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Robust Watermarking Based on the Warping of Pre-Defined Triangular Patterns

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ABSTRACT

Numerical information is volatile and watermarking is a solution to assist copyright protection.

During the detection step, the synchronisation of the mark is a great problem. Geometric transformations can defeat the detector of the mark by desynchronising the mark.

Our scheme is based on warping of pre-defined triangular patterns. The content of the image (feature points) is used to mark independently different regions. This allows the synchronisation of the mark for the detection step. Feature points mixed with a Delaunay tessellation permits to mark each triangle of the image.

The detection is performed by warping triangle to a reference pattern and correlating with a reference triangle.

Different algorithms have been developed in the spatial domain and in the frequential (DCT) domain. Our results show that our schemes are robust to Stirmark and other geometric transformations on different categories of images.

Keywords: watermarking, feature points, Delaunay tessellation, warping, stirmark

1. INTRODUCTION

Digital supports as CdRom and Dvd can contain a huge amount of information of great quality. Nevertheless a numerical media has two major drawbacks: it is volatile and it can be easily processed.

Consequently numerical content may be copied, modified or converted in other format in an easy way. The goal of Watermarking is to embed an information (called a mark) inside the content of the media. It permits to add functionality.

The mark can be an ID number for copyright, to prevent illegal copies. It can be a description of the content of the image for database retrieval in any image format. It can be a fragile mark to prevent tampering and allow authentication of images (cf fig 1).

Practical and concrete watermarking projects are initiated to control the copy of dvd,¹ and to solve the copyright problem of images over networks.²

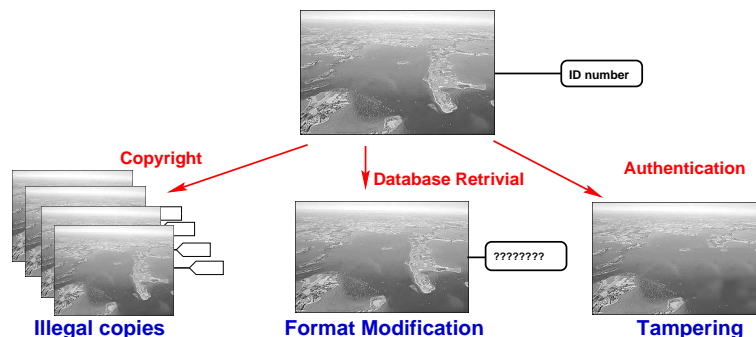


Figure 1. Multiple functionality of Watermarking: Copyright, Database Retrieval or Authentication.

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The mark embedded inside the media has to respect two strong constraints:

- be undetectable without a secret key
- be non-removable

In the field of digital images, the second condition implies that the mark has to be robust to image compression, quantization, D-A/A-D conversion, filtering (blurring or sharpening), and geometric transformations such as cropping, translation or rotation.

1.1. Previous Approaches

Embedding schemes consist in adding a mark in the spatial domain³ or in a transform domain such as the DCT coefficients,⁴ the DFT coefficients,⁵ the wavelets coefficients.⁶ The HVS (Human Visual Properties) may be exploited to improve the invisibility of the mark.⁷ This mark depends on a key and consequently is unique.

The detection step can be performed by two different ways: it can use the original image or not. Using an original is less practical and can improve piracy.⁸

2. CLASSICAL SCHEME AND GEOMETRICAL ATTACKS

Basically a mark W_{key} (dependent of a secret key key) is embedded in an image I by the operation :

$$T(I_w) = T(I) + W_{key} \tag{1}$$

where $T()$ is a domain transform (Identity, Dct, Wavelet, ...). T^{-1} is the inverse transform and $I_w = T^{-1}(I_w)$. Applying a visual model, W_{key} can also depend on the original image I .

The detection of the mark inside a test Image I_t is performed by computation of the correlation factor τ and comparing τ with a threshold:

$$\tau = \sum_{i,j} I_t(i,j) * W_{key}(i,j) \tag{2}$$

This correlation factor is computed with hypothesis that W_{key} and the mark inside I_t are synchronised. If I_t is translated about only few pixels, the correlation τ will not permit to prove the existence of the mark. We need to compute the correlation considering all possible translations inside the image but consequently the cpu time will dramatically increased. Moreover doing this we do not consider other geometric transformations such as rotation, cropping or rescaling. The robustness to geometrical transformation must also be a priority in watermarking .

This drawback is one of the basic feature of the software StirMark which uses small geometric distortions to defeat many watermarking schemes.⁹ In fig 2 we can observe the effect of StirMark, the image is slightly distorted and a classical watermarking detection could not find the mark.

To be invariant to rotation , translation and rescaling, Ruanaidh uses the Fourier-Melin¹⁰ space but the author must perform interpolation to inverse the transform. Hartung¹¹ divides the image in little blocs of arbitrary size (16×16) and performs correlation for small rotations and translations; the research domain is consequently reduced but it does not prevent any kind of transformation. The scheme described by Kutter¹² embeds a periodic watermark inside the image. The geometric transformation of the image is estimate applying a correlation of the image with itself.

3. GEOMETRIC REFERENCES INSIDE IMAGES

The goal of our work is to use content of the image to find references. These references will be robust to geometrical transformation as rotation, translation, scaling or even little morphing. The solution we have adopted is to use feature points inside images to provide references. Feature points are components of the image and therefore will survive to geometrical transformations.

Our previous works¹³ have shown that feature points detector are useful in the field of watermarking.

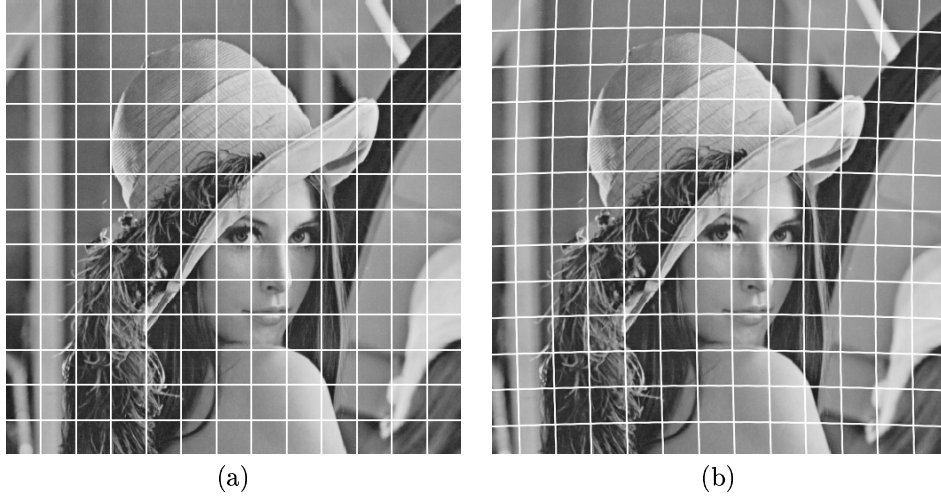


Figure 2. (a): original image,(b): image distorted using stirmark.3.0 (default values)

3.1. Feature Points Detectors

The principle of a feature points detector is to detect features of an image as corners, edges or high textured regions. We have tested the robustness of 3 different operators used in computer vision:

- (a) the detector developed by Harris¹⁴
- (b) the detector developed by Achard-Rouquet¹⁵
- (c) the Susan detector¹⁶

Detectors (a) and (b) evaluate the partial derivatives $I_x = \frac{\partial I(x,y)}{\partial x}$, $I_y = \frac{\partial I(x,y)}{\partial y}$ and $I_{xy} = \frac{\partial^2 I(x,y)}{\partial y \partial x}$. The criterion of the detector (a) is:

$$f(i, j) = \{I_x^2\}\{I_y^2\} - \{I_x I_y\}^2 - \lambda(\{I_x^2\} + \{I_y^2\})^2 \quad (3)$$

where $\{\}$ denotes gaussian filtering operation and λ is a parameter to adjust. The criterion of the detector (b) is:

$$f_2(i, j) = \frac{I_x^2 \langle I_y^2 \rangle + I_y^2 \langle I_x^2 \rangle - 2I_x I_y \langle I_x I_y \rangle}{\langle I_x^2 \rangle + \langle I_y^2 \rangle} \quad (4)$$

where $\langle \rangle$ is the mean in a 3×3 neighbourhood. Features points consist in finding the set of point ψ defined by:

$$\psi = \{(i, j)\} \quad / \quad f(i, j) > \eta \quad (5)$$

Detector (c) uses a circular mask and a segmentation around the middle of the mask to locate corners. After few trials we have seen that (c) is less robust to geometric transformations than (a) and (b). Feature points given by detector (a) and (b) are concentrated around corners, edges and textures. Because we want these points as references, we need to control the density of such points inside the image. Consequently we fix a criterion of local maximum:

$$\{p_{i,j} \in \psi\} \quad / \quad \forall (i', j') \in V_{i,j}, f(i, j) > f(i', j') \quad (6)$$

where $V_{i,j}$ represents the neighbourhood of the pixel (i,j) .

This criterion controls the density of points but also improves greatly the robustness of detectors against geometric transformations 3.

We also perform the detection of feature points on a low-frequency representation of the image to enhance robustness



Figure 3. results of the detector (1): (a) without the local maximum criterion, with (b) the local maximum criterion.

inside noisy or textured regions. Practically, we used a blur filter (mean) of size 5×5 .

4. SPATIAL EMBEDDING OF TRIANGLES

4.1. Insertion of the mark

The insertion of the mark can be divided in several steps:

- Detection of feature points with detector (a) or (b).
- Delaunay tessellation $\{T\}$ using feature points of the image. $\{T\}$ is composed by a set of triangle T_i
- Computation of a random sequence T_r delimited by a right-angled isosceles triangle of an arbitrary size (in our tests 64×64). A secret key generates the sequence. To be robust to positioning error of feature points, the random sequence is spread on 2×2 pixel blocs.
- For each triangle T_i :
 - We perform an affine transform on T_r to map the shape of T_i . We use a spline-cubic interpolation during the transformation to preserve high frequencies of T_r . The triangle T_{map} is then obtain, its magnitude depends of the variance of T_i .
 - We add T_{map} and T_i to obtain a marked triangle.

These different steps are described in figure 4 .

4.2. Detection

For the detection process

- Apply feature points detection an Delaunay tessellation to obtain a set of triangle $\{T\}$,
- Each triangle T_i is warp into a right-angled isosceles triangle T_{imap} ,
- To deal with eventual geometric transformation we examine the 6 different affine transforms,
- The decision is done examining the correlation between T_r and T_{imap} and comparing with a threshold.

These different steps are described in figure 5.

4.3. Wiener Filtering

The detection of the mark is done using a slight amount of information inside the random pattern ($32 \times 32/2$). We improve our detection scheme in textured triangle using Wiener prediction. This optimal detection has been first used in the watermarking context by Hernandez.¹⁷ It permits to eliminate part of the noise contribution due to the

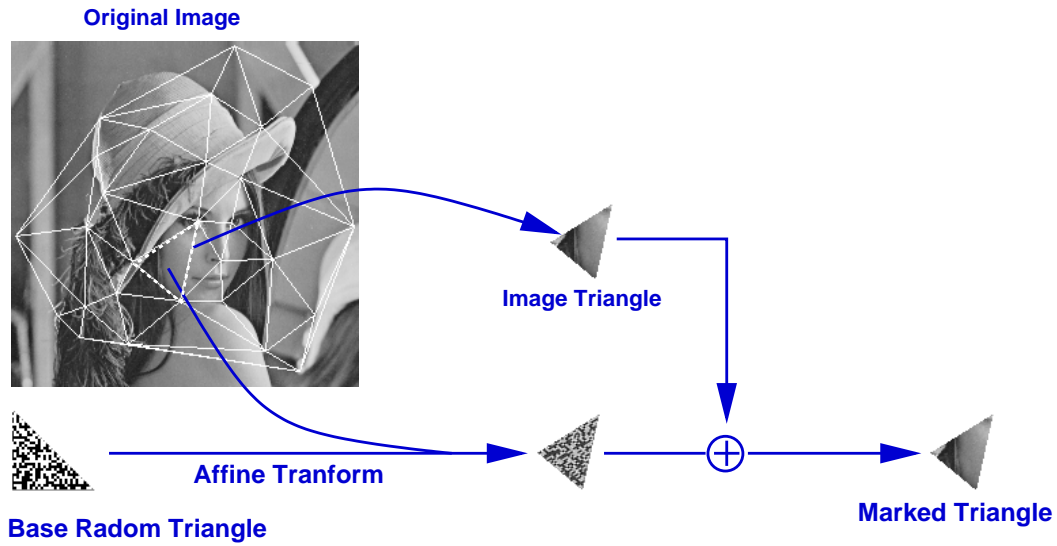


Figure 4. Embedding scheme by warping of pre-defined triangles in the spatial domain.

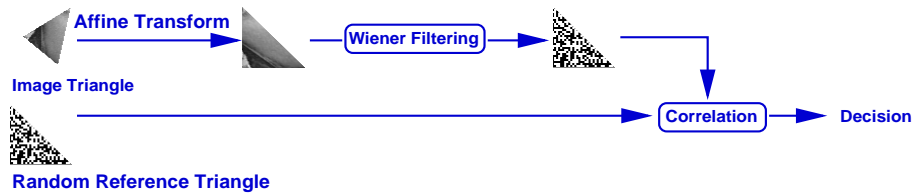


Figure 5. Detection scheme by warping of pre-defined triangles in the spatial domain.

original image.

Considering that the mark W and the image I are independent. We can make a prediction \hat{W} of W :

$$\hat{W}(x, y) = \frac{\sigma_w^2(x, y)}{\sigma_w^2(x, y) + \sigma_I^2(x, y)}(I(x, y) - m_I(x, y)) \quad (7)$$

where σ^2 represent the variance in the neighbourhood and m the mean in the neighbourhood. The figure 6 illustrates the improvement due to Wiener prediction before the correlation step.

4.4. Results

Features points detected in the original image may disappear after image processing. Consequently the tessellation will be locally modified. The detection of a mark will succeed if there is at least one triangle in the tessellation for which the mark is detected.

To test the efficiency of our scheme we used the “classic” image *lena* containing well defined edges and corners. The second test image we used named *arbre* is a textured image, more problematic for feature point detection. Our results (cf figures 9 and 10) show that the mark can be detected after jpeg compression, stirmark, rescaling, rotation or morphing.

We can note that on the image *arbre*, the tessellation is more modified by processing than in *lena*, the detection of interest point is more problematic with textured images.

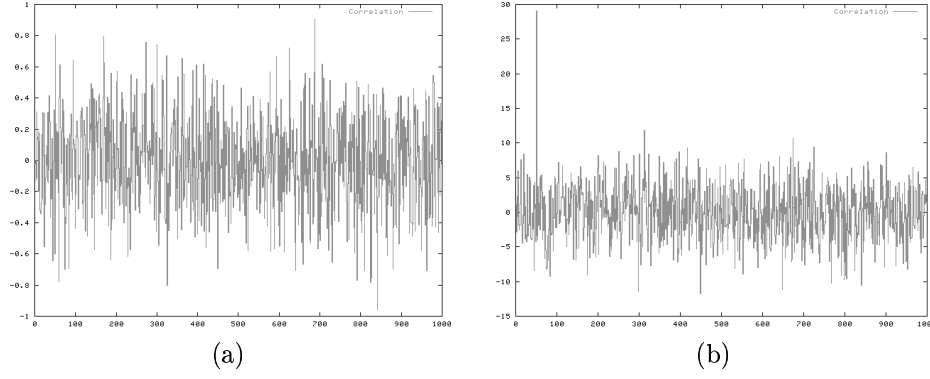


Figure 6. Correlation between T_r and a textured triangle with 1000 different keys, the mark is generated using the key 50. (a) without Wiener prediction, (b) with Wiener prediction.

5. FREQUENTIAL EMBEDDING OF TRIANGLES

Using triangular patterns, we have the possibility to perform a frequential embedding of the mark. The insertion on DCT components of the image will improve the invisibility and the detection of the mark inside textured areas. The technique we use evaluates the Discrete Cosinus Transform (DCT) of a triangle, such technique used in image and video coding.¹⁸

5.1. Insertion

After performing feature points detection and a Delaunay tessellation $\{T\}$, each triangle T_i will be marked individually in the following steps:

- (a): a random sequence T_r delimited by a right-angled isosceles triangle of an arbitrary size (in our tests 64×64) is created. A secret key generates the sequence.
- (b): T_r is symmetrized to obtain a 64×64 square bloc B_r ,
- (c): we perform an affine transform on T_i to map the shape of T_r
- (d): T_i is symmetrized to obtain a 64×64 square bloc S_i ,
- (e): we applied the DCT transform on S_i names as B_i . Due to properties of the DCT transform the bloc B_i is symmetric and only one half of B_i to reconstruct S_i .
- (f): we modulate our signal B_r with the sign of the coefficients of B_i to obtain the bloc B_w . Such embedding on absolute values of I will permit to reduce the dynamic of the coefficients during the detection.
- (g): we process an inverse DCT.
- (h): we reconstruct a right-angled isosceles triangle and we apply an affine transform to obtain the spatial representation of the mark W_s .
- (i): we substitute $T_m = W_s + T_i$ with T_i .

These different steps are described in figure 7.

5.2. Detection

For the detection process:

- (a): we apply feature points detection and Delaunay tessellation to obtain a set of triangle $\{T\}$,
 - (b): T_i is warp into a right-angled isosceles triangle T_{imap}
 - (c): T_{imap} is transformed into a symmetric bloc
 - (d): we apply the DCT transform on this bloc and obtain B_i
 - (e): the decision is performed examining the correlation between B_r and $abs(B_i)$ and comparing with a threshold.
- These different steps are described in figure 8.

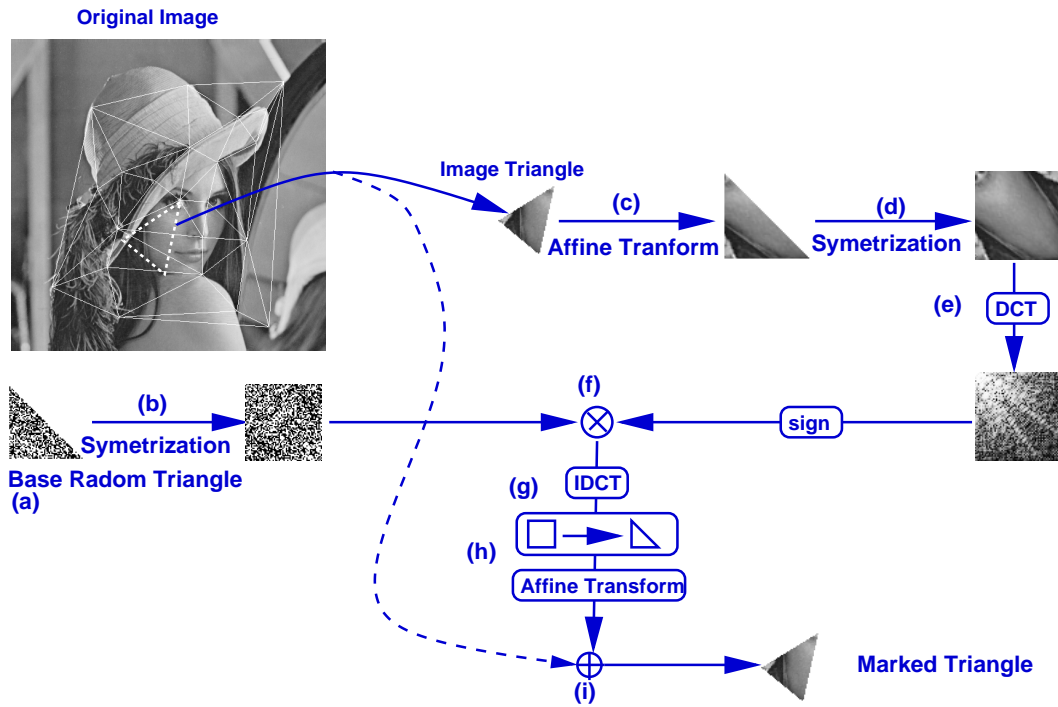


Figure 7. Embedding scheme by warping of pre-defined triangles in the frequential domain.

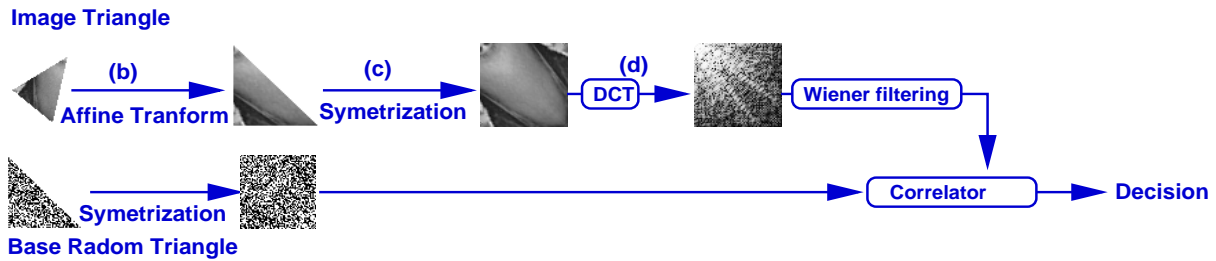


Figure 8. Detection scheme by warping of pre-defined triangles in the frequential domain.

5.3. Results

Preliminary results (cf figures 11) show that the mark can be detected after the distortion provided by Stirmark. But the number of detected triangles in the frequential domain is less important than in the spatial domain. This is due to the fact that a frequential insertion is more dependent to feature points positioning than a spatial insertion of a low-frequency mark.

6. CONCLUDING REMARKS

In this paper we have presented a new watermarking scheme base on the image content. This content permits to extract regions (using feature points detectors) and to mark theses regions independently. Regions are preserved. The detector locates the mark inside the image.

The scheme is based on the warping of pre-defined triangular patterns. Feature points detectors are used. Applying a Delaunay tessellation we mark different triangular regions of the image. Two different schemes are described: the first adds a random pattern in the spatial domain on each triangle of the partition; the second adds a random pattern on the frequential components of each triangle.

We had to deal with serious challenges: developing a feature point detector robust to geometrical transformations and inserting and detecting a mark into small triangles.

Our preliminary results show that the two scheme permits to be robust to different geometric transformations. An effort has to be developed on feature point detector for textured images.

Wiener prediction permits to enhance the detection of the mark into small region. Future works will also focus on using the HVS properties to improve the invisibility of the mark.

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(a) marked image: 30/34



(b) jpeg 30%: 9/37



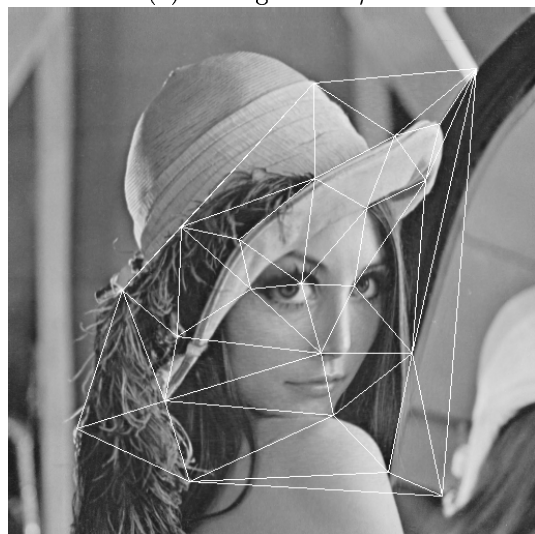
(c) stirmark (default options): 24/34



(d) scaling 75%: 7/32



(e) rotation 55^{deg} : 6/32:

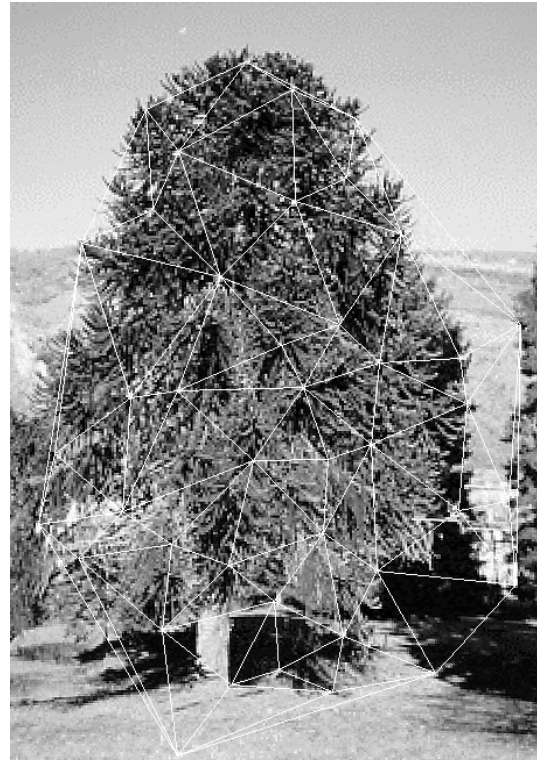


(f) wirl: 3/36

Figure 9. (a), (b), (c), (d), (e), (f): Results on lena512 using the Harris detector and spatial insertion. The left number is the number of triangles where a mark has been detected. The right number is the total number of triangles



(a) marked: 22/63



(b) stirmark (default options): 16/73

Figure 10. (a), (b): Results on arbre (454×652) using the Harris detector and spatial insertion. The left number is the number of triangles where a mark has been detected. The right number is the total number of triangles



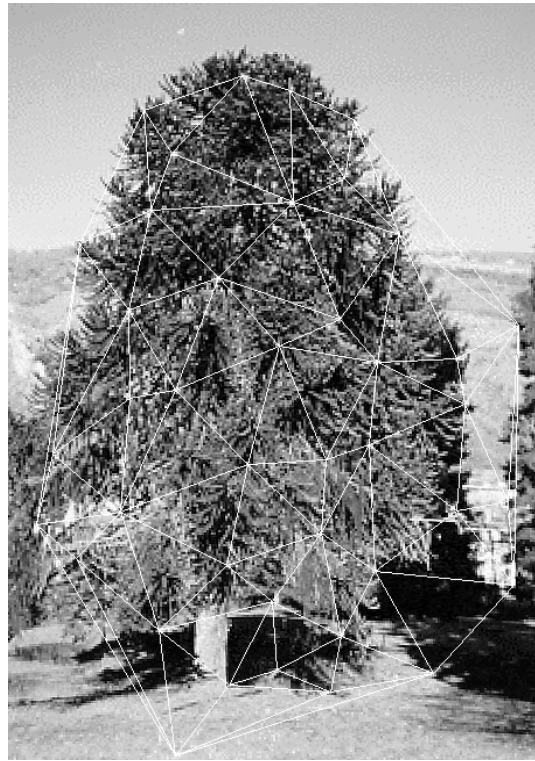
(a) marked: 31/34



(b) stirmark (default options): 19/32



(c) marked: 34/65



(d) stirmark (default options): 6/70

Figure 11. Results on lena512 ((a),(b)) and arbre (454×652) ((c),(d)) using the Harris detector and DCT insertion. The left number is the number of triangle where a mark has been detected. The right number is the total number of triangle.