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ECDS: An effective shape signature using electrical charge distribution on the shape

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ABSTRACT

Motivated by the fact that electrical charge distributions are almost the same for similar shapes but not vice versa when shapes reach their electrical equilibrium condition, we propose a novel shape signature based on the electrical charge distribution on the shape (ECDS). Compared to other shape signatures, ECDS has the following interesting properties: (1) ECDS is a local measure but computed in a global manner. Thus, it is more robust to noise and shape variations. (2) ECDS is articulation insensitive and therefore exhibits better performance by the introduction of generalized coulomb potentials. This allows it to better match shapes whose parts can move independently, such as scissors. (3) The sum of ECDS remains constant during the process of reaching electrical equilibrium, which does favor some applications. Numerous experiments have been done on several public shape databases (MPEG-7 database, articulated shape data set, Kimia silhouettes and ETH-80 data set), demonstrating that ECDS has the above properties and compares well with other shape descriptors in many kinds of shape retrieval and recognition tasks.

1. Introduction

Due to the rapid development of imaging technologies and the Internet, it is convenient for people to refer and obtain a large number of images, and applications such as image retrieval and recognition have become very common. However, textual annotation of images is inefficient and sometimes impossible in large image database. Retrieval by image content (CBIR) may be used instead of textual annotation [1]. The shape, as the most important feature of an image, plays a prominent role in the content-based search method. Compared to color or texture, shape alone can represent the whole object, but common shapes require hundreds of parameters to be represented explicitly [2]. In order to more easily handle, store and compare shapes, researchers propose to represent shapes by intelligent descriptors using simplified representations that carry most of the important information. Thus, finding meaningful and efficient shape descriptors is a fundamental problem in shape retrieval and recognition.

Since the contour or silhouette is the most important feature of a shape, various shape descriptors based on the contour are proposed in the literature. Early contour-based descriptors consider the contour as a whole and represent it by some global measures such as area, eccentricity, chord context, invariant moments, and spectral coefficients [3–7]. In general, global descriptors are compact and efficient for comparison. However, most of these descriptors have only low discrimination and are sensitive to large deformations of the shape. An example is shown in the first pair of shapes in Fig. 1. Since local geometry information is lost in global descriptors, it is not easy for global descriptors to capture the part similarity between the camels. Thus, recently proposed shape descriptors focus on local features and hybrid (global/local) descriptors. The shape signature is an important example of these kinds of descriptors.

Shape signature is usually defined as any 1-D function on a shape, derived from the shape contour points. Compared to other shape descriptors such as shape context or multi-scale shape descriptors, shape signatures can capture the essential information of the shape in a more compact manner. Early proposed signatures include centroid distance, complex coordinates, curvature, tangent angle, local diameters, etc. [3,4,8]. They are concise and compact representations of the shapes and widely used in many shape analysis and recognition tasks. But most of these shape signatures fail to discriminate shapes with large differences. Recently, Xu et al. [9] propose a novel shape signature called the contour flexibility, which represents the deformable potential at each landmark of the contour. The retrieval experiments in the MPEG7 shape database show that

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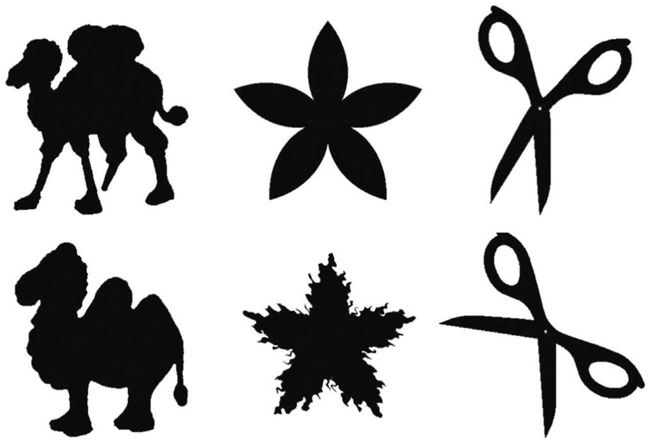

Fig. 1. Three pairs of shapes that may be mismatched by existing methods.

contour flexibility obtains the highest Bullseye scores among the shape signatures. However, although many kinds of shape signatures have been presented in the literature, the existing signatures have the following problems:

- Nearly all the shape signatures are estimated from the neighbors of each point, such as curvature, tangent angle, contour flexibility. Neighbor size is reported to usually have a significant impact on the signatures, especially when substantial noise is present. Noise is therefore widespread in the shape data (the second pair of shapes in Fig. 1). Introducing multi-scale or scale space techniques [10] can reduce this sensitivity but are computationally demanding for the shape matching process.
- Most shape signatures are not invariant to articulation (isometric transformation of the shape), since they are computed in a local way. As a result, the third pair of shapes in Fig. 1 may cause mismatching by these signatures, because articulation between two shapes introduces adverse information to the signatures. Effective shape signatures should capture both the local geometry information and part structure of the shape in a hybrid manner.
- In general, the existing signatures cannot yet provide entirely satisfactory solutions to describe the shape variations well and have low performance in shape retrieval and recognition experiments, since they are only 1-D functions on the shape. A natural improvement is utilizing *N*-D functions, such as shape context [11,12]. However, shape context is less compact and computationally demanding, like other multi-scale methods.

Based on the above observation, it is useful to propose a shape signature which can overcome the mentioned problems and perform as well as or even better than state-of-the-art shape descriptors. Aiming at this goal, we propose an effective shape signature named ECDS. Supposing that a 2D shape is a charged conductor, the basic idea of ECDS is representing the shape by its electrical charge distribution when the shape reaches the state of electrostatic equilibrium. Since charge tends to accumulate at a sharp convexity and vanish at a sharp concavity [13], the proposed ECDS descriptor captures the local curvature information and part structure of the shape. Meanwhile, ECDS is computed as the solution of a system of linear equations, which considers all data points at once. It makes ECDS more resilient to noise than other signatures, such as curvature.

The contributions are summarized as follows:

- A novel shape signature ECDS, which is invariant to translation, scale, rotation and insensitive to noise and articulation, is proposed.
- Different from the classic electrical charge distribution, ECDS is computed based on the generalized coulomb potential representing part-aware metric and long-range interactions, which significantly increases its descriptive power.
- Numerous experiments have been done on several public shape databases demonstrating that ECDS performs as well as or even better than the state-of-the-art shape descriptors, including the shape signatures, the shape context and the multi-scale descriptors.

The rest of this paper is organized as follows: Section 2 gives a brief overview of related work on shape representation methods. Section 3 presents ECDS representation and its computation. The generalized electrical potential and the characteristics of ECDS are also discussed in this section. Section 4 contains the description of the implementation and some experimental results. Finally, Section 5 summarizes the paper.

2. Related work

As a hot topic in computer vision, shape representation and analysis has been extensively studied. Since shapes commonly are 2D images which are projections from 3D objects, the silhouettes may change significantly if the viewpoint changes or 3D objects make non-rigid motions (e.g., articulation). To make things worse, shapes are extracted from 2D images. Heavy noise in shape data is unavoidable due to segmentation errors caused by partial occultation, lighting variation and so on. For the above reasons, many proposed shape descriptors are driven by different aspects of the problem such as robustness to noise or insensitivity to articulation. There are no entirely satisfactory solutions in the shape representation area. A good survey of general shape representation methods can been found in [3,14]. In this paper, we focus on descriptors requiring contour information only, which are different from descriptors based on the interior of the shape, such as representing each internal point in the interior by a value reflecting the mean time required for a random walk beginning at the point to hit the boundaries [15]. Thus, only some important contour-based shape descriptors are reviewed as follows.

Since shapes are represented by their contours, it is natural to define some simple global shape descriptors, such as area, eccentricity [7], and major axis orientation. However, these simple descriptors are coarse representations, and can only discriminate very different shapes. They usually need to be combined with other shape descriptors in order to be more effective. Moment-based [16] and spectral [6,17] are two more kinds of global descriptors. Moment invariants have been frequently used as some kinds of shape features. In order to reduce the computational burden for moments, Chen [5] presented improved moment invariants which are computed by the shape boundary only, and applied the moment invariants in shape discrimination. Since noise and boundary variations are common in shape data, representing that a shape in the spectral domain can alleviate these problems to some extent. Fourier-based shape descriptors [6] and wavelet-based shape descriptors [17] are proposed to transform the shape data into a spectral space, and represent the shape by their coefficients.

Noticing that representing a shape only in a global manner cannot give an entirely satisfactory solution, many recent publications pay great attention to local or hybrid (local/global) descriptors. Shape signature is a well-studied technique, which represents the shape by a one-dimensional function. The shape signature corresponds to a descriptive vector in a discrete setting, and is widely used in shape visualization, retrieval, and recognition. Common shape signatures include centroid distance, tangent angle, curvature, chord-length, etc.