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A mirror reflection and aspect ratio invariant approach to object recognition using Fourier descriptor

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ABSTRACT

Most of the shape recognition measures are rotation, translation and scale (RST) invariant. However, when the shape aspect ratio is changed or the mirror reflection of the object is considered for retrieval, some of these measures are not effectively useful. In consideration of the aforesaid issues, a Fourier descriptor based 'aspect ratio' and 'mirror reflection' invariant shape matching algorithm is presented here. This algorithm is also RST invariant.

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1. Introduction

Shape retrieval [2] has been receiving paramount importance in many computer vision applications. In general shape parameters based on boundary or regions are rotation, scaling and translation (RST) invariant [1]. In practice, however, the problem of mirror reflection and change in aspect ratio of the shape pattern are sometimes encountered. In view of this, a shape matching algorithm has been addressed here which is invariant to mirror reflection and aspect ratio changes. The algorithm is also invariant to RST.

Fourier descriptor, introduced by Zahn and Roskies in 1972 [5], is a well-known method in pattern recognition for representing boundary of any shape. The Fourier descriptor of any 2-D closed contour is invariant to rotation, scaling and translation and such descriptors can be used to restore the original image. Based on Fourier descriptors, a number of applications have been reported which include the use of complex Fourier descriptors to generate a sequence of closed curves starting from an initial curve to a final one [4]. Also the properties of the complex Fourier descriptors can be useful to embed a watermark on vector graphics [8]. Although very extensive work has been done on Fourier descriptors for shape recognition [6,7], none of these suggests an integrated approach, which is invariant to changes in aspect ratio, and mirror reflection, in addition to RST.

The paper is organized as follows: In Section 2, preliminary study of reflection invariant property of absolute value of Fourier descriptor is given and the shape retrieval algorithm is proposed with its limitations. In Section 3, a digit recognition example is considered to apply the proposed algorithm and results are studied. Additionally, a comparative study shows here that the proposed algorithm facilitates more accurate shape matching for reflected and rotated objects. We have also presented the cluster analysis to show the usefulness of the proposed technique. Finally concluding remarks are made in Section 4.

2. Methodology

2.1. Fourier descriptor based reflection invariant shape matching

Fourier descriptors [5] are concise and complex representation of object contours (see Fig. 1).

The shape is described by a set of N vertices $\{z(i): i=1, ..., N\}$ corresponding to N points of the outline. Each Zi represents a complex number made by the boundary coordinates (Xi, Yi). The Fourier descriptors $\{c(k): k=-N/2, .., N/2\}$ are the coefficients of the Fourier transform of z:

$$z(i) = \sum_{k=-(N/2)+1}^{(N/2)} c(k) \times \exp\left(2\pi \times j\frac{ki}{N}\right)$$

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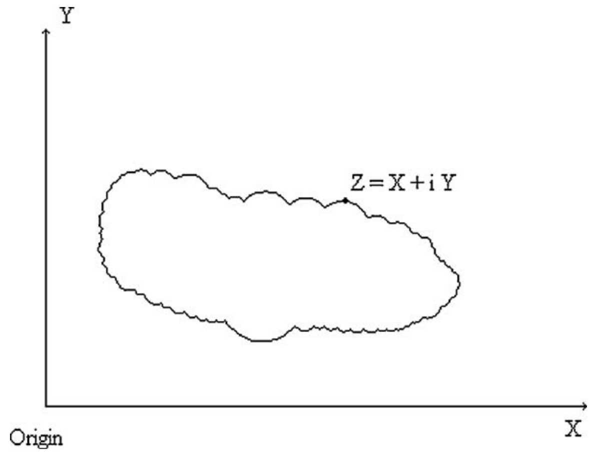

Fig. 1. Fourier descriptors from boundary points.

The inverse relationship exists between $c(k)$ and $z(i)$:

$$c(k) = \frac{1}{N}\sum_{i=1}^{N} z(i) \times \exp\left(-2\pi \times j\frac{ki}{N}\right)$$

The range of k can be restricted to $\{-(N/2)+1, N/2\}$ according to Shannon's theorem, the highest frequency is obtained for $k=N/2$, and any $c(k)$ with k greater than $N/2$ would be redundant since we use a discrete representation of the outline. The frequency content of these descriptors is also very relevant to describe low and high frequency processing separately. The descriptors $c(k)$ describe the frequency contents of the curve. If only a low frequencies subset of descriptors is used, we get a curve that just approximates the outline of a shape. By increasing the number of components in the description, high frequencies are also rendered, and simultaneously sharp curves can be generated.

These descriptors are rotation, scaling and translation invariant. Current study investigates its mirror reflection invariance property, based on which the following algorithm is proposed.

Step 1. Select a set of boundary points for both the original shape and mirror reflected version of it, starting from a common start point. In fact, the point on major axis of a shape which is farthest from the centre of the shape is selected as unique start point.
Step 2. Shift the centroids of both the shapes to the origin.
Step 3. Calculate the Fourier descriptors of the shapes obtained from Step 2.
Step 4. Match the descriptor pattern using any appropriate distance function.

Lemma 1. *The magnitude of Fourier descriptors of reflected images, whose centroids are shifted to origin, will be equal in magnitude.*

Proof. (Fig. 2)

Case 1. Simple reflected image.

Let us consider a digital image Z and its reflection Z' about the mirror L which is inclined at an angle α from positive X axis (see Fig. 3). A point in image Z is shown as (x, y) and its reflection about the mirror L as (x', y').

Now $\boldsymbol{z}$ is set of all the boundary points of origin shifted original image and $\boldsymbol{z}'$ is its counter reflected set. As the centroids of both the shapes have been shifted to origin which counterbalance the effect of translation, therefore it can be inferred from that

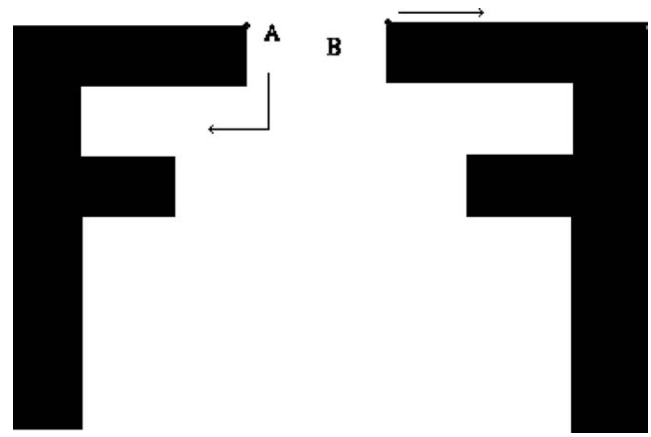

Fig. 2. Mirror reflection.

$$\sum_{i=1}^{N} x_i = 0; \quad \sum_{i=1}^{N} y_i = 0 \quad \text{and}$$

$$Z(k) = \sum_{n=1}^{N} \{x(n) + jy(n)\}\{\cos(2\pi kn) - j\,\sin(2\pi kn)\}$$

where i varies from 1 to N (assuming N boundary points) and Z_i represents ith boundary point starting from z_1 which is the common start point in original image. Fourier transform equation of all the boundary points z is given as:

$$Z(k) = \sum_{n=1}^{N} z(n)\,\exp(-j2\pi kn)$$

$$Z(k) = \sum_{n=1}^{N} \{x(n) + jy(n)\}\{\cos(2\pi kn) - j\sin(2\pi kn)\}$$

$$Z(k) = \sum_{n=1}^{N} \{x(n) + jy(n)\}(-1)^{nk}$$

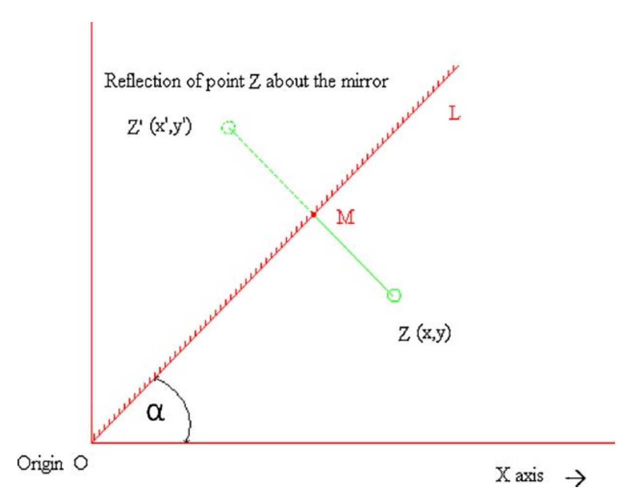

Fig. 3. Reflection of a point Z in image.

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