COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 96 (2009) 193–204

ELSEVIER

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Object density-based image segmentation and its applications in biomedical image analysis

*Jinhua Yu, Jinglu Tan**

Department of Biological Engineering, 215 Agricultural Engineering Building, University of Missouri, Columbia, MO 65211, USA

ARTICLE INFO

Article history:
Received 15 December 2008
Received in revised form
16 April 2009
Accepted 23 April 2009

Keywords:
Object density-based image segmentation
Medical images
Mathematical morphology
Marker estimation
Marker-controlled watershed
Fractal dimension
Active contour without edges

ABSTRACT

In many applications of medical image analysis, the density of an object is the most important feature for isolating an area of interest (image segmentation). In this research, an object density-based image segmentation methodology is developed, which incorporates intensity-based, edge-based and texture-based segmentation techniques. The proposed method consists of three main stages: preprocessing, object segmentation and final segmentation. Image enhancement, noise reduction and layer-of-interest extraction are several subtasks of preprocessing. Object segmentation utilizes a marker-controlled watershed technique to identify each object of interest (OI) from the background. A marker estimation method is proposed to minimize over-segmentation resulting from the watershed algorithm. Object segmentation provides an accurate density estimation of OI which is used to guide the subsequent segmentation steps. The final stage converts the distribution of OI into textural energy by using fractal dimension analysis. An energy-driven active contour procedure is designed to delineate the area with desired object density. Experimental results show that the proposed method is 98% accurate in segmenting synthetic images. Segmentation of microscopic images and ultrasound images shows the potential utility of the proposed method in different applications of medical image processing.

1. Introduction

Image segmentation is a procedure that partitions an image into disjointing groups with each group sharing similar properties such as intensity, color, boundary and texture. In general, three main image features are used to guide image segmentation, which are intensity or color, edge, and texture. In other words, image segmentation methods generally fall into three main categories: intensity-based (or color-based), edge-based, and texture-based segmentations.

Intensity-based segmentation assumes that an image is composed of several objects with constant intensity. This kind of methods usually depends on intensity similarity comparisons to separate different objects. Histogram thresholding [1,2], clustering [3,4], and split-and-merge [5,6] are typical examples of intensity-based segmentation methods. Edge-based segmentation has a strong relationship with intensity-based segmentation, since edges usually indicate discontinuities in image intensity. Edge-based segmentation uses different methods to approximate the salient edges in images. Then, the boundaries of objects are detected by edge grouping or edge-driven active contour construction. Widely used methods in edge-based segmentation include Canny [7], watershed [8] and snake [9,10]. Texture is another important characteristic used to segment objects from background. Most texture-based segmentation algorithms map an image into a texture feature space, then statistical classification methods [11] are usually used to segment different texture features.

* *Corresponding author*. Tel.: +1 573 882 2369; fax: +1 573 884 5650.
E-mail address: TanJ@missouri.edu (J. Tan).
0169-2607/$ – see front matter
doi:10.1016/j.cmpb.2009.04.013

Co-occurrence matrix [12], directional gray-level energy [13], Gabor filters [14], and fractal dimension [15,16] are frequently used methods to obtain texture features.

Besides intensity, color, contour, and texture; object density is another attribute humans use to partition a scene. For some applications, object density is the most important feature to differentiate regions. For instance, in pathological tissue images, the most obvious characteristic for separating the red and the white pulps is the density of lymphocyte nuclei. Conventionally, pathological diagnosis relies on accurate separation of different cells [17]. In ultrasound images, estimation of the ovarian volume and the density of follicles in that volume are the key features to diagnose polycystic ovary syndrome, which is one of the commonest endocrine disorders in women of reproductive age [18,19]. While many methods have been proposed for image segmentation, very few efforts have been devoted to object density-based image segmentation.

This paper presents a hybrid method for image segmentation based on the density of objects. Intuitively, density and texture bear an inextricable relationship with each other. The arrangement of objects and their relationships to the surrounding environment can be characterized by texture energy. When a region has a looser object distribution, the texture energy will be lower because of the slower alternation of patterns. When the number of objects increases within the region, the texture energy will increase because of the faster alternation of patterns. However, outlining regions with a specific density of object of interest (OI) cannot be achieved by using texture information only. First of all, OIs are usually mixed with other extraneous objects which may have similar properties, such as texture and shape, to those of the OIs. In order to focus on the OIs, they should be extracted from the background accurately. Second, the differences in OI density may be small and texture features may not be sufficient to discriminate regions of different densities. The method developed in this work uses intensity, edge and texture information to segment images based on object density. The algorithm consists of three parts: image preprocessing, object segmentation and final segmentation. Tests with synthesized and two types of real biomedical images show the effectiveness of the method.

The rest of the paper is organized as follows. Section 2 gives an overview of the methodology. Detailed descriptions about each stage of the method are then presented. The performance of the method is demonstrated and evaluated in Section 3. Section 4 concludes the paper.

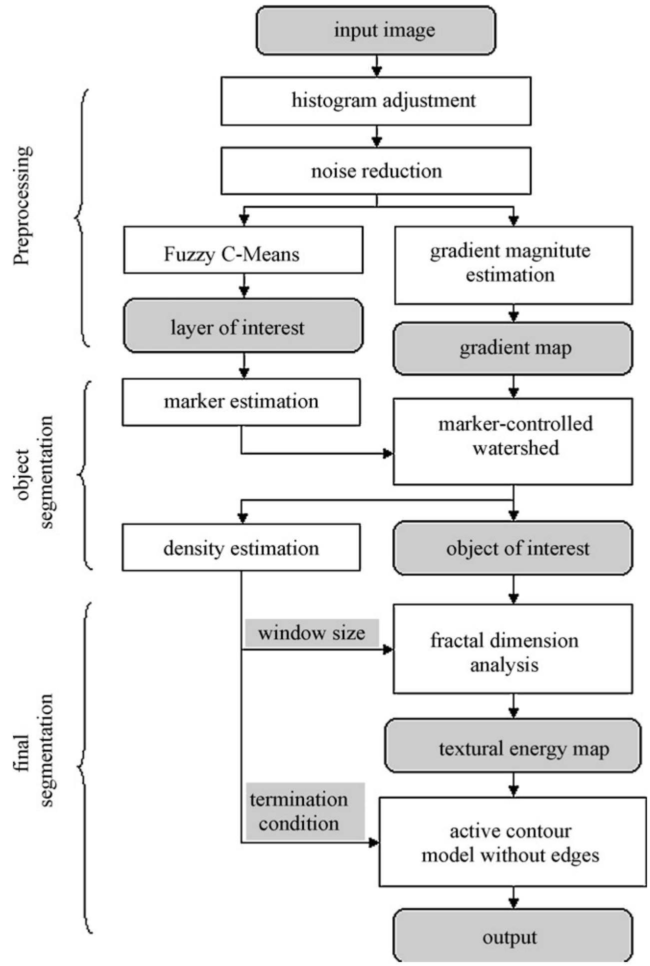

Fig. 1 – Flowchart of the proposed segmentation system.

2. Object density-based image segmentation

2.1. *Overview of algorithm*

Fig. 1 gives the flowchart of the segmentation algorithm proposed in this paper. The algorithm first uses histogram adjustment and morphological operations to enhance an image, reduce noise and detect edges. Then fuzzy C-means clustering is utilized to extract the layer of interest (LOI) from the image. Following preprocessing, conditional morphological erosion is used to mark individual objects. The marker-controlled watershed technique is subsequently employed to identify individual objects from the background. The main tasks of this stage are marker extraction and density estimation. The segmented objects are the starting point for the final stage, which then characterizes the object distribution as texture energy. A texture energy-driven active contour algorithm is designed to outline the regions of desired object density. During the final stage, two important parameters are determined by the result of object segmentation, which are the window size for fractal dimension computation and the termination condition for the active contour algorithm.

2.2. *Image preprocessing*

The preprocessing stage consists of several subtasks including image enhancement, noise reduction, gradient magnitude estimation and preliminary LOI extraction. For convenience of description, a microscopic tissue image is used to illustrate the procedure. Fig. 2 shows an image of rat spleen tissue. The tissue section was stained with haematoxylin and eosin (H&E) for visual differentiation of cellular components. Under a microscope, nuclei are usually dark blue, red blood cells orange/red, and muscle fibers deep pink/red. The density of the lymphocytes is a key feature to differentiate red and white