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A FIBONACCI LSB DATA HIDING TECNIQUE

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ABSTRACT

In this paper, a novel data-hiding technique based on the Fibonacci representation of digital images is presented. A generalization of the classical Least Significant Bit (LSB) embedding method is performed. The Fibonacci representation of grey level images requires 12 bit planes instead of the usual 8 planes of binary representation. Experimental results show that, such a redundant scheme outperforms the classical LSB method resulting in marked images having less perceptual distortion even if different planes from the lowest bit plane are selected for embedding. The computational cost of the embedding scheme is compatible with the classical LSB data hiding scheme.

1. INTRODUCTION

The use of multimedia digital data has become very popular in the last decade due to the spread of Internet-based services, and the introduction of the third-generation mobile communication systems (UMTS/CDMA2000).

Thanks to the availability of low cost editing tools, digital data can be easily captured or copied, modified and re-transmitted in the network by any user. To effectively support the growth of multimedia communications, it is essential to develop tools that protect and authenticate digital information.

In this contribution, we present a novel embedding scheme based on the Fibonacci decomposition. The results of the new scheme are compared with the classical LSB method with respect to PSNR.

In Section 2, the classical LSB scheme is described. Section 3 deals with the Fibonacci decomposition and its related properties. In Section 4, the embedding scheme is described; Section 5 reports the results of simulations. We conclude in Section 6 with some brief remarks.

2. LSB DECOMPOSITION

One of the simplest systems for embedding digital data into a digital cover is the Least Significant Bit method [10] Consider an NxM image in which each pixel value is represented by a decimal number in the range determined by the number of bits used. In a gray-scale image, with 8 bit precision per pixel, each pixel assumes a value between [0, 255] and each positive number β_{10} can be represented by:

$$\beta_{10} = b_0 + b_1 G^1 + b_2 G^2 + \cdots = \sum_{i=0}^{n} b_i G^i$$

where G is equal to 2. This property allows the decomposition of an image into a collection of binary images by separating the b_i into n bit planes.

In the classical LSB embedding methods, the secret message is inserted into the least-significant bit plane of the cover image either by directly replacing those bits or by modifying those bits according to a particular 'inverse' function. The embedding strategy can also be based on sequential insertion or selective embedding of the message in "noisy" areas or random scattering throughout the image. Recent methods apply LSB not only in the least significant plane but also in other bitplanes or a mixture of both [10] . The amount of data to be embedded may also be fixed or variable in size depending on the number of pixels selected depending on luminance and contrast features. The main advantage of such a technique is that the modification of the LSB plane does not affect the human perception of the overall image quality as the amplitude variation of the pixel values is bounded by ±1. The masking properties of the Human Visual System allows significant amounts of embedded information to be unnoticed by imperceptible by the average observer under normal viewing conditions. "Masking" refers to the phenomenon where a signal can be imperceptible to an observer in the presence of another signal. A detailed review of these techniques is given in [1] [3] [4] Other advantages of LSB data hiding included high embedding capacity and low computational complexity. The main disadvantages are the weaknesses with respect to robustness, tampering, geometric attacks, filtering, and compression.

3. FIBONACCI DECOMPOSITION

The classical Fibonacci numbers were introduced in the 13th century by Leonardo of Pisa a.k.a. Fibonacci in his book, *Liber Abaci* [2] He introduced there the famous rabbit problem leading to the sequence 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, ….

The sequence of Fibonacci numbers is defined by the following recurrent relation:

$$\begin{cases} 0 & n<0 \\ 1 & n=0 \\ F(n-1)+F(n-2) & n>0 \end{cases}$$

The basis F_n of the Fibonacci representation are the numbers of the sequences

$$F(n)=F(n-1)+F(n-2) \quad \forall n \geq 2$$

Table 1: The system of binary and Fibonacci numbers, for some values of n.

N	0	1	2	3	4	5	6	7	8	9	10
Bin	0	1	2	4	8	16	32	64	128	256	512
Fib	0	1	1	2	3	5	8	13	21	34	55

Table 2: Maximum bit error for each plane after embedding.

Bit Plane	1	2	3	4	5	6	7	8
Bin	+1	+2	+4	+8	+16	+32	+64	+128
Fib	+1	+2	+3	+5	+8	+13	+21	+34

From Table 1, it is easy to see the difference between the two representations:

- For the same number of bits (for N>2), a larger numeric range is available for binary representation. For 8 bits, the range is [0, 255] for binary representation compared to [0, 54] for Fibonacci representation.
- The binary representation does not introduce redundancy. To represent values in the range [0, 255] in Fibonacci domain, we need 12 bits, 4 bits more than in the binary representation. As a result, a grey level image will be represented in 12 bit Fibonacci planes.
- As shown in Table 2, the distortion amount introduced by changing the bit value in the planes is bigger in power of two representations than in Fibonacci representation.

The Fibonacci representation is redundant, since a given natural number can have many representations as a sum of Fibonacci numbers. For example, the number 16 can be represented as 13+3, as well as 8+5+3, or 8+5+2+1. Nevertheless, there is one Fibonacci representation, called the normal representation, which allow a unique decomposition of a natural number. It is based on Zeckendorf's theorem [8] which states that *"Each positive integer m can be represented as the sum of distinct numbers in the sequence of Fibonacci numbers using no two consecutive Fibonacci numbers."*

As a consequence of the Zeckendorf's theorem, any positive integer can be represented as

$$\beta_F = b_0 + b_1F^1 + b_2F^2 + \cdots = \sum_{i=0}^{n} b_iF^i$$

where there are no 2 consecutive 1's in the sequence.

4. EMBEDDING SCHEME

The embedding procedure consists of the following two steps. First, the selection of areas in an image to embed the mark is performed. In the classical scheme, one bit is embedded in each pixel of the image. To increase the amount of data to be embedded, more than one bit-plane may be used. These methods achieve high capacity but introduce noticeable distortions in the image. Recent studies show that the annoyance and visibility of artefacts depend on the saliency of the affected areas whose map can be computed by direct exploitation of the characteristics of the HVS [11] [12] [14] Psychophysical studies demonstrate that among the factors impacting the human attention, contrast, colour, motion, brightness, object size and shape are the most significant. The relative importance of these factors has yet to be determined. We have applied different strategies to select areas of embedding, including local variance [5] , spatial segmentation by LPA-ICI rule [9] . The selection of areas provides an embedding map for selecting pixels to be decomposed in the Fibonacci domain.

The watermark is a sequence of *N* bits B = $(b_0, b_1, .., b_{N-1})$ that is spread by a pseudo-random sequence p(x; y) of ±1 representing the secret key.

The second step in the embedding procedure is to decompose the selected pixels in the Fibonacci domain, and also to select the plane in which to embed. The same embedding scheme can be also applied to different planes resulting in more robust data hiding and possibly higher visual distortion. With respect to the classical LSB methods, Fibonacci LSB usually does not allow a fixed size embedding since not every pixel in the block is a "good candidate" for the embedding. To deal with Fibonacci redundancy, it is necessary to comply with Zeckendorf's theorem. If the selected pixel is not a "good candidate" (meaning that the current bit to be changed by 1 has a neighbour in the previous bit plane having also a value 1), then the next candidate pixel is selected and a side information table, containing embedding information, is updated.

It is important to note that the scope of this work was to determine if the Fibonacci domain is suitable for 'spatial' embedding. The robustness or security of the data hiding system are not fundamental as in any LSB based scheme. The final aim is to investigate the possibility of inserting a mark without altering the perceptual quality of the final image.

The extraction of the watermark requires the knowledge of the secret image S and the key K used for spatial dispersion of the watermark image. The extraction operation is the inverse of the embedding operation. The watermarked image under inspection is partitioned into areas in a manner similar to the selection of embedding area. Using the side information, only the selected pixels are tested for mark presence. Following, a de-spreading operation is performed, the received watermark is obtained.

5. EXPERIMENTAL TEST

To evaluate the performance of the proposed scheme, we have compared the results of LSB embedding performed in the binary domain [5] [6] [7] with the one adapted to the Fibonacci decomposition.

In [6] , the authors, in order to reduce the detectability of watermark, have used *m−sequences* to encode the LSB of the image data. Due to their balance, random appearance, and good autocorrelation properties (a single peak with no side-lobes), application of these codes does not introduce apparent image degradation or detectability by a casual viewer.

The *m−sequences* of maximal length (2n − 1) for a vector of length *n*, can be formed from starting vectors by a Fibonacci recursion relation. The main property is that the autocorrelation function (and hence, the spectral distribution) of the *m−sequences* resemble that of a random Gaussian noise distribution. This similarity becomes closer as the sequence length increases. That is, images encoded with *m−sequences* and one bit Gaussian noise are shown to be indistinguishable from the original and from each other.

In practice, longer *m−sequences* were employed that were commensurate with the image size (*2n*) and exhibited a null in the autocorrelation around the main peak. To insert a watermark, it is necessary to first generate a watermarking signal using a key to seed a generator for *m−sequences* (a maximum-length random sequence). The elements (binary valued) of the *m−sequences* are then arranged into a 2D watermarking signal. Thus, the obtained *m−sequences* are now embedded into the LSB of the image. The decoding process makes use of the unique and optimal autocorrelation function of *m-sequences*.

The second technique [15] , is based on the preliminary computation of a checksum of the image data, followed by the embedding of the checksum into the LSB plane of randomly chosen pixels. The goal is a selection of a checksum scheme without introducing artefacts in the image. A checksum is the modulo-2 addition of a sequence of fixed-length binary words. A uniformly distributed pseudo–random number generator is used to map the checksum bits onto a path of randomly selected pixel locations within the limits of the image *(random walk)*. At each location, the LSB of the pixel value is forced to match the value of the corresponding *n-th* checksum bit as *n* goes from 0 to N− 1. When adopting Fibonacci representation, only small modifications are needed in computing the checksum (sequences to be added are 8 − 11 bit segments) and to the final embedding scheme (which is not completely random due to Zeckendorf's representation).

The last scheme considered is based on [5] . The embedding algorithm can be summarized as follows:

- The cover image is partitioned into non-overlapping blocks of size (8×8) pixels.
- For each block the variance is computed and the blocks are then sorted according to their variance values.
- For each block, the LSB plane is selected and the mark inserted. The same scheme may also be applied to different planes resulting in more robust data hiding which might result in higher visual distortion.
- The watermark, after a classical spreading operation, is inserted pixel by pixel in each block, starting from blocks of lower variance.

The same method is also performed in the Fibonacci domain with only few modifications. The extraction of the watermark requires knowledge of the secret image *S* and the key *K* used for spatial dispersion of the watermark image. The watermarked image under inspection is partitioned into non-overlapping block of size 8×8 pixels. Using the side information, only the selected blocks are tested for mark presence. Following, a de-spreading operation, the watermark is recovered.

A qualitative estimation of the extracted watermark $\widetilde{W}(x,y)$, with respect to the embedded version $W(x,y)$, may be expressed as a Normalized Cross Correlation (NCC):

$$NCC = \frac{\sum_x \sum_y W(x,y)\widetilde{W}(x,y)}{\sum_x \sum_y \left[W(x,y)\right]^2}$$

where the maximum value of NCC = 1 corresponds to a perfect match.

We have performed several tests on images watermarked in both the binary and Fibonacci domains using PSNR and NCC as a performance measure. Our results indicate that embedding in the Fibonacci domain may introduce less perceptual distortion and higher PSNR. The LSB based methods are well known to be not robust. We have tried some simple modifications on to evaluate the "robustness" of the Fibonacci-based method. The following modifications were considered:

- Median filtering with 3x3 window;
- Additive Gaussian noise: variance 0.1 on the 50% of pixels of images;
- Resizing: the watermarked images were scaled to one half of their original size and back to the original dimensions;
- JPEG compression (compression ratio 1:45)
- Image cropping.

We have used three test images: Cameraman, Clock, and Fishing Boat. The results of the first three modifications are shown in Table 3.

From our simulations, we found that there are no significant differences in results obtained using binary and Fibonacci representations. The first embedding method modifies just the LSB plane resulting in little changes in the PSNR for both representations. Figure 1 (a) shows the Cameraman image used as a cover image (b) shows the watermark, M,

(c) and (d) are the watermarked images. Note that PSNR=46.71 dB means that the quality degradations could hardly be perceived by a human eye. In the Fibonacci domain, the PSNR for the watermarked image is about 57.92 dB. Robustness against different attacks for the third method is shown in Table 3.

Table 3. Performance comparison between the classical LSB and Fibonacci-based LSB embedding for the Cameraman image.

	Binary domain		**Fibonacci domain**	
	PSNR *dB*	NCC	PSNR *dB*	NCC
JPEG	31.268	0.7604	31.284	0.8360
Median	27.14	0.8004	27.14	0.8150
Noise	23.30	0.7658	23.33	0.6947
Resizing	26.204	0.7942	26.211	0.8270

We have performed a correlation test between the two representations. Usually, the computation of the correlation with original image is a useful way to measure the level of degradation introduced. Figure 2 shows this tendency. On the *x*-axis of both plots we have the normalized pixel value (from 0 to 1) of original image I, and on the *y*-axis we have the normalized pixel value of watermarked image I2 and the Fibonacci watermarked image (IF). When two images are similar, the correlation between pixels at the same location (x,y) is high. Hence, the closer are the points to the diagonal line, the higher is the correlation between corresponding pixels, and, therefore, the smaller is a degradation introduced.

6. CONCLUDING REMARKS

In this paper, we have presented our preliminary study on the use of Fibonacci representation of digital images for embedding purposes. The comparison has been performed with respect to the classical LSB embedding methods.

When Fibonacci representation is used under the constraint that the same embedding conditions are used as in the binary case, a similar or higher PSNR is obtained.

If the embedding is done not to the LSB, but previous bit-planes, the artefacts introduced are less annoying for Fibonacci than for a binary representation.

Test performed to measure the *robustness* against an additive noise confirms the weakness of the spatial domain LSB-based methods.

Finally, we have performed a test of the marked image cropping modification. To improve the method, a preliminary reshuffling of the mark data have been per-formed using a Fibonacci scrambling technique proposed in [13] . It demonstrated increased *robustness* relative to the LSB embedding method.

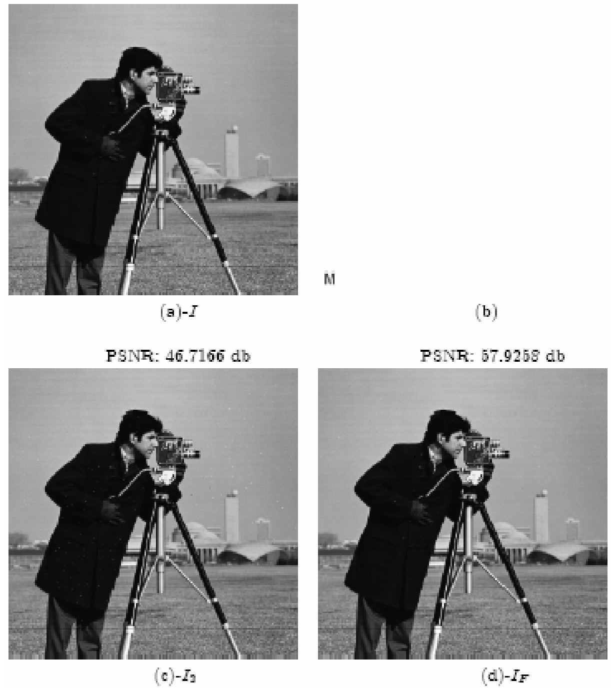

Figure 1: Figure (a) is the original image Cameraman 256x256. Figure (b) is the watermark used, two level image 16x16. Figure c) is the watermarked image binary representation, Figure (d) the watermarked image in Fibonacci domain.

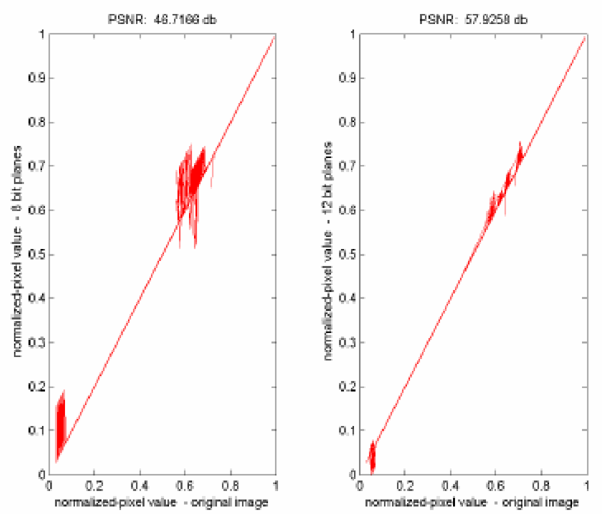

Figure 2: Correlation between images. The plot at left is between the original image I and the binary watermarked image I2; and at right – is between image I and the Fibonacci watermarked image IF

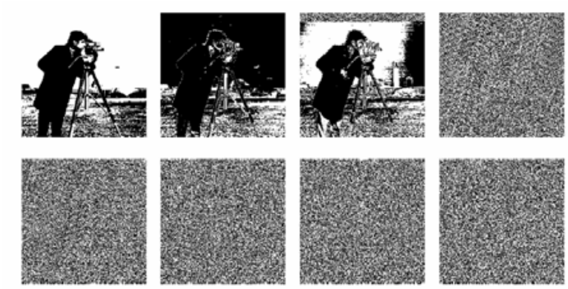

Figure 3: 8 bit planes decompositions.

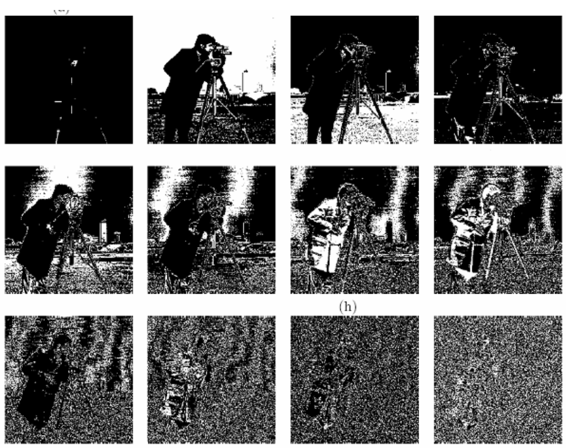

Figure 4: Fibonacci ‘s 12 bit planes decomposition.

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