WATERMARKING POLYGONAL LINES USING FOURIER DESCRIPTORS

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ABSTRACT

A method for watermarking of polygonal lines is proposed in this paper. The watermark is embedded in the Fourier descriptors of the polygonal line causing minor distortions to the coordinates of the vertices of the polygonal line. Watermarks generated by this technique can be successfully detected even after rotation, translation, scaling and reflection of the host polygonal line.

1. INTRODUCTION

Digital products can be easily copied and reproduced in a network environment. Therefore, copyright protection of multimedia data (digital audio, still images, video etc) using watermarking techniques has emerged as an important research topic. A digital watermark is a digital signal carrying information about the copyright owner and it is expected to be permanently embedded into the digital products. Among the various types of multimedia data still images were the ones that attracted the greatest attention. Almost all image watermarking methods proposed so far are dealing with watermarking of bitmap (or raster) images, i.e. images represented as a 2-D array of pixels [1]. In such images the watermark is embedded in the spatial domain [2] - [4], the DCT domain [5] -[9] or the DFT domain [10] -[12]. However, certain types of images, especially synthetic or computer generated images (line drawings, cartoons, maps, graphics images), can be represented and manipulated more efficiently using vector graphics i.e. file formats where the various objects are represented by means of a set of geometric primitives (i.e., polygonal lines, circles, ellipses, rectangles etc.)

Despite their importance, copyright protection of vector images draw zero attention within the watermarking community. In this paper a method for watermarking of closed polygonal lines, which are a key element in all vector graphics file formats is proposed. The proposed method introduces slight changes to the coordinates of the vertices of the polygonal line. The watermark is embedded in the magnitude of the Fourier descriptors of the line. The original polygonal line is not required in the watermark detection procedure.

Apart from its importance in copyright protection of vector graphics images the method can be also useful for the watermarking of certain types of bitmap images e.g. cartoons or computer graphics images especially binary ones. These images consist of large homogeneous regions where watermarks generated by typical bitmap image watermarking techniques would be rather visible and easily removable. To use the proposed technique in this case, the images should be first converted in vector representation, a procedure referred to as vectorization. The watermarked vector images are then rasterized to obtain the watermarked bitmap images. A similar procedure should be applied during the detection phase.

The outline of the paper is the following. Section 2 introduces the Fourier descriptor representation of polygonal lines. Watermark construction and embedding is described in section 3. Watermark detection is presented in section 4. Robustness to geometrical distortions is discussed in section 5. Experimental results are presented in section 6.

2. POLYGONAL LINE REPRESENTATION USING FOURIER DESCRIPTORS

In vector graphics image formats a polygonal line is represented as a series of vertices where two consecutive vertices define a line segment. Let L be such a closed polygonal line that consists of N vertices, each of them represented as a pair of coordinates $x(n), y(n)$. These coordinates can be combined to construct the complex signal $z(n) = x(n) + i \cdot y(n)$, $n = 0, ..., N-1$. Such a signal can be represented by its discrete Fourier transform coefficients $Z(k), k = 0, ..., N-1$ which in this case are called Fourier descriptors (FD) [13]. Representation of a polygonal line in terms of its Fourier descriptors has some interesting properties that can be exploited to devise a robust watermarking method as will be explained in the following sections.

3. WATERMARK CONSTRUCTION & EMBEDDING

The proposed algorithm embeds the watermark by changing the magnitude $Z(k)$ of the Fourier descriptors of a polygonal line using a general superposition law:

$$|Z'(k)| = |Z(k)| \oplus pW(k) \tag{1}$$

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 rather than the phase is that the magnitude is invariant to a number of geometric manipulations (see section 5). The watermark pattern $W(k)$ is generated using a two step procedure. In the first stage a $1-D$ zero mean, bi-valued signal $W_0(k)$ having

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length equal to the length of the polygonal line is constructed:

$$W_0(k) = \pm 1 \quad k = 0, \ldots, N-1 \tag{2}$$

Such a sequence can be produced by a random bit generator, or by thresholding a chaotic sequence [14]. The seed of the random generator or the starting point of the chaotic map constitute the key of the watermark. The actual watermark signal $W(k)$ is subsequently generated by setting certain watermark coefficients to zero, so as to limit alterations to mid-frequency terms:

$$W(k) = \begin{cases} W_0(k), & if\ aN < k < bN\ or \\ & (1-b)N < k < (1-a)N \\ 0, & otherwise \end{cases} \tag{3}$$

where $0 < a < b \leq 0.5$. It is obvious that by modifying a, b we can control the number of the non-zero elements of the vector W and subsequently control the Fourier descriptors that will be modified.

4. WATERMARK DETECTION

Let $|Z'(k)|$ be the magnitude of the FD of the watermarked polygonal line L'. The correlation c between $|Z'(k)|$ and the watermark signal W can be used to detect the presence of the watermark:

$$c = \sum_{k=0}^{N-1} W(k)|Z'(k)| \tag{4}$$

Assuming that $W(k), |Z(k)|$ are independent and identically distributed random variables, the mean value of c is:

$$\mu_c = \begin{cases} 2(b-a)\ N\ p & \text{if } W \text{ is the correct watermark} \\ 0 & \text{if } W \text{ is not the correct watermark} \\ 0 & \text{if no watermark is present} \end{cases} \tag{5}$$

(additive watermark)

$$\mu_c = \begin{cases} 2(b-a)\ N\ p\ \mu_{|Z(k)|} & \text{if } W \text{ is the correct watermark} \\ 0 & \text{if } W \text{ is not the correct watermark} \\ 0 & \text{if no watermark is present} \end{cases} \tag{6}$$

(multiplicative watermark)

where $\mu_{|Z(k)|}$ is the mean value of $|Z(k)|$

In case of a multiplicative watermark, evaluation of μ_c requires the calculation of $\mu_{|Z(k)|}$. Using the fact that W has zero mean value it is easy to prove that $\mu_{|Z(k)|} = \mu_{|Z'(k)|}$.

Instead of c, a normalized correlator $c' = c/\mu_c$ can be used. The mean value of c' is 1 if W is the correct watermark and 0 otherwise.

Detection is performed by comparing c' against a properly selected threshold T:

L' is watermarked by W if $c' \geq T$

L' is not watermarked by W if $c' < T$.

For a certain threshold T , two probabilities must be estimated, 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.

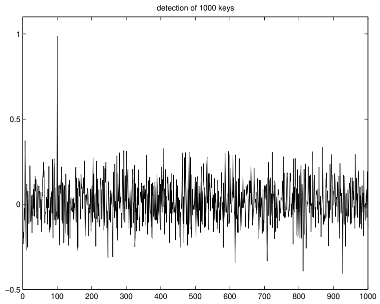


Figure 1: Detection for 1000 different keys. The polygonal line is watermarked by the key 100.

Since the empirical pdf of c' can be approximated by a normal distribution, false alarm and false rejection probabilities can be computed using the error function $erf(x)$. For example the false alarm probability is given by:

$$P_F = 1 - \frac{1}{2} erf\left(\frac{T}{\sqrt{2\sigma^2_{c'}}}\right). \tag{7}$$

where $\sigma^2_{c'}$ is the empirically calculated variance of c' in the case of a non-watermarked line.

5. ROBUSTNESS TO MANIPULATIONS

Using properly selected values for constants a, b (equation (3)) the method presented above can be robustified to polygonal line smoothing. Furthermore, the method is inherently robust to geometrical distortions such as translation, rotation, scaling, change of the traversal starting point, inversion of the traversal direction and reflection. The robustness results from the properties of the Fourier descriptors as will be explained in the sequel.

5.1. Translation

Translation of the polygonal line affects only the first Fourier descriptor $Z(0)$ i.e. the DC term. Therefore, by generating a watermark that does not affect $Z(0)$ i.e. by setting $a > 0$, we obtain watermark immunity to translation.

5.2. Rotation

Rotation of the polygonal line by an angle θ results in constant phase shift of the Fourier descriptors. Thus, the magnitude of the Fourier descriptors remains invariant to rotation which grants the method immunity to such modifications.

5.3. Scaling

Scaling of the polygonal line by a factor s results in the scaling of the Fourier descriptors by the same factor. Therefore 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.

5.4. Change of the polygonal line starting point

Another distortion that can occur in a polygonal line is the change of its starting point which is equivalent to a circular shift of the whole sequence:

$$z'(n) = z((n + n_0) mod\, N) \quad (8)$$

This is a modification that affects only the polygonal line representations within the file and has no effect on how the line is displayed. Changing the starting point results in phase modulation of the Fourier descriptors. Thus the FD magnitude remains unaltered and this distortion imposes no problem to the proposed method.

5.5. Inversion of the traversal direction

Inversion of the traversal direction is another modification that 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 is equivalent to mirroring:

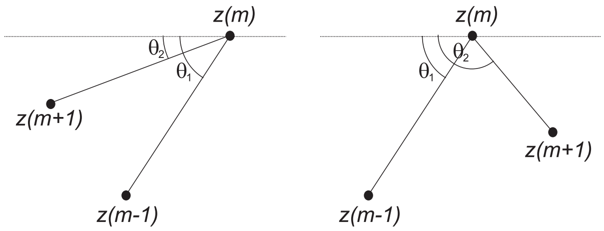
$$z'(n) = z(N - 1 - n) \quad (9)$$

In order to deal with such a manipulation we can construct watermark signals W that are symmetrical with respect to the DC term:

$$W(i) = W(N - 1 - i) \quad (10)$$

Alternatively one can embed and detect the watermark using always the same traversal direction (e.g. the clockwise direction). To do so a way of determining the traversal direction is required. Such an algorithm is presented below:

- *Step 1* Find the vertex $z(m)$ that has the largest y coordinate. If there are more that one such vertices, pick the one that satisfies the inequality $y(m-1) < y(m)$.
- *Step 2* From the values of $z(m-1)$, $z(m)$ and $z(m+1)$ calculate the angles θ_1 and θ_2 ($0 \leq \theta_1, \theta_2 \leq \pi$) (Fig. 2).
- *Step 3* Compare θ_1 and θ_2. If $\theta_1 \geq \theta_2$ (Fig. 2a) then the traversal direction is anticlockwise. In the opposite case (Fig. 2b) the traversal direction is clockwise.

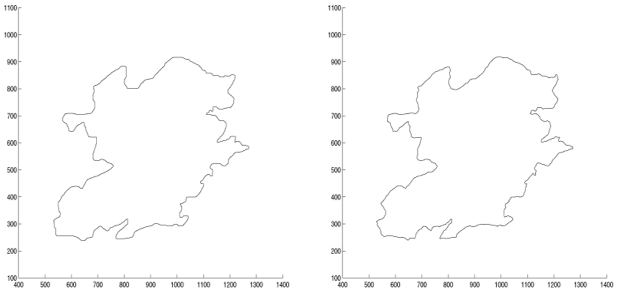


(a) (b)

Figure 2: Evaluation of the traversal direction: (a) anticlockwise (b) clockwise

5.6. Reflection

Reflection with respect to an arbitrary point does not affect the magnitude of the FD. Thus, the proposed method is robust to reflection.



(a) (b)

Figure 3: (a) Original line (b) Watermarked line

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.

6. SIMULATION RESULTS

The proposed algorithm has been tested with excellent results in polygonal lines from various vector graphics images. The polygonal line that we used to illustrate the results is a map elevation curve (Figure 3 a). The number of the vertices in this line is $N = 1635$. We have chosen a polygonal line with a small number of vertices in order to illustrate the fact that the method performs well even in small data sets. The watermarked polygonal line can be seen in Figure 3b.

The distortions that were introduced in the watermarked polygonal line were the following (Figure 4): (a) 30^o rotation around the center of the polygon line (Figure 4b), (b) translation by -100 units in the x-axis and 200 units y-axis (Figure 4d), (c) scaling by a factor of 2 (Figure 4f), (d) change of the traversal starting point (Figure 4h). For each of these distortions the empirical pdfs of c' for non-watermarked and watermarked lines have been evaluated using 1000 distinct watermarks for each case. These pdfs can be seen in Figures 4a, 4c, 4e, 4g. It is obvious that the two pdfs are sufficiently separated to achieve perfect detection. The method was also successfully tested in other distortions that included anisotropic scaling, smoothing and combinations of various distortions.

The method has been also tested on vectorized cartoon bitmap images. Such an image can bee seen in Fig. 5 along with its watermarked version. The experimentally evaluated false alarm and false rejection probabilities for this image were lower than 10^{-4}.

REFERENCES

[1] M. Swanson, M. Kobayashi, and A. Tewfik. Multimedia data-embedding and watermarking technologies. *Proceedings of the IEEE*, 86(6), June 1998.

[2] Martin Kutter, Frederic Jordan, and Frank Bossen. Digital watermarking of color images using amplitude modulation. *Journal of Electronic Imaging*, 7(2):326–332, 1998.

[3] G. Voyatzis and I. Pitas. Embedding robust watermarks by chaotic mixing. In *Proceedings of 13th International Confer-*

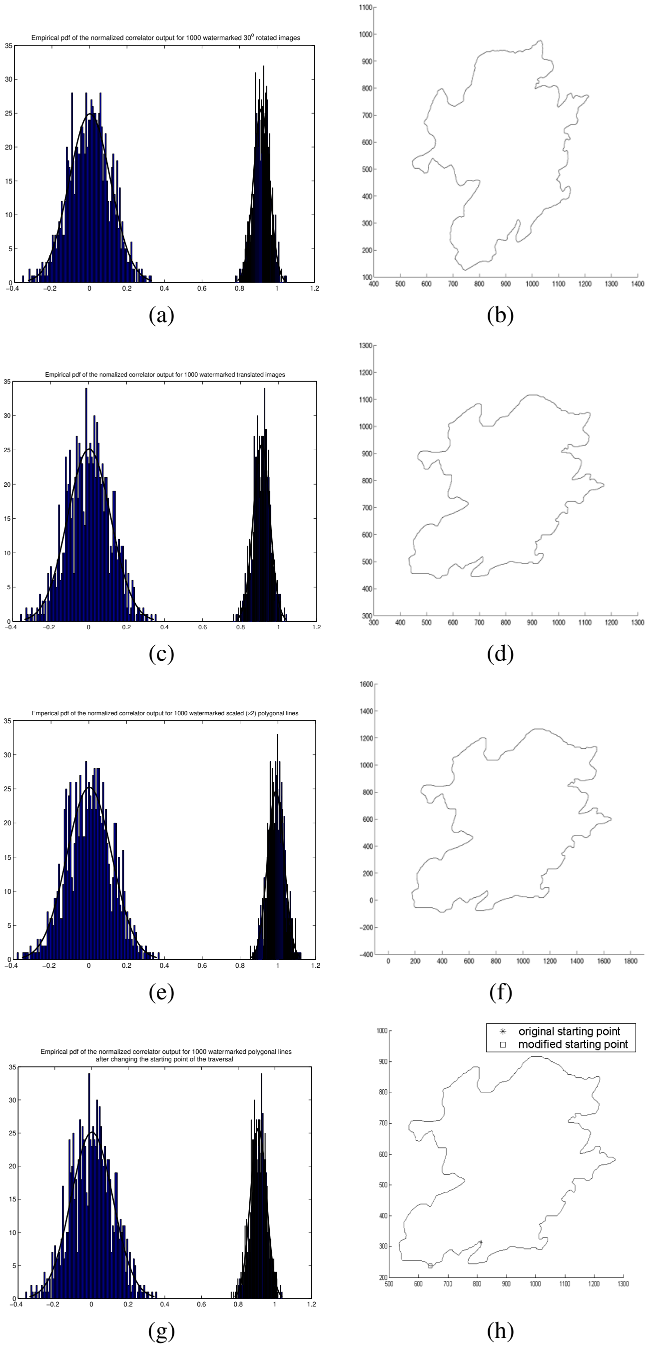


Figure 4: (b) polygonal line rotated by 30^o, (d) Translated polygonal line (x-axis translation -100, y-axis translation $+200$), (f) polygonal line scaled by a factor of 2, (h) polygonal line with a different starting point. (a),(c),(e),(g): corresponding empirical pdfs of the normalized correlator output c' for the non-watermarked (left distribution) and the watermarked line (right distribution).

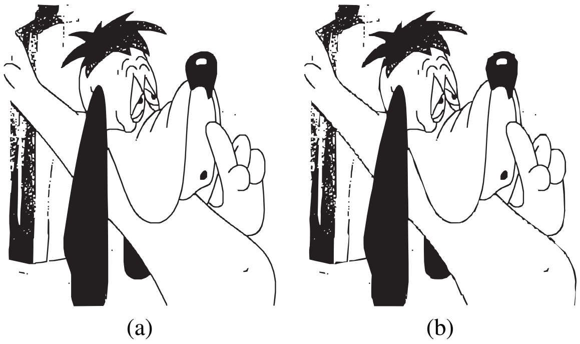


Figure 5: (a) Original cartoon image (b) Watermarked cartoon image.

ence on Digital Signal Processing, volume 1, pages 213–216, Santorini, Greece, July 2-4 1997.

[4] N. Nikolaidis and I. Pitas. Robust image watermarking in the spatial domain. *Signal Processing, sp.issue on Copyright Protection and Access control*, 66(3):385–403, 1998.

[5] M. D. Swanson, B. Zhu, and A. H. Tewfik. Transparent robust image watermarking. In *Proceedings of ICIP'96*, volume III, pages 211–214, Lausanne, Switzerland, September 1996.

[6] I. J. Cox, J. Kilian, F. T. Leighton, and T. Shamoon. Secure spread spectrum watermarking for multimedia. *IEEE Transactions on Image Processing*, 6(12):1673–1687, 12 1997.

[7] A. G. Bors and I. Pitas. Image watermarking using dct domain constraints. In *Proceedings of ICIP'96*, volume III, pages 231–234, Lausanne, Switzerland, September 1996.

[8] M.Barni, F.Bartolini, V.Cappelini, and A.Piva. A blind dct-domain system for robust image watermarking. *to appear in IEEE Journal of Selected Areas of Communications*.

[9] C. T. Hsu and J.L. Wu. Hidden signatures in images. In *Proceedings of ICIP'96*, volume III, pages 223–226, Lausanne, Switzerland, September 1996.

[10] J. Ó Ruanaidh, W. J. Dowling, and F. M. Boland. Phase watermarking of digital images. In *Proceedings of ICIP'96*, volume III, pages 239–242, Lausanne, Switzerland, September 1996.

[11] J. Ó Ruanaidh and T. Pun. Rotation, scale and translation invariant digital image watermarking. In *Proceedings of ICIP'97*, volume I, pages 536–539, Atlanta, USA, October 1997.

[12] V. Solachidis and I.Pitas. Circularly symmetric watermark embedding in 2-d dft domain. In *Proceedings of ICASSP99*, volume 6, pages 3469–3472, Phoenix, Arizona, USA, March 15-19 1999.

[13] Anil K. Jain. *Fundamentals of digital image processing*. Prentice hall, Englewood Cliffs NJ 07632, 1986.

[14] G. Voyatzis and I.Pitas. Chaotic watermarks for embedding in the spatial digital image domain. In *Proceedings of ICIP'98*, volume II, pages 432–436, Chicago, Illinois, USA, October 1998.