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Phase preserving Fourier descriptor for shape-based image retrieval

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ABSTRACT

Shape is one of the most important discriminative elements for the content based image retrieval and the most challenging for quantification and description. Fourier descriptors are a very efficient shape description method used in shape-based image retrieval tasks. In order to achieve invariance under rotation and starting point change, most Fourier descriptor implementations disregard the phase of Fourier coefficients, consequently losing valuable information about the shape. This paper proposes a novel method of extracting Fourier descriptors that preserve the phase of Fourier coefficients. We introduce specific points, called *pseudomirror* points, and use them as a shape orientation reference. They facilitate the extraction of phase-preserving Fourier descriptors which are invariant under translation, scaling, rotation and starting point change. The proposed descriptor was tested on four popular benchmarking datasets: MPEG7 CE-1 Set B, Swedish leaf, ETH-80 and Kimia99 datasets. Performance and computational complexity measures indicate that the proposed method outperforms other state-of-the-art phase-based Fourier descriptors. In addition, it outperforms other state-of-the-art magnitude-based Fourier descriptors, and many non-Fourier based shape description methods in terms of performance – complexity ratio.

1. Introduction

The shape of the presented objects on images is an important feature for image understanding. Thus, shape is widely used as a discriminative element in the field of content-based image retrieval (CBIR). In many applications, shape captures most of the perceptual information of the observed objects on images, while color and texture can often be omitted without affecting retrieval performance. Unfortunately, shape may be subject to significant changes, such as deformation, scaling, changes in orientation, noise, and partial concealment. Hence, accurate description of the shape remains a challenging technical problem.

A variety of shape description techniques have been developed over the years [1]. Best shape descriptors are typically described using the following attributes: compact, easy to compute, informative, discriminative, tolerant to geometric transformations, efficient. It is very hard to satisfy all these requirements. The aim of many researchers in this field is to improve descriptor performance and reduce computational costs.

Shape description methods usually belong to one of the following four classes: (1) global, (2) local, (3) combined global and local methods, and (4) post-processing/learning shape similarity methods.

Global methods capture the object's global shape information and are relatively fast to compute and compare. Although they are robust to noise, they exhibit poor

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performance when it comes to discriminating occluded shapes or do partial matching. In contrast, local techniques precisely represent local shape features. However, they are sensitive to noise and often more computationally complex than global techniques. The choice between local and global descriptor is context-dependent. Recently, a palette of so-called "rich" (as called by Wang et al. [2]) descriptors has been proposed. These descriptors combine both local and global shape characteristics. Therefore, they obtain good retrieval rates on popular benchmark datasets, at a cost of more complicated descriptor computation and matching. The last group of shape descriptors consists of those that use either training sets and machine learning techniques to "learn" shape similarity, or use information about other shape retrievals in order to increase the retrieval rate.

In this paper, Phase-including Fourier Descriptor (PIFD) is introduced. It is a novel global, spectrally hierarchical, information-preserving, contour-based shape description technique. Development of PIFD is inspired by the work on magnitude-based Fourier descriptor (FD) by Zhang and Lu [3–5] and by a recent work of Sokic and Konjicija [6]. We use the term magnitude-based FDs to denote FDs which use only the magnitude of Fourier coefficients. Magnitude-based FD is established as very compact, efficient and effective global shape descriptors. We propose to improve the retrieval performance of FD even more, while attaining the same computational complexity. This is obtained by preserving the phase of the Fourier coefficients. In order to achieve invariance of the Fourier coefficients under rotation and starting point change, we propose to use so-called *pseudomirror* points for determining the nominal orientation of the shape. Obtained experimental results demonstrate that PIFD is superior to other Fourier descriptor based methods in terms of retrieval performance and discrimination ability. Although being a global technique, experiments confirm that PIFD is also comparable to other state-of-the art shape description methods, while having much lower computational complexity.

The main contributions of this paper are

- introduction of a novel method for determining nominal shape orientation(s),
- development of a versatile phase-preserving Fourier descriptor which is invariant under translation, rotation, scaling, starting point change and optionally mirror transformations,
- development of a shape descriptor with one of the best retrieval performance- computational complexity ratios.

The rest of the paper is organized as follows. A brief review of related work is given in Section 2. In Section 3, Phase-including Fourier Descriptor (PIFD) is introduced. Experimental results are demonstrated and discussed in Section 4. Concluding remarks and future research directions are given in the last section.

2. Related work

Shape description methods may be classified into two groups: region based and contour based [1,7]. Region based techniques use the boundary of the shape as well as the interior of the shape, while contour based techniques take into account only the contour of the shape. Contour based approaches are generally more compact, faster and sometimes perform better than region based methods. On the other hand, contour based methods find it difficult to identify shapes which consist of disjoint parts, such as trademarks, logos and characters [8].

The contour of the shape is commonly described using shape signatures. They are one-dimensional functions which capture most of the perceptual features of the shape [9]. Shape signatures are sensitive to noise and distortions and often dependent on rotation, translation and scaling. To overcome these problems, different transformations are conducted over shape signatures.

Fourier descriptors (FD) are obtained by applying the discrete Fourier transform (DFT) over a shape signature [3]. By disregarding phase information, descriptors become invariant under rotation, translation, scale and change of the starting point of the contour. They also show good retrieval accuracy, compactness, insensitivity to noise and have a hierarchical representation in spectral domain.

Magnitude-based Fourier descriptors have been derived from several shape signatures: Complex coordinates [6], Centroid/Radial distance, Tangent angle [5], Curvature function, Area function, Triangle-area representation [10], Triangular centroid area, Chord length [4], Polar coordinates, Farthest point distance [11], Perimeter area function [12], Improved arc-height function [13], Rectangle centroid distance [14] and many others.

Apart from being a global shape description technique and having hierarchical representation only in spectral domain, there are essentially two main disadvantages of magnitude-based Fourier descriptors.

Fourier descriptors are not information-preserving, which means that the original shape cannot be reconstructed from descriptor coefficients. Therefore, they are not suitable for shape evolution problems or shape retrieval tasks where rotation invariance is not desirable (e.g. traffic signs recognition [15]). However, information-preserving property is not always a required attribute of a CBIR system, hence the usability of the descriptor is not significantly limited. Moreover, this drawback is compensated by their compact notation and simple matching.

The most important drawback of magnitude-based Fourier descriptors is that they disregard phase information in order to obtain invariance under rotation and starting point change. Using this simplistic approach, valuable information contained in shape description is lost. To illustrate this fact, two completely different shapes with equal magnitudes of Fourier coefficients are depicted in Fig. 1. Interestingly, Oppenheim and Lim [16] in 1981. showed that phase contains a lot of valuable information about the shape and that even, with specific initial assumptions, images may be reconstructed using the