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An Adaptive Steganography Scheme Based on Visual Quality and Embedding Capacity Improvement

Mojtaba Bahmanzadegan Jahromi*, Karim Faez**

* Department of Computer Engineering, Science and Research Branch, Islamic Azad University, Qazvin, Iran
** Electrical Engineering Department, Amirkabir University of Technology, Tehran, Iran

Article Info	ABSTRACT
	In this paper, a steganography technique using LSB substitution and PVD method is presented as an adaptive scheme in the spatial domain. Our method partitions the grayscale image into several non-overlapping blocks with three consecutive pixels. The embedding algorithm can both replace the secret data with the LSBs of the middle pixel and embed it in the difference values between the middle pixel and its two neighboring pixels of the cover-block. The number of secret bits is determined adaptively based on the range divisions for embedding in the difference value. We define a new range division on gray level which takes into account a larger embedding capacity for bits. After the embedding, the proposed method detects the pixels which are sensitive to hyper distortion. Then, the embedding process will be repeated to produce insignificant visual distortion in those pixels. Our experimental results demonstrate that this iterative steganography scheme prevents significant visual distortion into stego-image. The generated PSNR values are higher than the corresponding values of the most commonly used methods, discussed in this study. Furthermore, the experimental results show that the hiding capacity increased enormously when the proposed range division is used. Finally, we illustrate that the method can pass RS and steganalysis detector attacks.

Corresponding Author:

Mojtaba Bahmanzadegan Jahromi,
Faculty of Computer and Information Technology Engineering,
Qazvin Branch Islamic Azad University,
Barajin University Road, Qazvin, Iran.
Email: bahmanzadegan@qiau.ac.ir

1. INTRODUCTION

In recent years, data security has become one of the most important issues of human societies due to increased data transmission over computer networks [1]. In this context, secret communication science has been presented to increase information security. Steganography is one of the most important techniques used to provide safe communication and hide secret messages [2]. It has been used since ancient times and then turned into an integral part of the digital era after the development of computers [3]. In fact, steganography is carried out by hiding secret messages into a cover media such as text, image, video, etc. In this paper, an image has been used as the cover-image and the result image of the embedding process is named stego-image. In contrast, steganalysis is the science of finding such hidden messages [4].

Visual quality, embedding capacity, and information security are three features investigated by researchers in steganographic evaluation. Moreover, the purpose of steganography is to render secret messages imperceptible. Although it is impossible to achieve excellent results for all these features in a steganography scheme, acceptable levels can be realized. However, none of them should be prioritized over the other two.

In a steganography method, the secret message hiding process involves two basic steps. The first step is embedding and the second is extracting. In the embedding phase, a cover image is chosen based on the steganography algorithm performance, suitably for secret data and the cover characteristics. The steganography scheme specifies appropriate regions of the cover-image and then embeds the secret message into them. Then, the resulting stego-image is forwarded to the receiver. In the extracting phase, the receiver gives the stego to the extraction function and the secret message will be extracted.

In view of putting secret data into the cover-image, existing steganography methods can be divided into two general groups: (i) Transform domain methods, (ii) Spatial domain methods. The transform domain approaches [5]-[9] convert the cover-image into another domain (like the frequency) first, and then embed the secret message into the transformed coefficients. Although these methods adequately resist against steganalysis attacks, their time complexity is high. In proposed spatial domain methods [10]-[21], the secret data is embedded directly into the cover-pixel value. Due to their low time complexity, these methods are quite common. Although these techniques provide high embedding capacity, the stego-image quality is consumedly reduced at higher hiding capacities. Increase in their embedding capacity while maintaining acceptable quality appears to have become a challenge. Here, we proposed a method to provide good stego quality at higher capacities.

Spatial domain approaches can be divided into three main categories: (i) LSB replacement methods, (ii) Edge adaptive methods, (iii) Hybrid methods. In LSB replacement methods, LSBs of pixels are used to hide secret messages [10]-[13]. The LSB substitution is a well-known technique in this group. Although these methods provide a large embedding capacity, they are very susceptible to steganalytic attacks. In general, eyes detect changes in smooth areas with additional capabilities than edge areas based on human visual system (HVS) characteristics. The second type of spatial domain methods [14]-[17] is the edge adaptive methods using this feature. The PVD method [14] is an example of this group. This method computes the secret data embedding capacity by the difference values between each pixel and its neighboring pixels. Although the edge adaptive methods produce high visual quality, their hiding capacity is low compared with other techniques like LSB and the like. Recently in [18]-[21], the LSB substitution and the edge adaptive methods have been combined. Thus, the third type of spatial domain methods is the hybrid methods which hide in both LSBs and difference values between neighboring pixels. These are the approaches with which researchers have tried to obtain acceptable values for each of the three features important in the steganographic evaluation. The scheme proposed by Khodaei et al. [19] offers acceptable visual quality and large embedding capacity of stego-image among other methods in this category.

In this paper, a hybrid technique is proposed using LSB replacement and PVD method. The scheme both enhances the hiding capacity and improves the visual quality at higher capacities. Three different advantages of our scheme in comparison with other methods are as follows:
1. By defining new range division on gray level R=[0,255], we are able to embed large secret bits, higher than the Yang et al.'s [15], the Wu et al.'s [18] and the Khodaei et al.'s [19] techniques.
2. Our scheme prevents large difference values between the cover image and its stego-image's pixels, unlike the Khodaei et al.'s [19] technique. Thus, it produces insignificant visual distortion in hidden messages.
3. Finally, our algorithm resists against RS steganalysis attack, unlike the Wu et al.'s [18] and the Yang et al.'s [15] methods.

The remainder of this paper is organized as follows. In Section 2, we review two well-accepted data embedding schemes using the LSB replacement and the PVD method. Then, in Section 3, we present our proposed method. Experimental results will be described and compared with the Yang et al.'s [15], the Wu et al.'s [18] and the Khodaei et al.'s [19] methods in Section 4. Finally, the conclusion follows in Section 5.

2. ANALYSIS OF RELEVENT APPROACHES
Here, we will describe two most commonly used methods in the next subsections. These techniques use the combination of LSB replacement and the PVD method in spatial domain.

2.1. Steganographic Method using LSB Substitution and PVD
Wu et al. [18] proposed a steganographic method for grayscale images in 2005. Suppose that $R_j = [l_j, u_j]$ and (j = 1,2, ...,5) where l_j and u_j are the lower and upper bound values and $|R_j|$ is the length of the R_j range. This approach divides the R=[0,255] range to the sub-ranges $R_1 = [0, 15]$, $R_2 = [16, 31]$, $R_3 = [32, 63]$, $R_4 = [64, 127]$ and $R_5 = [128, 255]$. The *div* defines the location of range divisions where $div \in \{15,31,63,127\}$. Then, the sub-ranges which are lower than *div* fall into the 'lower level' and the other

sub-ranges are located in the 'higher level'. For instance, Figure 1 shows a division on the gray level when $div = 31$.

At first, this method partitions the cover-image into several non-overlapping blocks having two consecutive pixels, denoted by (p_i, p_{i+1}). For each block, the difference value d_i is calculated by $d_i = |p_i - p_{i+1}|$ where i is the block number. Afterwards, two scenarios may occur in the secret data embedding process:

> Case 1 (If the difference value d_i falls into the lower level): in this case, the LSB replacement method is used to embed 6bits of secret data.
>
> Case 2 (If the difference value d_i is placed in the higher level): the PVD method is used to embed the secret bits. In this case, the number of embedded bits t_i is calculated by $t_i = |log_2(|R_j|)|$.

2.2. Adaptive Steganographic Method using LSB Substitution and PVD

Khodaei *et al.* [19] introduced an adaptive steganographic method for grayscale images in 2011. Suppose that $R_j = [l_j, u_j]$ and (j = 1,2, ... ,5) where l_j and u_j are the lower and upper bound values. The length of R_j is denoted by $|R_j|$. As demonstrated in Figure 2, this method locates the sub-ranges $R_1 = [0, 7]$, $R_2 = [7, 15]$, $R_3 = [16, 31]$, $R_4 = [32, 63]$ and $R_5 = [64, 255]$ in two levels, denoted by 'lower level' and 'higher level'. Then, it defines *Type1* and *Type2* divisions on the gray level. In the *Type1* division shown in Figure 2a, the sub-ranges $R_1 = [0, 7]$، $R_2 = [7, 15]$ and $R_3 = [16, 31]$ are located in the 'lower level' and the sub-ranges $R_4 = [32, 63]$ and $R_5 = [64, 255]$ fall into the 'higher level'. It hides $t_j = 3$ bits of secret data in the sub-ranges of the lower level, and conceals $t_j = 4$ bits of secret data in the sub-ranges of the higher level. Also, in *Type2* division shown in Figure 2b, the sub-ranges $R_1 = [0, 7]$, $R_2 = [7, 15]$, $R_3 = [16, 31]$ and $R_4 = [32, 63]$ belong to the 'lower level' and $R_5 = [64, 255]$ is assigned to the 'higher level'. In this division type, the number of secret bits t_i is calculated in the lower level, by $t_j = |log_2(|R_j|)|$ and in the higher level, by $t_j = |log_2(|l_j|)|$.

At first, this method partitions the cover-images into several non-overlapping blocks with three consecutive pixels, denoted by B_i where i is the block number. The k and $k\epsilon\{3,4,5,6\}$ define the number of secret bits that can be embedded in the LSBs. Therefore, the embedding capacity will grow as k is increased. The type of range division and the k value should be selected in the data embedding process first. For each cover block, the k-bits of secret data are substituted for the k-LSB of middle pixel p_{ic} and p'_{ic} is obtained. Then, the values d_{i1} and d_{i2} are calculated by the difference between the middle pixel p'_{ic} and its two neighboring pixels p_{i1} and p_{i2}. The R_{j1} and R_{j2} ranges to which d_{i1} and d_{i2} belong, are selected from the considered range division. The new difference values d'_{i1} and d'_{i2} are calculated by the number of secret bits t_{j1} and t_{j2} and the upper and the lower bounds of their ranges. Finally, taking the new difference values d'_{i1} and d'_{i2} into consideration, the method produces two values for each pixel. Whereas one of them has much difference compared with the original value of cover-image, the similar value is chosen for its stego-image.
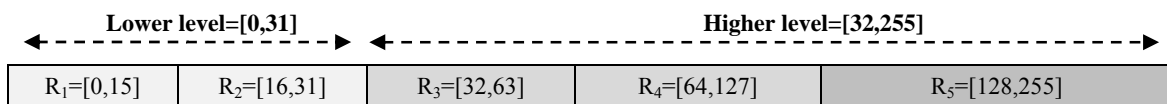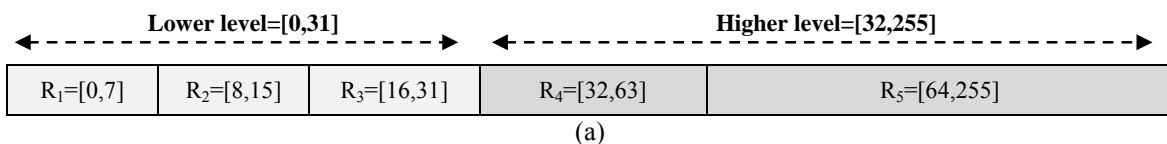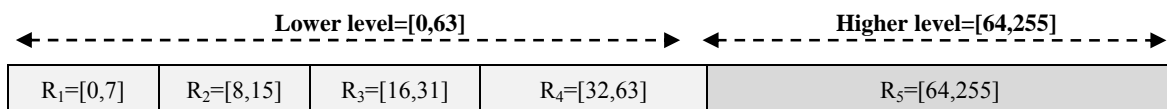
Lower level=[0,31]		Higher level=[32,255]		
R₁=[0,15]	R₂=[16,31]	R₃=[32,63]	R₄=[64,127]	R₅=[128,255]

Figure 1. An example of range division on gray level (R=[0,255]) into 'lower level' and 'higher level' in the *Wu et al.* method (*div*=31)

Lower level=[0,31]			Higher level=[32,255]	
R₁=[0,7]	R₂=[8,15]	R₃=[16,31]	R₄=[32,63]	R₅=[64,255]

(a)

Lower level=[0,63]			Higher level=[64,255]	
R₁=[0,7]	R₂=[8,15]	R₃=[16,31]	R₄=[32,63]	R₅=[64,255]

(b)

Figure 2. Two range divisions on gray level ($R = [0,255]$) into 'lower level' and 'higher level' in the *Khodaei et al.* method, a) Type1, b) Type2

3. THE PROPUSED METHOD

In this section, we will define our proposed method for grayscale images. The aims of proposing this method are finding sensitive pixels to the hyper distortions and extending the data embedding process recursively. Also, the method will be increase the hiding capacity through defining a new range division. Our proposed method is presented in three phases: *(i)* Range division on gray level phase, *(ii)* Data embedding process, (iii) Data extracting process, in the following subsections.

3.1. Range Divisions on Gray Level Phase

Here, we consider two range divisions on gray level, *Type1* and *Type2*. The *Type1* division is used to compare the proposed method with the other related methods based on the visual quality, specified by the Khodaei *et al.* [19] method. Additionally, the *Type2* division is defined as our proposed range division in order to achieve a larger embedding capacity. First, suppose that $R_j = [l_j , u_j]$ and (j = 1,2, ... ,5) where l_j and u_j are the lower and upper bound values. The width of R_j is denoted by $|R_j|$.

3.1.1. Type 1 Division

Here, the sub-ranges $R_1 = [0, 7]$, $R_2 = [7, 15]$, $R_3 = [16, 31]$ and $R_4 = [32, 63]$ are put in the 'lower level' and the sub-range $R_5 = [64, 255]$ in the 'higher level', according to the Khodaei *et al.'s* division shown in Figure 2b. In this type of range division, the number of secret bits t_i is calculated by $t_j = |log_2(|R_j|)|$ in the sub-ranges of the lower level and by $t_j = |log_2(|l_j|)|$ in the higher level. So, the number of the embedded bits for R_j where (j = 1,2, ... ,5) will be $t_1 = 3$, $t_2 = 3$, $t_3 = 4$, $t_4 = 5$ and $t_5 = 6$.

3.1.2. Type 2 Division

We assign the sub-range $R_1 = [0, 7]$ to the 'lower level', the sub-ranges $R_2 = [7, 15]$, $R_3 = [16, 31]$ and $R_4 = [32, 63]$ to the 'middle level', and the sub-range $R_5 = [64, 255]$ to the 'higher level', in the proposed *Type2* division shown in Figure 3. Here, the number of secret bits t_i is calculated by $t_j = |log_2(|R_j|)|$ in the sub-range of the lower level, by $t_j = |log_2(|l_j|)|+1$ in the middle level, and by $t_j = |log_2(|l_j|)|$ in the higher level. Thus, it will be $t_1 = 3$, $t_2 = 4$, $t_3 = 5$, $t_4 = 6$ and $t_5 = 6$ for R_j and (j = 1,2, ... ,5).

3.2. Data Embedding Process

First, one of the *Type1* or the *Type2* divisions should be selected. The flow diagram of the proposed steganography scheme is illustrated in Figure 4. We suggest 12 steps for the proposed data embedding process in the following procedure:

Step 1: A grayscale image is partitioned into non-overlapping bocks having three consecutive pixels. The first pixel, middle pixel and second pixel are denoted by (p_{i1}, p_{ic}, p_{i2}), where *i* is the number of the block. *S* also denotes the secret data.

Step 2: Consider the *k* value where $k\epsilon\{3,4,5,6\}$ is the number of the secret bits that can be embedded in LSBs. Then, the embedding capacity is increased by the higher value of *k*. Thus, p'_{ic} is obtained by putting *k-leftmost* bits of the binary secret data (*S*) into *k-rightmost* bits of LSBs of p_{ic}.

Step 3: Compute the difference value *d* between LSB_i and s_{ic} using Eq. (1).

$$d = LSB_i - s_{ic} \tag{1}$$

where LSB_i is the decimal value of *k-rightmost* LSBs of p_{ic} and s_{ic} is the decimal value of *k-leftmost* bits of *S*.

Step 4: Use optimal pixel adjustment process (OPAP) [15] and alter the value of p'_{ic}, as shown in Eq. (2).

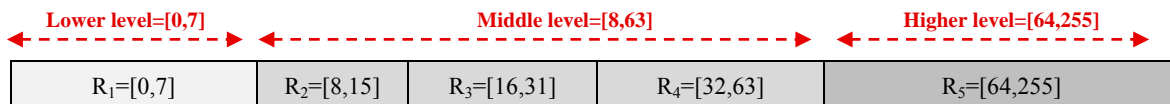| Lower level=[0,7]	Middle level=[8,63]			Higher level=[64,255]
R_1=[0,7]	R_2=[8,15]	R_3=[16,31]	R_4=[32,63]	R_5=[64,255]

Figure 3. The new proposed *Type2* division on gray level ($R = [0,255]$) containing the 'lower level', the 'middle level' and the 'higher level
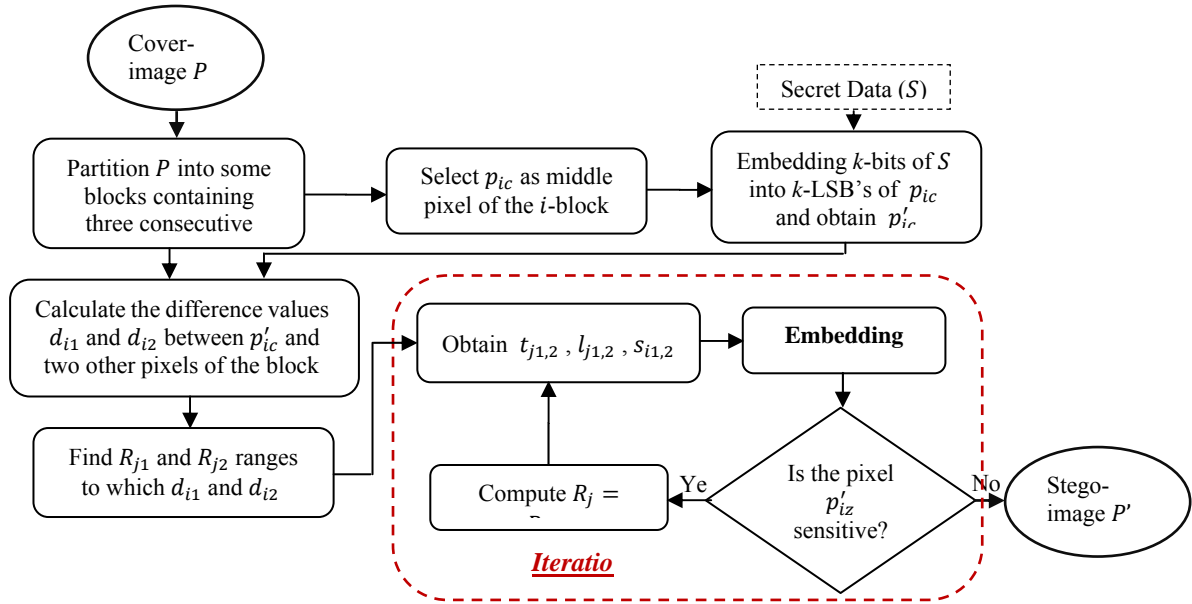
Figure 4. Block diagram of the iterative embedding process

$$p'_{ic} = \begin{cases} p'_{ic} + 2^k & if \ \ d > 2^{k-1} \ \ and \ \ 0 \le p'_{ic} + 2^k \le 255 \\ p'_{ic} - 2^k & if \ \ d < -2^{k-1} \ \ and \ \ 0 \le p'_{ic} - 2^k \le 255 \\ p'_{ic} & otherwise \end{cases} \quad (2)$$

Step 5: Calculate the difference values, d_{i1} and d_{i2}, between the middle pixel p'_{ic} and its two neighboring pixels p_{i1} and p_{i2} of the cover-block by Eq. (3).

$$d_{i1} = |p_{i1} - p'_{ic}| \quad , \quad d_{i2} = |p_{i2} - p'_{ic} \quad (3)$$

Step 6: Find the R_{j1} and R_{j2} ranges of the range division in question if d_{i1} and d_{i2} belong to the ranges.
Step 7: Obtain the numbers of binary secret bits t_{j1} and t_{j2} and find the lower bounds l_{j1} and l_{j1} of the corresponding R_{j1} and R_{j2} ranges.
Step 8: Select t_{j1} and t_{j2} bits of S, and transform the two bit sequences to decimal values s_{i1} and s_{i2}.
Step 9: Calculate the new difference values d'_{i1} and d'_{i2} using Eq. (4).

$$d'_{i1} = l_{j1} + s_{i1} \quad , \quad d'_{i2} = l_{j2} + s_{i2} \quad (4)$$

Step 10: Calculate p'_{i1} and p'_{i2} values for the first and the third pixels in the block, by obtaining the difference between the original value and the new value of them using Eq. (5).

$$p'_{i1} = \begin{cases} 1. \ p'_{ic} - d'_{i1} & if \ p'_{ic} \ge d'_{i1} \\ 2. \ p'_{ic} + d'_{i1} & if \ p'_{ic} < d'_{i1} \end{cases}, \ p'_{i2} = \begin{cases} 1. \ p'_{ic} - d'_{i2} & if \ p'_{ic} \ge d'_{i2} \\ 2. \ p'_{ic} + d'_{i2} & if \ p'_{ic} < d'_{i2} \end{cases} \quad (5)$$

Step 11: Detect the sensitive pixels: four conditions will be checked for p'_{iz} in this step where $z\epsilon\{1,2\}$ and (p'_{i1}, p'_{i2}).
    I.   If $(p'_{iz} < 0)$: the under-flow problem occurred.
    II.   If $(p'_{iz} > 255)$: the over-flow problem happened.
    III.   If $(d'_{iz} \notin R_j)$: the difference value between stego and its cover is wrong.
    IV.   If $(l_{jz} > 0)$: the embedding process can be repeated.
       Thus, if at least one of the first three conditions as well as the last condition are satisfied, or $((p'_{iz} < 0) \lor (p'_{iz} > 255) \lor (d'_{iz} \notin R_j)) \land (l_{jz} > 0)$ is true, the p'_{iz} is sensitive on the embedded secret bits and the embedding procedure can also be repeated.
Step 12: Define two cases for p'_{iz} where $z\epsilon\{1,2\}$ and (p'_{i1}, p'_{i2}) as follows
    I. Case 1 (p'_{iz} is sensitive)

- Find R_{jz-1} range as the previous range through R_{jz} of the selected division.
- Redo embedding process from step 7 to 11 for p'_{iz}.

II. Case 2 (p'_{iz} is insensitive)

- Consider the value of p'_{iz} calculated in Step10. When p'_{iz} falls into the under-flow or in the over-flow problem, the second value should be calculated in Step10.

Finally, the stego-block will be produced. Please note that the above procedure should be repeated for each cover-block. Thus, the secret message will be embedded completely in the cover image and its stego-image will be produced.

3.3. Data Extracting Process

For secret message extraction, suppose that the type of range division and the k value used in the embedding phase are available. Meanwhile please note that their values have been considered based on the purpose of hiding. This procedure is started with dividing the stego-image into non-overlapping blocks each of which 3×3 pixels. For each block as i-block, k-bits of the middle pixel p'_{ic} should be selected. This sequence of bits is placed in the rightmost of secret bits (S). Then, we calculate the difference values d'_{i1} and d'_{i2} between the middle pixel p'_{ic} and its two neighboring pixels p'_{i1} and p'_{i2} of the stego-block, using Eq. (6).

$$d'_{i1} = |p'_{i1} - p'_{ic}| \quad , \quad d'_{i2} = |p'_{i2} - p'_{ic}| \tag{6}$$

The R_{j1} and R_{j2} ranges to which d'_{i1} and d'_{i2} belong are. The lower bound values l_{j1} and l_{j2} and the number of embedded bits t_{j1} and t_{j2} are chosen, considering these ranges. Therefore, the secret values are calculated by Eq. (7).

$$s_{i1} = d'_{i1} - l_{j1} \quad , \quad s_{i2} = d'_{i2} - l_{j2} \tag{7}$$

In the final step, s_{i1} and s_{i2} values are converted into their binary sequences based on the number of the bits t_{j1} and t_{j2}. Then, these binary sequences should be added to the rightmost of the secret bits (S). Finally, the secret message will be extracted properly without any distortion.

3.4. Simple Example of the Proposed Method
In this section, we will implement a simple example of the proposed method. The next subsections present the data embedding and extracting processes. Thus, we will demonstrate that secret bits are properly embedded and extracted using our proposed method.

I. Data embedding process: *Step1*, we will use *Type1* division and $k = 3$ for this example. The secret message is $S = (1101000011010)$ and the selected block contains the three pixels $p_{i1} = 109$ and $p_{ic} = 44$ and $p_{i2} = 3$. *Step2*, the k-leftmost of secret bits should be replaced with k-LSBs of p_{ic}. The binary value of the middle pixel is $p_{ic} = 44 = (101100)_2$, so the decimal value will be $p'_{ic} = (101110)_2 = 46$. *Step3*, the difference value d is calculated between $LSB_i = 4$ that is the decimal value of k-LSBs of p_{ic} and $s_{ic} = 6$ that is the decimal value of k-leftmost of the secret bits by $d = 4 - 6 = -2$. *Step4*, we obtain $p'_{ic} = 46$ using OPAP [21]. *Step5*, the difference value is calculated between p'_{ic} and the other two pixels p_{i1} and p_{i2} by $d_{i1} = |109 - 46| = 63$ and $d_{i2} = |3 - 46| = 43$. *Step6*, the value $d_{i1} = 63$ is in R_4 and $d_{i2} = 43$ is in R_4 considering the *Type1* division. *Step7*, the values $t_{j1} = 5$ and $t_{j2} = 5$ that are the number of secret bits and $l_{j1} = 32$ and $l_{j2} = 32$ that are the lower bound values of the corresponding ranges are obtained. *Step8*, the five bits of the secret message is selected and converted into the decimal value as $s_{i1} = (10000)_2 = 16$. In addition, five of secret bits are transformed to the decimal value as $s_{i2} = (11010)_2 = 26$. *Step9*, the new difference values is calculated using (4) as $d'_{i1} = 32 + 16 = 48$ and $d'_{i2} = 32 + 26 = 48$. *Step10*, the new values $p'_{i1} = 94$ and $p'_{i2} = -12$ are calculated. *Step11*(z = 1), the p'_{i1} is an insensitive pixel because of the ($p'_{i1} > 0$) and ($p'_{i1} < 255$) and ($d'_{i1} \in R_4$) conditions. *Step12*(z = 1), $p'_{i1} = 94$ should be considered in accordance with the first stage of this step. *Step11*(z = 2), based on two conditions ($p'_{i2} < 0$) and ($l_{j2} > 0$), the p'_{i2} is a sensitive pixel. *Step12*(z = 2), therefore, we consider $R_{4-1} = R_3$ range of *Type1* division based on the second case of this step. Then, the embedding process repeats step 7 to 11 for p'_{i2}. *Step7*, the number of secret bits and the lower bound value are $t_{j2} = 4$ and $l_{j2} = 16$ based on R_3 range of *Type1* division. *Step8*, the four bits of the secret message is chosen and converted into the decimal value as $s_{i2} = (1101)_2 = 1$. *Step9*, the difference value is calculated as $d'_{i2} = 16 + 13 = 29$. *Step10*, the new value $p'_{i2} = 17$ is calculated. *Step11*, there are three conditions ($p'_{i2} > 0$) and ($p'_{i2} < 255$) and ($d'_{i2} \in R_3$). So, p'_{i2} is an insensitive pixel. *Step12*, based on the first case of this step, the final

value is $p'_{i2} = 17$. Finally, the secret message $S = (110100001101)$ is embedded properly in the three pixels $p'_{i1} = 94$ and $p'_{ic} = 46$ and $p'_{i2} = 17$ of the stego-block.

　　　　II. Data extracting process: We used *Type1* division and $k = 3$ and divided the cover image into some blocks having three pixels in the embedding phase. At first, the value of the middle pixel p'_{ic} is converted into binary value as $p'_{ic} = (101110)_2$. The *three LSBs* of p'_{ic} are selected as the *three rightmost* bits of secret data. Then, we calculate the difference values $d'_{i1} = |94 - 46| = 48$ and $d'_{i2} = |17 - 46| = 29$ by Eq. (6). Based on the *Type1* division and the R_4 range to which d'_{i1} belongs, the values $l_{j1} = 32$ and $t_{j1} = 5$ are obtained. So, s_{i1} is $s_{i1} = 48 - 32 = 16$ by Eq. (7) and its binary value is $s_{i1} = (10000)_2$. Moreover, $t_{j2} = 4$ and $l_{j2} = 16$ are considered using the *Type1* division and the R_3 to which d'_{i2} belongs. Based on Eq. (7), the value of $s_{i2} = 29 - 16 = 13$ is $s_{i2} = (1101)_2$, when $t_{j2} = 4$. The s_{i1} and s_{i2} bit sequences are added to the secret bits (S). Finally, we could extract the secret message $S = (110100001101)$, correctly.

4.   EXPERIMENTAL RESULTS AND ANALYSIS
　　　　In this section, we demonstrate the effectiveness of our proposed scheme compared with the Wu *et al.'s* [18], the Yang *et al.'s* [15] and also the Khodaei *et al.'s* [19] methods. We present some experimental results obtained using 10 cover images with 512×512 image resolutions. All the cover images have been transformed to grayscale images. Cover images include *Baboon*, *Barbara*, *Boat*, *Cameraman*, *Lena*, *Livingroom*, *Peppers*, *Pirate*, *Tiffany* and *Zelda*. Furthermore, the secret bits are produced by a Random Number Generator (RNG). Generally, visual quality, hiding capacity and information security are used in evaluations of a given steganography algorithm. The proposed method provides high data security with higher visual quality while its embedding capacity will be larger than the well-known methods.

　　　　The Peak Signal to Noise Ratio (PSNR) value is used to evaluate the distortions of stego-image. We compute the PSNR value in dB by Eq. (8), where the Mean Square Error (MSE) is calculated, as shown in Eq. (9). In Eq. (9), *m* is the shared size of cover *P* and stego *P'* images.

$$PSNR = 10 \times Log\left(\frac{(255)^2}{MSE}\right) \tag{8}$$

$$MSE = \frac{1}{m}\sum_{i=1}^{m}(p_i - p'_i)^2 \tag{9}$$

　　　　Furthermore, let *E* be the total bits of an embedded message into a stego-image. As shown in Eq. (10), we calculate E_{bpp} as the average capacity in bit per pixel(bpp), where S is the number of secret bits and m is the size of the cover-image.

$$E_{bpp} = S/m \tag{10}$$

4.1. Visual Quality
　　　　Here, we will measure the visual quality of stego-images produced by our proposed method using subjective and objective means of measurement. In addition, the number of sensitive pixels will be calculated to justify the effectiveness of our proposed method to provide better visual quality.

4.1.1. Subjective Measurement
　　　　The secret message imperceptibility to the human eye is the main goal of all steganography techniques. In other words, the human eye, as a means of as a subjective measurement, should be unable to notice the secret message in cover. Our first test case measured the stego-image by the vision system. We embedded the maximum secret data using the *Type1* division and various *k* values on *Peppers* cover-image. Figure 5a and Figure 5b show the cover and its stego. Moreover, the difference between the selected region of the stego and the corresponding region of its cover is presented in Figure 5c.
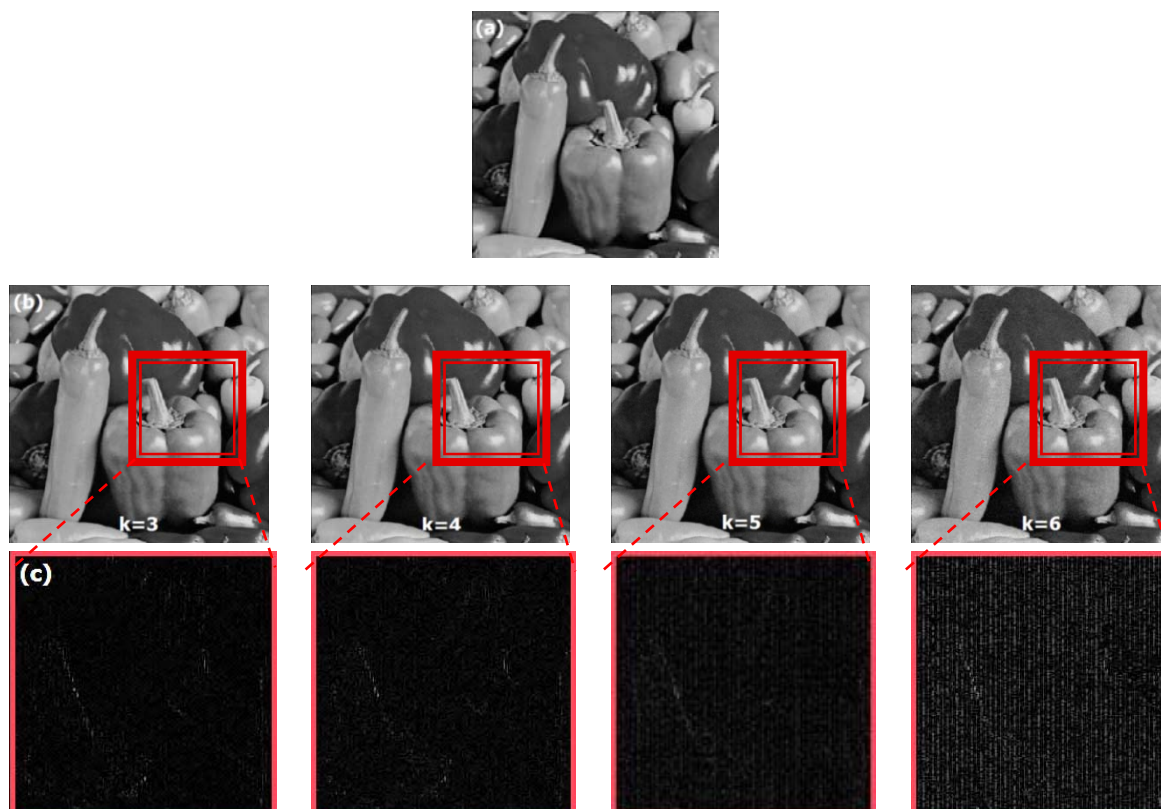
Figure 5. *Stego-image quality analysis*: Embedding the secret bits by using the proposed method with *type1* division and $k = 3$, a) cover-image, b) stego-images, c) difference between the selected region of stego-image and its corresponding cover-image region (*k=3*: $PSNR = 38.95$ dB, $Capacity = 806058$ bits. *k=4*: $PSNR = 36.64$ dB, $Capacity = 896273$ bits. *k=5*: $PSNR = 33.46$ dB, $Capacity = 1002440$ bits. *k=6*: $PSNR = 32.61$ dB, $Capacity = 1157767$ bits

Unlike the Khodaei *et al.'s* [19] technique, our scheme prevents large difference values between the cover and its stego-image's pixels. Thus, the emergence of significant visual distortion is prevented through the proposed method, and the secret message is invisible as tested by the human visual system (HVS).

4.1.2.   Objective Measurement

We experiment our proposed method using the *Type1* and *Type2* divisions and different *k* values on the cover images. Table 1 presents the number of the sensitive pixels and the PSNR values of the stego-images. The proposed method has found the sensitive pixels to prevent high difference values. As per an objective measurement, the results show that the PSNR values are higher than 30 (dB). Then, its embedding process was modified on these sensitive pixels. Of course, the increased number of the sensitive pixels using the *Type2* division is because of its higher embedding capacity compared with the *Type1* division.

In Figure 6a, we compared the PSNR values of our proposed method with the Wu *et al.'s* [15] and Yang *et al.'s* [18] and also Khodaei *et al.'s* [19] methods where the x-axis presents the stego-image and the y-axis shows the PSNR value. As demonstrated in this figure, the mean PSNR value (37.65 dB) for the stego-images produced by the Adaptive steganography method using LSB replacement and PVD (with $div = 63$, $k = 3$) [19] is better than the corresponding values (37.35 dB and 37.33 dB) of the steganography methods using LSB replacement and PVD [18] and Edge adaptive LSB method (with *division*3-4) [15]. However, the quality of 'Tiffany' and 'Cameraman' stego-images produced by the Adaptive method is reduced due to the large number of sensitive pixels in these images (calculated in Table 1). Furthermore, as shown in Table 1, the number of sensitive pixels is low in 'Zelda' and also in 'Boat' using *Type1*. Thus, the quality of them has increased slightly. Based on Figure 6a, the PSNR values of our method (with *Type1* division, $k = 3$) is also more than the Adaptive steganography method. In addition, the quality of 'Baboon' stego-image produced by the proposed method soared in comparison with the others due to the large number of sensitive pixels in it. Therefore, we provide a better visual quality of stego-image than these other methods.

Table 1. *Visual quality analysis*: The number of sensitive pixels ($Sens_{pixel}$) and the PSNR (*dB*) values of stego-images produced by the proposed method (with *Type1* and *Type2* division and different *k* values)

Cover-images	PSNR, dB	Sens, Pixel	PSNR, dB	Sens, Pixel	PSNR, dB	Sens, Pixel	PSNR, dB	Sens, Pixel
Type1 division								
Baboon	38.76	691	35.88	728	32.49	960	31.21	1518
Barbara	37.42	119	34.18	85	31.47	99	30.72	103
Boat	37.48	22	35.27	38	32.21	29	31.41	69
Cameraman	39.41	272	37.94	263	34.71	419	32.81	1140
Lena	38.10	12	36.05	11	32.61	20	31.53	26
Peppers	38.95	251	36.64	377	33.46	701	32.61	1641
Livingroom	39.44	154	37.20	174	33.24	237	32.21	386
Pirate	39.75	12	37.44	19	33.35	16	32.41	27
Tiffany	39.22	591	37.04	691	33.22	820	32.37	868
Zelda	39.18	4	37.05	17	33.14	49	31.73	245
Average	38.76	212	36.46	240	32.99	335	31.90	602
Type2 division								
Baboon	38.23	3 703	35.45	3 925	32.11	4 585	30.74	4 890
Barbara	37.01	2 238	33.66	2 822	31.06	4 152	30.29	4 760
Boat	37.03	1 945	34.82	2 654	31.83	4 520	30.94	5 390
Cameraman	39.00	1 018	37.55	1 728	34.34	4 437	32.20	5 797
Lena	37.64	1 983	35.68	2 752	32.18	4 476	31.13	5 412
Peppers	38.51	2 143	36.30	2 840	33.04	4 510	32.17	5 541
Livingroom	38.98	2 408	36.84	3 033	32.77	4 460	31.73	5 251
Pirate	39.29	2 288	37.01	2 904	32.89	4 478	31.93	5 368
Tiffany	38.87	2 380	36.53	3 023	32.76	4 540	31.88	5 322
Zelda	38.78	1 769	36.49	2 602	32.69	4 493	31.26	5 571
Average	38.33	2 187	36.03	2 828	32.56	4 465	31.42	5 330

4.2. Embedding Rate

In this test case, we produce stego-images by our proposed method with the *Type1* and *Type2* division and various *k* amounts. Table 2 shows the capacity of embedded secret bits and the average capacity in bit per pixel (E_{bpp}) for each range division with different *k* values. As per the experimental results, the capacity and the E_{bpp} values using the *Type2* division are higher than those using the *Type1* division. According to Table 2, the E_{bpp} values are in the [3.037- 4.529] range using *Type1* and in the [3.097- 4.667] range using *Type2*. Also, all $Capacity_{bit}$ average values by *Type2* are higher than their corresponding values using *Type1* (when $k = 4$ and *Type1*: the average Capacity = 912290 bits, when $k = 4$ and *Type2*: the average Capacity = 935101 bits). Thus, the hiding capacity is increased by using our proposed *Type2* division.

In Figure 6b, we compare these results with the Wu *et al.'s* [18], Yang *et al.'s* [15] and Khodaei *et al.'s* [19] methods. This figure shows that the embedding capacity of the proposed method (with *Type2* division, $k = 3$) is larger than the Steganography method using LSB replacement and PVD [18], the Edge adaptive LSB method (with *division* 3-4) [15] and also the Adaptive steganography method using LSB replacement and PVD (with $div = 63$, $k = 3$) [19]. In Figure 6b, the x-axis and the y-axis show the stego-image and the embedding capacity. Thus, we provide a higher embedding capacity than these other methods.

4.3. Information Security

Here, the security of the proposed method is tested in terms of RS and steganalysis detector attacks. The RS steganalysis by Fridrich *et al.* [22] in 2001 can show exactly whether a stego-image resists without visual check. This steganalysis method classifies all the stego-image pixels into three groups by using dual statistical methods: the regular group (R_m or R_{-m}), the singular group (S_m or S_{-m}), and the unusable group. The relation between the percentage of the regular groups and the singular groups is $R_m + R_{-m} \leq 1$ and $S_m + S_{-m} \leq 1$. Here R_m and S_m are percentages with the mask m, and R_{-m} and S_{-m} are percentages with the mask $-m$ of the regular and the singular groups, respectively. If $R_m \cong R_{-m}$ and $S_m \cong S_{-m}$, the stego-image will pass the RS attack. Otherwise, the stego-image is detected as a suspicious object.

Figure 7a shows the result of the RS steganalysis (by two masks $m = [0\ 1\ 1\ 0]$ and $-m = [0 - 1 - 1\ 0]$) of the stego-images produced by the proposed method. In this figure, the x-axis presents the embedding capacity percentage and the y-axis shows the percentage of the regular and the singular groups. According to Figure 7a, we were right in expecting that the R_m and S_m relative numbers are respectively equal to those of R_{-m} and S_{-m} (i. e. $R_m \cong R_{-m}$ and $S_m \cong S_{-m}$).

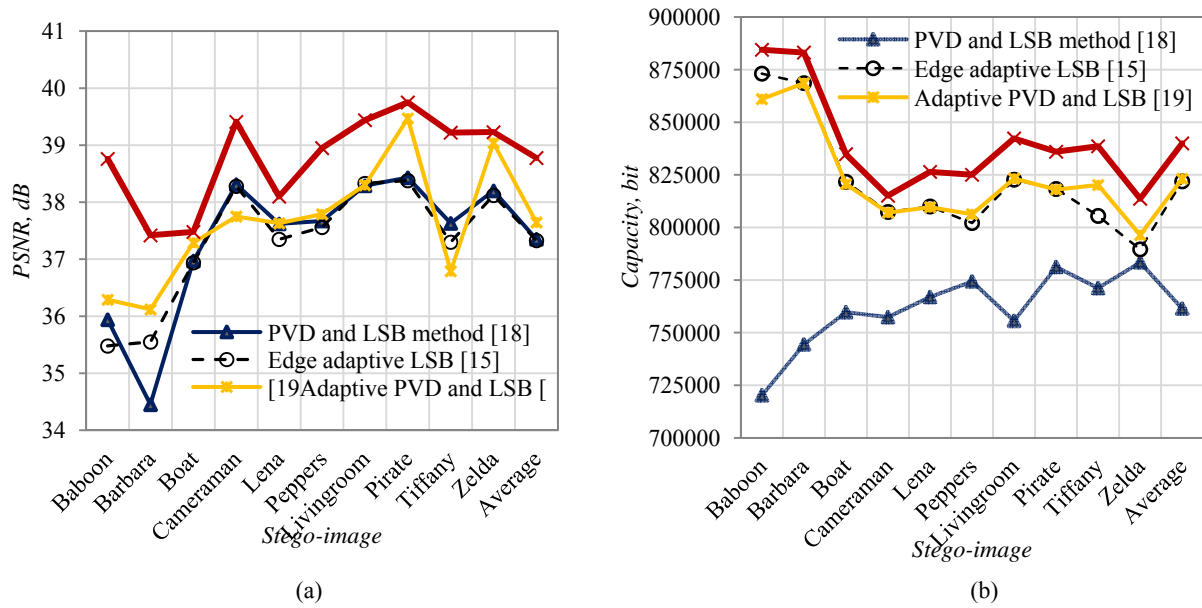(a)   (b)

Figure 6. Comparisons between our proposed method and the steganography method using LSB replacement and PVD, the edge adaptive LSB method (*division*3-4), and the adaptive steganography using LSB replacement and PVD ($div = 63$, $k = 3$), a) *Visual quality comparison*: (the proposed method with the *Type1* division and $k = 3$), b) *Embedding capacity comparison*: (the proposed method with the *Type2* division and $k = 3$)

Table 2. *Embedding capacity analysis*: The capacity of embedded secret bits ($Capacity_{bit}$) and the average capacity in bit per pixel (E_{bpp}) of stego-images produced by the proposed method (with the *Type1* and *Type2* division and different *k* values)

| Cover-images	Capacity, Bit	E, bpp	Capacity, bit	E, bpp	Capacity, bit	E, Bpp	Capacity, bit	E, Bpp
				Type1 division				
Baboon	860 314	3.281	950 637	3.626	1 050 556	4.007	1 187 380	4.529
Barbara	867 520	3.309	956 601	3.649	1 057 542	4.034	1 198 693	4.529
Boat	819 703	3.126	908 886	3.467	1 011 899	3.860	1 165 134	4.444
Cameraman	806 761	3.077	895 346	3.415	994 191	3.792	1 155 610	4.408
Lena	809 618	3.088	898 347	3.426	1 004 140	3.830	1 160 592	4.427
Peppers	806 058	3.074	896 273	3.419	1 002 440	3.824	1 157 767	4.416
Livingroom	823 061	3.139	913 089	3.483	1 017 395	3.881	1 169 106	4.459
Pirate	818 061	3.120	907 784	3.462	1 011 600	3.858	1 165 940	4.447
Tiffany	819 664	3.126	909 729	3.470	1 014 292	3.869	1 167 518	4.453
Zelda	796 393	3.037	886 217	3.380	993 463	3.789	1 153 358	4.399
Average	822 715	3.138	912 290	3.480	1 015 751	3.874	1 168 109	4.455
				Type2 division				
Baboon	884 446	3.373	974 688	3.718	1 080 148	4.120	1 211 679	4.622
Barbara	883 112	3.368	977 224	3.727	1 088 385	4.151	1 223 579	4.667
Boat	834 824	3.184	930 727	3.550	1 045 733	3.989	1 194 801	4.557
Cameraman	815 096	3.097	910 897	3.474	1 033 271	3.941	1 182 964	4.512
Lena	826 429	3.152	922 421	3.518	1 041 088	3.971	1 188 839	4.535
Peppers	825 030	3.147	921 125	3.513	1 038 398	3.961	1 186 898	4.539
Livingroom	842 295	3.213	937 972	3.587	1 052 439	4.014	1 195 459	4.560
Pirate	836 018	3.189	931 338	3.552	1 046 856	3.993	1 192 161	4.547
Tiffany	838 590	3.198	933 930	3.562	1 049 521	4.003	1 194 319	4.555
Zelda	813 666	3.103	910 696	3.474	1 031 402	3.934	1 182 297	4.510
Average	839 950	3.204	935 101	3.567	1 050 724	4.008	1 195 299	4.559
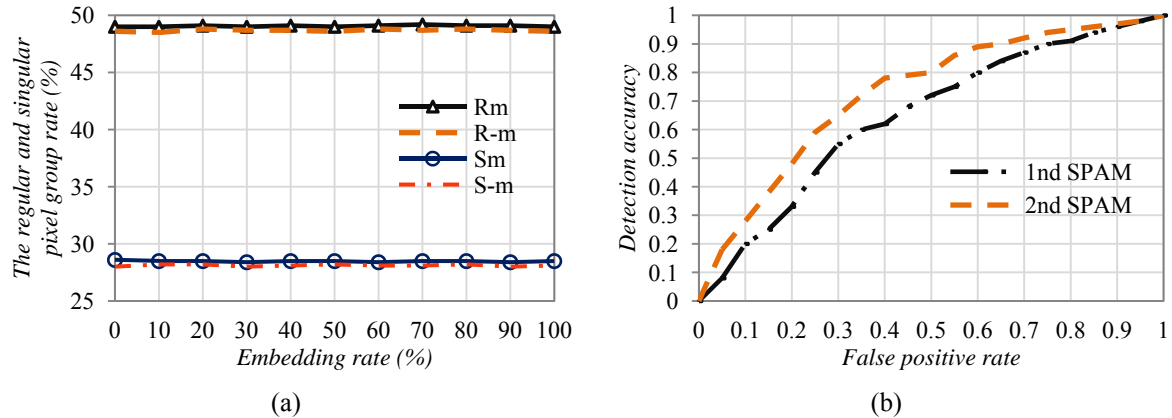
Figure 7. *Information security analysis*: a) RS-diagram of stego-images produced by the proposed method, b) receiver operating characteristic curve of steganalyser using the SPAM features with threshold $T = 3$

Figure 7b illustrates the receiver operating characteristic curve, plotted by steganalysis detector using the SPAM features and the support vector machines classifier with a Gaussian kernel [23]. According to Figure 7b, we can see that the security of the proposed method against detector attack using first-order SPAM features is almost similar to themselves second-order.

Unlike the Wu *et al.'s* [18] and the Yang *et al.'s* [15] methods, our proposed method resists the RS steganalysis attack, according to Figure 7a. Also, the security of the proposed method against detector attack using first-order and second-order SPAM features is generally better than Khodaei *et al.'s* that is presented in [19].

5. CONCLUSION

To evaluate the proposed method, the difference between the cover-image and its stego-image was calculated. In addition, we computed the PSNR value and the embedding capacity using various range divisions. As per the experimental results, the visual quality obtained by our method is higher than its corresponding value achieved by the other related methods, explained in this paper. Furthermore, we hide larger embedding capacity compared with these methods using our new range division. Finally, our proposed method was robust against RS and steganalysis detector attacks.

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BIOGRAPHIES OF AUTHORS

Mojtaba Bahmanzadegan Jahromi. Student of Faculty of Computer and Information Technology Engineering, Qazvin Branch Islamic Azad University, Qazvin, Iran. *Research Interests:* Image Processing, Computer Security, Fuzzy Logic, etc.
Education:
Payam Noor *University,* Jahrom, Iran. B.Sc. in Computer Science, 2010,

Karim Faez. Professor of EE Department Amirkabir University of Technology, Tehran, Iran
Research Interests: Computer Security, Image Processing, Pattern Recognition, etc.
Education:
Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran. B.Sc. in Electrical Engineering, 1973,
University of California, Los Angeles. M. Sc. in Computer Science, 1977.
University of California, Los Angeles. Ph. D. in Computer Science, 1980.