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# Wavelet and Multichannel Wavelet Based Watermarking Algorithms for Digital Color Images

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## Abstract

Protection of digital images copyright is a critical point for the multimedia Web applications. In this work we face the problem using watermarking techniques. In particular we present the analysis, development, implementation and application of wavelet and multichannel wavelet based watermarking algorithms for digital color images from a viewpoint of an effective usability and availability in a real applicative background.

*Keywords:* `Wavelet, multichannel wavelet, digital color image processing, watermarking algorithm.`

## 1. Introduction.

Copyright is a sort of protection provided by laws to the authors of "original works of authorship". Unfortunately when the objects at issue are a digital works, the protection becomes a complex problem. One of the popular approaches considered as a tool for providing copyright protection is the *digital watermarking*. General idea of the digital watermarking is to embed a unique identifier in an image, called *watermark*. The watermark must be undetectable by the human eye.
In this paper we focus our attention to watermarking techniques applied to digital color images belonging to web virtual images galleries.
Generally watermarking algorithms are based on a dual scheme: the *embedding* phase and the *detection* phase. These two phases are temporarily independent, but without the embedding phase the detection phase would not have reason to be. The watermarking algorithms are classified in different ways. In particular they can be *public* if the watermark is detected from the watermarked image without the necessity to have the original one, or *private* otherwise. Another classification criterion distinguishes wa-

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termarking schemes into *spatial domain* and *frequency domain* techniques in relation to the approach using during the images process.
In the spatial domain techniques watermarking scheme works directly on the pixel bit of the image [24]. These techniques are based on the identification of image regions where the human eye is less sensitive to noise [25].
In the frequency domain techniques the watermark is embedded by altering some frequency bins obtained by transforming the image in the frequency domain by Discrete Cosine Transform (DCT) [21] or Discrete Wavelet Transform (DWT) [8,14] and another transforms. In this context robust means resistant to digital alteration, called "attacks", that can modify, delete, or substitute the watermark [26].
Over the last years *multiwavelet* functions have been introduced in watermarking techniques. Multiwavelets of multiplicity $r$ are vector valued functions. In the existent literature (eg. [19,30]) the decomposition/reconstruction algorithms are performed on each plain of the RGB (Red, Green, Blue) images by means multiwavelet functions with multiplicity $r = 2$ as GHM [16] and Chui-Lian [10]. That is, the authors consider a image as a scalar signal and they convert it to a vector valued signal by combining successive data elements into 2 input components.
In this work we present a different approach. In fact we apply a *multichannel wavelet transform* (DMCWT) using full rank filters with multiplicity $r = 3$ [12]. This function allow to only one multiwavelet decomposition/reconstruction step on the whole color image.
In this article we compare the robustness and invisibility properties relative to wavelet based watermarking algorithm and multichannel wavelet based watermarking one.
The work is organized into three parts. In the first part we introduce a mathematical background. In the second part we describe the realized watermarking algorithms for digital color images. In the third part we show the results relative to the large experimentation to verify the properties of imperceptibility and robustness to different attacks and we compare these results relative of our two algorithms.

## 2. Mathematical background

Historically, the concept of wavelets is originated from the study of time-frequency signal analysis, wave propagation, and sampling theory. In 1982, Jean Morlet [22,23] first introduced the idea of wavelets as a family of functions constructed by using translation and dilation of a *mother wavelet* for the analysis of nonstationary signals. Today wavelet analysis is an excellent method for solving difficult problems in several disciplines

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with applications as diverse as data compression, image processing, pattern recognition [11,15].
One generalization of wavelets are multiwavelets [18,27], which have been around since the early 1990s. Unlike the scalar case, some extra degrees of freedom are allowed, which can be used to construct functions with several desirable properties, combining, for example, orthogonality, symmetry, short support and vanishing moments [28]. All these properties are needed for efficiently processing two-dimensional signals, hence multiwavelets are more powerful than wavelet in image processing. In the other hand the application of the multiwavelet decomposition/reconstruction scheme requires two additional steps respect to the scalar case. The first consists in finding from a given set of input data $\{y_1, y_2, ....., y_m\}$, $r$ sequences of initial coefficients $\left\{c_i^{k,0}\right\}_{k\in Z}$, $i = 1, ...., r$, needed by the analysis phase. This step is called *prefiltering* of the data, since it can be seen as the application of a filter to the initial data. The second step is called *postfiltering*. It consists in finding the output data from a vector of $r$ entries obtained from the synthesis phase. The pre and postfiltering are crucial points in multiwavelet analysis. In fact a bad filter, which does not take into account the properties of the assigned basis, can give rise to bad results in applications. Moreover these steps increase the computational cost of the whole multiwavelet transform but it can be avoided if *full rank* filters are used.
In [6,7] the *multichannel wavelet* theory has been presented. In this case the pre and postfiltering steps are never required. The multichannel wavelet functions are due to process signals with $r$ *vector-valued* signal by means suitable decomposition/reconstruction schemes. In fact they allow to process signals as a multichannel signals with possibly intricate correlations between some of these channels. A good example of multichannel signal is a color digital image because color image has at least three components in according to the color model representation. The color pixels are vectors. In RGB system, e.g., each point $\mathbf{c}$ can be interpreted as a vector $\mathbf{c} = [c_R, c_G, c_B]^T$. The components of $\mathbf{c}$ are the RGB components of a color image at a point [17].
In this work we have used a new class of full rank filters with multiplicity $r = 3$ constructed via *Lifiting* and *Dual Lifting* scheme built in [12]. The lifting scheme was born as an iterative procedure to construct biorthogonal wavelet bases and it has been introduced by Sweldens in [29]. In [5,13] and [6] have been presented and developed generalizations to the case of multiwavelet and multichannel wavelet respectively.
The lifting scheme provides valuable intuition about the degrees of freedom made available in the multiwavelet and multichannel wavelet cases

and it motivates some new design criteria for using these new degrees of freedom effectively. All compactly supported biorthogonal multiwavelet and biorthogonal multichannel wavelet bases can be achieved by applying a finite sequence of simple lifting steps to a simple initial bases. The used multichannel filters have multiplicity $r = 3$ and they are a *perfect reconstruction filters*.

## 3. Watermarking algorithms

In this section we introduce the realized watermarking algorithms for digital color images belonging to web virtual images galleries. They embed an *invisible* the watermark into digital color images and detect the watermark comparing the original and watermarked images (*private* algorithm). Our algorithms are domain frequency based. They process digital color images in HSV (Hue, Saturation, Value) color model in according to Human Visual System study. In fact this indicates that the human eye is less sensitive to noise in those areas of the image where the brightness is high or low. Therefore the watermark is inserted in the Value plane of HSV model of the original image. We apply our algorithms on images of a real database. So they have generally different sizes and can be square, rectangular with high and low resolution.

The watermark is encoded altering some frequencies obtained by transforming these matrices in the frequency domain by Discrete Wavelet Transform (DWT) and Discrete MultiChannel Wavelet Transform (DMCWT). These functions must be computed on matrices which number of columns and rows are divisible by $2^l$, with $l$ decomposition level. Therefore, in embedded and detection schemes, we introduce two very additional important steps that transforms the associate Value plane matrix in a suitable dimension matrix and vice versa: *preprocessing* and *postprocessing* steps (see [3]). In *embedding process* we compute the watermarking signal depending on the values of statistic functions of the image. The input image to watermark are in JPEG format. It is represented by a three dimensional matrix $I \in \mathbb{R}^{n\times m\times 3}$. In *wavelet based algorithm* the first step consists to convert it from RGB color model to HSV one. We apply the preprocessing step in order satisfying the mathematical condition of decomposition. We extract the third matrix plane $V$ relative to the Value component. Then we compute the DWT $l$-times, where $l$ is the suitable decomposition level in accordance with the order of matrix $V$. The watermark signal is embedded by an additive formula in according to two elements: $\omega$ and $\alpha_i$, $i = 1, 2, 3$. $\omega \in \mathbb{R}$ is a global parameter accounting for watermark strength. While

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$\alpha_i$, $i = 1, 2, 3 \in \mathbb{R}^{\frac{n}{2^l} \times \frac{m}{2^l}}$ are weight matrices indispensable for the invisibility of watermark. We apply $l$ steps of Inverse Discrete Wavelet Transform (IDWT) to three modified high frequencies sub-matrices and to the low original sub-matrix obtaining a new Value component of watermarked image. Then we obtain a new matrix relative to the Value component of watermarked image, while the Hue and Saturation plain are relative to the original image ones.

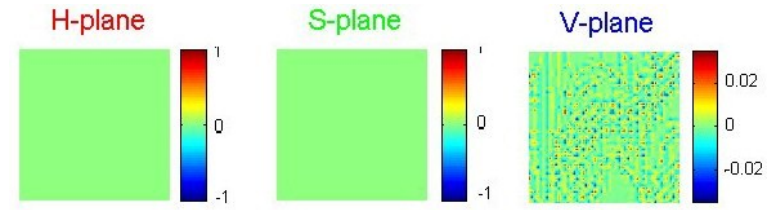
The embedding process of the *multichannel wavelet based algorithm* is composed of similar step. In this case we decompose by means DMCWT function the three dimensional matrix $I$ representing the original image in HSV color model after the pre-processing step. We modify by a similar additive formula a high frequencies of the third matrix plane relative to the Value component. So we apply the Inverse Discrete MultiChannel Wavelet Transform (IDMCWT) to three modified high frequencies sub-matrices and to the low original sub-matrix obtaining a new watermarked image.

In the embedding phase our efficient watermarking algorithms balance the properties of imperceptibly and robustness of the mark in an accurate way by a good choice of $\omega$ and $\alpha_i$, $i = 1, 2, 3$. The watermarked image is stored in JPEG format to distribute it on web.

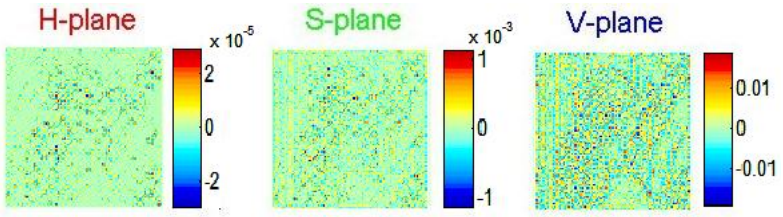
In Fig. 1 the difference between the original and watermarked planes of images are shown. It is important to pay attention to the Figure 1(b). In fact, we modify the multichannel wavelet coefficients of Value plane. After the IDMCWT the Hue and Saturation plane are also changed.

In the *detection process* the watermark signal is recognized analyzing the correlation between the original and watermarked images. The watermarked image could be different in pixel and dimension from the watermarked image output of embedded process. In fact this image could have been modified by attacks changing its dimension as cut or resize. Therefore we introduce a new step called *synchronization* step [2]. It consists to make equal the dimension of the original and watermarked images computing some statistic values of two images. The correlation between the watermarked image coefficients and the watermark signal is estimated. In both algorithms the detection is obtained minimizing the probability of missing detection to given probability of false alarm, according to the Neyman-Pearson statistic criterion [8]. It determines a detection threshold minimizing the probability of missing detection respect to the given probability of false alarm.

For further details on the algorithms you see [1] and [4].




(a) Wavelet-based algorithm




(b) Multichannel Wavelet-based algorithm

Fig. 1. Difference between the original and watermarked planes images

## 4. Experimental test

In this section we describe the experimental tests executed to analyze the properties of our algorithms and we compare the results. In particular we estimate the invisibility of our embedded watermark by testing on classical test images by means *Peak Signal to Noise Ratio* (PSNR) and *Weight Peak Signal to Noise Ratio* (WPSNR). The second part of experimental tests on the our algorithms has the aim to verify their robustness. To estimate it we apply several geometric attacks (i.e. resize, distortion, StirMark) to the watermarked image before executing the detection process. This important property has been tested on different kind of images, in high and low resolution, building the a real database.

### 4.1. *Invisibility property*

The first test verifies the invisibility of the adding watermark. We consider four classic test color images *Lena*, *Baboon*, *Airplane* and *Peppers*. To measure the error, in our case is the watermark, in the watermarked image that we use PSNR (*Peak Signal to Noise Ratio*) and WPSNR (*Weight Peak Signal to Noise Ratio*) values. PSNR is commonly used from the image processing community because it is a logarithmic measure which correlates with the logarithmic response to image intensity of HSV. In fact experimental evidence indicates that the brightness is a logarithmic function of the light intensity incident on the eye. It is not completely reliable so another

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measure is introduced: WPSNR. It is based on the Contrast Sensitive Function (CSF) [9]. WPSNR gives most weight to the edge of the error checks and relatively little weight to the central portion of each check. In Table 1 we show the results relative of this test. In particular we can observe that obtain better results applying the watermark by means the multichannel wavelet based algorithm than wavelet based one. In both cases we embed a not visible watermark (see Figure 2).

Table 1. PSNR and WPSNR of the watermarked images

| **Wavelet-based algorithm** | | | | |
|---|---|---|---|---|
| | *Lena* | *Baboon* | *Peppers* | *Airplane* |
| **PSNR** | +33.72 | +29.87 | +32.32 | +33.15 |
| **WPSNR** | +50.71 | +48.54 | +48.76 | +52.86 |
| **Multichannel wavelet-based algorithm** | | | | |
| | *Lena* | *Baboon* | *Airplane* | *Peppers* |
| **PSNR** | +35.74 | +32.00 | +33.77 | +34.90 |
| **WPSNR** | +52.61 | +49.34 | +49.70 | +53.65 |

(a) Original image (b) Watermarked image 1 (c) Watermarked image 2

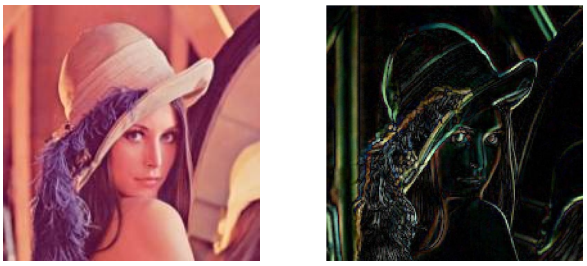
Fig. 2. The watermark signals embedded by wavelet based algorithm 2(b) and multichannel wavelet based one 2(c) in the original *Lena* image 2(a) are not visible

### 4.2. *Robustness property*

To analyze the *robustness* of the algorithms we apply some attacks on a set of color digital images belonging to a real database. The differences of historical-artistic images considered during the experimental tests have given a diversified and complex survey. Tests have been directed towards an effective usability and availability in a real applicative background. All the images are in JPEG format. They are obtained by different acquisition processes (photo CD, digital camera, scanning from negative film, scanning of photographs). In the executed experimentations to test the watermarking algorithm behavior in according with image features, the images have been grouped according to the following features:

1. details clearly defined on uniform background;
2. objects on not uniform background;
3. much contrast;
4. not much contrast;
5. faces (as painted, fresco);
6. contours are not clear.

We apply the following attacks: *blurring*, *distortion*, *rotation*, *noise*, *cutting part of images*, *resize* and *StirMark*, with a ratio more than 88%. StirMark is a more dreaded attack [26]. In fact it simulates a resampling process, it applies a geometric distortion and then resamples using bi-linear interpolation. By means a transfer function, it emulates the small non-linear analog/digital converter imperfection. A medium compression JPG is applied at the end. Fig. 3 shows the attacked images by StirMark (Fig. 3(a)) and the difference between this and the original image (Fig. 3(b)). The ob-



(a) Attacked Lena

(b) Difference between original and attacked images

Fig. 3. Example of the StirMark effect

tained results with the second algorithm are better than wavelet based one (Table 2). Furthermore it is very important to note that the percentage of *success* respect to StirMark attack is 91% against of the results relative to digital watermarking commercial software in [20].

## 5. Conclusion

We have been involved the watermarking algorithms for digital color images from a viewpoint of an effective usability and availability in a real applicative background. In this article we have presented two watermarking algorithms based on wavelet and multichannel wavelet functions. They have the following characteristics: invisible, private algorithms enjoying robustness, imperceptible properties. We have described the large experimentation and the important numerical results. In particular the differences

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Table 2. Results of the attacks applied on the watermarked image in percentage of success. The used images are 79 and belong to real database

| Algorithm | Blur | Distor-tion | Rota-tion | Noise | Cut | Resize - | Resize + | Stir-Mark |
|---|---|---|---|---|---|---|---|---|
| **Based on wavelet** | 100% | 97% | 100% | 97% | 98% | 88% | 100% | 91% |
| **Based on multichannel wavelet** | 94% | 99% | 99% | 90% | 97% | 99% | 94% | 100% |

of historical-artistic images considered during the experimental tests have given a diversified and complex survey.

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