities of trace multi sets would not change due to embedding which is shown in Figure 5. Such a $C_m$ does not help in estimating the length of embedding. If the image contains only such $C_m$s, steganalysis is unreliable using RS steganalysis, LSM and SPM.

The transformation we propose randomly flips $50\%$ of the LSBs of all pixels in the image, so that the image meets the above criteria. Hence after the transformation the above methods show very high amount of hidden data when no data is hidden. The results remain the same after embedding any amount of data. In nutshell the transformation causes these methods to show highly inaccurate estimated lengths especially with low amounts of hidden data. In fact estimation error is maximum on cover images and it decreases with increase in hidden data.

The drawback of our method is that the estimation error tends to be 0 as embedded ratio becomes $100\%$. However our method can be used in combination with dynamic compensation [11] to increase the security of LSB steganography. Dynamic compensation gives maximum estimation errors at $100\%$ embedding. Estimation error decreases with decrease in hidden data. When ratio of embedding is less than $50\%$ our method can be used and otherwise dynamic compensation can be used to give maximum estimation error. Our method causes detection of cover images as stego images. Dynamic compensation causes stego images to be detected as cover images. Both together cause false positives to be $100\%$ and missed detection to be almost $100\%$ [11]. Thus the transformation proposed together with dynamic compensation increases the security of LSB steganography scheme.

## V. Experimental results

We selected two standard test images (lena and peppers) of size 512x512 pixels for testing the proposed preprocessing algorithm. We created a series of stego images by embedding messages of length 0%, 3%, 5%, 10%, ...,100% into the two images using random LSB replacement method. Then we estimated the hidden message length from these stego images using RS method, SPA method and LSM method. We got test results which are almost equal to those given in table I. The values given in the table I are as reported in [3].

| Embedded message length (%) | Lena[3] | | | Peppers[3] | | |
|---|---|---|---|---|---|---|
| | RS | SPA | LSM | RS | SPA | LSM |
| 0 | 1.43 | 0.49 | 0.19 | 1.48 | 0.65 | 0.26 |
| 3 | 4.63 | 3.51 | 2.81 | 4.40 | 3.61 | 3.34 |
| 5 | 6.35 | 5.37 | 4.72 | 6.55 | 5.56 | 5.09 |
| 10 | 11.91 | 10.77 | 10.20 | 11.66 | 10.71 | 10.56 |
| 20 | 22.19 | 21.23 | 20.40 | 22.90 | 21.05 | 20.83 |
| 30 | 32.22 | 31.27 | 30.57 | 32.70 | 31.03 | 30.07 |
| 40 | 41.48 | 40.69 | 40.26 | 41.90 | 40.46 | 40.20 |
| 50 | 51.36 | 50.48 | 49.99 | 52.98 | 50.77 | 50.50 |
| 60 | 61.23 | 60.56 | 60.18 | 59.81 | 60.40 | 60.00 |
| 70 | 70.48 | 70.31 | 70.21 | 72.07 | 70.62 | 70.33 |
| 80 | 79.89 | 78.77 | 79.05 | 79.67 | 78.65 | 79.04 |
| 90 | 91.07 | 89.07 | 89.99 | 91.08 | 90.70 | 90.19 |
| 100 | 96.60 | 97.72 | 98.95 | 96.95 | 97.80 | 99.16 |

TABLE I
ESTIMATED MESSAGE LENGTH RESULTS (IN PERCENT) FOR TWO STANDARD IMAGES BEFORE PROPOSED TRANSFORMATION

We did the proposed transformation on the above two standard images. Afterwards we created a series of stego images with hidden data of length 0%, 3%, 5%, 10%, ...,100%. Then the hidden message length was estimated using RS method, SPA method and LSM method. The test results are shown in table II.

The results show that before the transformation these three methods estimate the hidden message length very accurately. However after the transformation these methods estimate hidden message length as almost 100% irrespective of the amount of embedded data.

We performed tests on a set of one hundred 24-bit color images downloaded from *www.nationalgeographic.com* (mostly Photo of the day images from National Geographic Channel), which were originally stored as high-quality JPEG images. For our test purposes, we resized them to $800X600$ pixels. The test results are shown in table III. These images also showed almost $100\%$ embedding after the transformation irrespective of the amount of embedded data.

Thus the transformation proposed causes the most accurate steganalysis methods in the literature to give inaccurate results thereby increasing the reliability of LSB steganography. The absolute average error shown by three methods for the set of $100$ images is given in figure 6. From the graph it is clear that false alarm rate is $100\%$ and the estimation error is maximum when the amount of hidden data is smaller.

## VI. Conclusion

In this paper we discussed a transformation method for cover images for increasing the reliability of LSB replacement steganography in spatial domain. After the proposed transformation the images show very high embedding ratio

| Embedded message length (%) | Lena | | | Peppers | | |
|---|---|---|---|---|---|---|
| | RS | SPA | LSM | RS | SPA | LSM |
| 0 | 96.60 | 97.72 | 98.95 | 96.95 | 97.80 | 99.16 |
| 3 | 95.80 | 97.93 | 98.97 | 96.15 | 97.67 | 99.20 |
| 5 | 95.70 | 97.89 | 98.91 | 96.27 | 97.79 | 99.32 |
| 10 | 96.40 | 97.31 | 98.82 | 96.38 | 97.48 | 99.02 |
| 20 | 94.30 | 96.32 | 98.81 | 95.98 | 96.50 | 99.01 |
| 30 | 96.20 | 97.41 | 98.99 | 96.72 | 98.12 | 99.08 |
| 40 | 95.30 | 97.52 | 98.65 | 96.89 | 97.45 | 99.38 |
| 50 | 94.60 | 96.02 | 98.12 | 96.12 | 97.23 | 99.24 |
| 60 | 96.10 | 98.02 | 98.98 | 96.34 | 97.12 | 98.94 |
| 70 | 95.91 | 97.81 | 98.31 | 96.16 | 97.39 | 99.37 |
| 80 | 95.23 | 97.12 | 98.05 | 96.39 | 96.98 | 99.43 |
| 90 | 96.10 | 96.35 | 98.23 | 96.89 | 97.21 | 99.42 |
| 100 | 95.70 | 97.11 | 98.19 | 96.85 | 97.78 | 99.41 |

TABLE II
ESTIMATED MESSAGE LENGTH(IN PERCENT) FOR TWO STANDARD IMAGES AFTER PROPOSED TRANSFORMATION

| Embedded message length (%) | before | | | after | | |
|---|---|---|---|---|---|---|
| | RS | SPA | LSM | RS | SPA | LSM |
| 0 | 1.26 | 0.52 | 0.17 | 96.76 | 97.43 | 98.89 |
| 3 | 4.63 | 3.51 | 2.81 | 96.15 | 97.67 | 99.20 |
| 5 | 6.35 | 5.37 | 4.72 | 96.27 | 97.79 | 99.32 |
| 10 | 11.91 | 10.77 | 10.20 | 96.38 | 97.48 | 99.02 |
| 20 | 22.19 | 21.23 | 20.40 | 95.98 | 96.50 | 99.01 |
| 30 | 32.22 | 31.27 | 30.57 | 96.72 | 98.12 | 99.11 |
| 40 | 41.48 | 40.69 | 40.26 | 96.89 | 97.45 | 99.38 |
| 50 | 51.36 | 50.48 | 49.99 | 96.12 | 97.23 | 99.24 |
| 60 | 61.23 | 60.56 | 60.18 | 96.34 | 97.12 | 99.11 |
| 70 | 70.48 | 70.31 | 70.21 | 96.16 | 97.39 | 99.37 |
| 80 | 79.89 | 78.77 | 79.05 | 96.39 | 96.98 | 99.43 |
| 90 | 91.07 | 89.07 | 89.99 | 96.89 | 97.21 | 99.42 |
| 100 | 95.70 | 97.11 | 99.19 | 96.85 | 97.78 | 99.41 |

TABLE III
ESTIMATED MESSAGE LENGTH (IN PERCENT) FOR HUNDRED IMAGES BEFORE AND AFTER PROPOSED TRANSFORMATION

irrespective of the amount of hidden data. The transformation increases the false alarm rate to 100% and decreases the accuracy of prediction.The length estimation is highly inaccurate especially with small amount of embedding. Thus the transformation we proposed increases the reliability of LSB steganography. The steganalysis results can be made more inaccurate in combination with dynamic compensation method proposed by Luo et. al. Both methods together can detect stego images as cover images and cover images as stego images. Stego images with low amount of hidden data can be detected as cover images or as stego images with very large amount of hidden data. These two methods in combination with random LSB steganography can thus defeat the most accurate steganalysis methods in the literature thereby increasing the security of LSB replacement steganography.

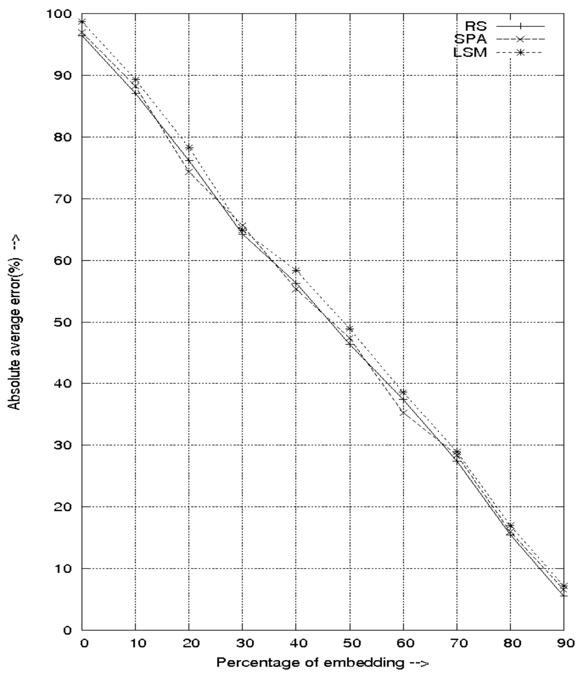


Fig. 6. Absolute average error shown by 100 test images

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