Local prediction based reversible watermarking framework for digital videos

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Abstract : ***In digital image processing domain security area occupies an important role to protect the data from unauthenticated process. Although tremendous progress has been made in the past years on reversible watermarking, there still exist a number of problems. We believe that the most important one is related to the reversible watermarking such as robustness and the conventional schemes designs are not allowed the recovery of the same predictor at detection, without any additional information. The proposed local prediction is general and it applies regardless of the predictor order or the prediction context. For the particular cases of least square predictors with the same context as the median edge detector, gradient-adjusted predictor or the simple rhombus neighborhood, the local prediction-based reversible watermarking clearly outperforms the state-of-the-art schemes based on the classical counterparts. Experimental results show better performance over traditional state of art methods.***

Keywords: Digital image, Reversible watermarking, local prediction, least square predictors

1. INTRODUCTION

Rapid advances in Internet-based technologies and an increasing network bandwidth have led to the exchange and transfer of a tremendous amount of online digital information, including digital images as well as video and audio files. Security issues involving interception, modification and reproduction of these digital contents are subsequently emerging, explaining the increasing importance of copyright protection in information security research. Reversible watermarking technology protects digital copyrights by embedding a watermark into the original video. The watermark can then be later extracted from the watermarked image to allow the possessor to authenticate the image. Owing to the sensitivity of some applications such as in the military and medical sectors, the reversible watermarking algorithm has been developed to restore the original video from the watermarked one. Generally, the reversible watermarking technology is categorized as a fragile watermarking, so this technology cannot tolerate lossy compression, image processing, and possibly malicious attacks.

During the last decade, reversible watermarking has found a huge surge of experimentation in its domain as there is a huge need to recover the original video after extracting the watermark arises in various applications such as law enforcement, medical and military image system, it is crucial to restore the original video without any distortions. Encoding an identifying code into digitized music, video, picture or other file is known as a digital watermark. The main purpose to embed code into digital signal is to trace ownership or protect privacy (content protection or authentication).

The watermarking scheme is used for content authentication and copywriting issues. There are two major constraints: the reversible data hiding scheme should provide a high embedding capacity and the embedding distortion should be low. Further, the video is not protected once the watermark is removed. This is the reason why, there is still a need for reversible techniques that introduce the lowest distortion possible with high embedding capacity. Figure 1 shows the block diagram of a basic reversible watermarking system.

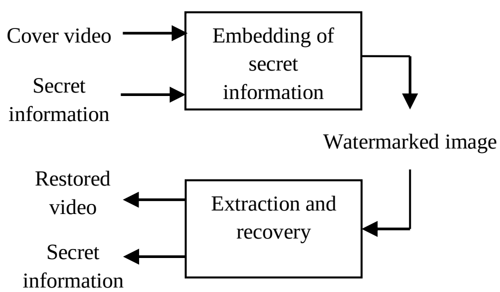

Figure 1: Basic Reversible Video Watermarking Scheme

2. DIFFERENCE EXPANSION REVERSIBLE WATERMARKING

We briefly remind the basic principles of the difference expansion with histogram shifting (DE-HS) reversible watermarking for the case of prediction-error expansion (also called prediction-error expansion). The section introduces the LS prediction as well.

Basic Reversible Watermarking Scheme:

Let $\hat{x}_{i,j}$ be the estimated value of the pixel $x_{i,j}$. The prediction error is

$$e_{i,j} = x_{i,j} - \hat{x}_{i,j} \quad \ldots (1)$$

Let T >0 be the threshold. The threshold controls the distortion introduced by the watermark. Thus, if the prediction error is less than the threshold and no overflow or underflow is generated, the pixel is transformed and a bit of data, b, is embedded. The transformed pixel is:

$$x'_{i,j} = x_{i,j} + e_{i,j} + b \ldots \ldots (2)$$

The embedded pixels are also called carrier pixels (see [12]). The pixels that cannot be embedded because $|e_{i,j}| \geq T$ (the non-carriers) are shifted in order to provide, at detection, a greater prediction error than the one of the embedded pixels. These pixels are modified as follows:

$$x'_{i,j} = \begin{cases} x_{i,j} + T, & \text{if } e_{i,j} \geq T \\ x_{i,j} - (T-1), & \text{if } e_{i,j} \leq -T \end{cases} \quad \ldots \ldots (3)$$

The underflow/overflow cases are solved either by creating a map of underflow/overflow pixels or by using flag bits . Let us suppose that, at detection, one gets the same predicted value for the pixel $x_{i,j}$. The prediction error at detection is

$$e'_{i,j} = x'_{i,j} - \hat{x}_{i,j} \quad \ldots . . (4)$$

The discrimination between embedded and translated pixels is provided by the prediction error If

$-2T \le e'_{i,j} \le 2T+1$ one has an embedded pixel. For the embedded pixels one has $e'_{i,j}=2e'_{i,j}+b$ and b follows as the LSB of$e'_{i,j}$. The original pixel is immediately recovered as

$$x = \frac{x'_{i,j} + \hat{x}_{i,j} - b}{2} \quad \dots (5)$$

For the shifted pixels, the original pixel recovery follows by inverting equation (3). As long as at detection one has the same predicted value, the reversibility of the watermarking scheme is ensured. The same predicted value is obtained if the pixels within the prediction context are recovered before the prediction takes place. Let us suppose that the watermarking proceeds in a certain scan order.

The decoding should proceed in a reverse order. The first pixel restored to its original value is the last embedded one. Obviously, for the last embedded pixel, one has the same prediction context both at detection and at embedding. Once the last embedded pixel has been restored, one recovers the context for the prediction of its predecessor and so on. Usually, anti-causal predictors are used and the embedding is performed in raster scan order, row by row, from the upper left to the lower right pixel. The use of anti-causal predictors with the normal raster scan has the advantage of using for prediction only the original pixel values.

Before going any further, a comment should be made. In fact, as shown , it is not the predicted value that should be exactly recovered at detection, but the expanded prediction error The embedding capacity of the basic DE HS scheme is given by the number of pixels that are embedded with equation (2), namely the pixels having the absolute prediction error lower than the threshold. Obviously, the capacity depends on the prediction error, i.e. on the quality of the prediction.

Linear Prediction

As said above, adaptive predictors can provide better results than fixed predictors like MED, GAP, the average on the four horizontal and vertical neighbors, etc. We shall focus on linear predictors. By linear prediction, image pixels $x_{i,j}$ are estimated by a weighted sum over a certain neighborhood of $x_{i,j}$

In order to simplify the notations, we consider an indexing of the neighborhood (prediction context), p=1,...,k, namely

$x^1_{i,j}$,..., $x^k_{i,j}$,wherek is the order of the predictor. Let $v=[x_1,\dots, x_k]$ be the column vector with the coefficients of the predictor. Let xi,j be the row vector obtained by ordering the context of xi,j according to the indexing. The predicted pixel can be written in closed form as

$$\hat{x}_{i,j} = XV \quad \dots (6)$$

A rather similar form, used mainly in linear regression, includes also a constant term

$$\hat{x}_{i,j} = v_0 + \sum_{p=1}^{k} v_p \; x^p_{i,j} \quad \dots\dots (7)$$

When the constant term is used, the vector $x_{i,j}$is extended by adding a first element, $x_{i,j}$=1. We shall consider mainly this latter form. The predicted value and the prediction error depend onv. We shall further write $\hat{x}_{i,j}$ (v) and $e'_{i,j}(v)$ .A popular solution to the linear regression problem is the least square (LS) approach. We remind that the LS considers the weights that minimize the sum of the squares of the prediction error. The LS predictor is the one that provides.

$$\min_{v} \sum_i \sum_j e_{i,j}(v)^2 \quad \text{.... (8)}$$

Let y be the column vector obtained by scanning the image along the rows and let X be the matrix whose rows are the corresponding context vectors as defined above. The prediction error vector is y−Xv. Equation (8) corresponds to the minimization of$(y - Xv)'$ (y−Xv),where" ' " denotes vector/matrix transposition. By taking the partial derivatives of the square error with respect to the components of v and by setting them equal to zero one gets XX' v=X ' y and, finally

$$v = (X'X)^{-1}X'\,y \quad ...(9)$$

3. LOCAL PREDICTION REVERSIBLE WATERMARKING

In order to illustrate the reduction of the prediction error provided by using a distinct predictor for each pixel, a simple example is presented. Let us consider the case of the rhombus context and let us evaluate the mean squared prediction error for local LS prediction computed on a $B \times B$ sliding window. The improvement depends on the video content, namely it is more significant for images with a high content of texture or fine details than for the ones with large uniform areas.

A. Local Prediction

Next, we investigate the computation of a distinct predictor for each pixel. Obviously, the embedding of the predictors coefficients into the image is out of the question. Therefore, instead of computing the predictors on original image blocks, we investigate the computation on blocks containing both original and modified pixels.

Let the pixels be embedded in a raster-scan order, pixel by pixel and row by row, from the upper left corner to the lower right one. Obviously, the decoding proceeds in reverse order, from bottom to top, starting with the last embedded pixel.

If the prediction context has k pixels, the central pixel takes part in k other prediction equations. There are two solutions:

1) The vector corresponding to the central pixel, $\boldsymbol{x_{i,j}}$, as well as the ones that contain the central pixel ($x_{l,m}$, with $\boldsymbol{x_{i,j}} \in x_{l,m}$) are eliminated from $X_{i,j}$and the central pixel as well as the pixels $x_{l,m}$are eliminated from $y_{i,j}$;

2) Before the construction of $X_{i,j}$ and $y_{i,j}$, the central pixel of the block $\boldsymbol{x_{i,j}}$ is replaced by an estimate $\tilde{x}_{i,j}$ computed by using a fixed predictor as the one of equation (10).

$$\tilde{x}_{i,j} = \frac{x_{i-1,j} + x_{i+1,j} + x_{i,j-1} + x_{i,j+1}}{4} \quad ...(10)$$

The first solution is simple, but does not consider the pixels close to the current pixel as sample data for the computation of the current predictor. The second solution eliminates this drawback, even if instead of the true central pixel value we use an estimate.

B. Proposed Scheme

In raster scan order ,the image pixels has been processed which is started from the upper left corner.

The proceedings for each pixel $x_{i,j}$ are as follows :

1). Following or using the local LS prediction scheme or the fixed predictor , we are computing the pixel $x_{i,j}$ as

- The pixel $x_{i,j}$ which is centered for the block $B \times B$ is extracted :
- Having the block which is extracted is replaced with the pixel $\tilde{x}_{i,j}$

- Scanning the block by creating $X_{i,j}$ and $y_{i,j}$
- By solving $y_{i,j} = X_{i,j} v_{i,j}$ the local predictor $v_{i,j}$ is computed
- Compute $\hat{x}_{i,j}$.

2). Compute the prediction error $e_{i,j}$.

3). If $|e_{i,j}| < T$ compute $x'_{i,j}$ with eq (2) or otherwise with eq(3).

4). If $x'_{i,j} \in [0, T-1]\, U[255-T, 255]$, replace $x_{i,j}$ by $x'_{i,j}$ if $x'_{i,j} \in [0,255]$.

5). Do not replace $x_{i,j}$ if $x'_{i,j} \nexists [0,255]$ and if the flag bit b=0 insert it to the next embeddable pixel.

4. RESULTS

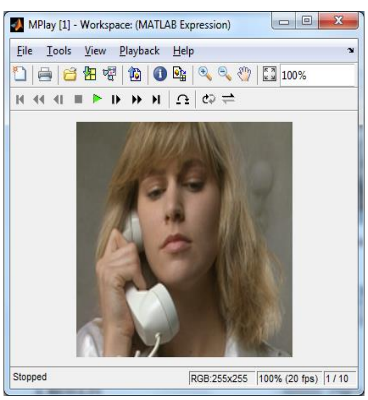

Figure 2: Input video

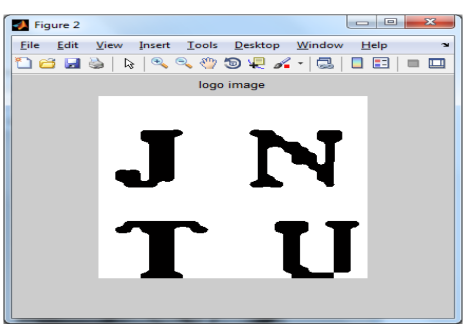

Figure 3: Logo image

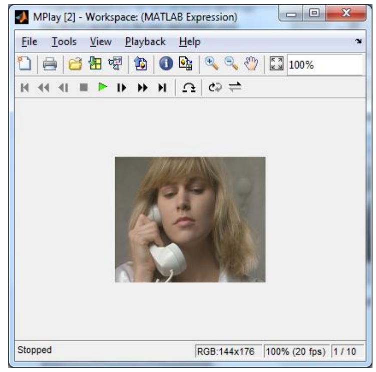

Figure 4: Watermarked video

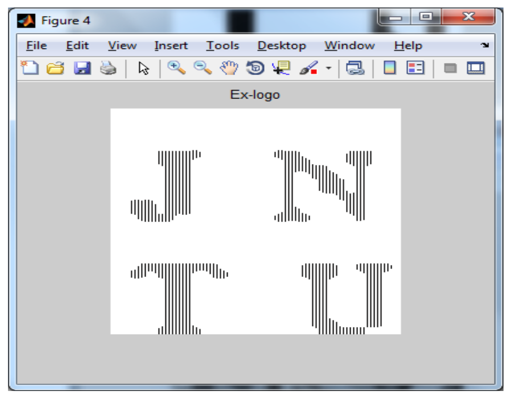

Figure 5: Ex-logo image

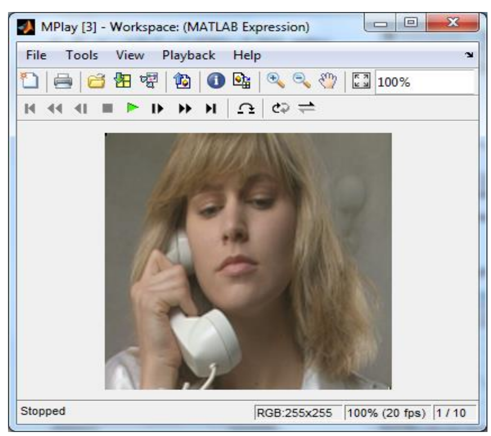

Figure 6: Input video

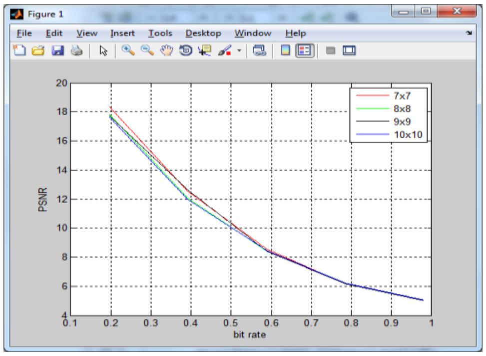

Figure 7: PSNR vs bit rate

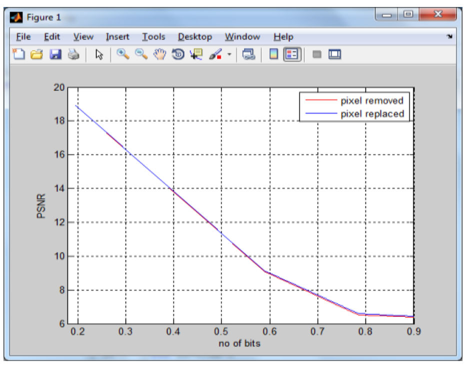

Figure 8: PSNR vs Number of bits

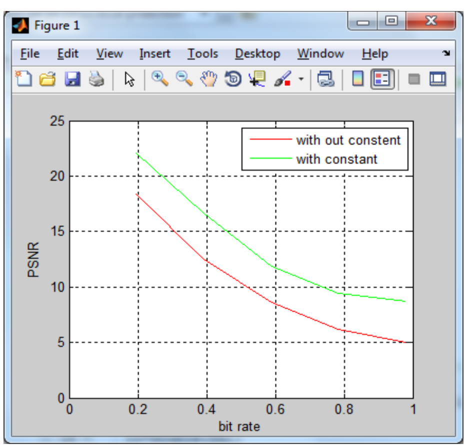

Figure 9: PSNR vs BER

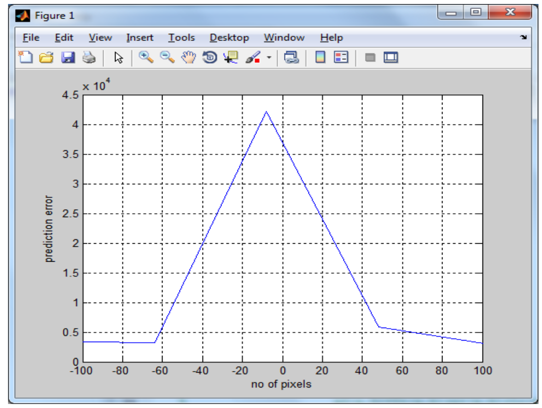

Figure 10: Prediction error vs number of pixels

5. CONCLUSION

The use of local prediction based reversible watermarking has been proposed. For each pixel, the least square predictor in a square block centered on the pixel is computed. The scheme is designed to allow the recovery of the same predictor at detection, without any additional information. The local prediction based reversible watermarking was analyzed for the case of four prediction contexts, namely the rhombus context and the ones of MED, GAP and SGAP predictors. The appropriate block sizes have been determined for each context. They are 12 × 12 (rhombus), 8 × 8 (MED), 10 × 10 (SGAP), 13 × 13 (GAP). The gain obtained by further optimization of the block size according to the image is negligible. The results obtained so far show that the local prediction based schemes clearly outperform their global least square and fixed prediction based counterparts. Among the four local prediction schemes analyzed, the one based on the rhombus context provides the best results. The results have been obtained by using the local prediction with a basic difference expansion scheme with simple threshold control, histogram shifting and flag bits.

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