Innovative Image Watermarking Technique Using Psychovisual and Spatial Approaches

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Summary
Nowadays, wide world web access has made easier than ever to get digital contents and to distribute them, often going beyond copyright controls. We often think first of music, but the problem also arises for images and videos. To resolve such problems, digital watermarking field provides many techniques depending on the application. In this paper, we completed a design to insert watermarks into an original image. Strict standardized methods for the assessment of the sound quality were adapted to our image context leading to a new approach of image watermarking evaluation. Subjective tests done on laboratory show that perceptual quality are preserved. Objectives tests show that our work can lead to medical and forensics applications.

Key words:
Digital watermarking, image watermarking technique, watermarks, secret key, PSNR, MSE.

1. Introduction

Image watermarking is special changes in the image as adding distinctive mark to it such as a copyright sign or a text. A digital watermark is a signature added to a digital content which can be a document, an audio or an image generally but can also be placed in a text file, a video or a 3D model. First watermarking techniques aimed to identify the owner of a document by placing on it a set of bits called watermarks. These can be visible or invisible. Adding a visible watermark is quite simple, since it is only put on the document a distinctive mark. The problem is that advanced signal processing techniques often allow to easily remove watermarks. As alternative, invisible watermarking techniques have raised. In this case, inserted information is done in a manner so it does not alter the quality of the image. The change is invisible to the naked eye. Invisible watermarks, usually protected by a secret key, permit to add plenty of information like author biography, creation date, etc [1].

In conclusion, digital watermarking, is primarily an integrated visual signature to a document added explicitly, or invisible marks protected by a key to prevent attacks.

2. Image watermarking systems

2.1 Watermark visibility

Digital watermarks are divided into two types: visible watermarks and invisible ones.

Visible watermarks fix a perceptual mark such a logo or another image to mark the owner in the case of a picture. They are widely used in the field of photo agencies under copyright form ("©"). This watermarking technique can be done quite easily using a drawing program and therefore it has a major drawback. The fact that the watermark is visible allows any external person to remove it because it is not complicated; a little research on the web permit to find a suitable software that could remove a piece of the image and reshape the image without it.

Invisible watermarks consist on the placing of a mark but is designed to be imperceptible to the naked eye. The information in this case can be of different nature such as a permission for the use of the document, the owner of the document or the holder of the copy or a serial number. This type of watermarks needs some criteria to be efficient [2]:

- Imperceptibility: The principle is to be invisible, it is necessary that the watermark has to be sufficiently hidden not to change the initial perception of the image and also to be difficult to find by pirates.
- Robustness: The watermark should in general resist to the usual transformations such as compression, data extraction, printing, etc.
- Security: The watermark should be able to cope with external attack that seeks to change or destroy it.

2.2 Watermark capacity and data payload

Visible and invisible watermarks are divided into two subcategories: fragile watermarks and robust ones.

The fragile watermarking is used essentially to prove the authenticity of the document. The protection of this watermarks is very low. In general, the digital content that

Manuscript received October 5, 2016
Manuscript revised October 20, 2016

it carries the hidden information is not really important. The mark is part of the document. Thus when the carrier is modified, the marking is also. This type of watermark is still important: it allows, in fact, to prove that a document has undergone a transformation, it does not prove who the author of the document is.
The robust watermark is harder to detect and extract. It must resist to various signal processing operations. According to KERCKHOFFS principle who stated that “a cryptographic system should be secure even if everything about the system, except the key, is public knowledge” [3], a watermarking system should be designed in way assuming that all the pirates know the tagging algorithm. Having said this, any distortion of the watermark should introduce a visible deterioration of the document.

2.3 Areas of use

Today, documents are accessible to all. Anyone can edit, copy or take ownership. This is why digital watermarking methods were first introduced. Protecting the authenticity and tracing of fraudulent copies are among the main objectives of this process.

2.3.1 Protection of authenticity

The main function of a digital watermarking is first to protect the rights of authors, it is possible to add information about the copyright in a work. This information is used to verify the membership of each digital document and to determine its beneficiaries.
Authentication in image watermarking refers to the integrity assurance of the image [4]. It is possible to make a verification of content using a watermarks as proof. The existence of the mark when it is possible will proves that the document has not undergone any modification. Messages in an image are aimed to verify the authenticity thereof.

2.3.2 Tracing fraudulent copies

It has become easy to copy documents. To ensure the protection of copyrights, watermarking is used to trace unauthorized changes. Tracing is made possible by the insertion of a safe and robust watermark. For this, an invisible signature is incorporated into this document. This signature is used to determine the owner or origin and thus check the integrity of documents or allow authentication. They can be used to trace fraudulent copies circulating on the Internet.

2.3.3 Others use

Digital watermarking has a very wide range of use. It can be used for annotation and privacy control for example in Medical domain. Here Robustness may not be relevant if the watermarking system resides in a secured and closed environment. It is also used for Media forensics where the investigation should give scientifically valid information for court evidence [5]. Digital watermarks do not apply only to images but may be involved in the field of cinema. For example, to identify the place of capture of a screen or music as a method of Digital Rights Management.

2.4 Choosing the space

One of the most important steps in elaborating a watermarking algorithm is to choose the appropriate space [6]. The earlier watermarking algorithms aimed to insert watermarks in the least significant bits (LSB). This method ensure invisibility but it is characterized by a low level of robustness.

2.4.1 Spatial methods

Watermarking spatial methods consist on binaries modifications. Three methods are discussed in literature: substitution method (LSB), binary addition method and patchwork method based on luminosity variation.

2.4.2 Frequential methods

There are large of frequential methods. Most of them try to introduce useful distortion on Fourrier transformation, DCT transformation (Discrete Cosinus Transformation), Discrete Wavelet Transform, etc.

2.4.3 Psychovisual based methods

Some schemes which operate on DCT domain use perceptual masks like Bartolini & al. on [7], kankanhalli & al. on [8] or Podilchuk & Zeng on [9].
In the Table 1, we give an idea about image watermarking methods and their responses to intentional and unintentional attacks. In summary, Watermarking technology has applications in various interesting domains like preserving the intellectual property, fighting the piracy or forensics investigations. It consists in embedding useful data like copyright labels inside a data source without changing its perceptual quality. There are many image watermarking methods. The most popular of them are: Spatial methods, Frequency methods and Psychovisual based methods. After a comparison between these methods we choose to complete a design using Psychovisual based technique and implement it using a simulation software.

Table 1. Comparison summary between the most popular image watermarking methods

	Spatial techniques	Frequency techniques	Psychovisual Based techniques
Brief Description	It is considered as the most direct approach. The basic idea of this method is modify pixel values in order to encode the watermark. In general, it consists on embedding data by replacing the least significant bit of each pixel by a coded binary string	The basic idea of this method is take advantage from frequency transforms characteristics such as Discrete Cosine Transform (DCT) and Discrete Fourrier Transform (DFT) in order to hide useful data	This method take advantage from Human Vision System. It operates on both spatial and frequency domains using psychovisual filters.
Robustness	Poor immunity. Useful only in digital-to-digital environments	Robust to noise attacks	Moderate resistance to attack
Capacity and Data payload	Large capacity	Moderately low capacity	Moderately Large capacity
Imperceptibility	Visual noise may be introduced	Watermark may be noticeable because of its noise addition concept	Imperceptible
Security	Useless in real watermarking applications	If perfect compression scheme exists in future, embedding of pseudo random sequence may be trivial or impossible.	Find place in many applications like Authentication and Media Forensics
Secret key	Use of secret key	Use of secret key	Use of secret key
Implementation	Very simple. Easy to implement	Easy to implement	Easy to implement
Computational Cost			
Blind Detection of Watermark	Blind watermarking	Blind watermarking	Blind watermarking

3. Watermarking Technique based on psychovisual and spatial approaches: Design and implementation

3.1 Basic idea

In this paper, we choose to conceive an image watermarking technique based on psychovisual and spatial approaches. In our system we study the original content and based on its characteristics, we choose in automatic manner where to hide information in a way that preserves the quality of the image yet and hiding useful information.

As represented in figure 1, our system is divided on two blocs:

- Bloc of watermarks insertion. It contains a process of hiding marks into an original image.
- Bloc of watermarks extraction. It contains processes of detecting presence of watermarks and extracting them

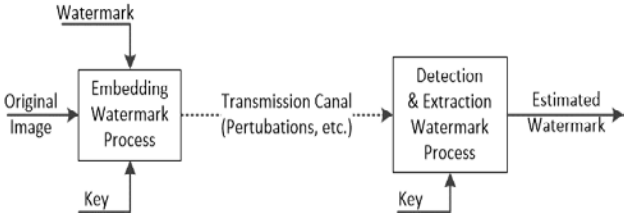

Figure 1. Basic watermarking scheme

3.2 Implementation of the encoder and decoder

Using the basic scheme of watermarking system, we completed a new design for an intelligent watermarking algorithm. Our method embeds useful information into an original image taking into account psychovisual approach for better imperceptibility and also its self-experience. Our general embedding function is written:

$$I_w(x,y) = I_o(x,y) + f_w(x,y) \times I_o(x,y) \quad (1)$$

Where

$$f_w(x,y) = \alpha_w(x,y) \times M_v(x,y) \times W(x,y) \quad (2)$$

$I_w(x,y)$ is the watermarked image
$I_o(x,y)$ is the original image
$\alpha_w(x,y)$ is a function that controls the trade-off between robustness and perceptibility of the watermark
$M_v(x,y)$ is psychovisual mask
$W(x,y)$ is watermark binary

3.3 Embedding process

The encoding process consists on implementing the equation 1. Prior to hiding operation, we perform a quick evaluation of the original image and compare its properties with our database. By this manner, we have a system with self-learning process capable of choosing optimal parameters based on previous experience (see figure 2). After a pre-processing operations, we use a secret key to insert watermark into image. Then we evaluate the output.

If it passes our inbox tests it is considered as validate and we obtain the watermarked image. Other way it is considered as non-validated and we perform another iteration taking into account the previous non-validated iteration(s).

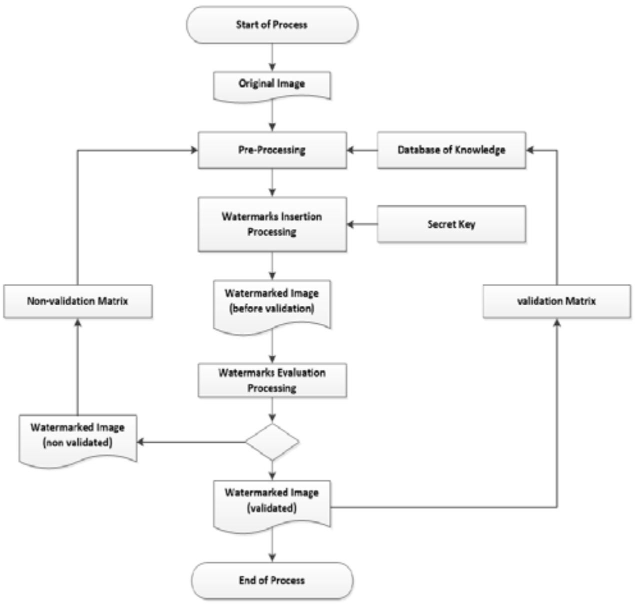

Figure 2. Embedding watermarks process scheme

3.4 Extracting process

The extracting process is performed using secret key. Our algorithm contains two steps. First step consists on detecting a pattern. Then second step, if the pattern detected successfully, we then perform watermark detection and extraction (see figure 3). This approach allows us minimize time of processing. This is useful if we perform detection of watermarked images among a bunch of image, for example, in forensic scenario when we’re looking for authenticated images from non-authenticated. Pattern and watermark can be protected by different secrets keys.

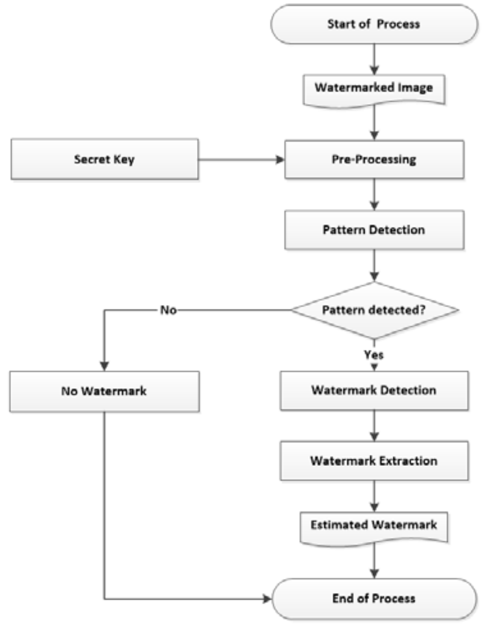

Figure 3. Detecting and extracting watermarks process scheme

4. Tests and simulations

4.1 Presentation

In order to validate our method, many tests were performed over large amount of simulations. The results mentioned in this paper are based on 100.000 simulations per image (30 different images). We inserted randomly 10 to 100 characters encoded using 8-bits ASCII code. The text spread over the whole image and it is repeated as much as possible for higher robustness.

4.2 Testing perceptibility

In order to test the imperceptibility of a watermarking technique, several methods have been discussed in literature. Here, we choose to do the perceptibility test of our system based on the ITU-R BS 1116-1 recommendations [10].

4.2.1 Scope

In order to perform subjective evaluations of our digital watermarking system, we were inspired from ITU-R BS.1116-1 recommendations which are used to evaluate systems that introduce degradations so small that they are not detectable without rigorous control of experimental conditions and without appropriate statistical analysis.

In our approach, we selected two groups of participants:

- People who are experts in the field of image processing and familiar with the concepts of watermarking
- "Average" People without any prior training in the field of image processing

In our case, statistics were calculated based on 40 participants: 20 are experts and 20 are considered as "average" people in image processing. This number is often recognized as sufficient to draw the appropriate conclusions.

4.2.2 Test Method

In our approach we have based on the method called "double-blind triple-stimulus with hidden reference". This method is very sensitive, stable and can accurately detect small impairments:
To do this, the participant is free to choose among three stimuli ("A", "B", "C"). The known reference is always present as stimuli "A". The hidden reference and test object are available simultaneously but are allocated in a random manner to "B" and "C".
At each stage, the participant should evaluate the degradation of "B" compared to "A" and "C" compared to "A" on the continuous degradation scale of 5 notes. The images can be displayed until the participant has provided its assessment
One of stimuli, "B" or "C", should be the same as "A"; the other can present degradation. Any differences detected between the reference and other stimulus should be interpreted as degradation.
The rating scale will be treated continuously considering "benchmarks" of the impairment scale 5 ratings (see Table 2.) taken from the ITU-R BS.1284 recommendation [11].

The following table shows the rating system that our participants are asked to give for rating this perception during tests. It shows also de Subjective Difference Grade (SDG) values according to impairments:

Table 2. ITU-R five-grade impairment scale

Impairment	Rating	Subjective Difference Grade (SDG)
Imperceptible	5.0	0.0
Perceptible, but not annoying	4.0	-1.0
Slightly annoying	3.0	-2.0
Annoying	2.0	-3.0
Very annoying	1.0	-4.0

Where:

$$SDG = Score_{Signal\_Under\_Test} - Score_{Reference\_Signal} \qquad (3)$$

To normalize the results of each participant, we applied the following equation to normalize the results while maintaining the original scale:

$$Z_i = \left(\frac{x_i - x_{si}}{s_{si}}\right) \times s_s + x_s \qquad (4)$$

x_i score given by the result of the participant "i"
x_{si} average rating of the participant "i" during the session "s"
s_{si} standard deviation for the participant "i" during the session "s"
x_s average score of all participants in the session "s"
Z_i normalized result for participant "i"
s_s standard deviation for all participants in the session "s"

4.2.3Results

As original images, we used the USC-SIPI image database, which is a collection of digitized images published by University of Southern California. It is maintained to support research in image processing, image analysis and machine vision. We selected 30 images for our test purposes [12]. Table 3 shows USC website references of these selected images and some of their characteristics.
Figure 4 shows an examples of original images and their watermarked version. As noticed, it is very unlikely to distinguish between them as perceptibility is highly maintained.

Figure 4. Comparison between original images and their watermarked version

As it was expected, there is a difference in perceptibility tests results between the two types of participants. For "average" people, the watermarks are highly imperceptible. And for experts (who already expect to seek for differences), the watermarks maybe sometimes perceptible but not without difficulty. However, in general watermarks are imperceptible. Table 3 presents these results:

Table 3. Files description and Subjective tests results

					Experts		"Average" Pepole	
Internal Reference	Filename (website: sipi.usc.edu)	File Description	Size	Type	Average SDG	Interpretation	Average SDG	Interpretation
A1	4.1.01	Girl	256	Color	-0,46	Imperceptible	-0,01	Imperceptible
A2	4.1.02	Couple	256	Color	-0,13	Imperceptible	0,36	Imperceptible
A3	4.1.03	Girl	256	Color	-0,48	Imperceptible	-0,27	Imperceptible
A4	4.1.04	Girl	256	Color	-0,59	Imperceptible	-0,29	Imperceptible
A5	4.1.05	House	256	Color	-0,55	Imperceptible	-0,17	Imperceptible
A6	4.1.06	Tree	256	Color	-0,55	Imperceptible	-0,19	Imperceptible
A7	4.1.07	Jelly beans	256	Color	-0,45	Imperceptible	-0,16	Imperceptible
A8	4.1.08	Jelly beans	256	Color	-0,55	Imperceptible	-0,17	Imperceptible
A9	4.2.01	Splash	256	Color	-0,59	Imperceptible	-0,13	Imperceptible
A10	4.2.02	Girl (Tiffany)	256	Color	-0,44	Imperceptible	-0,35	Imperceptible
A11	4.2.03	Mandrill (a.k.a. Baboon)	256	Color	-0,42	Imperceptible	-0,12	Imperceptible
A12	4.2.04	Girl (Lena, or Lenna)	256	Color	-0,92	Perceptible but not annoying	-0,09	Imperceptible
A13	4.2.05	Airplane (F-16)	256	Color	-0,46	Imperceptible	-0,08	Imperceptible
A14	4.2.06	Sailboat on lake	256	Color	-0,38	Imperceptible	-0,41	Imperceptible
A15	4.2.07	Peppers	256	Color	-0,52	Imperceptible	-0,19	Imperceptible
A16	house	House	256	Color	-0,47	Imperceptible	-0,07	Imperceptible
A17	2.1.01	San Diego (Miramar NAS)	512	Color	-0,13	Imperceptible	0,00	Imperceptible
A18	2.1.03	San Francisco (Golden Gate)	512	Color	-0,29	Imperceptible	0,10	Imperceptible
A19	2.1.04	Oakland	512	Color	-0,32	Imperceptible	-0,09	Imperceptible
A20	2.1.05	San Diego (North Island NAS)	512	Color	-0,49	Imperceptible	-0,11	Imperceptible
A21	2.1.06	Woodland Hills, Ca.	512	Color	-0,44	Imperceptible	-0,06	Imperceptible
A22	2.1.07	Foster City, Ca.	512	Color	-0,44	Imperceptible	-0,32	Imperceptible
A23	2.1.09	San Diego (Point Loma)	512	Color	-0,42	Imperceptible	-0,12	Imperceptible
A24	2.1.10	San Diego (Shelter Island)	512	Color	-0,36	Imperceptible	-0,17	Imperceptible
A25	2.1.11	Earth From space	512	Color	-0,45	Imperceptible	-0,16	Imperceptible
A26	2.1.12	San Diego (Downtown)	512	Color	-0,47	Imperceptible	-0,08	Imperceptible
A27	2.2.04	Richmond, Ca.	1024	Color	-0,35	Imperceptible	-0,02	Imperceptible
A28	2.2.09	San Francisco	1024	Color	-0,39	Imperceptible	-0,05	Imperceptible
A29	2.2.11	Stockton	1024	Color	-0,53	Imperceptible	-0,08	Imperceptible
A30	2.2.14	Shreveport	1024	Color	-0,55	Imperceptible	-0,45	Imperceptible

The following graphics (Figure 5) shows SDG results for both types of participants. We remark that sometimes the SDG is greater than zero which mean that sometimes the participants tend to see the watermarked image as better and more authenticate that the original one. It was the case of "average" people with some images.

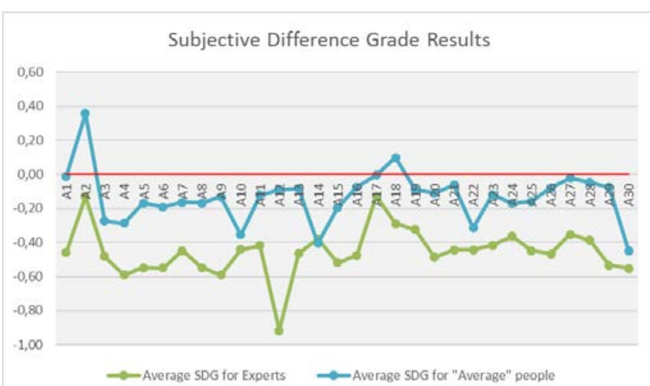

Figure 5. Subjective Difference Grade Results

4.3 Measuring fidelity

Tests to measure the amount of degradation caused to original image are important to assure high quality of the watermarked signal. In general, content owners are more concerned with the degradation of the watermarked signal than users as they have access to both original signal and watermarked one. Hence, we talk about fidelity, which refers to the similitude between the original image and the watermarked image. Thus measuring fidelity consists on measuring the distortion induced by watermarks [13] & [14].

Many difference metrics have been discussed in the literature, but the most common is peak signal-to-noise ratio (PSNR) which is an expression for the ratio between the maximum possible value (power) of a signal and the power of distorting noise that affects the quality of its representation. By noise, we mean the noise induced by inserting data into the original signal. This PSNR is generally expressed in decibels as follow:

$$PSNR = 10 \times \log\left(\frac{(2^n - 1)^2}{MSE}\right) \tag{5}$$

Where MSE is the Mean Square Error. As we perform tests in 16 bits image, this expression becomes:

$$PSNR = 10 \times \log\left(\frac{255^2}{MSE}\right) \quad (6)$$

In our results MSE is the mean of MSE calculated in each color of RGB.

$$MSE = \left(\frac{MSE_R + MSE_G + MSE_B}{3}\right) \quad (7)$$

Where the expression of MSE is :

$$MSE_i = \frac{1}{nr \times nc} \sum_{i=1}^{nr \times nc} (p_{io} - p_{iw})^2 \quad (8)$$

The following table show the average MSE and PSNR for each image calculated over the 100.000 simulation per image.

Table 4. MSE and PSNR Results

Image Ref.	MSE	PSNR
A1	21,87	34,75
A2	14,98	36,40
A3	20,32	35,12
A4	13,06	37,24
A5	19,48	35,27
A6	7,36	39,46
A7	15,67	36,19
A8	11,57	37,71
A9	16,56	35,94
A10	9,91	38,28
A11	18,57	35,50
A12	20,53	35,02
A13	20,56	35,13
A14	14,09	36,67
A15	18,00	35,92
A16	14,33	37,01
A17	12,94	37,04
A18	20,68	35,09
A19	19,35	36,76
A20	18,43	35,60
A21	24,01	34,34
A22	10,29	38,43
A23	19,75	35,24
A24	16,00	36,31
A25	21,91	34,75
A26	10,55	37,90
A27	17,77	35,64
A28	28,29	33,79
A29	28,42	33,85
A30	30,98	33,57

In literature, one could expect to have perceptible distortion for SNR values of 36 dB. We note that PSNR values in our case is under this value. Thus, the quantity of distortion that a watermark imposes on a signal is tolerable (see figure 6).

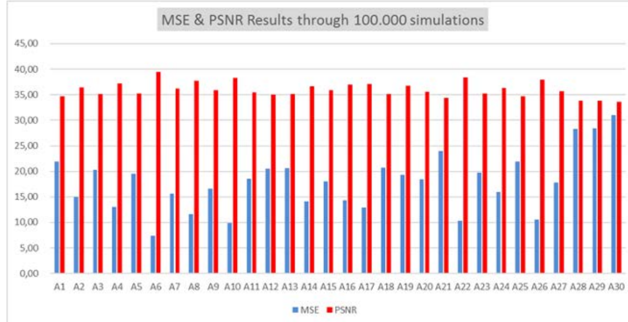

Figure 6. MSE & PSNR Results through 100.000 simulations

5. Conclusion

In this paper, current state-of-the-art watermarking schemes are briefly summarized. Psychovisual based technique was chosen for implementation because of its simplicity, high imperceptibility and resistance to common signal processing in comparison with other techniques. Thus, we made a new algorithm using its self-previous-experience to build more fast and robust watermarking process that allows embedding data into image. The redundancy of the watermark information makes the algorithm robust, and the embedded data can in many cases be recovered from just a small portion of the watermarked image. The embedded information is imperceptible. In subjective tests, two types of participants were differentiated: "average" people and experts. Perceptual tests show that watermarks are imperceptible for both of them. The watermark information is protected by a secret key and the watermarked image undergo some validation operations before the end of embedding process. Furthermore, the system presents good responses against usual signal processing operations. Different tests were performed over our algorithm. The results are interesting and promising. Our algorithm can very likely to be used in forensics scenarios to preserve authenticity of images.

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