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Purely edge-based prostate segmentation in 3D TRUS images using deformable models

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We propose to address the difficult task of segmenting prostate volumes from 3D transrectal ultrasound images with deformable models. We use a modified radial bas-relief approach to obtain smooth prostate edges that we feed to a classical edge-based active surface. The method achieves accurate segmentation, suggesting that edges, often deemed unusable in TRUS, convey useful information.

1 Introduction

Low dose rate brachytherapy is a common treatment for prostate cancer that aims at delivering radiation directly within the gland by permanently inserting grain-sized radioactive seeds through the perineum. The procedure is supervised under transrectal ultrasound (TRUS) guidance. The dosimetric protocol requires a delineation of the whole prostate volume prior to the insertion of the radioactive seeds. Due to the low quality of TRUS images (speckle noise, weak or invisible prostate edges, low contrast, presence of shadow artifacts...), accurate manual delineation is a long and tedious task subject to both inter- and intra-observer variability. There is therefore a need for computer assisted automatic or semi-automatic segmentation. Based on existing literature there is currently a clear lack of such 3D segmentation algorithms for use with TRUS images [1].

An effective prostate edge detection technique is the radial bas-relief method (RBR) [2]. RBR takes advantage of the fact that the prostate is mostly a hypoechoic region at the center of the field of view surrounded by more echoic tissues. A rough binary edge map of the prostate can therefore be obtained by computing the difference image between the original TRUS image and its enlarged, negated version. However, raw RBR edge maps contain many spurious or missing edges (Fig. 1b),

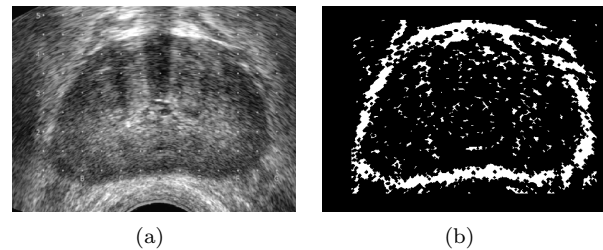


Figure 1: Prostate edge detection using the RBR method. (a) TRUS image (b) RBR edge map

and are therefore not directly useable in an edge-based segmentation framework.

In this paper, we propose a semi-automatic method for 3D prostate segmentation using edge-based deformable models. The originality of our approach lies in a new edge term derived from RBR information. Prostate edges are obtained by regularizing RBR maps with the help of Vector Field Convolution (VFC, [3]), exploiting the property of VFC to converge towards the medial axis of objects [4]. More specifically, we compute the divergence of the RBR-based VFC field, producing cleaner edge maps that allow the model to better converge towards the true edges of the gland. We validate our method on clinical images manually delineated by an expert radiation oncologist.

2 Methodology

2.1 Vector Convergence Map detector

Starting from a 3D RBR edge map \mathcal{R} [2] (Fig. 1b), we reduce the amount of spurious edges by filtering its axial slices with a 2D median filter, obtaining a 3D map

\mathcal{R}^{MF} (Fig. 2a). We then compute a 3D VFC external force field \mathcal{F} by convolving \mathcal{R}^{MF} with a *vector field kernel* \mathcal{K}^0 , a vector kernel oriented towards its center with decreasing magnitude [3]:

$$\mathcal{F} = \mathcal{R}^{\text{MF}} * \mathcal{K}^0, \quad (1)$$

producing a smooth vector field oriented in the directions of the medial axes of \mathcal{R}^{MF} [4]. An example VFC field is shown in Fig. 2b. We define a scalar *Vector Convergence Map* (VCM) edge map \mathcal{V} from the divergence of the vector field \mathcal{F} :

$$\mathcal{V} = -\nabla \cdot \mathcal{F}. \quad (2)$$

We then set regions where $\mathcal{V} < 0$ to 0 and rescale VCM values between 0 and 1 in all slices, obtaining a clean edge map where most spurious edges are removed and missing edges are filled thanks to the ability of VFC fields to preserve visually connected boundaries (Fig. 2c).

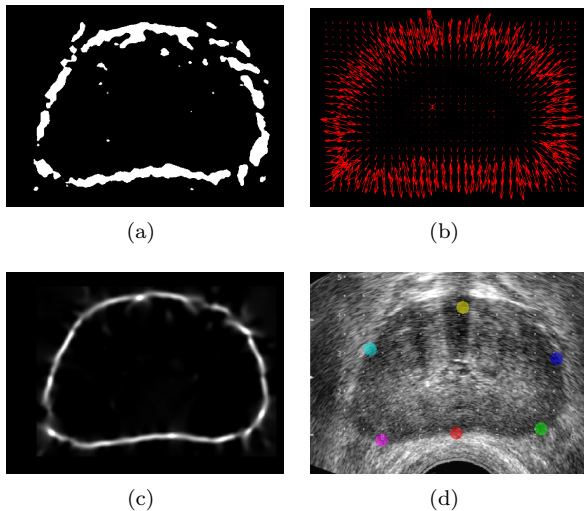


Figure 2: (a) RBR edge map, median filtered (b) RBR-based VFC field (c) proposed VCM edge map (d) initial mid-gland landmark points for model initialization

2.2 Deformable model

Using the proposed VCM edge map, we compute an external force field \mathbf{F} by convolving a Vector Field Kernel \mathcal{K} with \mathcal{V} . For initialization, we manually define 8 landmark points on the TRUS image : 6 in the mid-gland image (Fig. 2d), 1 at the base and 1 at the apex. A prostate triangulated surface template model S^0 is then placed at the landmark barycenter and warped to the image landmarks via thin plate spline warping [5]. The surface is finally evolved until convergence according to the following Euler-Lagrange evolution equation [6]:

$$S_t = \alpha \Delta S - \beta \Delta^2 S + \kappa \mathbf{F}, \quad (3)$$

where, Δ is the surface Laplacian, parameters α and β control the tension and rigidity of the model, and κ controls the external force strength.

3 Results

We validated our approach on a set of 10 TRUS images acquired at the Brest University Hospital, France. Our segmentation results were compared to ground truth provided by expert manual delineations using the Dice similarity criterion (DSC) and the volumetric error (V_{err}) [1]. Parameters were optimized so as to maximize the mean DSC in the dataset and were set equally for all images. For one image, average processing time excluding landmark positioning was less than 15 seconds.

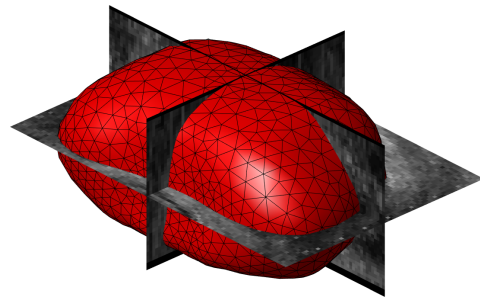


Figure 3: Example 3D segmentation result

Figure 3 shows a typical result obtained by the proposed deformable model, suggesting a meaningful segmentation. Table 1 summarizes the DSC scores obtained for our dataset. Due to poorer edge identification around basal and apical regions, DSC scores are smaller than the DSC^{20} corresponding to the 20 slices closer to the mid-gland shown in table 1. Volumetric errors in these slices (V_{err}^{20}) are also shown. The results obtained are comparable with state of the art approaches [1].

Table 1: Quantitative clinical segmentation results

| DSC | DSC^{20} | V_{err}^{20} |
|-----------------|-------------------|-----------------------|
| 0.89 ± 0.02 | 0.93 ± 0.02 | $6.64\% \pm 1.62$ |

4 Conclusion

We have proposed a purely edge-based deformable model for TRUS prostate volume segmentation based on a Vector Convergence Map that allows for better localisation of the prostate edges. Results are comparable to state of the art in the central slice and suggest that TRUS edges convey useful information, which is often neglected in the prostate segmentation literature.

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