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RESEARCH ARTICLE

Reversible Watermarking Based on Invariant Image Classification and Dynamic Histogram Shifting

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Abstract: In this paper, we propose new reversible water- marking scheme. One first contribution is a histogram shifting modulation which adaptively takes care of the local specificities of the image content. By applying it to the image prediction-errors and by considering their immediate neighborhood, the scheme we propose inserts data in textured areas where other methods fail to do so. Furthermore, our scheme makes use of a classification process for identifying parts of the image that can be watermarked with the most suited reversible modulation. This classification is based on a reference image derived from the image itself, a prediction of it, which has the property of being invariant to the watermark insertion. In that way, the watermark embedded and extractor remain synchronized for message extraction and image reconstruction. The experiments conducted so far, on some natural images and on medical images from different modalities, show that for capacities smaller than 0.4 bpp; our method can insert more data with lower distortion than any existing schemes. For the same capacity, we achieve a peak signal-to-noise ratio (PSNR) of about 1–2 dB greater than with the scheme of Hwang et al., the most efficient approach actually.

Index Terms—Medical image, reversible/lossless watermarking, signal classification

I.   INTRODUCTION

For about ten years, several reversible watermarking schemes have been proposed for protecting images of sensitive content, like medical or military images, for which any modification may impact their interpretation [1].

These methods allow the user to restore exactly the original image from its watermarked version by removing the watermark. Thus it becomes possible to update the watermark content, as for example security attributes (e.g., one digital signature or some authenticity codes), at any time without adding new image distortions. However, if the reversibility property relaxes constraints of invisibility, it may also introduce discontinuity in data protection. In fact, the image is not protected once the watermark is removed. So, even though watermark removal is possible, its imperceptibility has to be guaranteed as most applications have a high interest in keeping the watermark in the image as long as possible, taking advantage of the continuous protection watermarking offers in the storage, transmission and also processing of the information [4]. This is the reason why, there is still a need for reversible techniques that introduce the lowest distortion possible with high embedding capacity.

Since the introduction of the concept of reversible watermarking in the Barton patent [5], several methods have been proposed. Among these solutions, most recent schemes use Expansion Embedding (EE) modulation [9], Histogram Shifting (HS) [7] modulation or, more recently, their combination. One of the main concerns with these modulations is to avoid under- flows and overflows. Indeed, with the addition of a watermark signal to the image, caution must be taken to avoid gray level value underflows (negative) and overflows (greater than for a bit depth image) in the watermarked image while minimizing at the same time image distortion. Basically, EE modulation introduced by Thodi *et al.* [9] is a generalization of Difference Expansion modulation proposed by Tian *et al.* [6] which expands the difference between two adjacent pixels by shifting to the left its binary representation, thus creating a new virtual least significant bit (LSB) that can be used for data insertion. Since then, EE has been applied in some transformed domains such as the wavelet domain [8], [9] or to prediction errors. EE is usually associated with LSB substitution applied to "samples" that cannot be expanded due to the signal dynamic limits or in order to preserve the image quality. In introduced the well-known Histogram Shifting (HS) modulation. HS adds gray values to some pixels in order to shift a range of classes of the image histogram and to create a 'gap' near the histogram maxima. Pixels which belong to the class of the histogram maxima are then shifted to the gap or kept unchanged to encode one bit of the message '0' or '1'. Other pixels are simply shifted. In- stead of working in the spatial domain, several schemes apply HS to some transformed coefficients [10] or pixel prediction errors [11], [12] , histograms of which are most of the time concentrated around one single class maxima located on zero.

II. DYNAMIC HISTOGRAM SHIFTING

As stated above, prediction errors that encode the message belong to the carrier other prediction errors are non-carriers. This predicate is static for the whole image and does not consider the local specificities of the image signal. Moreover, because prediction acts as a low-pass filter, most pre- diction-error carriers are located within smooth image regions. Highly textured regions contain non-carriers. The basic idea of our proposal is thus to gain carriers in such a region by adapting the carrier-class depending on the local context of the pixel or of the prediction-error to be watermarked. We propose a Dynamic Histogram Shifting modulation to achieve this goal. Let us consider the dashed pixel block also assume that we aim only at modulating the prediction errors indicated by leaving intact their immediate neighborhood. Because of the local stationary of the image signal we can assume without too much risk that contiguous prediction-errors have the same behavior. As a consequence, we suggest considering the prediction-error neighborhood so as to better define the location of on the prediction-error dynamic.

III. PROPOSED SCHEME

As mentioned previously, our scheme relies on two main steps. The first one corresponds to an "invariant" classification process for the purpose of identifying different sets of image regions. These regions are then independently watermarked taking advantage of the most appropriate HS modulation. From here on, we decided distinguishing two regions where HS is directly applied to the pixels or applied dynamically to pixel prediction errors respectively. We will refer the former modulation as PHS (for "*Pixel Histogram Shifting*") and the later as DPEHS (for "*Dynamic Prediction-Error Histogram Shifting*"). Our choice is based on our medical image data set, for which PHS may be more efficient and simple than the DPEHS in the image black background, while DPEHS will be better within regions where the signal is non-null and textured (e.g., the anatomical object). In the next section we introduce the basic concept of the invariance property of our classification process before detailing how it

interacts with PHS and DPEHS. We also introduce some constraints we imposed on DPEHS in order to minimize image distortion and then present the overall procedure our scheme follows.

IV. DPEHS AND DISTORTION MINIMIZATION

In order to minimize the distortion, we also propose two other refinements or constraints to be satisfied by DPEHS watermark- able pixels (or blocks). Firstly, like some others we do not watermark blocks or pixels of too large estimator biases. These pixels belong to highly textured blocks. They can be identified through the standard deviation from their block of reference. Thus is watermark- able if it also satisfied where the standard deviation of is and is a threshold we define in this study as the standard deviation mean of all reference blocks. Contrary and others [13], our extractor will retrieve computing it by itself, and will achieve the same classification. Along the same line, we do not DPEHS watermark blocks which carrier-class cannot be identified accurately. These blocks are characterized by a prediction-error neighborhood of high standard deviation. Thus is modified if where corresponds to the mean of over the whole image. It is important to notice that, the prediction error neighborhood considered here is the same as in Section II-B. This one is computed replacing in (2) the value of pixels considered for embedding by their predicted values.

A) Overall Scheme

To sum up, our algorithm runs through the image between one and four times. Each embedding pass is conducted independently from the other on one quarter of the image pixels considering the following procedure:

1. Considering a specific run into the image, possibly based on a secret key, pixels are classified into PHS region or DPEHS region.
2. One part of the message is embedded in the PHS region along with some overhead in case of overflows/underflows.

B) Image Database And Measures Of Performance

The previous watermarking scheme has been tested and com- pared with some recent methods [9]–[12]. All have been applied to several natural gray-scale images (like Lena and Baboon (see Fig. 4), used as reference in the literature), and different series of medical images issued from five distinct modalities. These image sets, illustrated in Fig. 5, contain respectively:

• Three 12 bit encoded Magnetic Resonance Image (MRI) volumes of 79, 80 and 99 axial slices of 256 x 256 pixels respectively; three 16 bit encoded Positron Emission Tomography (PET) volumes of 234, 213 and 212 axial slices of144 x 144 pixels respectively; three sequences of 8 bit encoded Ultrasound (US) images. The first sequence contains 14 images of 480 592 pixels, and the two others 9 and 30 images of 480 472 pixels respectively;

• Forty two 12 bit encoded X-ray images of 2446 2010 pixels, and; thirty 8 bit encoded retina images of 1008 x 1280pixels. To objectively quantify achieved performance, different

V. CONCLUSION

In this paper, we have proposed a new reversible water- marking scheme which originality stands in identifying parts of the image that are watermarked using two distinct HS modulations: Pixel Histogram Shifting and Dynamic Prediction Error Histogram Shifting (DPEHS). The latter modulation is another original contribution of this work. By better taking into account the signal content specificities, our scheme offers a very good compromise in terms of capacity and image quality preservation for both medical and natural images. This scheme can still be improved. Indeed, like most recent schemes, our DPEHS can be combined with the expansion embedding (EE) modulation, as well as with a better pixel prediction. However, this method is fragile as any modifications will impact the watermark. Even though some solutions have already been proposed [18], [19], questions about watermark robustness are largely open. This is one of the upcoming challenges.

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