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Segmentation of blurred objects by classification of isolabel contours

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ABSTRACT

Segmentation of objects with blurred boundaries is an important and challenging problem, especially in the field of medical image analysis. A new approach to segmentation of homogeneous blurred objects in grayscale images is described in this paper. The proposed algorithm is based on building of an isolabel-contour map of the image and classification of closed isolabel contours by the SVM. Each closed isolabel contour is described by the feature vector that can include intensity-based features of the image area enclosed by the contour, as well as geometrical features of the contour shape. The image labeling procedure for construction of the training base becomes very fast and convenient because it is reduced to clicking on isolabel contours delineating the objects of interest on the isolabel-contour map. The proposed algorithm was applied to the problem of brain lesion segmentation in MRI and demonstrated performance figures above 98% on real data, both in sensitivity and in specificity.

1. Introduction

Automatic identification of objects with blurred boundaries in the images is one of challenging problems in the area of pattern recognition. In the case of grayscale images, typical in medical image analysis applications, the problem becomes even more complicated. Moreover, medical images are the most common example of images with blurred objects due to imperfections of imaging devices, partial volume effect and non-handmade nature of imaged objects. An example is shown in Fig. 1.

Although many image segmentation approaches are based on the estimation of the object's edges as the regions of abrupt change of gradient, there are a plenty of methods for which this information is not primary. The simplest of such algorithms uses intensity thresholding [1]. This approach can be applied when the prior intensity distribution of the object of interest is known and it differs from the intensity distributions of other objects and background. However, in most cases the object's intensity distribution overlaps with those of other objects in the image. For the same reason other approaches that use only pixel intensity information, such as clustering, also have a limited scope of application [3] or need further post-processing steps [2]. Segmentation of objects based on fuzzy connectedness principles was introduced in [4] and was used for medical image segmentation in several works [5,6]. The idea of the method is to estimate the measure of connectivity between image pixels using their relative intensity and spatial relation, and select groups of pixels whose connectivity is higher than a specified threshold. Although the algorithm benefits from taking into account not only intensity but also spatial information, it still has some practical limitations such as high computational complexity and the requirement of selection of object seeds.

All the mentioned methods have some common limitations. Firstly, it is difficult to find appropriate thresholds and other parameters. Secondly, these methods work with separate pixels, and so they cannot take into account valuable prior information like object global characteristics, intensity or shape.

More sophisticated methods utilize a priori knowledge by introducing geometric models [7] that can be deformable [8]. In the past decades active shape models [9] and active appearance models [10] have been widely used for segmentation of objects that belong to a certain class of shapes and have a particular appearance. Active shape models adapted for the three-dimensional case are called active volume models [11]. Both active shape and appearance models require careful initialization and the final segmentation result crucially depends on it. Although there are some works describing attempts to find a good initial approximation of the object [12,13], it is still a challenging problem.

Some methods aimed directly at segmentation of blurred objects have been developed. One fundamental work in this direction is [14]. The method is based on active contour model but is also suitable for segmentation of objects with uncertain boundaries. Rather than detecting the object edges according to the image gradient, it tries to estimate the object boundary by minimizing the intensity variance inside and outside the object. The main assumption is that the object, except for its boundaries, is mostly homogeneous. Although

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0031-3203/

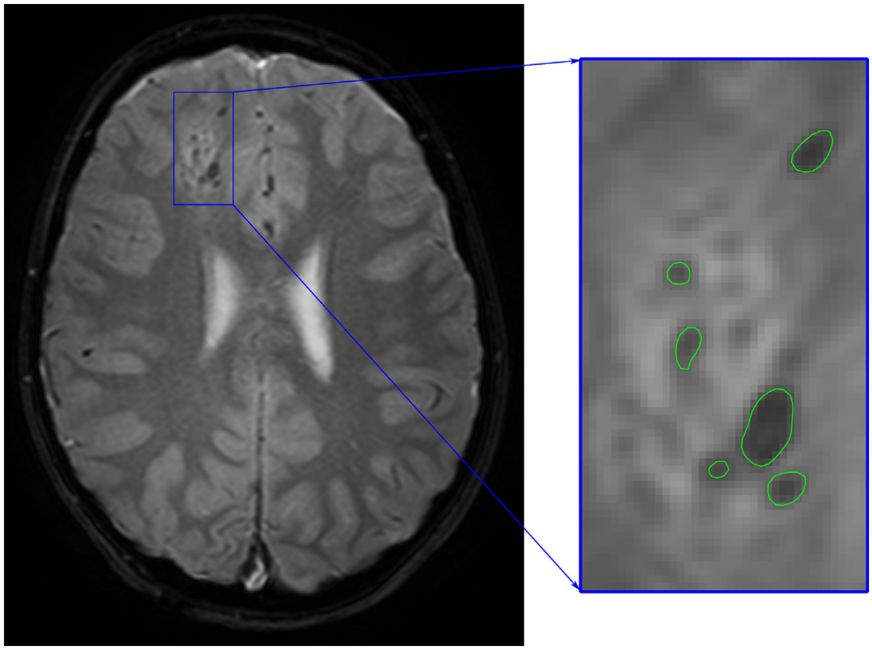

Fig. 1. Magnetic resonance imaging slice of the human brain with diffuse axonal injury lesions.

introduction of region-based active contour methods is an important step towards segmentation of blurred objects, the author of [15] states that these methods tend to achieve mathematical optimization instead of finding a solution preferable for a human. The method proposed in [15] tries to estimate the object boundary which is closest to the one indicated by a human. In order to achieve this, a statistical description of the object boundary is built using the training base of blurred objects with manually delineated boundaries. This statistical model is based on a distance from the maximum gradient point to the curve along the normal direction to the curve. An evolution of the level set function is employed in order to snap the initial estimation of the object boundary to the real boundary. In [16] the authors use wavelet transform for detection of three types of singularities: transitions, peaks and lines. The search is performed in three different scales.

The algorithm proposed in this paper is suitable for segmentation of mostly homogeneous objects with blurred boundaries. It aims to incorporate maximum a priori knowledge about the objects into the segmentation process by including intensity- and shape-based features used by a human during the visual analysis. At the same time the method does not require the initial estimation. It is based on the machine learning, but in contrast with existing algorithms that use classification of pixels, segments or clusters, the proposed algorithm is based on the classification of isolabel contours. Isolabel contours can accurately describe the boundaries of blurred homogeneous objects. Training on the manually labeled database allows for automatic incorporation of human preference into the process of boundary detection. The labeling procedure itself becomes very simple because it is reduced to specifying necessary isolabel contours on the isolabel-contour map.

The main parameters of the algorithm are the intensity range and the step size for building of the isolabel-contour map. These parameters can be easily tuned. The application of the proposed algorithm to the problem of segmentation of the diffuse axonal injury (DAI) lesions in T2*-weighted magnetic resonance images (MRI) of the human brain is demonstrated.

The rest of the paper is organized as follows. Section 2 describes the proposed algorithm for segmentation of blurred objects. The experimental results and the discussion are provided in Section 3. The conclusions are drawn in Section 4.

2. Segmentation of the objects of interest

The proposed algorithm for segmentation of blurred objects consists of three steps: building of an isolabel-contour map of the image, selection of closed isolabel contours from this map and classification of these closed isolabel contours into two classes: “object” and “background”.

2.1. Isolabel-contour map

Isolabel contours were first used for image segmentation in [17]. The notion of isolabel contours is derived from topography. An isolabel contour in the image is an analogue of an isoelevation contour on a topographic map. The pixel intensity plays the role of the elevation. Without loss of generality, let us assume that our goal is segmentation of blurred homogeneous objects whose intensity is *lower* than average. If we consider all the pixels in the image whose intensity is lower or equal than a threshold T, they will form several sets of connected pixels. The pixels that lie on the boundaries of these sets form isolabel contours. Isolabel contours corresponding to the set of successive thresholds $T_1 < T_2 < \cdots < T_n$ form an isolabel-contour map. Isolabel contours possess an enclosure relation. Isolabel contours for threshold T_i enclose isolabel contours for threshold T_{i-1} because the set of pixels with intensity $I \le T_i$ encompasses the set of pixels with intensity $I \le T_{i-1}$. So one object in the image whose intensity is mostly homogeneous inside but gradually changes near its boundaries will be marked by several isolabel contours, one inside another. It can be seen in Fig. 2 that they can describe well the boundaries of blurred objects with varying degrees of object coverage.

In order to reduce the computation time and increase the robustness of the segmentation algorithm the user may specify one or more rectangular regions of interest (ROIs) in the image that surely contain the objects under consideration. In this case an