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ANALYZING THE FIRST DIFFERENCE VALUE OF INTEGER TRANSFORM FOR SECURING TRANSMITTED DATA

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Abstract. *Digital technology development contributes much to the current technology, especially in image processing and communication technology. Data are converted into binary digits, manipulated, and transmitted through the Internet, whose security is a major issue in this context. Here, the data hiding technique is one of the methods to ensure data security during transmission by embedding them into a multimedia file such as an image. One of the existing methods is difference expansion, where information redundancy between pixels is exploited to carry private data. In previous studies, various integer transform schemes have been introduced. However, there is still a challenge to achieve an affordable embedding capacity and visual quality. This paper proposes difference integer transform schemes and adopts the reduced difference expansion to minimize the difference between original and stego images. This method selects zero, the minimum, or maximum pixel as the first difference to keep the base point for the other three differences. The outcomes prove that the proposed schemes perform well in payload and visual quality, where 196608 bits can be embedded to achieve around 41 dB and 34 dB for medical and non-medical (common) images, respectively.*
Keywords: Difference integer transforms, Data protection, Network infrastructure, Information security, Data hiding

1. **Introduction.** At present, the Internet is the main tool in data sharing, which is necessary for our daily life. Protecting the data is a concern, considering integrity and confidentiality. The data is represented in the digital format (0 or 1), so unauthorized users may intercept, modify, and forward those fake data. Data hiding is a method to anticipate this activity dealing with protecting data using a medium like video [1], audio [2], image [3], and text [4], in an imperceptible way. Here, the concealed data have a direct relationship with its cover. It means that the secret message can be fully extracted at the destination, and the medium is recovered; additionally, extra data added in the carrier significantly degrade the quality. It is unacceptable, especially for those requiring high accuracy. For example, in a medical environment, image distortion may result in false diagnosis; a similar condition applies to a military system, and imagery [5].

A file holding embedded data is known as stego, which is supposed to be similar to the original one to meet the imperceptibility property; so that the public cannot perceive the existence of auxiliary data within it. There is a trade-off between embedding capacity and visual quality. In this case, high embedding capacity results in high distortion. A good

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data hiding algorithm should allow high embedding capacity for low distortion. With this objective, various techniques have been developed, for example, those in [3].

In this research field, any data hiding algorithm is assessed based on certain essential factors [6]. Many algorithms require a location map to mark one pixel or a group of pixels carrying private data. Various data hiding algorithms have been proposed to obtain high visual quality, embedding capacity, or both of them, such as in [3, 7].

This study proposes strategies for getting better integer transform to obtain the difference between two nearby pixels. Then, we adopt the Reduced Difference Expansion (RDE) [8] to analyze which base point is suitable when a block of 2×2 pixels is implemented. This finding is helpful to reach an appropriate stego quality level that around 41 dB and 34 dB for respectively medical and non-medical images can be achieved.

This paper is organized as follows. In Section 2, the proposed method is described, that we explain how to calculate the difference in a 2×2 pixel block. Then, the analysis of the experimental results is carried out in Section 3. Finally, we draw the conclusion in the last section.

2. Determining the First Difference.

Similar to other difference expansion-based data hiding schemes, this proposed method goes through two phases: embedding and extraction. It comprises two more difference integer transforms to compute the differences within a block. Unlike [9] that takes a reference pixel and logarithmic predictor to maintain the embedding, this research combines the RDE approach from [8] and the base point proposed in [10], where it is possible to manage the stego quality by using either smoothness levels or threshold values.

Different from [10], the proposed method defines the first difference to be zero, the minimum, or the maximum pixel among those available in the corresponding block. It reduces the number of unusable blocks, intended to obtain high embedding capacity and better visual quality. Moreover, the difference is reduced except the one that is zero (see (1) and (2)), where u_n and u_{n+1} are two successive pixels and d_n is the difference between these pixels which is computed as $d_n = u_{n+1} - u_n$.

$$\left.\begin{aligned} d_0 &= u_0 - u_2 \\ d_1 &= u_1 - u_2 \\ d_2 &= 0 \\ d_3 &= u_3 - u_2 \end{aligned}\right\} \tag{1}$$

$$d'_n = \begin{cases} d_n - 2^{\lfloor \log_2(d_n) \rfloor} + \lfloor \log_2(d_n) \rfloor, & \text{if } d_n > 0 \\ d_n - 2^{\lfloor \log_2(d_n) \rfloor} + \lfloor \log_2(d_n) \rfloor, & \text{if } d_n < 0 \\ d_n, & \text{if } d_n = 0 \end{cases} \tag{2}$$

The proposed method is also different from the algorithm presented in [11], where the first pixel in a block is considered as the base point. Furthermore, the proposed transform scheme is shown in (3). In this expression, after sorting pixels in ascending order, the smallest (minimum) pixel is taken as the value of the first difference. If there is more than one pixel with the same values, the smallest pixel obtained while screening the pixel block is given the highest priority. We also propose another integer transform scheme where the first difference is taken from the maximum pixel value in a quad pixel block ($d_0 = u\max_n$), while the other differences (d_1, d_2, d_3) are the same as in (3).

$$\left.\begin{aligned} d_0 &= u\min_n \\ d_1 &= u_1 - u_0 \\ d_2 &= u_2 - u_1 \\ d_3 &= u_3 - u_1 \end{aligned}\right\} \tag{3}$$

Similar to the first proposed method, if more than one pixel has the same maximum value, that first maximum pixel obtained is the one to be taken. Once the difference is held, it is reduced before the embedding takes place, which is done by adopting the method in [12] whose formula is provided in (4). Here, d'_n is the reduced difference, and n is the index that can be 0 or 1 for pixel, and 0 for difference and secret bits. This difference is reduced if it is greater than 1; otherwise, it remains unchanged. After the reduction, secret bits are inserted in this differences using (5) for expandable and (6) for changeable pixel blocks. Here, the non-changeable one is ignored because it results in either an overflow or underflow problem.

$$d'_n = \begin{cases} d_n, & \text{if } d_n < 2 \\ d_n - 2^{\lfloor \log_2(d_n) \rfloor}, & \text{if } d_n \geq 2 \end{cases} \tag{4}$$

$$\left.\begin{aligned} d''_1 &= 2 \times d_1 + b_1 \\ d''_2 &= 2 \times d_2 + b_2 \\ d''_3 &= 2 \times d_3 + b_3 \end{aligned}\right\} \tag{5}$$

$$\left.\begin{aligned} d''_1 &= 2 \times \left\lfloor \frac{d_1}{2} \right\rfloor + b_1 \\ d''_2 &= 2 \times \left\lfloor \frac{d_2}{2} \right\rfloor + b_2 \\ d''_3 &= 2 \times \left\lfloor \frac{d_3}{2} \right\rfloor + b_3 \end{aligned}\right\} \tag{6}$$

In order to identify the pixel category and block carrying confidential data, we adopt the Location Map (LM) of [12]. Here, LM_1 is assigned the value 1 ($LM_1 = 1$) if the block is expandable and assigned the value 0 ($LM_1 = 0$) if the block is changeable. If a block is identified as non-changeable, it is assigned the value minus 1 ($LM_1 = -1$). The expandable is categorized into expandable RDE and expandable non-RDE, where the former is identified by $LM_2 = 1$ while the latter is $LM_2 = 0$.

After the payload has been embedded into the reduced difference, stego pixels are constructed by assigning the minimum pixel to the first difference, as presented in (7). Furthermore, the first stego pixel in a block is assigned the original minimum pixel value. For the maximum pixel as the first difference, (8) is applied. This process results in the stego image, which may be transmitted to the destination. In the extraction process, the reverse operation is performed by employing the stego image and location map. For this purpose, the method in [13] is used.

$$\left.\begin{aligned} u'_0 &= u\min_n \\ u'_1 &= d''_1 + u'_0 \\ u'_2 &= d''_2 + u'_1 \\ u'_3 &= d''_3 + u'_2 \end{aligned}\right\} \tag{7}$$

$$\left.\begin{aligned} u'_0 &= u\max_n \\ u'_1 &= d''_1 + u'_0 \\ u'_2 &= d''_2 + u'_1 \\ u'_3 &= d''_3 + u'_2 \end{aligned}\right\} \tag{8}$$

3. **Experimental Results.** For evaluation, we apply the proposed scheme to different types of image data sets. It includes five grayscale medical images taken from [14] and five common images taken from [15]. The secret message is random binary bits generated using the Matlab function: randi(). The quality of the stego image is measured by calculating

the PSNR (Peak Signal to Noise Ratio) value represented in decibel (dB) as provided in (9). The MSE (Mean Square Error) value is firstly obtained by using (10). In this case, N is the number of pixels in the image; I_i is the original image, and I_i' is the stego image.

$$PSNR = 10 \times \log_{10} \frac{255^2}{MSE} \tag{9}$$

$$MSE = \frac{1}{N} \sum_{i=1}^{N} (I_i - I_i')^2 \tag{10}$$

3.1. **Medical image.** We compare the obtained results when the first difference in the integer transform is assigned various values (zero, maximum or minimum pixel). First, the results show that the algorithm performs better in terms of embedding capacity when the minimum pixel is assigned to the first difference, except the head image whose performance is low, as shown in Figures 1, 2 and 3. It is followed by the case where the first difference is zero. Then, the lowest embedding capacity is obtained when the maximum pixel as the first difference is used. It is likely caused by a high number of unused pixel blocks. If it is small, the embedding capacity becomes high.

The second evaluation shows that the method performs better when the first difference is assigned with 0. It is shown in Figures 1, 2 and 3 where PSNR value is relatively high. Overall, the PSNR obtained from the maximum is better than that from minimum pixels due to the high distortion caused by the high number of bits embedded. On the contrary, its payload is lower than the others.

In more details, the performance of difference integer transform is compared by considering the payload capacity that can be supported and its corresponding PSNR value (see Figures 1(a), 2(a) and 3(a)); the payload capacity and the number of unused pixel blocks (see Figures 1(b), 2(b) and 3(b)); and the number of unused pixel blocks and PSNR value (see Figures 1(c), 2(c) and 3(c)). For the difference integer transform which the first difference is assigned the maximum value, we find that the visual quality of 32.81 dB is obtained for a chest image whose capacity is 191556 bits. It is followed by 31.35 dB obtained for leg image with 194484 bits. It is because almost all pixel blocks in hand and leg images carry confidential data depicting that the visual quality does not depend only on the amount of embedded data but also on the number of used blocks. It is found that whenever all blocks in the image are used, high embedding capacity can be achieved for reasonable visual quality.

Next, we observe that if the number of unused blocks is small, a higher embedding capacity can be achieved. It is found in the hand image that by taking four unused blocks, the maximum embedding capacity can be obtained, which is 196596 bits (see Figure 2(b)). Similarly, as shown in Figure 2(c), a fewer number of unused blocks leads to a high number of PSNR values. It is observed on the head, chest, and abdominal.

Depending on the number of unused blocks and the nature of the image (smoothness, rough), the PSNR value may be higher or lower depending on the embedding capacity. It means that with fewer unused pixel blocks, the stego image is more similar to the original image. Therefore, high dissimilarity appears when the number of unused pixel blocks is higher.

3.2. **Common image.** In common images, it is depicted that the algorithm's performance is better for both embedding capacity and visual quality when the first difference is assigned to 0. It is presented in Tables 1, 2, and 3 that high performance is obtained on Lena followed by Elaine images, where all pixel blocks are used to carry secret bits. For difference integer transform based on maximum and minimum pixels, the performance is moderate. The embedding capacity is relatively higher, but as the trade-off, the visual quality is lower, caused by a high number of non-changeable pixel blocks.

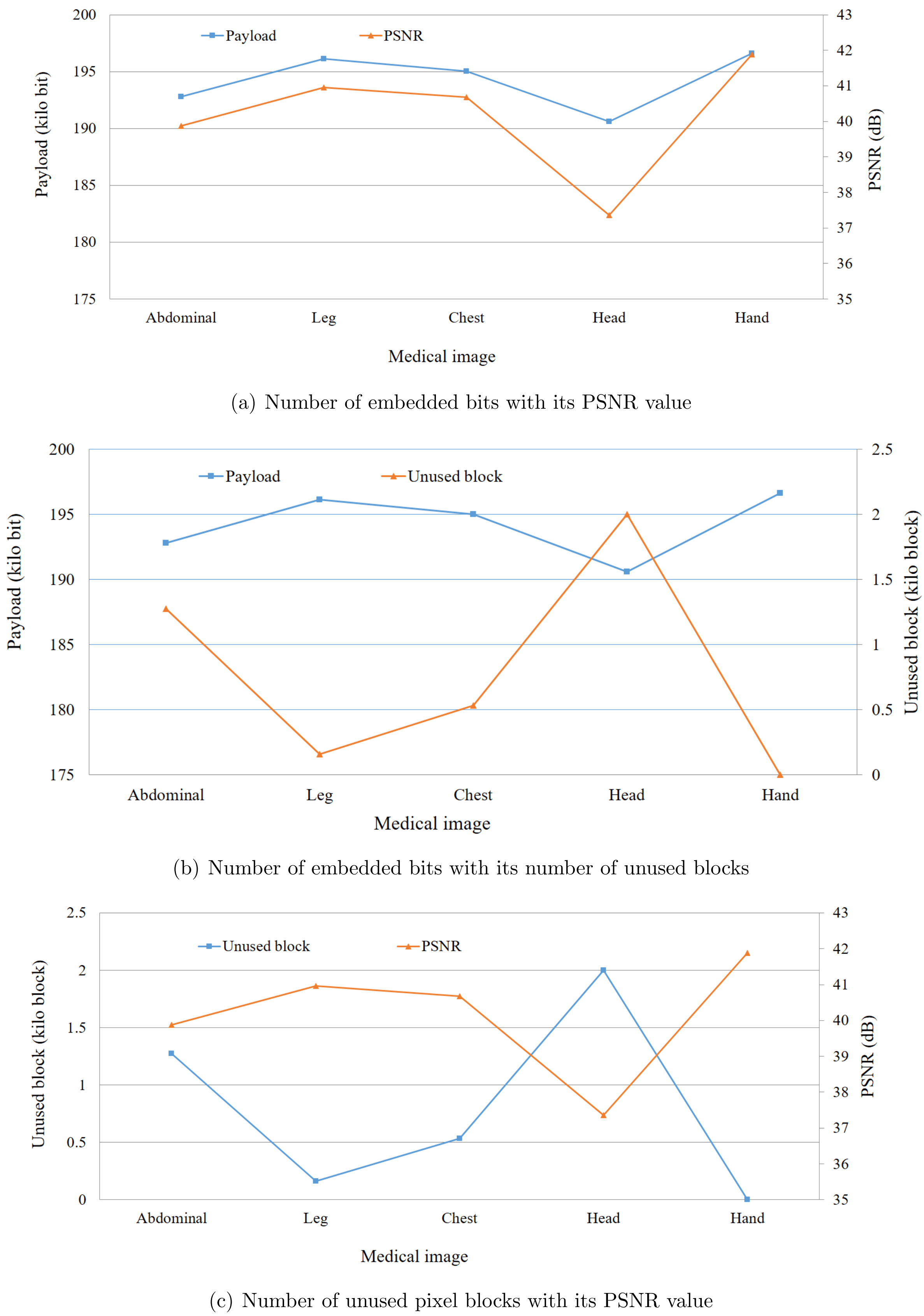
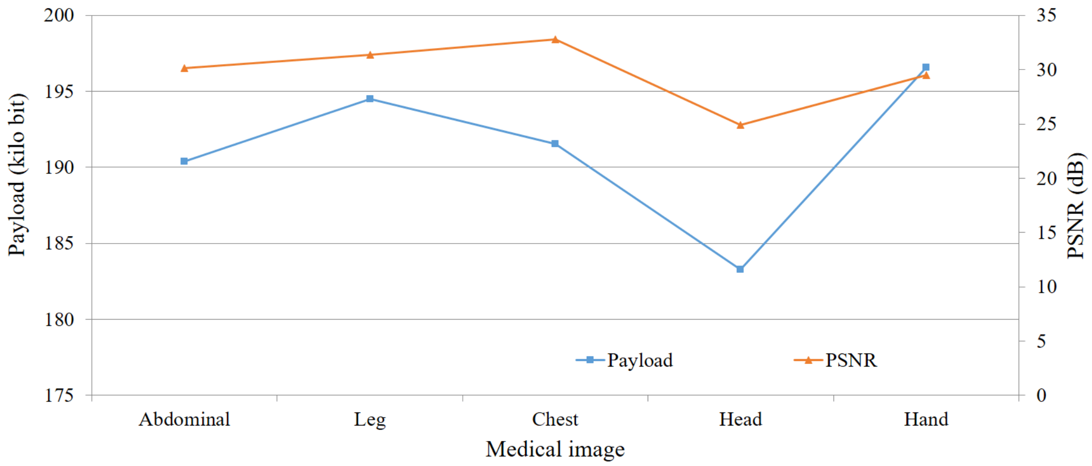
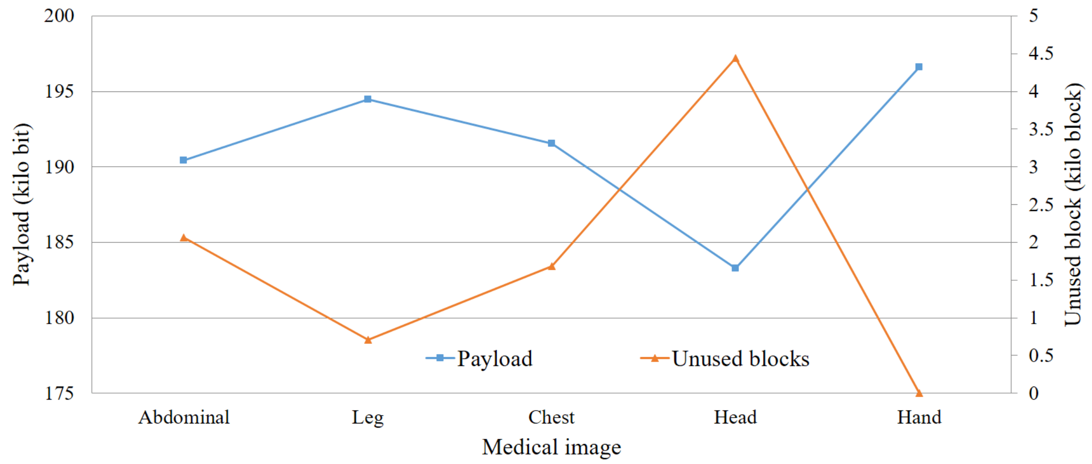


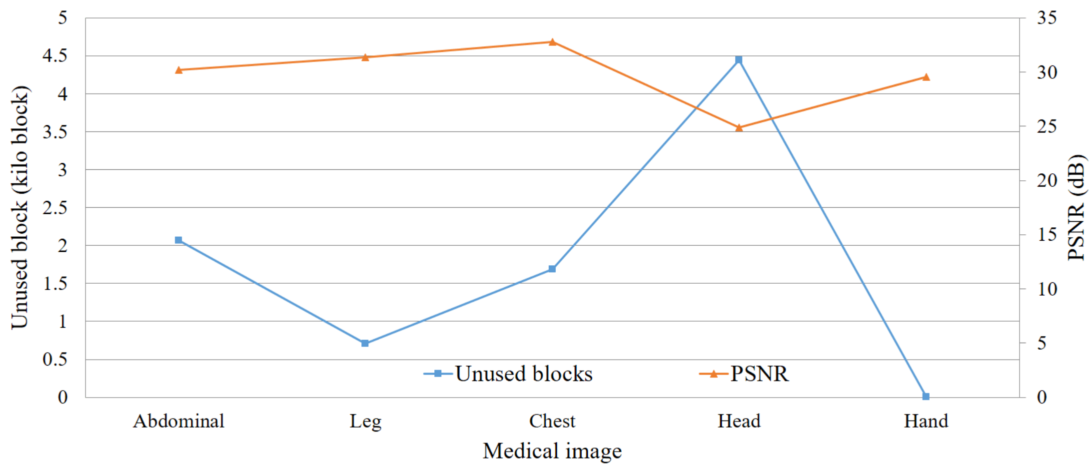
FIGURE 1. Experimental results where the first difference is zero with medical images



(a) Number of embedded bits with its respective PSNR value

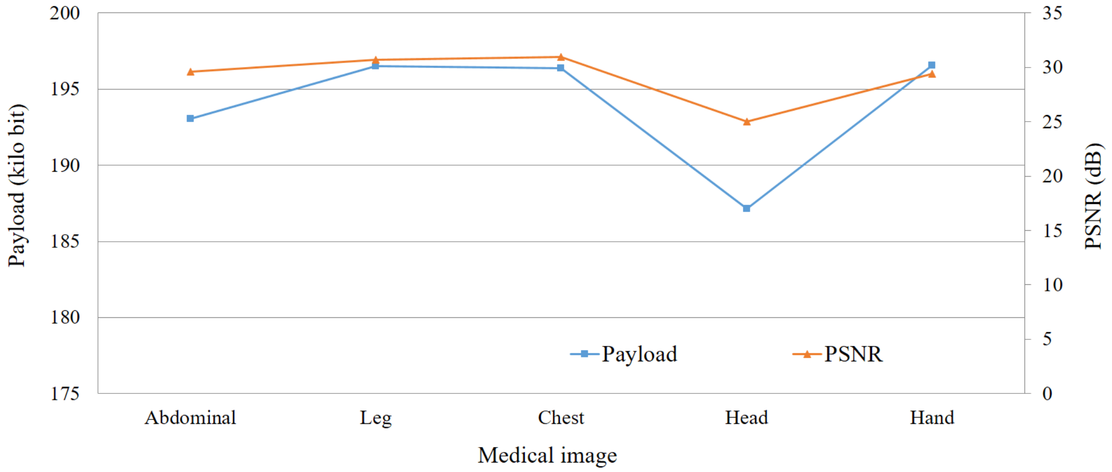


(b) Number of embedded bits with its respective number of unused blocks

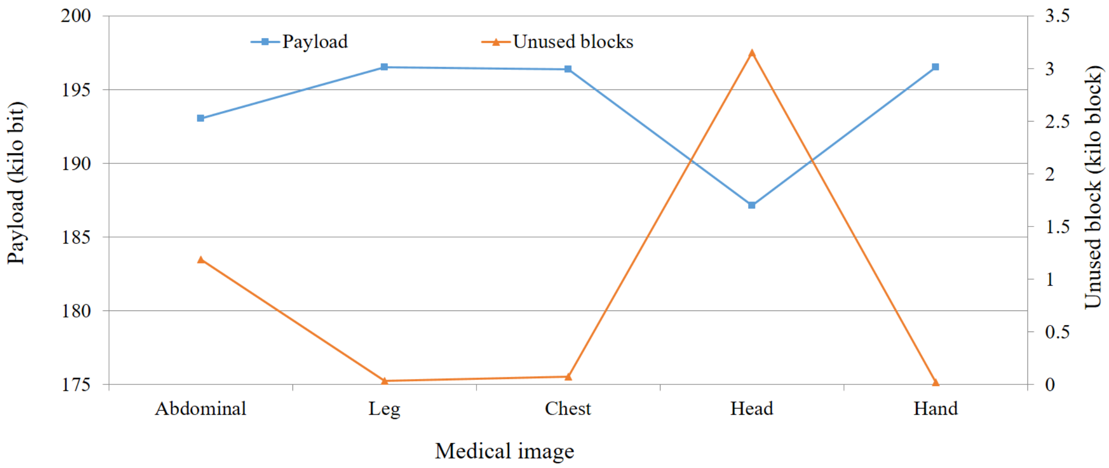


(c) Number of unused pixel blocks with its respective PSNR value

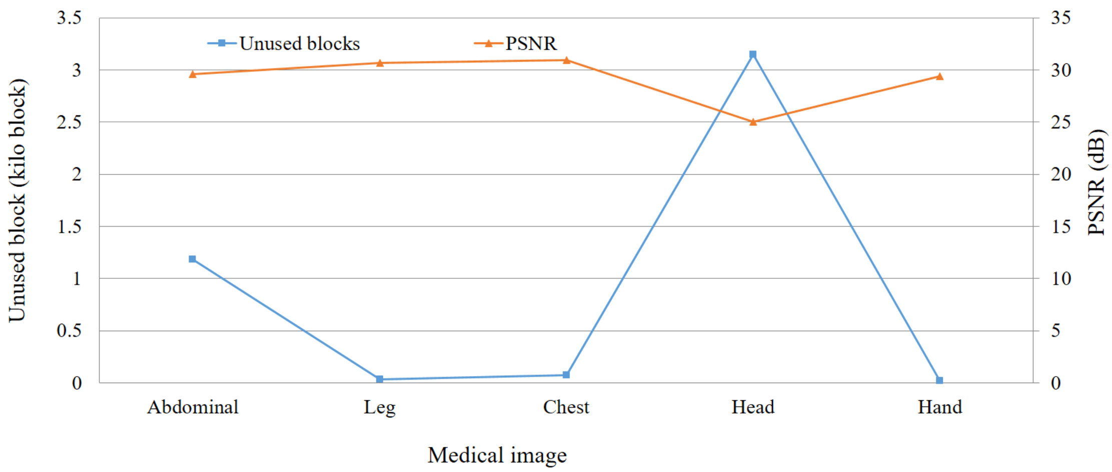
FIGURE 2. Experimental results where the first difference is maximum with medical images



(a) Number of embedded bits with its respective PSNR value



(b) Number of embedded bits with its respective number of unused blocks



(c) Number of unused pixel blocks with its respective PSNR value

FIGURE 3. Experimental results where the first difference is minimum with medical images

Table 1. The experimental results of the zero as the first difference using grayscale common images

Image	Payload (bit)	PSNR (dB)	Unused block
Pepper	196605	33.58	1
Lena	196608	34.64	0
Elaine	196608	33.62	0
Boat	196605	32.30	1
Baboon	196581	28.01	9

Table 2. The experimental results of the maximum value as the first difference using grayscale common images

Image	Payload (bit)	PSNR (dB)	Unused block
Pepper	193557	22.24	1017
Lena	195255	22.83	451
Elaine	196347	21.27	87
Boat	194790	20.29	606
Baboon	188040	16.15	2856

Table 3. The experimental results of the minimum value as the first difference using grayscale common images

Image	Payload (bit)	PSNR (dB)	Unused block
Pepper	195504	21.84	368
Lena	196020	21.98	196
Elaine	195795	20.97	271
Boat	194610	20.08	666
Baboon	190581	15.66	2009

We observe that the Lena image has a slightly higher payload capacity and PSNR than Pepper, opposite to the number of unused blocks. The same trend happens to Elaine, Boat, and Baboon. Moreover, Baboon suffers from lower PSNR, which is about 15 dB. As before, the number of unused blocks is different between images leading to a better or worse algorithm performance on specific images. It is shown that high embedding capacity is achieved when all pixel blocks are used. Here, embedding 196608 bits leads to 34.64 dB and 33.62 dB for Lena and Elaine, respectively.

Still, in Tables 1-3, we figure out that a high number of unused pixel blocks, low visual quality, and low embedding capacity are obtained from Baboon image; while high embedding capacity, high visual quality, and zero unused pixel blocks are applied to Elaine image. These results are presented where the first difference is assigned with zero, the maximum and minimum pixel values in pixel blocks. Compared to [9], this method can carry more data; nevertheless, its quality is challenging. The same pattern is likely to happen to medical images.

We realize that by combining (4) and (11), the resulted approach is reversible. We also notice that the proposed difference integer transform schemes combined with RDE [8] gives an irreversible method.

$$\left.\begin{aligned} u_1' &= d_1'' + avg \\ u_2' &= d_2'' + avg \\ u_3' &= d_3'' + avg \end{aligned}\right\} \tag{11}$$

4. **Conclusion.** In this paper, two difference integer transform schemes have been proposed: the minimum and maximum pixel considered the first difference during the computation of differences in a pixel block. We also combine a quad-based difference expansion where the first difference is assigned 0, and the same RDE is applied.

The experimental results depict that its performance is better for medical images when the visual quality is the focus. The best performance is gained for some common images when both embedding capacity and visual quality are considered. However, in case only high payload capacity is considered, other remaining images can be used.

We also notice that when the number of non-changeable blocks is low, the embedding capacity and visual quality are maximal. Hence, in future research, RDE can be enhanced by reducing the number of non-changeable blocks.

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