Pattern Recognition 84 (2018) 97–111

Contents lists available at ScienceDirect

Pattern Recognition

journal homepage: www.elsevier.com/locate/patcog

Circular mesh-based shape and margin descriptor for object detection

Malu G.[a,*], Sherly Elizabeth[a], Sumod Mathew Koshy[b]

[a] Indian Institute of Information Technology and Management- Kerala, Technopark, Kerala 695 581 India
[b] Regional Cancer Centre, Thiruvananthapuram, Kerala 695 011 India

ARTICLE INFO

Article history:
Received 17 November 2017
Revised 21 May 2018
Accepted 1 July 2018
Available online 5 July 2018

Keywords:
Shape descriptor
Structural and global descriptor
Circular mesh-based shape and margin descriptor
Convex and concave regions
Lesion detection
Dynamic contrast enhanced magnetic resonance imaging

ABSTRACT

In many engineering and medical imaging fields, shape, and margin descriptors play an important role in challenging pattern recognition and classification problems. This paper presents a circular mesh-based shape and margin descriptor (CMSMD) for object recognition and classification. This shape descriptor is the first to have the functions of both structural and global contour-based descriptors. In the proposed descriptor, object contours are embedded in a circular mesh and labelled using circular mesh-based border labelling. New features can also be derived using the proposed descriptor. Further, an algorithm that employs the CMSMD characteristics can be utilised to identify the convexity and concavity of the embedded contours in linear complexity. The effectiveness of the proposed descriptor was demonstrated by performing lesion detection using dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) results. The obtained accuracy of 94.69% shows that the proposed descriptor is superior to the existing shape descriptors used for lesion detection in DCE-MRI.

1. Introduction

Computer vision is concerned with the automatic extraction, analysis, classification, and understanding of useful information from images. Patterns or objects are identified using computer vision based on features such as texture, colour, size, and shape. Shape is an inherent feature in object retrieval, recognition and classification, alignment and registration, and approximation and simplification [1]. Although nonnumeric shape representations such as graphs preserve shape and margin characteristics, analysis conducted using them in computerised image processing applications produces weak results and is difficult. Accurate and precise representation of shapes using descriptors plays a significant role in object identification. A descriptor can be employed to characterise object shapes uniquely and obtain information consistent with that provided by human vision. A good shape descriptor should tolerate the geometric differences among objects from the same category but should simultaneously enable the discrimination of objects from different shape classes.

There are two categories of shape descriptors: contour- and region-based descriptors. These categories are further divided into structural and global descriptors. In the structural approach, which is discrete, the shape boundary is divided into segments called primitives using certain criteria and the contour is subdivided into sections to generate strings or trees according to a distinct syntax and is used to check the similarity of different shapes. Chain codes, polygons, B-splines, areas, Euler numbers, and grids are some structural descriptors. In contrast, global descriptors are continuous and do not involve shape division into subparts. In global representations, vectors are generated using the characteristic features of the contour or region such as its eccentricity, perimeter, circularity, geometric moment invariants, shape matrix, and area. In both structural and global descriptors, the feature vectors derived from the integral boundary are used to describe the shape. The measure of shape similarity is usually a metric distance between the acquired feature vectors [2].

A more accurate classifier for shapes is essential because descriptors attempt to quantify shapes in ways that agree with human intuition. Shape features that satisfy properties such as identifiability; invariance to translation, rotation, and scale; affine invariance; noise resistance; occultation invariance; statistical independence; and reliability are considered to be admissible features for shape descriptors. In addition, it is desirable to select features that are application independent and have low computational complexity [3].

Although global and structural descriptors convey more effective features, they are insensitive to various representations and, in some cases, are computationally inefficient. The global contour-shape technique provides better accuracy, but it requires an excessive amount of storage because of the large descriptor size. In

* Corresponding author.
E-mail addresses: malu.res11@iiitmk.ac.in (M. G.), sherly@iiitmk.ac.in (S. Elizabeth).

https://doi.org/10.1016/j.patcog.2018.07.004
0031-3203/

addition, simple global measures are inadequate to represent important local changes. Meanwhile, local shape descriptors are unable to capture the fine details of noisy border irregularities. A global shape descriptor should be compact, noise-resistant, and capable of detecting even fine irregularities such as concavity, convexity, spiculation, and lobulation, which are prominent features that convey shape and margin characteristics [2].

A priori knowledge of the shape boundary properties and noise details is also relevant for structural descriptors. Structural descriptors can handle occlusion and enable partial matching but are computationally complex. Visual systems can easily be employed to extract the convexities and concavities of objects, but in computer vision, this task is difficult because a structural description of shapes in terms of parts along their contours is required.

Thus, this paper proposes a new circular mesh-based shape and margin descriptor (CMSMD) that can extract the relevant characteristics of both structural and global contour-based descriptors and function as a combined descriptor. The features derived from this descriptor can enable the analysis and classification of objects with various shapes—such as round, oval lobular, and irregular—and margins such as smooth, irregular, and spicular. The CMSMD is compact, has low computational complexity and high efficiency, and can be used in various applications. The descriptor size is fixed dynamically such that it increases as the borders vary from smooth to irregular. If the borders are smooth, the fine details are not relevant, and so a descriptor with fewer elements is generated; meanwhile, if they are irregular, fine details are required, so a descriptor with more elements is generated. This dynamic generation enables the CMSMD to represent the shape of an object, and object reconstruction is possible without losing any details, provided that the descriptor size is appropriate. This feature facilitates the accommodation of any type of large or small contours within a compact storage size because only the relevant details are stored. The disadvantage of structural descriptors is alleviated here by dynamic generation based on the irregularity of the border characteristics. An algorithm is also proposed to find the convexities and concavities of contours using the CMSMD, which requires only very simple calculations with linear computational complexities.

The proposed combined structural and global descriptor consists of a dynamically generated circular mesh framework for shape description. The circular mesh embeds the contours of the object having different shapes with a minimum number of unfilled cells, which reduces memory wastage. The circular mesh is represented by a polar coordinate system comprising track and sector values, which facilitates effective border labelling. The cells possessing equal areas in the circular mesh are labelled using circular mesh-based cell labelling (CCL), and the object borders are embedded in the mesh and labelled using circular mesh-based border labelling (CBL), which conveys pertinent information about their shapes and margins. Through CBL, new properties can be identified, and new features can be derived. In addition, statistical and structural formulae, convexity, and concavity of borders can be derived via CBL.

The circular mesh creation and labelling procedures are thus automated for shape description and feature extraction. The proposed circular mesh can be applied to detect the malignancy of the suspected cancerous regions of the breast in dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI), as shape is an important characteristic in malignancy detection. By embedding the suspected border-extracted regions from images on the CMSMD and labelling the borders using CBL, new features can be derived. This technique also enables the concave and convex regions in the contours in breast images to be distinguished through simple steps and facilitates the identification of contours as lobular or spicular, which is a crucial step in malignancy detection. The irregularity detection measures of many existing techniques fail, or they require very complex procedures for convexity or concavity calculations. In the proposed method, after feature extraction, feature selection is conducted using the ReliefF algorithm and Ranker's algorithm. Finally, lesion malignancy classification is performed using a multilayer neural network perceptron. The CMSMD provides 94.69% malignancy identification accuracy, thus outperforming the existing shape descriptors. Furthermore, it involves simple techniques that include several features of the existing global and structural descriptors. A new feature extraction technique, including convexity and concavity detection, was also developed using the CMSMD.

Section 2 presents a brief literature review of the existing shape descriptors. Section 3 describes breast DCE-MRI and the characteristics of malignant regions. Section 4 presents the proposed CMSMD and the convexity and concavity detection algorithm. Section 5 presents and analyses the experimental results obtained. Section 6 provides concluding remarks.

2. Literature review

Numerous shape description techniques have been developed in the past five decades [2,3]. Chain codes, polygons, B-splines, invariants, Fourier descriptors, wavelet descriptors, scale spaces, geometric moments, grid methods, shape matrices, convex hulls, media axes, and cores have all been employed for shape representation and description [2,3]. Features such as shape signatures, signature histograms, shape invariants, moments, curvature, shape contexts, shape matrices, and spectral features are derived from these descriptors [2,3]. Some popular and recent works related to shape description are reviewed in this section.

In the early 1990s, Flusser [4] developed a square model matrix and Taza [5] developed polar model matrix descriptors using an $M \times N$ matrix to represent the shape of a region. These descriptors are good in terms of translation, rotation, scale invariance, and occlusion resistance, but they are ineffective for affine transforms, in the presence of noise, and for non-rigid deformations. The computational complexity of the square model is average, whereas that of the polar model is low.

Triangle area representation (TAR) [6], projective invariant contexts [7], learned pooling function [8], height function [9], and bag of contour fragment [10] are contour-based descriptors and deal with local, global, or both local and global contour details. Hasegawa et al. [11] proposed a shape descriptor combining a random transform, amplitude extraction, and log-mapping. This descriptor is rotation, scale, and translation invariant, and its efficiency has been confirmed using different kinds of datasets.

The use of integral invariants can be viewed as a structural approach as they represent shapes in terms of boundary primitives. An advantage of such a structural invariant approach is the ability to handle occlusions and the possibility of partial shape matching. These approaches are of considerable importance in medical imaging. More recently, shape classification using line segment statistics [12], bending invariants [13], and skeletonisation [14–15] of shapes have been applied successfully for shape description and retrieval, taking advantage of the information inside shapes. Janan used eccentricity for shape description and matching because of the undistorted shape representation that it provides [16].

Several studies have been conducted on the detection of concave and convex regions in images. Most of the techniques employed in these studies involved complicated calculations and procedures. In curvature scale space, the optimal parameter is required for each scale, and this method is not effective for convex shapes [17]. TAR presents a measure of the convexity or concavity of each contour point using the signed areas of triangles formed by boundary points at different scales and is effective for representing both local and global shape characteristics [6]. Schmidtmann