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● *Original Contribution*

CELL-COMPETITION ALGORITHM: A NEW SEGMENTATION ALGORITHM FOR MULTIPLE OBJECTS WITH IRREGULAR BOUNDARIES IN ULTRASOUND IMAGES

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Abstract—Segmentation of multiple objects with irregular contours and surrounding sporadic spots is a common practice in ultrasound image analysis. A new region-based approach, called cell-competition algorithm, is proposed for simultaneous segmentation of multiple objects in a sonogram. The algorithm is composed of two essential ideas. One is simultaneous cell-based deformation of regions and the other is cell competition. The cells are generated by two-pass watershed transformations. The cell-competition algorithm has been validated with 13 synthetic images of different contrast-to-noise ratios and 71 breast sonograms. Three assessments have been carried out and the results show that the boundaries derived by the cell-competition algorithm are reasonably comparable to those delineated manually. Moreover, the cell-competition algorithm is robust to the variation of regions-of-interest and a range of thresholds required for the second-pass watershed transformation. The proposed algorithm is also shown to be superior to the region-competition algorithm for both types of images. (E-mail: chung@ntu.edu.tw)   © 2005 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Segmentation, Multiple objects, Ultrasound images, Breast lesions, Region competition, Cell competition, Watershed transform.**

INTRODUCTION

Ranging from volume measurement and tissue characterization to dynamics analysis, boundary information plays versatile roles in quantitative and qualitative ultrasound (US) image analyses. For instance, the shape, spiculation and anfractuosity of lesion boundary serve as crucial descriptors for breast lesion malignancy (Chou et al. 2001; CM Chen et al. 2003). Accurate prostate boundaries are critical information for prostate brachytherapy (Zimmern and Leach 1995), including gland volume study, pubic arch interference determination, dosimetry planning and postoperative dosimetric evaluation (Pathak et al. 2000). The wall thickness and size of ovarian follicles are useful indicators for characterization of follicles (Krivanek and Sonka 1998). Luminal and medial-adventitial borders are the basis for volumetric assessment of coronary plaques in intravascular US images (Klingensmith and Vince 2002). Deformation dynamics of cardiac structure contours are valuable attributes for diagnosing cardiac diseases (Chalana et al. 1996; Mikic et al. 1998).

To facilitate quantitative and qualitative US image analyses, numerous automatic or semiautomatic boundary detection approaches have been proposed for various clinical applications. Some distinguished approaches are parametric deformable models (Chalana et al. 1996; Mikic et al. 1998; DR Chen et al. 2003), level set methods (Corsi et al. 2002; Chang et al. 2005), edge-linking methods (Wolf et al. 2002; Ye et al. 2002; Klingensmith and Vince 2002), model-based methods (Bosch et al. 2002; Shen et al. 2003), region-based methods (Potocnik et al. 2002; Drukker et al. 2002), classification (Dokur and Olmez 2002; Kotropoulos and Pitas 2003) and thresholding (Zimmer et al. 1996). Generally speaking, these approaches usually perform well if the object of interest has a reasonably well-defined boundary and homogeneous interior or exterior, at least in the

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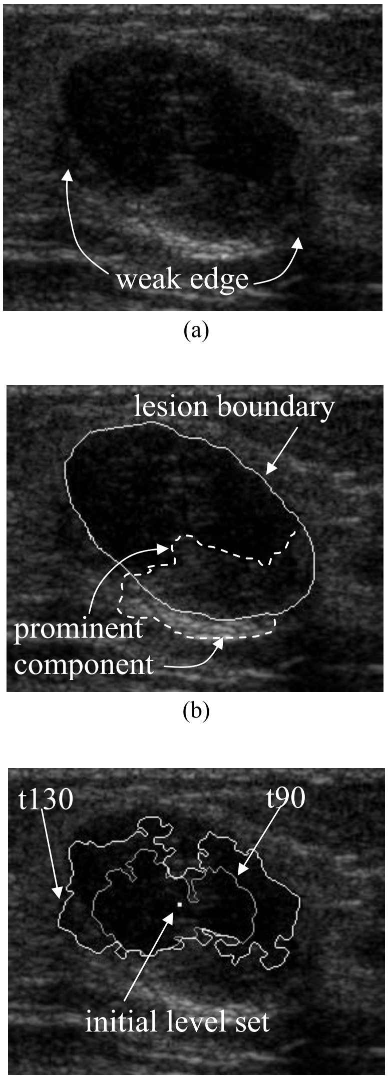
vicinity of the boundary. For some clinical applications (*e.g.*, segmentation of sonographic prostates), the shape of the object of interest does not vary with each individual dramatically. In this case, by taking advantage of the statistics of the shapes, some model-based approaches (*e.g.*, the active appearance motion model) (Bosch et al. 2002) may still achieve good results, even if the boundary is corrupted by speckles and artifacts.

Regardless of the promising performances repeatedly reported by previous approaches, boundary detection on a sonogram, however, remains as a hard task and is far from being practical for clinical uses in general. The difficulty may be mainly accredited to the notoriously complex nature of an US image constituted by speckle, tissue-related textures and artifacts. These three classes of ingredients further form several undesirable sonographic features commonly observed in an US image, such as irregular textural patterns, nonuniform mean grey-level distributions, heterogeneous boundary conditions, weak or missing edges and multiple prominent components for objects of interest. A "prominent component" is a contiguous region that has a visually perceivable boundary enclosing a largely homogeneous area, which might be a noise, an artifact, a substructure of a tissue or a part of object of interest. As an example, Fig. 1a shows a clip of breast sonogram with a benign lesion, the boundary of which is manually delineated with the solid white curve in Fig. 1b. The irregular textural patterns, nonuniform mean grey-level distributions and heterogeneous boundary conditions are clearly observable in Fig. 1a. Moreover, weak edges may be found in the bottom right and middle left portions of the lesion boundary, as indicated in Fig. 1a, and a portion of lesion boundary is connected to two prominent components, which are demarcated by dashed white curve in Fig. 1b.

Given that the object shapes may vary with individuals in general clinical applications, these sonographic features form different types of obstacles for different classes of previous approaches. For example, determination of the optimal threshold for thresholding is usually difficult because of the heterogeneous textural patterns and grey-level distributions. Derivation of effective classification rules or functions is hardly successful caused by the heterogeneous boundary conditions and the spatially variant image property. The parametric deformable models are easily trapped or blocked by the false edges of the prominent components, unless the initial contours are close to the desired boundaries.

For the level-set methods starting with a single level set and the region-growing approaches with a single seed, prominent components and weak edges cause opposite effects in curve and region deformations, respectively. Unlike the parametric deformable models, both classes of approaches are capable of getting around the potential hindrance imposed by the isolated prominent components. However, both of them may be blocked by a prominent component that is adhered to the desired boundary. As time passes by, although the zero level set may go across the border of the blocking prominent component because of the nonzero deformation speed, it may leak from the weak edges of the object boundary in the meanwhile. This phenomenon is illustrated in Fig. 1c, in which two snapshots of the level-set evolution plus the initial level set are illustrated. The two snapshots are zero-level sets captured at time steps 90 and 130, which



(a) (b) (c)

Fig. 1. (a) Breast lesion with weak edges commonly found in a breast sonogram; (b) the boundary of the lesion manually delineated, surrounded by two prominent components; (c) the zero-level sets captured at time steps (grey contour) 90 and (white contour) 130.