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A New Data Embedding Method with a New Data Embedding Domain for JPEG Images

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***Abstract*—Data embedding for digital images is a kind of technology which embeds message, i.e., data stream, into image(s). The design of data embedding may vary according to different applications such as watermarking, data hiding, authentication, steganography, etc. However, the basis of data embedding is the embedding domain. In this paper, we discover a new embedding domain, rounding/truncation error (RTE) domain, which is obtained due to the rounding/truncation error during the decompression of JPEG image, for JPEG image data embedding. To demonstrate the viability of the domain, we propose a new data embedding method which could be exploited for data hiding and authentication. Experimental results indicate that the proposed data embedding method possesses certain embedding capacity and achieves excellent performance when considering imperceptibility of the embedded image.**

***Index Terms*—Data Embedding, embedding domain, data hiding, JPEG image embedding, rounding/truncation**

I. Introduction

In the past two decades, digital image data embedding technologies, which usually embed a data stream into image(s), has been developed rapidly due to the increasing demand of image data embedding applications such as watermarking [1], data hiding [2], steganography [3], authentication [4], etc. Different applications usually possess different requirements according to their specific needs. Watermarking usually requires high robustness [5] to the potential post-processings such as compression, resizing, etc. Data hiding usually demands a reasonable embedding capacity with small image quality degradations or sometimes no degradation, i.e., the algorithm can fully recover the cover image after the data is extracted from the stego image. Steganography usually needs high fidelity with the ability to resist the steganalysis attacks [6]. Authentication usually requires fragileness [7] that the embedded data should not be successfully decoded after the carrier image is attacked.

Although different data embedding applications require different designs, the basis of these designs is the data embedding domain. With a viable data embedding domain, different designs can carry out different embedding strategies. Over the past years, researchers have discovered many data embedding domains which can be categorized into spatial domain class and frequency domain class. The spatial domain class includes the traditional pixel domain [8], histogram domain [9], prediction error domain [10], etc., while the frequency domain class includes Discrete Cosine Transform (DCT) domain [11], Discrete Wavelet Transform (DWT) domain [12], etc.

To explore more possibilities in JPEG image embedding, in this paper, we present our newly discovered embedding domain, named Rounding/Truncation Error (RTE) domain. This domain, which only exists in JPEG images and belongs to the spatial domain class, was originally named error image and employed in [13] for double jpeg compression detection. Recently, we discovered the data embedding potential of the RT error domain and developed a new data embedding method, called Distortion Reducing Data Embedding (DRDE), which possesses the potential to be applied to data hiding and authentication, for the demonstration of the new domain.

The rest of the paper is organized as below. Section II introduces the RT error domain in JPEG images and its potential for data embedding. Section III proposes a viable method to embed data into the new domain. Experimental results are given in Section IV and Section V concludes the paper. Note that the images mentioned in this paper are grayscale images for convenience. For color image data embedding, a straightforward approach is to apply the grayscale method to the luminance component of the color image.

II. Rounding/Truncation Error Domain

Since the rounding/truncation error domain only exists in JPEG images, JPEG compression and decompression [14] are introduced first. The flowchart of a standard JPEG system is shown in Fig. 1(a). In compression stage, the system firstly divide the input image X into non-overlapping $8*8$ blocks. Then the current block $X_{m,n}$ will be processed by DCT to obtain the transformed block DCT$\{X_{m,n}\}$ where DCT$\{.\}$ stands for the DCT transform. After DCT, quantization is performed to DCT$\{X_{m,n}\}$ and Q(DCT$\{X_{m,n}\}$) is generated. At last, JPEG compression is finished with an entropy coding step and the compressed block $Y_{m,n}$ is generated. Similar to JPEG compression procedures, in theory, JPEG decompression just reverses the compression procedures.

However, in real implementations, due to the quantization error caused in compression, X' contains floating pixel values rather than the $[0, 255]$ integer values. Some pixel values may be even out of range, i.e. $X'(i,j) < 0$ or $X'(i,j) > 255$.

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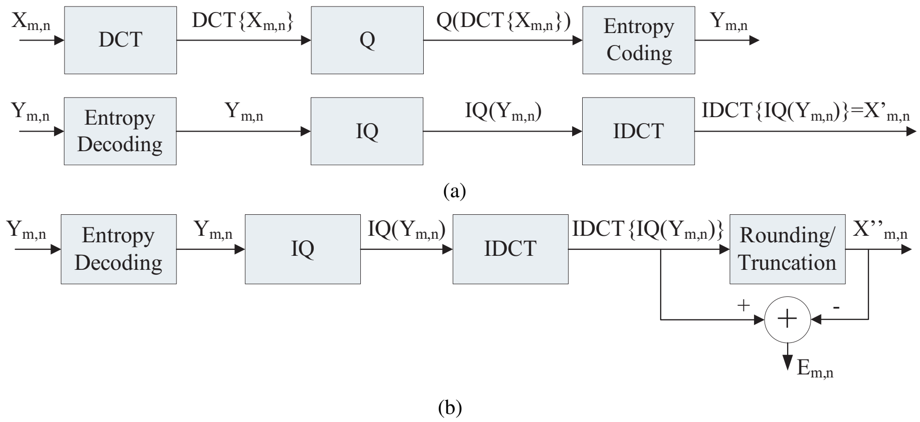


Fig. 1. (a) JPEG compression and decompression system flow in theory. (b) JPEG decompression in real implementations.

Both of the cases are invalid for real displays. Thus people resolve the problem by perform a rounding/truncation step as Fig. 1(b) shows. Basically, this rounding/truncation step rounds the floating numbers to integers, and truncates the out-of-range values to 255 or 0, respectively. The error caused by this step can be calculated via (1).

$$E = \text{IDCT}\{\text{IQ}(Y)\} - X'' \tag{1}$$

where IDCT$\{.\}$ and IQ$(.)$ stands for the inverse DCT operation and inverse quantization operation respectively.

This rounding/truncation error E possesses the potential to serve as a new data embedding domain. By considering the small floating values and the rounding/truncation process, the embedding distortions can be designed to be small, even zero sometimes, which is critical for the data embedding applications with the requirement of high imperceptibility such as watermarking and data hiding. Since this RTE domain only contains small values (mostly smaller than 1), the embedded data can be designed to be fragile to further processing while bypass the JPEG compression when generating the stego images. This fragileness is highly demanded by the application which have certain requirement such as authentication.

III. A Data Embedding Method in RTE Domain

With the new RTE domain, researchers can thus explore to develop new data embedding methods. Here we propose a new method, called Distortion Reducing Data Embedding (DRDE), to demonstrate the application of the RTE domain. Note that this specially designed DRDE is intended to be generally applied to data hiding and authentication.

Usually, by causing minimal distortions to the cover image, embedding the to-be-embedded data S, which should be extractable at the decoder side, is highly desired. By denoting the distortion caused during the embedding process as D_c and the distortion between the extracted S_e and the original S as D_s, similar to [15], the data embedding problem can be formulated as (2) shows.

$$\begin{aligned} &\min\ D_c \\ &s.t.\ D_s < \epsilon \end{aligned} \tag{2}$$

where ϵ controls the correct decoding rate of S_e and is user defined according to different applications.

In DRDE, the carrier image Y will be decomposed to calculate the RTE domain by the system shown in Fig. 1(b). Then the data S is embedded by manipulating the values in each $E_{m,n}$. To minimize the distortions ΔE caused by the manipulation, DRDE defines D_c as (3) shows.

$$D_c = \sum_{m,n} \{|R(X''_{m,n} + E_{m,n} + \Delta E_{m,n}) - R(X''_{m,n} + E_{m,n})|\} \tag{3}$$

where $R(.)$ stands for the rounding operation. Note that the truncation operation is not considered in (3), because it is only needed for few pixels in the whole image and only provides positive effects in the data embedding process, i.e., if the embedding modifications amend the pixel values out of the range $[0, 255]$, the truncation process helps to reduce the embedding modifications for the final decompressed embedded images at the decoder side.

Since both data hiding and authentication usually requires 100% correct decoding rate of the embedded data, DRDE is designed to achieve this objective by forcing the distortion D_s between the extracted data S_e and the original data S to be 0. This $D_s = 0$ can be achieved by designing an embedding mechanism which can survive the degradation of the quantization as follows.

DRDE embeds each bit of S to a block of E by amending the odd/even property of the summed selected decimal place of each pixel, as shown in (4).

$$\lfloor \sum_{k,l} \{(E_{m,n}(k,l) + \Delta E_{m,n}(k,l)) * 10^{\alpha}\} \rfloor \ mod\ 2 = S(u) \tag{4}$$

where α selects the α-th decimal place, k, l are the pixel indexes in a block, u stands for the u-th bit of the data to be embedded and $\lfloor . \rfloor$ stands for the flooring operation.

During the embedding process, to constrain the amendment ΔE to survive the quantization, DRDE consider ΔE can be fully re-calculated after the compression and decompression (without rounding/truncation) process in (5).

$$\sum_{m,n}\{\text{IDCT}\{\text{IQ}(\text{Q}(\text{DCT}\{X''_{m,n}+E_{m,n}+\Delta E_{m,n}\}))\} \\ -(X''_{m,n}+E_{m,n}+\Delta E_{m,n})\}=0 \tag{5}$$

where Q(.) stands for the quantization operation.

By substituting (3) into (2), and replacing $D_s < \epsilon$ with (4) and (5), DRDE can be formulated as (6) shows.

$$\min_{\Delta E} \sum_{m,n}\{|R(X''_{m,n}+E_{m,n}+\Delta E_{m,n})-R(X''_{m,n}+E_{m,n})|\} \tag{6}$$

$$s.t.\ \lfloor\sum_{k,l}\{(E_{m,n}(k,l)+\Delta E_{m,n}(k,l))*10^{\alpha}\}\rfloor\ mod\ 2=S(u)$$

$$\sum_{m,n}\{\text{IDCT}\{\text{IQ}(\text{Q}(\text{DCT}\{X''_{m,n}+E_{m,n}+\Delta E_{m,n}\}))\} \\ -(X''_{m,n}+E_{m,n}+\Delta E_{m,n})\}=0$$

Since DRDE embed every bit independently into each block of the carrier image with identical procedure, solving ΔE can be simplified to solving every $\Delta E_(m,n)$. Then the problem can be reduced to (7).

$$\min_{\Delta E_{m,n}} |R(X''_{m,n}+E_{m,n}+\Delta E_{m,n})-R(X''_{m,n}+E_{m,n})| \tag{7}$$

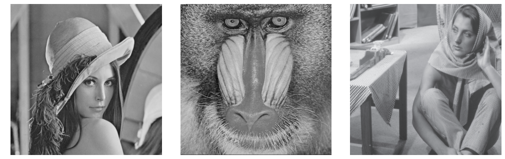
$$s.t.\ \lfloor\sum_{k,l}\{(E_{m,n}(k,l)+\Delta E_{m,n}(k,l))*10^{\alpha}\}\rfloor\ mod\ 2 \\ =S(u) \\ \text{IDCT}\{\text{IQ}(\text{Q}(\text{DCT}\{X''_{m,n}+E_{m,n}+\Delta E_{m,n}\}))\} \\ =(X''_{m,n}+E_{m,n}+\Delta E_{m,n})$$

Unfortunately, to our best knowledge, due to the rounding, floor, DCT and quantization operations, (7) does not possess a closed-form solution. However, we can still manage to solve the problem as follows.

Since modifying $E_{m,n}$ results in modifications to the DCT coefficients in $\text{DCT}\{X''_{m,n}+E_{m,n}+\Delta E_{m,n}\}$, the smallest modifications $\Delta E_{m,n}$, which can survive after quantization, should be added or subtracted to a single DCT coefficients with $q(k,l)$, which is the quantization step. In this case, with (7), DRDE calculates the best modification candidate for each DCT coefficient. Then DRDE selects the best candidate and performs inverse DCT to obtain the solution $\Delta E_{m,n}$.

With $\Delta E_{m,n}$, the embedded image Y' can be easily obtained by performing regular JPEG compression on $X''_{m,n}+E_{m,n}+\Delta E_{m,n}$. Note that the actual modifications to the stego image will be negated by the rounding/truncation step in decompression. If $q(k,l)=1$, the modifications may even be removed. Thus we may conclude that this embedding approach can reduce the data embedding distortions or eliminate them under certain circumstances.

At the decoder side, once the receiver possesses the knowledge about the decimal place selection, the embedded data can be successfully extracted by calculating the rounding/truncation error and then check the odd/even property of the summed selected decimal place for each block.



(a) (b) (c)

Fig. 2. Test images. (a) 'Lena', (b) 'Baboon', (c) 'Barbara'.

After the DRDE baseline is constructed, three conditions is considered to improve the imperceptibility with the cost of capacity reduction. Firstly, since modifications of the DC values usually give large distortions, DRDE-condition only embeds data into the AC coefficients. Secondly, DRDE-condition also rejects the modification candidates from zero AC coefficients since this kind of modifications also cause large distortions. Thirdly, to maintain the 100% correct decoding ability, DRDE-condition will not consider the modification candidates which will amend the AC coefficients to zero. Note that the escape condition, i.e., a block cannot satisfy the above three conditions, may exists. According to our experiments, this kind of blocks are rare and usually contains only one nonzero AC coefficients. Then DRDE-condition just amends the non-zero AC coefficients to zero for decoding consistency. The data extraction steps for DRDE-condition is similar to baseline except for skipping the blocks which only contain DC component.

IV. Experimental Results

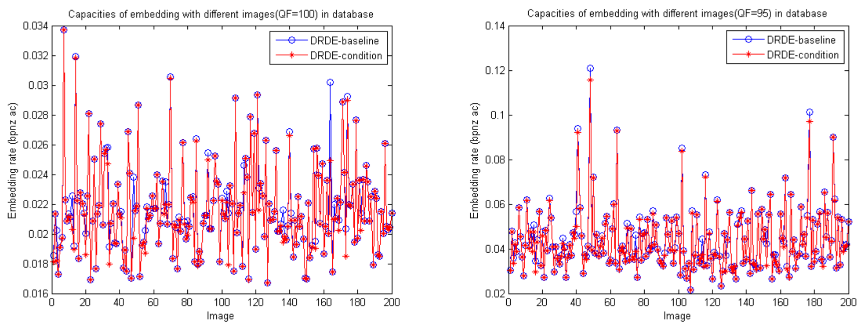
In this section, different characteristics of DRDE including capacity, imperceptibility and fragileness will be evaluated accordingly. The test images employed in different experiments are 'Lena', 'Baboon' and 'Barbara' in Fig. 2 and 200 test images, which are selected from the popular Bossbase1.01 image dataset [16] and resized to $512*512$ for convenience.

A. Capacity Test

For the DRDE-baseline, the embedding capacity is fixed to be the total block number (for a typical $512*512$ grayscale image the capacity is 4096 due to the 8*8 JPEG block size). However, since DRDE-condition will skip the blocks which only contains DC components, the capacity of DRDE-condition will vary according to the image content. Fig. 3 shows the embedding capacities (in bpnz ac) of DRDE-baseline and DRDE-condition for 200 different JPEG images. The average capacity for DRDE-baseline and DRDE-condition is listed in Tab. I. As we can conclude, although the embedding capacity is not very large, DRDE does not demand extra error correction codes to guarantee the correctness of extracted data.

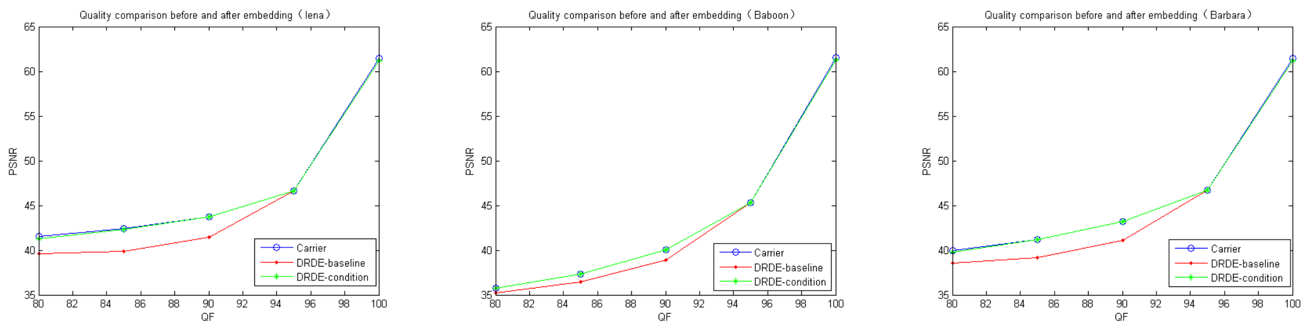
B. Imperceptibility Test

Imperceptibility test focuses on examine the image quality degradation after the data embedding process. Fig. 4 presents the different degradations at different QF levels. As we can



(a) (b)

Fig. 3. Embedding capacities of DRDE-baseline and DRDE-condition for 200 different images. (a) QF=100, (b) QF=95.



(a) (b) (c)

Fig. 4. Image qualities before and after embedding. The test images employed in the tests are (a) 'Lena', (b) 'Baboon', (c) 'Barbara'.

TABLE I
AVERAGE CAPACITY FOR 200 DIFFERENT JPEG IMAGES (IN BPNZ AC)

QF levels	DRDE-baseline	DRDE-condition
95	0.0441	0.0437
100	0.0218	0.0216

observe, both the DRDE-baseline and DRDE-condition gives almost no degradations when $QF = 95, 100$. However, when $QF \leq 90$, DRDE-baseline gives certain distortions while DRDE-condition still introduces distortions which can be neglected.

V. Summary and Future Work

In this paper, a new data embedding domain, rounding/truncation error domain, is discovered for JPEG image data embedding. This RTE domain is obtained by calculating the rounding/truncation error during the decompression of JPEG image. With the new domain discovered, a new data embedding method DRDE, which can be generally applied to data hiding and authentication, is designed to demonstrate the usage of RTE domain. DRDE embeds data by modifying the RTE domain values according to the guidelines that the amendments should be reduced after the rounding/truncation step at the JPEG standard decoder side, which can thus improve the imperceptibility of the proposed method. Experimental results indicate that the proposed data embedding method, which possesses certain embedding capacity and achieves excellent performance in imperceptibility test.

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