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Short Communication

# Multi-scale contour flexibility shape signature for Fourier descriptor ☆

Xin Shu [a,b,*], Lei Pan [a], Xiao-Jun Wu [b]

[a] School of Computer Science & Engineering, Jiangsu University of Science & Technology, Zhenjiang 212003, PR China
[b] School of Internet of Things Engineering, Jiangnan University, Wuxi 214122, PR China

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ABSTRACT

Shape signature and Fourier descriptor are common techniques for shape description and they are widely used in pattern recognition and computer vision applications. In this paper, a novel shape signature is proposed, namely, multi-scale contour flexibility shape signature. After the discrete Fourier transform is performed on the multi-scale contour flexibility shape signature, the Fourier descriptor will be obtained. As a contour line function, contour flexibility based Fourier descriptor not only describes the whole deformation characteristics of the two dimensional shape profiles, but also reflects the local deformation characteristics of the contour sampling points. Thus, the proposed method incorporates the global and local features of the shape. Multi-scale technique could solve the problem of elastic parameter selection skillfully and describe the shape features from coarse to fine. In addition, contour flexibility is also easy to be calculated. Experiments conducted in the MPEG-7 shape database show that the best retrieval results are achieved by the multi-scale contour flexibility based Fourier descriptor compared with other representative shape signatures based Fourier descriptor.



## 1. Introduction

Shape description is a fundamental technique for many applications of pattern recognition and computer vision, including object recognition, image retrieval, pose estimation, industrial inspection, target tracking, etc. A good shape representation should be compact and retain the essential features of the shape. Meanwhile, invariant to rotation, scale, and translation are also required since such invariance is consistent with the human vision perception system. MPEG-7 [1] standard has suggested several principles for evaluating a shape descriptor. The main requirements of the standard are good retrieval accuracy, compact features, general application, low computational complexity, robustness to noise and hierarchical coarse to fine representation.

There are a great variety of shape descriptors that have been proposed in the literature during the past decades. Comprehensive surveys on methods of shape description have been reported [2–6]. In general, shape description techniques are divided into two distinct categories: the region-based technique and the contour-based technique.

In the region-based technique, all the pixels within a shape are used to obtain the shape representation. Popular region-based shape descriptors include moment invariants [7,8], generic Fourier descriptors [9], multi-scale Fourier based description [10]. The common moment based descriptors include geometrical moments [7,8], Zernike moments [11] and Legendre moments [12]. Geometrical moments were first proposed by Hu in 1962. Hu's moment invariants are based on the theory of algebraic invariants, which are translation, rotation and scale independent. The deficiency of the geometric moments is the high degree of information redundancy since the bases are not orthogonal and high-order moments are sensitive to noise. The Zernike moment descriptor has such desirable properties: rotation and scale invariance, robustness to noise, expression efficiency, fast computation and multi-level representation for describing the various shapes of patterns. Legendre moments use Legendre polynomials as basis functions. These polynomials are orthogonal and cause Legendre moments to extract independent features within the image, with no information redundancy. Though Legendre moments have good retrieval properties, they are not invariant to linear operation and rotation. Zernike moments and Legendre moments are both proposed by Teague [12]. Generic Fourier descriptor is another notable region-based technique, which is extracted from the spectral domain by applying 2D Fourier transform to polar raster sampled shape image. Compared with Zernike moments, Generic Fourier descriptor has no redundant features and captures the features of the

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* Corresponding author at: School of Computer Science & Engineering, Jiangsu University of Science & Technology, Zhenjiang 212003, PR China.
*E-mail address:* shuxin@just.edu.cn (X. Shu).

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shape in both polar and radial directions. Multi-scale Fourier based descriptor is a recently proposed region-based technique, which is a novel image-based multi-scale description using a low-pass Gaussian filter (LPGF) and a high-pass Gaussian filter (HPGF), separately. Using the LPGF at different scales represents the inner and central part of an object more than the boundary. On the other hand, using the HPGF at different scales represents the boundary and exterior parts of an object more than the central part. In general, the region-based approaches extract the global features of a shape and can be applied to generic shapes, but they often comprise intensive computation and fail to capture many important shape details which are the significant factor for distinguishing similar objects.

The contour-based technique has been very popular in the past decades due to its good performance in applications. We only review the most recent approaches which are related to ours. The well-known contour-based shape descriptors include Fourier descriptor [13–15], multi-scale technique [16–18], contour flexibility [19], shape contexts [20–22], etc. [23–27]. Fourier descriptor is based on the well-developed theory of Fourier analysis and is obtained from the Fourier transform on a shape signature. For easy implementation, Fourier descriptor can meet the real-time requirements in many applications. Shape representation based on the theory of the multi-scale is also popular in recent years. These kinds of methods mainly use the characteristics of concave and convex of the plane curve, which are significant for human visual identification. In addition, these approaches are more robust to noise since the dominant features are those that persist across scales. There are many contour-based multi-scale description techniques such as curvature scale space (CSS) [14], multi-scale convexity concavity (MCC) [15], triangle area representation (TAR) [16]. The CSS image consists of several arch-shape contours representing the inflection points of the shape as it is smoothed. The maxima of the curvature zero-crossing are used to represent the shapes of object boundary contours. In MCC representation, contour convexities and concavities at different scale levels are represented using a 2D matrix. Then, the curvature of each boundary point is measured based on the relative displacement of a contour point with respect to its position in the preceding scale level. TAR utilizes the areas of the triangles formed by the boundary points to measure the convexity/concavity of each point at different scales. The area value of every triangle is a measure for the curvature of corresponding contour point, and the sign of the area is positive, negative or zero when the contour point is convex, concave or on a straight line, respectively. Contour flexibility is a kind of rich descriptor for planar contours, which depicts the deformable potential at each point along a curve. Contour flexibility provides the information about how extensively the neighborhood of a contour point is connected to the main body and about the deformation tolerance of an object at this point. Shape context (SC) is a significant milestone in the region of shape description and matching. Shape context captures the spatial distribution of all the other sample points relative to it. The spatial distribution is represented by a coarse histogram, and the bins in the histogram are uniform in log-polar space, which makes the descriptor more sensitive to nearby sample points than to points farther away. The modified shape context can also be used to describe 3D shape [22]. Most the contour-based methods extract information from the boundary of a shape only and ignore the rich information contained in the shape region. In addition to the above two kinds of shape description methods, many scholars have done a lot of other excellent work in the region of shape description and recognition, including UNL-Fourier [28], logarithmic-polar-Fourier [29], modified UNL [30] and others [31–35].

In this paper, we focus on signature based shape description and propose a new shape signature for Fourier descriptor, named multi-scale contour flexibility shape signature. The proposed method utilizes the advantage of contour flexibility that depicts the deformable potential at each point along a curve and the superiority of multi-scale technique that describes the shape features from coarse to fine.

The rest of the paper is organized as follows: Section 2 introduces the proposed multi-scale contour flexibility shape signature. Section 3 explains how the Fourier transform along with a normalization scheme is applied to the shape signatures. In Section 4, experimental results are presented to compare the proposed signature with other frequently used shape signatures. Conclusions derived from the study and suggestions for future work are presented in Section 5.

## 2. Shape signature

In general, shape signature is a one dimensional function derived from the boundary points of the shape. After years of development, many shape signatures have been proposed such as radius distance (also called centroid distance), complex coordinates, tangent angle, curvature, cumulative angular function, triangular area and farthest point distance. Good reviews on methods of shape signatures have been reported [36,37]. But most of them involve only the landmark points on a shape contour and the shape centroid during their building process. For a given landmark point on the shape contour, the signature obtained usually does not have a clear physical meanings and only reflects the local representations of the shape features. In addition, most of the exist shape signatures are sensitive to noise and not robust. In this research, we suggest a novel shape signature, namely multi-scale contour flexibility shape signature and compare it with other frequently used shape signatures in MPEG-7 shape database. The proposed shape signature fuses both the local area and global contour characteristics and is extracted from the boundary of object. Contour flexibility with 2D shape was proposed by Xu et al. [19] firstly, which represents the deformable potential at each point along a contour. We briefly investigate the contour flexibility in the following.

Let $\Gamma$ and $D$ be the closed contour and the region of a 2D planar shape, and the centroid of the contour has been moved to the origin of the 2D coordinate system. For a point on the contour, a function of distance transform on $\mathrm{IR}^2$ is defined as

$$\kappa(p) = d(p,x), \quad x \in \mathrm{IR}^2 \tag{1}$$

where $d(\cdot,\cdot)$ is the Euclidean distance between points $p$ and $x$. In fact, the function of distance transform defined by us is slightly different from that in [19]. The $\kappa(p)$ in this paper denotes the Euclidean distance between points $p$ and $x$. However, the $\kappa(p)$ denotes the Euclidean distance between two sets in [19]. The slight change greatly reduce the computational complexity for extracting the contour flexibility.

For a point $p$ on the contour $\Gamma$ and a selected radius $r$ (also called bendable parameter), the interior flexibility $w_+$ and exterior flexibility $w_-$ at $p$ are defined respectively as

$$w_+(p,r) = \frac{\int_{C^+_{p,r}} \kappa_+(x)dx}{\int_{C^+_{p,r}} dx} \tag{2}$$

$$w_-(p,r) = \frac{\int_{C^-_{p,r}} \kappa_-(x)dx}{\int_{C^-_{p,r}} dx} \tag{3}$$

where $C^+_{p,r}$ and $C^-_{p,r}$ are the connected components containing $p$ in the sets $\{x \in D \mid \|x-p\| \leqslant r\}$ and $\{x \in \mathrm{IR}^2 \setminus int(D) \mid \|x-p\| \leqslant r\}$ respectively, and $int(\cdot)$ is the interior of a set.

Fig. 1 illustrates three examples of $C^+_{p,r}$ and $C^-_{p,r}$ with respect to point $p$. For a well-tuned bendable parameter $r$, $w(p,r)$ provides