FOURIER DESCRIPTORS WATERMARKING OF VECTOR GRAPHICS IMAGES

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ABSTRACT

A blind method for watermarking of vector graphics images through polygonal line modification is proposed in this paper. The watermark is embedded in the Fourier descriptors of the polygonal lines, causing invisible distortions to the vertices coordinates. The properties of the Fourier descriptors ensure that watermarks generated by this technique withstand rotation, translation, scaling, reflection, change of traversal starting point/direction and smoothing.

1. INTRODUCTION

Copyright protection of multimedia data using watermarking techniques has emerged recently as an important research topic. A copyright protection digital watermark is a digital signal carrying information about the copyright owner, is constructed so as to be permanently embedded into the digital products. Among the various types of multimedia data, still images were the ones that received the greatest research interest. Image watermarking methods proposed so far are dealing with watermarking of bitmap (raster) images. In such images, the watermark can be embedded in a multitude of domains (spatial domain, DFT, DCT, DWT domain). The interested reader can consult any of the comprehensive review papers that exist in the literature [1]-[4] However, certain types of images, especially computer generated images (line drawings, cartoons, maps, graphics images), can be stored and manipulated more efficiently if the various image objects are represented by means of a set of geometric primitives (i.e., polygonal lines, circles, ellipses, rectangles etc.). Such file formats are usually referred to as vector graphics file formats. Despite the fact that the protection of vector graphics images can be of importance in many application scenarios, copyright protection of vector images drew zero attention within the watermarking community. In this paper, a method for watermarking of such images by polygonal line modification is proposed. The watermark is embedded in the magnitude of the Fourier descriptors of the line and introduces slight changes to the vertices coordinates. The method is a blind one, i.e., the original polygonal line is not required in the watermark detection procedure.

2. FOURIER DESCRIPTORS REPRESENTATION OF POLYGONAL LINES

Within vector graphics file formats a polygonal line is represented as a sequence of vertices, two consecutive vertices defining a line segment. Let S be such a closed polygonal line that consists of N vertices, each represented as a pair of coordinates $x(n), y(n)$, $n = 0, ..., N-1$. These coordinates can be combined to construct the complex signal $z(n) = x(n)+iy(n)$ which in turn can be represented by its discrete Fourier transform coefficients $Z(k), k = 0, ..., N-1$. This representation is called the Fourier descriptors (FD) representation of a line [5]. Representation of a polygonal line in terms of its Fourier descriptors has some interesting properties:

- Translation of the line S affects only the DC term $Z(0)$ of the Fourier descriptors.
- Rotation of the line S by an angle θ results in constant phase shift of the Fourier descriptors.
- Scaling of the polygonal line S by a factor s results in the scaling of the Fourier descriptors by the same factor.
- Selection of another vertex as a starting point for traversing the line $z'(n) = z(n - n_0)$ results in phase modulation of the Fourier descriptors. Note that this is a modification that affects only the polygonal line representation and has no visual effect on the line.
- Reflection with respect to the vertical or horizontal axis (mirroring) does not affect the magnitude of the Fourier descriptors but causes an indexing reversal:

$$|Z_{reflection}(k)| = |Z(N-1-k)| \qquad (1)$$

- Inversion of the traversal direction affects only the polygonal line representation within the vector graphics file and does not alter the visual appearance of the line. Inversion of the traversal direction results in the same indexing reversal for the Fourier descriptors:

$$Z_{invertion}(k) = Z(N-1-k) \tag{2}$$

These properties can be exploited to devise a robust watermarking method as will be explained in section 4.

3. WATERMARK GENERATION AND EMBEDDING

The proposed algorithm embeds the watermark $W(k)$ by modifying the magnitude $|Z(k)|$ of the Fourier descriptors using an additive or a multiplicative embedding law:

$$|Z'(k)| = |Z(k)| + pW(k) \tag{3}$$

$$|Z'(k)| = |Z(k)| + p|Z(k)|W(k) \tag{4}$$

where $k = 0, 1, ..., N-1$ and p is a factor that determines the power of the watermark. The reason for selecting the FD magnitude for the embedding is that, as described in the previous section, the magnitude is invariant to certain geometric manipulations while alterations caused by other distortions can be easily coped with.

A two step procedure is used to generate the watermark pattern $W(k)$. In the first stage, a one-dimensional zero mean, binary signal $W_0(k)$ having length equal to the length of the polygonal line is constructed:

$$W_0(k) = \pm 1 \quad k = 0, \ldots, N-1 \tag{5}$$

Such a sequence can be generated by a pseudorandom bit generator, or by thresholding a sequence generated by the successive application of a chaotic map [6]. The seed of the random generator or the starting point of the chaotic map constitute the watermark key. The actual watermark signal $W(k)$ is subsequently generated by setting certain samples of the watermark sequence to zero:

$$W(k) = \begin{cases} W_0(k), & if\ aN < k < bN\ or \\ & (1-b)N < k < (1-a)N \\ 0, & otherwise \end{cases} \tag{6}$$

where $0 < a < b \leq 0.5$. By modifying a, b we can control the number of the non-zero elements of the vector W and thus, control the Fourier descriptors that will be modified (e.g. limit alterations to mid-frequency terms).

4. WATERMARK DETECTION

Watermark detection is based on the evaluation of the correlation c between $W(k)$ and the FD magnitude $|Z'(k)|$ of the watermarked polygonal line S':

$$c = \sum_{k=0}^{N-1} W(k)|Z'(k)| \tag{7}$$

The mean value of c for additive and multiplicative watermark embedding and for the case of correct watermark presence is given by the following equations:

$$\mu_c = 2(b-a)\ N\ p \quad \text{(additive embedding)} \tag{8}$$

$$\mu_c = 2(b-a)\ N\ p\ \mu_{|Z|} \quad \text{(multiplicative embedding)} \tag{9}$$

where $\mu_{|Z|}$ is the mean value of $|Z|$. If the polygonal line is not watermarked or is watermarked with a different watermark than the one that we are trying to detect, the mean value of c is zero. Obviously, in the case of multiplicative watermark embedding, evaluation of μ_c requires the calculation of $\mu_{|Z|}$. Using the fact that W has zero mean value it can be proven that $\mu_{|Z|} = \mu_{|Z'|}$.

The normalized correlation $c' = c/\mu_c$ can be evaluated using the above formulas. The mean value of c' is one if W is the correct watermark and zero otherwise. Detection is performed by comparing c' against a properly selected threshold T. For a certain threshold T the system performance is characterized by two probabilities, namely the false alarm probability which is the probability to detect a watermark in an unmarked line or in a line watermarked with a different watermark and the false rejection probability which is the probability of not detecting the watermark in a marked line. In order to do so, the empirical pdf of $c^{'}$ for the two cases (correct watermark presence, erroneous watermark presence) should be evaluated. These pdfs can be approximated by a normal distribution. Thus, false alarm and false rejection probabilities can be computed using the error function $erf(x)$. For example the false alarm probability is given by:

$$P_{F_a} = 1 - \frac{1}{2} erf\left(\frac{T}{\sqrt{2\sigma^2_{c'}}}\right). \tag{10}$$

where $\sigma^2_{c'}$ is the empirically calculated variance of c' in the case of a line marked with a different watermark than the one uner investigation. In the ideal case, the values of these probabilities should be zero. By plotting these two probabilities as a function of the threshold T the receiver operating characteristic (ROC) curve for the corresponding watermark system results. This curve conveys all the necessary system performance information.

Using properly selected values for constants a, b (equation (6)) the method presented above can be robustified to polygonal line smoothing. Furthermore, due to the properties of the Fourier descriptors described in section 2, the method is inherently robust to a multitude of geometric distortions listed below:

- Translation: since translation affects only the coefficient $Z(0)$ (DC term), by generating a watermark that does not affect $Z(0)$, i.e., by setting $a > 0$, translation immunity can be achieved.
- Rotation: the magnitude of the Fourier descriptors remains invariant to rotation a fact that grants the method immunity to this distortion.
- Scaling: the FD magnitude of a polygonal line scaled by a factor s is $s|Z(k)|$. In the case of multiplicative embedding both the numerator and the denominator of the normalized correlator output c' are multiplied by s and thus the value of c' is not affected by scaling.
- Change of the polygonal line starting point: the FD magnitude remains unaltered under this manipulation and thus this kind of distortion imposes no problem to the proposed method.
- Inversion of the traversal direction: since inversion of the traversal direction results to indexing reversal in the Fourier domain, this manipulation can be coped with by introducing watermark signals W that are symmetrical with respect to the middle sample:

$$W(k) = W(N-1-k) \quad k = 0, \ldots (N-1)/2 \;\; Nodd \tag{11}$$

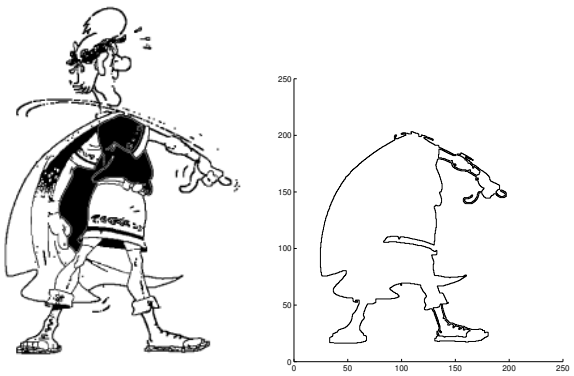
- Reflection: this manipulation can be handled exactly like the traversal inversion, i.e., by using a watermark sequence that is symmetric with respect to its middle sample.

It should be noted here, that the method is robust not only to each of the above distortions but also in any combination of them, as will be exemplified in the next section.

5. EXPERIMENTAL RESULTS

The proposed algorithm has been tested with excellent results in polygonal lines from various vector graphics images. Such an image can be seen in Figure 1a. The polygonal line that has been selected for marking can be seen in Figure 1b. The number of vertices in this line was 1880. The watermark was embedded using multiplicative embedding with the following embedding parameters (equations (4) and (6)): $p = 0.23$, $a = 0.1$, $b = 0.3$. The watermarked image as a whole, along with the watermarked polygonal line can be seen in Figures 2a,b. It is obvious that the changes induced by the watermarking scheme are invisible. The ROC curve obtained when detecting the watermark in an image that has not been distorted can be seen in Figure 4.

In order to test the robustness of the algorithm to various geometric distortions the following combination of manipulations has been applied to the image under investigation:



(a) (b)

Figure 1: (a) Original vector graphics image. (b) Original polygonal line selected for watermarking.

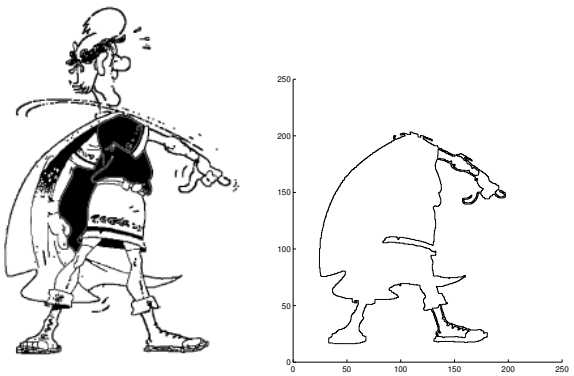
- Rotation by 30^0 (counterclockwise, with respect to the image center).
- Uniform scaling by a factor of 0.75 (decimation).
- Translation by 200 pixels in the vertical and 250 pixels in the horizontal direction.
- Change of the starting point.

The geometrically distorted image can be seen in Figure 3 along with the original one. Despite the combined distortions the performance of the algorithm remains very satisfactory as can be judged from the corresponding ROC curve that is displayed in Figure 4. The small decrease in the system performance is due to the roundoff errors introduced during rotation and scaling operations.

The robustness of the proposed watermarking scheme to polygonal line smoothing has been also tested. The vertex coordinates of the watermarked line have been smoothed using a median filter of window size $N_w = 7$. The corresponding ROC curve can be seen in Figure 4. Although the detection performance is inferior in this case, the deterioration is within acceptable limits.

6. CONCLUSIONS

In this paper, the properties of the Fourier descriptors are utilized in order to devise a blind watermarking scheme for vector graphics images that is robust to a multitude of geometric manipulations and smoothing. Despite its effectiveness, the method is still not robust to polygonal line cropping and insertion/deletion of vertices. Research is underway to enhance the method towards this direction.



(a) (b)

Figure 2: (a) Watermarked image. (b) Watermarked polygonal line.

Figure 3: Rotated, scaled and translated vector graphics image. A change in the polygonal line starting point has also been induced.

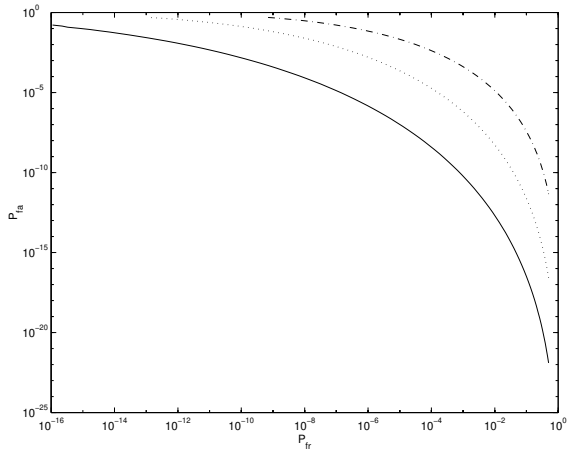


Figure 4: ROC curves for (a) undistorted image (solid line), (b) geometrically distorted image (dotted line), (c) image with smoothed polygonal lines (dash-dotted line).

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