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● *Original Contribution*

CELL-BASED TWO-REGION COMPETITION ALGORITHM WITH A MAP FRAMEWORK FOR BOUNDARY DELINEATION OF A SERIES OF 2D ULTRASOUND IMAGES

JIE-ZHI CHENG,* CHUNG-MING CHEN,* YI-HONG CHOU,† CURTIS S. K. CHEN,‡
CHUI-MEI TIU,† and KUEI-WU CHEN*

*Institute of Biomedical Engineering, National Taiwan University, Taipei, Taiwan; †Department of Radiology, Taipei Veterans General Hospital and National Yang Ming University, Taipei, Taiwan; and ‡Division of Oral Radiology, Dept. of Oral Medicine, School of Dentistry, University of Washington, Seattle, WA

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Abstract—To ensure the delineated boundaries of a series of 2-D images closely following the visually perceivable edges with high boundary coherence between consecutive slices, a cell-based two-region competition algorithm based on a maximum *a posteriori* (MAP) framework is proposed. It deforms the region boundary in a cell-by-cell fashion through a cell-based two-region competition process. The cell-based deformation is guided by a cell-based MAP framework with a posterior function characterizing the distribution of the cell means in each region, the salience and shape complexity of the region boundary and the boundary coherence of the consecutive slices. The proposed algorithm has been validated using 10 series of breast sonograms, including seven compression series and three freehand series. The compression series contains two carcinoma and five fibroadenoma cases and the freehand series contains two carcinoma and one fibroadenoma cases. The results show that >70% of the derived boundaries fall within the span of the manually delineated boundaries. The robustness of the proposed algorithm to the variation of regions-of-interest is confirmed by the Friedman tests and the *p*-values of which are 0.517 and 0.352 for the compression and freehand series groups, respectively. The Pearson's correlations between the lesion sizes derived by the proposed algorithm and those defined by the average manually delineated boundaries are all higher than 0.990. The overlapping and difference ratios between the derived boundaries and the average manually delineated boundaries are mostly higher than 0.90 and lower than 0.13, respectively. For both series groups, all assessments conclude that the boundaries derived by the proposed algorithm be comparable to those delineated manually. Moreover, it is shown that the proposed algorithm is superior to the Chan and Vese level set method based on the paired-sample t-tests on the performance indices at a 5% significance level. (E-mail: chung@ntu.edu.tw) © 2007 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Boundary delineation, Image series, Maximum *a posteriori*, Cell-based deformation, Two-region competition, EM algorithm.**

INTRODUCTION

Segmentation of objects of interest in a series of 2-D images is an essential process for various quantitative ultrasound image analyses. By identifying the object boundaries in a series of 2-D sonograms, higher-level information may be derived and integrated to characterize the functional properties of the objects (Noble and Boukerroui 2006). Typical examples are using 3-D volume and surface irregularity to characterize the malignancy of a breast lesion (Chen et al. 2003), quantitative analyses based on boundary information of vessel walls and lumens in a series of intravascular ultrasound images (Lee et al. 1995; Nissen et al. 2001) and characterizing the contour deformation for the same 2-D object as a function of time, *e.g.*, deforming contours of the cardiac structures in 2D + T frames (Mulet-Parada and Noble 2000; Ye and Nobel 2002; Papademetris et al. 2002) or other physical variables, *e.g.*, lesion deformation caused by probe compression (Moon et al. 2005).

Boundary delineation in a sonogram, however, is generally a hard task. Manual demarcation may be the first solution but it suffers at least two deficiencies. The contours drawn by two experts, or by the same expert at different times, may diverge substantially. Moreover, for

Address correspondence to: Chung-Ming Chen, Institute of Biomedical Engineering, College of Medicine, National Taiwan University, #1, Sec. 1, Jen-Ai Road, Taipei, Taiwan. E-mail: chung@ntu.edu.tw

a series of 2-D images, the manually delineated boundaries in consecutive slices may vary abruptly, leading to the problem of interframe boundary discontinuity.

To avoid these potential deficiencies of manual delineation, many segmentation algorithms have been proposed previously to identify the object boundaries in a 2-D series. Most of these algorithms may be classified into three categories, namely knowledge-based, model-based and general approaches. The knowledge-based approaches incorporate the intrinsic shape properties of the object of interest as the prior knowledge, *e.g.*, the shapes of cardiac structures (Ye and Noble 2002; Dydenko et al. 2006). Because of the prior knowledge incorporated, these approaches are usually application specific.

The model-based approaches find the 2-D boundaries based on the mathematical shape models describing the common characteristics of the objects of interest or on the shape models constructed from the training data. Some notable approaches are modeling prostate shapes as deformable superellipses (Gong et al. 2004) and representing the object boundaries as a linear combination of the mean shape and a set of eigenshapes (Bosch et al. 2002; Xie et al. 2005). Because the model-based approaches assume implicitly that the object shapes do not vary significantly, they may not be applicable to capture irregular object boundaries.

The general approaches do not incorporate the shape information into the segmentation algorithms. Some of these approaches use the boundary obtained in the previous slice as a prior or a constraining template for the current slice. For examples, Hass et al. (2000) and Martin-Fernandez et al. (2005) use 1-D and 2-D Markov random fields (MRFs) to regularize the shape and control the smoothness of the contour points. Some other approaches utilize the correlated image properties, *e.g.*, optical flow estimates (Mikic et al. 1998), between adjacent slices to ensure the boundary continuity in the 2-D series. Although the general approaches can potentially be applied to different types of objects of interest, they are less robust to the noise compared with the other two categories.

All three categories of approaches are basically pixel-based approaches. That is, the search process for the desired contour is realized in a pixel-by-pixel fashion. A common problem shared by these type of approaches is that the derived boundary points may not locate on the visually perceivable edges. To capture the irregular 2-D boundaries in a series of 2-D images and to ensure that the derived boundary points are on visually perceivable edges, a novel cell-based two-region competition algorithm based on a MAP framework, called C2RC-MAP algorithm, is proposed in this study. The basic idea of the C2RC-MAP algorithm is to perform two-region competition in a cell-based fashion slice-by-slice while using the contour of the previous slice as the reference to ensure the contour coherence between adjacent slices. The optimization process is guarded by a MAP framework. The posterior is maximized by an expectation-maximization (EM) algorithm (Dempster et al. 1977).

The unique feature of the C2RC-MAP algorithm lies in its cell-based notion. Although using the contour obtained in the previous slice as a reference is a common practice for segmenting a series of 2-D slices, cell-based deformation assures that the derived boundary points locate on the visually perceivable edges. Moreover, to have a high-quality cell-based deformation, a new cell-based MAP framework is formulated to integrate contour information from the previous slice and cell-based boundary information in the current slice.

MATERIALS AND METHODS

The proposed C2RC-MAP algorithm has been designed with two essential ideas, namely, cell-based two-region competition and cell-based MAP framework. For a series of 2-D images, the C2RC-MAP algorithm begins with any slice for which the object boundary is available. Suppose the object boundary of slice i_0, called *initial slice*, is first delineated by any effective segmentation algorithm for ultrasound images. Assuming the region-of-interest (ROI) selected for the initial slice applicable to the entire series, all other slices will be processed either forward or backward consecutively from the initial slice. For the k^{th} slice ($k \neq i_0$), the ROI is first decomposed into a set of homogeneous areas, each called a cell, using the two-pass watershed transformation scheme used in Chen et al. (2005). The object of interest in the ROI is assumed to be constituted by one or multiple cells and the object boundary is a composition of cell boundaries. The object boundary derived from the previous slice is used as the *reference contour* to partition the cells in the k^{th} slice into bipartite regions, namely initial object-region (OR) and background-region (BR). The contour separating both initial object- and background-regions serves as the initial regional contour for the search of the desired boundary.

Starting from the initial regional contour, the object boundary of the current slice is sought by iteratively deforming the object- and background-regions based on the cell-based two-region competition mechanism. In each iteration, the object- and background-regions compete the cells along the boundary in-between both regions, called *regional contour*. Constrained by the reference contour, the cell-based two-region competition is guided by a cell-based MAP framework maximized by an EM algorithm iteratively. As the iterative process converges, the final regional contour defines the object