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Embedding Change Estimation for Universal Steganalysis using 3-way Tensor Model

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***Abstract*— This paper proposes a novel Universal Steganalysis framework which can be applied for spatial domain and JPEG Domain Steganography algorithms. The objective is to develop a steganalysis algorithm which has to identify any distribution (uniform or non-uniform) of stego-payloads. The framework proposed uses a 3-way tensor model to extract the image features which is important for estimating the embedded change irrespective of domain. To obtain the accurate results and to analyze the error, 360 degree bit change estimation is done. The experimental results evaluated on 3000 images which shows a good detection rate in both domains and a reasonable false acceptance rate and false rejection rate based on the pay load when tested with most of the steganography algorithms.**

Keywords- Spatial Domain, Jpeg Domain, Steganalysis, Tensor, SVM

I. INTRODUCTION

Steganalysis is the art of discovering hidden data in images/video. The Steganalysis techniques are classified into two categories. 1. Specific Steganalysis 2. Universal Steganalysis. Specific Steganalysis are designed for a targeted embedding technique [13],[5]. Thus they yield very accurate decisions when they are used against the particular steganographic technique. In universal technique, the dependency on the behavior of the individual embedding techniques is removed by determining and collecting a set of distinguishing statistics that are sensitive to a wide variety of embedding operations. It has been identified that most of the research objectives focused on identifying the embedded data instead of extracting the data [1],[2],[3],[5],[6]. Quantitative Steganalysers are important forensic tools because the number of embedding changes correlates with the message length.

Steganography can be done in two major domains. 1. Spatial domain. 2. JPEG Domain. It has been identified that design of steganalysis algorithm is focused mainly on JPEG Domain[2],[4]. The algorithm which has been designed for JPEG domain is partially working for Spatial Domain [2],[3],[14],. Therefore the spotlight of this paper is mainly on Spatial Domain Steganalysis as well as Jpeg Domain which can be a Universal Steganalysis frame work.

Tomas Pevny etal [4] focused their assumptions more on JPEG domain. Since this research proposes to concentrate more on spatial domain steganography algorithm as well as JPEG Domain, it is difficult to predict how well the results will compare to Tomas Pevny results. Jan Kodovsky and

Jessica Fridrich [1] assumed that both training and testing images were generated based on uniformly distributed payloads. This assumption leads to a development of a steganalysis algorithm which has to identify any distribution (uniform or non-uniform) of stego-payloads. The validation is done by the literature survey based on non-uniform distribution of stego-payloads as follows.

T.Pevny etal.[15] highlighted about the challenge of steganalysis researchers for advanced content adaptive steganographic methods. Even though J.fridrich etal. [2] proposes a universal steganography detector which successfully attacked LSB matching revisited algorithm (LSBMR) proposed by LUO etal.[16]. Edge adaptive Image Steganography Based on LSB Matching Revisited (EALSBMR)[17] algorithm was not successfully attacked by [2] because of the adaptive methodology. Shunquan Tan etal. [18] proposes Targeted steganalysis of EALSBMR and it was successful only for the proposed steganography algorithm.

There are many adaptive steganography algorithm where an embedding redundancy in LSB matching to select modification direction and takes the dependency of neighbouring pixels into consideration. Since the neighboring pixel dependency is considered the universal steganalysis may be a challenging part in my research [18]. A combined spatial domain embedding and transform domain embedding makes difficulty in the attack [19].

Based on the above validation and discussion, This paper proposes an unique frame work based on 3 way tensor model which will accompany adaptive steganalysis as well as steganalysis of uniform payload distribution. Also the frame work satisfies the requirement of steganalysis in the spatial domain as well as the JPEG Domain

This paper is organized as follows. In section II , a Frame work has been proposed using 3-way tensor model and we discussed the details of SCI, Forward cycling and backward cycling of matrices and bit change rate estimation. The Results and Discussion claims the successful working of the framework by analyzing in various test bed created based on the steganography algorithms which is mentioned in the section III. Finally the conclusion is summarized in section V.

II. FRAME WORK

In our system, the frame work proposed in figure 1 clearly shows the importance of tensor representation. The mathematical model of this frame work proposed is adopted from [20], [21] and [22] which give the foundation of tensor representation and manipulation

A. SCI Generation

The first step in SCI Generation is to partition the image into N slices, where N is denoted as the number of bit slices. If the image is composed of N-l bit slices, ranging from slice 0 for least significant bit to slice N-l for the most significant bit. In terms of N bit slices, slice 0 contains all the lowest order bits in the bytes comprising the pixels in the image and slice N-1 contains all the high order bits. Therefore by separating the image into bit slices, we immediately have a method of identifying more important and less important information which is suitable for extracting the image features.

The image can be divided into bit slices by the following steps.

- Let I be an image where every pixel value is n-bit long
- Express every pixel in binary using n bits
- Form out of I n binary matrices

where the i-th matrix consists of the i-th bits of the pixels of I.

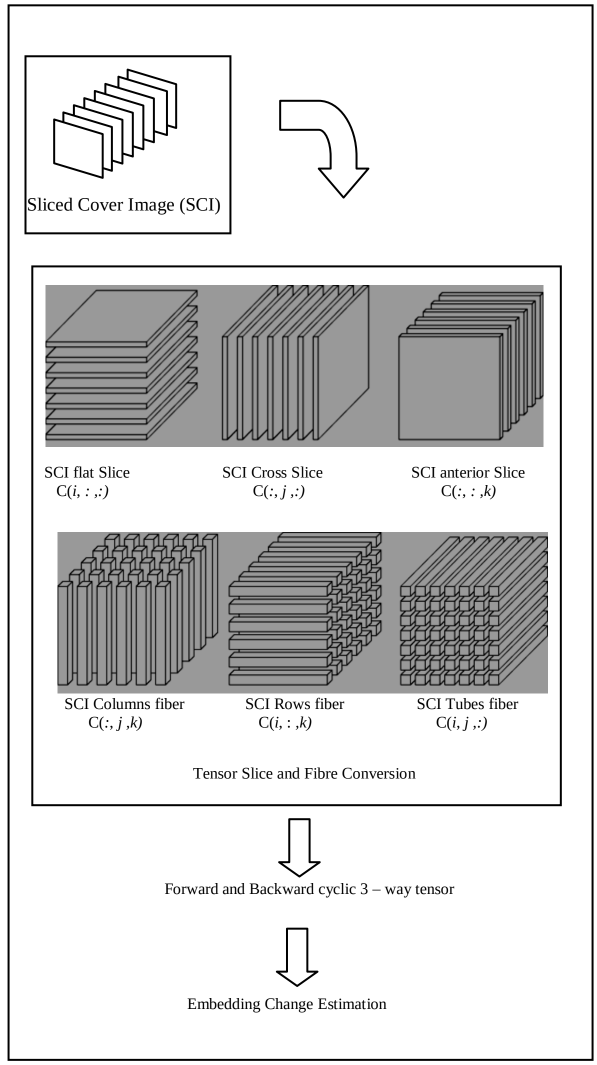


Figure 1: Proposed Frame work

B. Tensor Slice and Fibre Conversion

Let C be a Bit Sliced Tensor of dimension

$$C_1 \times C_2 \times \cdots \times C_N.$$

The *order* of C is N. The nth *dimension* (or *mode* or *way*) of C is of size C_n.

Let $C(i,:,:)$ acquiesce the ith SCI flat slice,
$C(:,j,:)$ the j th SCI Cross slice, and
$C(:,:,k)$ the kth SCI anterior slice
$C(:,j,k)$ yields a column fibers,
$C(i,:,k)$ yields a row fibers, and
$C(i,j,:)$ yields a so-called *tube* fibers
as shown in Figure 1..

Typically, a tensor is matricized such that all of the fibers associated with a particular *single* dimension are aligned as columns of the resulting matrix. In other words, we align the fibers of dimension n of tensor C to be the columns of the matrix. The resulting matrix is typically denoted by $\mathbf{C}_{(n)}$. The columns can be ordered in many ways. As discussed in [21], the ordering can be given as

C $\quad C_{(1)}, C_{(2)}, C_{(3)}$

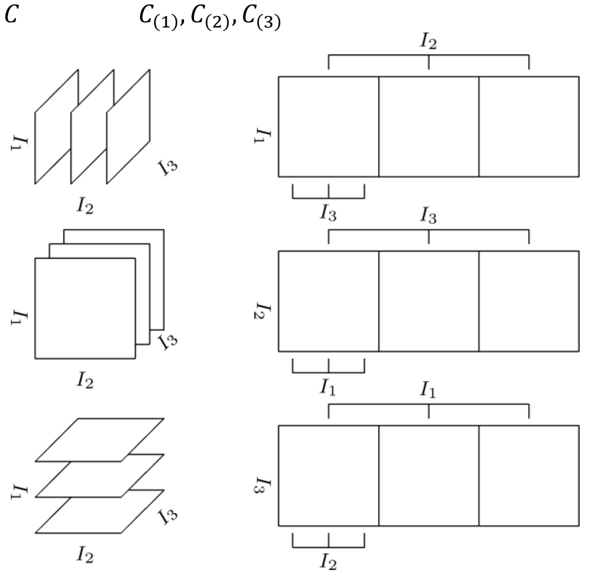


Figure 2: Backward cyclic matricizing a three-way tensor.

$$\{c_1, \ldots, c_L\} = \{n-1, n-2, \ldots, 1, N, N-1, \ldots, n+1\},$$

and this ordering is named as *backward cyclic*. As per [23], the ordering is specified as follows

$$\{c_1, \ldots, c_L\} = \{n+1, n+2, \ldots, N, 1, 2, \ldots, n-1\},$$

and this ordering is mentioned as *forward cyclic* or "fc" for short. This framework uses both backward and forward cyclic which is helpful for identifying the bit change rate.

Based on the matricizing process an Nth-order tensor is represented as follows

$$C \in \mathrm{R}^{I1 \times I2 \times \cdots \times IN}$$

The matrix Unfolding is represented as follows.

$$C_{(n)} \in \mathrm{R}^{I1In \times (In+1In+2 \cdots INI1I2 \cdots In-1) \times I2 \times \cdots \times IN}$$

C $\quad C_{(4)}, C_{(5)}, C_{(6)}$

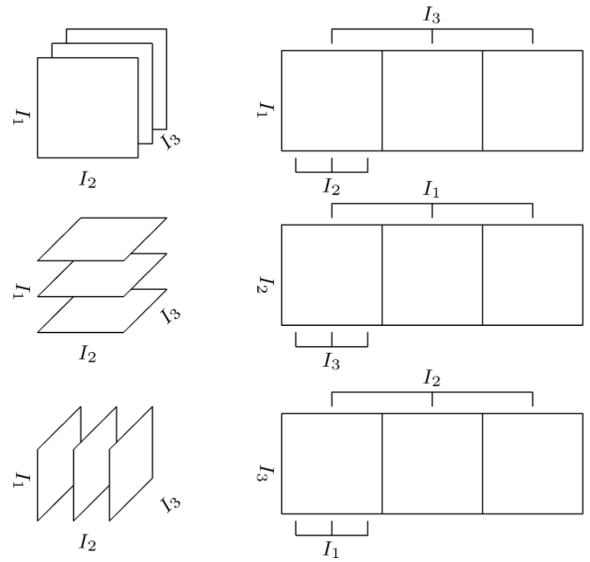


Figure 3. Forward cyclic matricizing a three-way tensor.

Which contains the element $a_{i1i2\cdots iN}$ at the position with row number i_n and column number equal to

$$(i_{n+1}-1)\ I_{n+2}\, I_{n+3} \ldots.\ I_N\, I_1\, I_2 \ldots..\ I_{n-1} + (i_{n+2}-1)\, I_{n+3}\, I_{n+4} \ldots.\ I_N\, I_1\, I_2 \ \ldots \ldots . I_{n-1} + (i_N - 1)\, I_1\, I_2 \ldots . I_{n-1} (\, i_1 - 1)\, I_2\, I_3 \ldots\ I_{n-1}$$

C. Embedding Change Estimation

Forward cyclic and backward cyclic matricizing creates 6 matrices from 3 way tensor. Rate of intensity change in a particular region of an image always have slight variation. Therefore by analyzing the change in the bit rate, embedding change rate can be estimated. To estimate the embedding change rate we use a methodology called as hamming distance.

Let us take the same elements which are shown in the previous section.

The element $a_{i1i2\cdots iN}$ at the position with row number i_n and column number equal to

$$(i_{n+1}-1)\ I_{n+2}\, I_{n+3} \ldots.\ I_N\, I_1\, I_2 \ldots..\ I_{n-1} + (i_{n+2}-1)\, I_{n+3}\, I_{n+4} \ldots.\ I_N\, I_1\, I_2 \ \ldots \ldots . I_{n-1} + (i_N - 1)\, I_1\, I_2 \ldots . I_{n-1} (\, i_1 - 1)\, I_2\, I_3 \ldots\ I_{n-1}$$

which is XORed with row number i_{n+1} and the corresponding column number is

$$(i_{n+2}-1)\ I_{n+3}\, I_{n+4} \ldots.\ I_N\, I_2\, I_3 \ldots..\ I_{n-2} + (i_{n+3}-$$

$$1)\ I_{n+4}\ I_{n+5} \ldots.\ I_N\ I_2\ I_3\ \ldots\ldots.I_{n-2} + (i_N - 1)\ I_2\ I_3 \ldots.I_{n-2}(\ i_2 - 1)\ I_2\ I_3 \ldots\ \ I_{n-1}$$

The number of change in bits can be estimated by counting the number of ones. This process can be repeated for all unfolded matrices.

Once the process is over, a graphical analysis can be done by plotting the rows of the unfolded matrix in the x axis and bit count change in the y axis as shown in the figure 4 and Table 1 and Table 2. Table 1 show 6 unfolded matrix bit change where $C_{(j)}$ and $C_{(k)}$ shows the bit change in original and embedded image in spatial domain using LSB matching steganography algorithm [12]. Table 2 show 6 unfolded matrix bit change where $C_{(j)}$ and $C_{(k)}$ shows the bit change in original and embedded image in Transform domain using LSB matching steganography algorithm [12].
The graph shown in the figure clearly shows that the input image given is the stego image since the bit change is not linear and it scatters.

III. Results and Discussions

The framework proposed is successfully tested in the data base provided by BOWS-2[34]. All images are tested with spatial domain steganography algorithms and Transform Domain Steganography algorithms. False Identification Rate (FIR) represents that the framework incorrectly identified that some bits are modified which concludes as a stego image. False Rejection Rate represents that the framework incorrectly identified that not bits are modified which concludes as a normal image. Table 3 clearly shows that the average detection rate for spatial domain is good with the proposed framework on the steganography algorithms [12], [16], [29], [30] is having less detection rate since the framework is applied to the full image. Detection rate can be increased by extracting the regions of an image and for each region the frame work can be applied. The average detection rate is based on the pay loads. The detection rate is less for low pay load where as good for high pay load.

IV. Conclusion

In this paper, a novel framework has been proposed based on 3 way tensor model. As a start of this invention, excellent results obtained for algorithms irrespective of domain. Also the framework was successful in both uniform and non uniform distribution of Stego-payloads. The disadvantage was the low average detection rate for [29] & [30] for spatial domain steganography algorithms and [27], [32] & [33] for transform domain steganography algorithms. To increase the average detection rate and to decrease the Average false acceptance rate and average false rejection rate, the proposed framework can be applied to regions in an image. If such implementation is done, then the steganalysis can be done for less payload and hence the average detection rate increases.

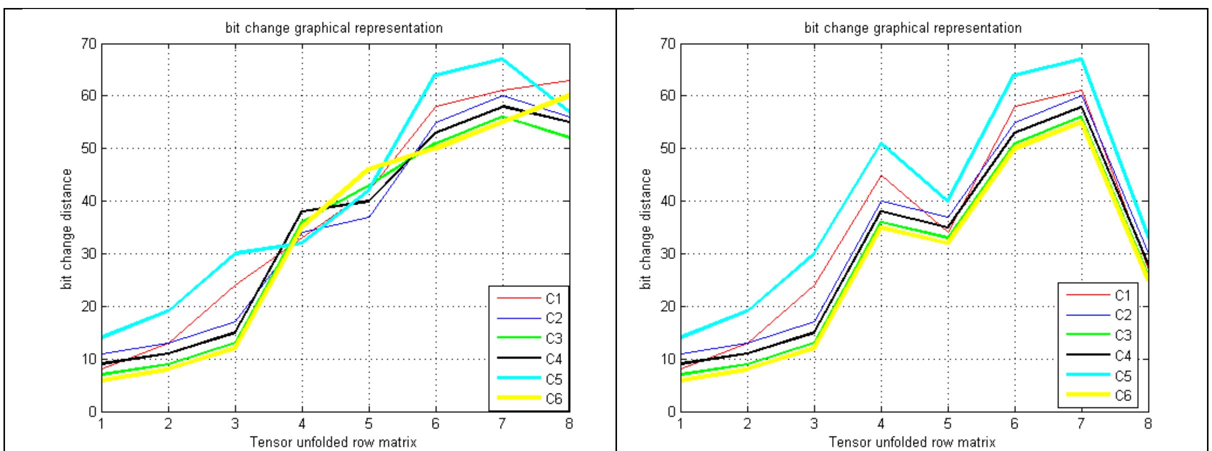


Figure 4 Spatial Domain (a) Bit change Estimation of Original Image (b) Bit change Estimation of Embedded Image as proposed in [12]

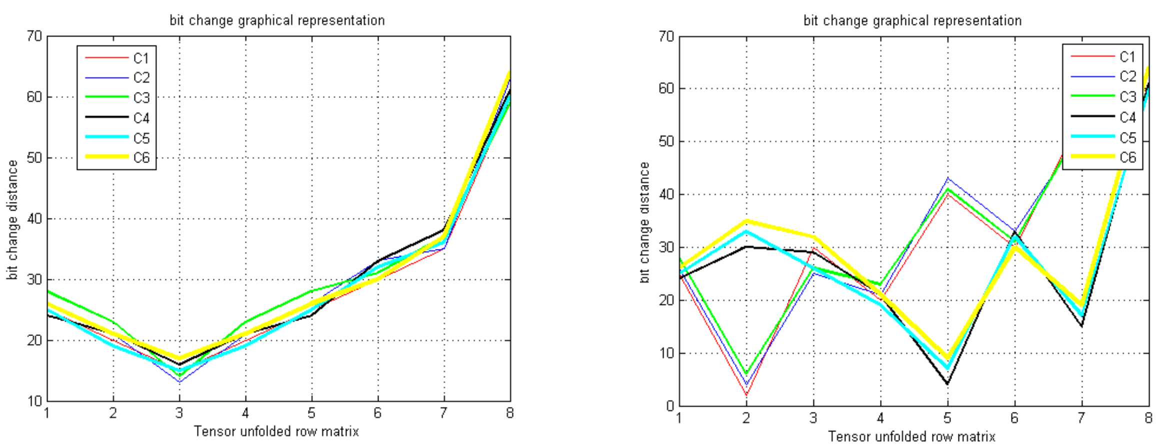
(a) (b)

Table 1: Change Estimation in the Forward and backward cyclic Matrix in spatial domain as per [12]

Unfolded Row Matrix	$C_{(1)}$		$C_{(2)}$		$C_{(3)}$		$C_{(4)}$		$C_{(5)}$		$C_{(6)}$	
	$C_{(j)}$	$C_{(k)}$	$C_{(j)}$	$C_{(k)}$	$C_{(j)}$	$C_{(k)}$	$C_{(j)}$	$C_{(k)}$	$C_{(j)}$	$C_{(k)}$	$C_{(j)}$	$C_{(k)}$
i_n	8	8	11	11	7	7	9	9	14	14	6	6
i_{n+1}	13	13	13	13	9	9	11	11	19	19	8	8
i_{n+2}	24	24	17	17	13	13	15	15	30	30	12	12
i_{n+3}	33	45	34	40	36	36	38	38	32	51	35	35
i_{n+4}	42	34	37	37	43	33	40	35	42	40	46	32
i_{n+5}	58	58	55	55	51	51	53	53	64	64	50	50
i_{n+6}	61	61	60	60	56	56	58	58	67	67	55	55
i_{n+7}	63	27	56	30	52	26	55	28	57	33	60	25

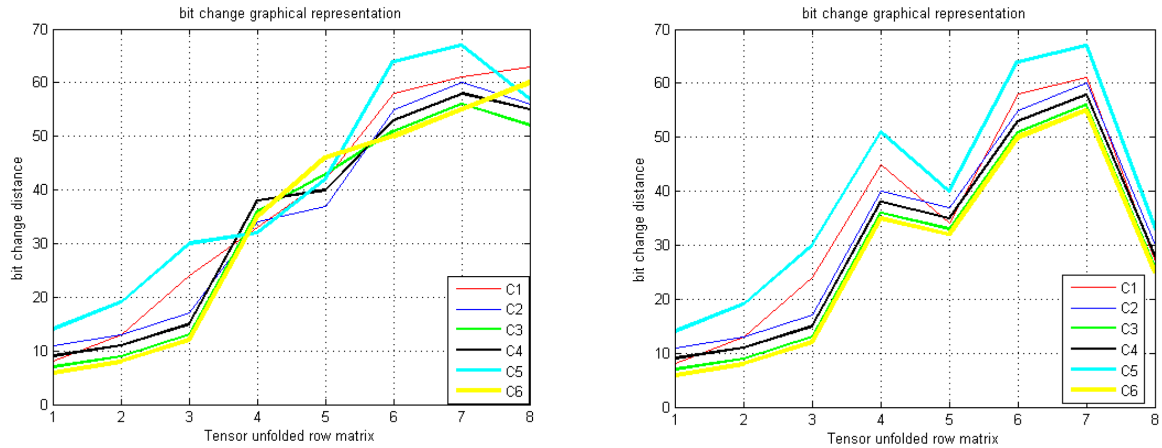
Table 2: Change Estimation in the Forward and backward cyclic Matrix in transform domain as per [27]

Unfolded Row Matrix	$\mathbf{C_{(1)}}$		$\mathbf{C_{(2)}}$		$\mathbf{C_{(3)}}$		$\mathbf{C_{(4)}}$		$\mathbf{C_{(5)}}$		$\mathbf{C_{(6)}}$	
	$\mathbf{C_{(j)}}$	$\mathbf{C_{(k)}}$	$\mathbf{C_{(j)}}$	$\mathbf{C_{(k)}}$	$\mathbf{C_{(j)}}$	$\mathbf{C_{(k)}}$	$\mathbf{C_{(j)}}$	$\mathbf{C_{(k)}}$	$\mathbf{C_{(j)}}$	$\mathbf{C_{(k)}}$	$\mathbf{C_{(j)}}$	$\mathbf{C_{(k)}}$
$\mathbf{i_n}$	**2**	**2**	**3**	**3**	**2**	**2**	**0**	**0**	**1**	**1**	**1**	**1**
$\mathbf{i_{n+1}}$	**5**	**5**	**6**	**6**	**4**	**4**	**7**	**7**	**5**	**5**	**6**	**6**
$\mathbf{i_{n+2}}$	**15**	**3**	**13**	**4**	**14**	**3**	**16**	**24**	**15**	**25**	**17**	**26**
$\mathbf{i_{n+3}}$	**20**	**4**	**21**	**5**	**23**	**3**	**21**	**33**	**19**	**32**	**21**	**30**
$\mathbf{i_{n+4}}$	**25**	**25**	**26**	**26**	**28**	**28**	**24**	**24**	**25**	**25**	**26**	**26**
$\mathbf{i_{n+5}}$	**30**	**30**	**33**	**33**	**31**	**31**	**33**	**33**	**32**	**32**	**30**	**30**
$\mathbf{i_{n+6}}$	**35**	**35**	**35**	**35**	**37**	**37**	**38**	**38**	**36**	**36**	**37**	**37**
$\mathbf{i_{n+7}}$	**40**	**40**	**39**	**39**	**38**	**38**	**39**	**39**	**41**	**41**	**40**	**40**



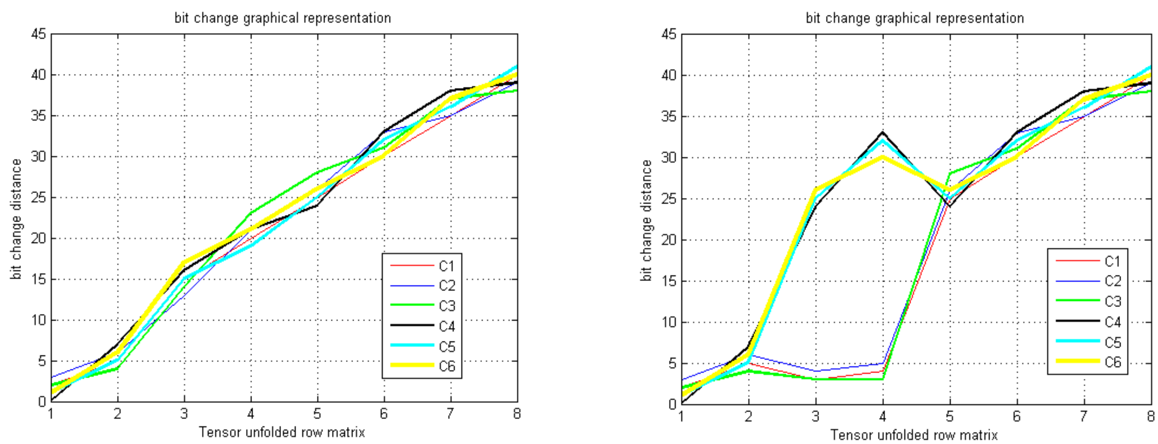
(a) (b)

Figure 5 Spatial Domain (a) Bit change Estimation of Original Image (b) Bit change Estimation of Embedded Image as proposed in [16]



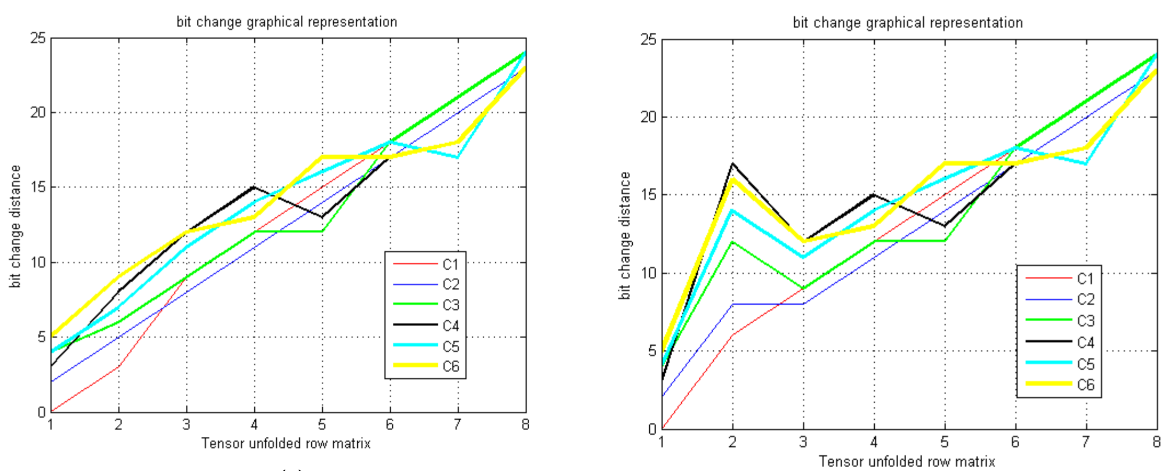
(a) (b)

Figure 6 Spatial Domain (a) Bit change Estimation of Original Image (b) Bit change Estimation of Embedded Image as proposed in [29]



(a) (b)

Figure 7 Transform Domain (a) Bit change Estimation of Original Image (b) Bit change Estimation of Embedded Image as proposed in [27]



(a) (b)

Figure 8 Transform Domain (a) Bit change Estimation of Original Image (b) Bit change Estimation of Embedded Image as proposed in [28]

Table 3: Detection Analysis of Spatial Domain Algorithms			
Algorithm	Average Detection Rate	Spatial Domain	
		Average False Acceptance Rate	Average False Rejection Rate
[12]	76.23%	3.6%	.25%
[16]	82.1%	4.12%	1.67%
[29]	65.76%	9.55%	8%
[30]	72.03%	5.21%	5.34%

Table 4: Detection Analysis of Transform Domain Algorithms

Algorithm	Average Detection Rate	Spatial Domain	
		Average False Acceptance Rate	Average False Rejection Rate
JP Hide&Seek (JPHS) [31]	86.23%	0.32%	0
Jsteg [28]	89.51%	0.76%	0.47%
MBS1 [27]	76.39%	1.43%	0.238%
MMx [32]	74.12%	1.58%	1.3%
nsF5 [33]	70.28%	3.2%	1.72%

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