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Segmentation of urinary bladder in CT urography*

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Abstract— **We are developing a Conjoint Level set Analysis and Segmentation System (CLASS) for bladder segmentation on CTU, which is a critical component for computer aided diagnosis of bladder cancer. A challenge for bladder segmentation is the presence of regions without contrast (NC) and filled with IV contrast (C). According to the characteristics of the bladder in CTU, CLASS is designed to perform number tasks such as preprocessing, initial segmentation, 3D and 2D level set segmentation and post-processing. CLASS segments separately the NC and the C regions of the bladder. In the post-processing stage the final contour is obtained based on the union of the NC and C contours. 70 bladders were segmented. Of the 70 bladders 31 contained lesions, 24 contained wall thickening, and 15 were normal. The performance of CLASS was assessed by rating the quality of the contours on a 5-point scale (1= "very poor", 3= "fair", 5 = "excellent"). The average quality ratings for the 12 completely no contrast (NC) and 5 completely contrast-filled (C) bladder contours were 3.3±1.0 and 3.4±0.5, respectively. The average quality ratings for the 53 NC and 53 C regions of the 53 partially contrast-filled bladders were 4.0±0.7 and 4.0±1.0, respectively. Quality ratings of 4 or above were given for 87% (46/53) NC and 77% (41/53) C regions. Only 4% (2/53) NC and 9% (5/53) C regions had ratings under 3. After combining the NC and C contours for each of the 70 bladders, 66% (46/70) had quality ratings of 4 or above. Only 6% (4/70) had ratings under 3. The average quality rating was 3.8±0.7. The results demonstrate the potential of CLASS for automated segmentation of the bladder.**

I. Introduction

Bladder cancer is a common type of cancer that can cause substantial morbidity and mortality among both men and women. Bladder cancer causes 14,880 deaths per year in the United States [1]. Early detection of bladder cancers is very important. The survival rate for patients whose cancers were detected and treated early is high [1]. Early diagnosis and treatment of these lesions can improve the morbidity, mortality and their attendant costs compared to diagnosis at a later, more symptomatic stage that might involve deep invasion and/or metastasis. However, only 75% of cancers are detected in early localized stage.

Multi-detector row CT (MDCT) urography is a very promising new imaging modality for evaluation of urothelial neoplasms [2-5]. It offers the advantage of providing essentially complete imaging of the urinary tract and of the remainder of the abdomen and pelvis in a single study. Patients with suspected or known urinary tract neoplasms are often imaged with intravenous pyelogram (IVP), ultrasound, abdominal CT, and even MR. With MDCT urography, the need for other imaging studies are substantially reduced. CT urography (CTU), therefore, may spare the patient the considerable effort of undergoing a potentially large number of alternative imaging studies and also reduce health care costs.

Preliminary studies [6] have suggested that CTU may have superior sensitivity in detecting urinary tract lesions compared with all available alternative imaging studies. Recent research has demonstrated that CTU can detect urothelial neoplasms that are very small (measuring as small as 2-3 mm in maximal diameter). It has also been reported that CT urography could detect bladder lesions that were missed by cystoscopy, a procedure which has been traditionally considered to be the "gold-standard" for non-surgical diagnosis of bladder abnormalities.

However, there are a number of technical difficulties related to CTU. Each CT scan for urinary tract produces, on average, about 300 slices at a slice interval of 1.25 mm with a range of 200 to 600 slices. Interpretation of a CTU study demands extensive reading time from a radiologist who has to visually track the upper and lower urinary tracts and look for abnormal lesions usually small in size. The interpreting radiologists frequently need to adjust window settings and use zooming on a display workstation to improve visualization. The possibility of multiple lesions demands the radiologist's attention throughout the urinary tract. In addition, reported results in the literature [7, 8] show that substantial interobserver variability exists among the radiologists in detection of bladder cancer on MDCTU (sensitivity varied in a range of 59%-92%).

Many different findings may also be present in any individual CT urogram. The interpreting radiologist must spend extensive time and effort identifying these findings, and then must also determine how likely each of them represents a urothelial neoplasm. Any technique which would assist the radiologist in identifying areas of the urinary tract that may contain urothelial neoplasms would be useful.

With the increase in radiologists' workload, the chance for oversight of subtle lesions may not be negligible. Computer-aided detection (CAD) will likely play an important role in the reading of CTU. We are developing a CAD system for detection of bladder cancer in CTU. A critical component of such CAD system is the accurate segmentation of the bladder from the surrounding anatomical structures. The purpose of this study is to develop a computerized system for bladder segmentation on CTU exams.

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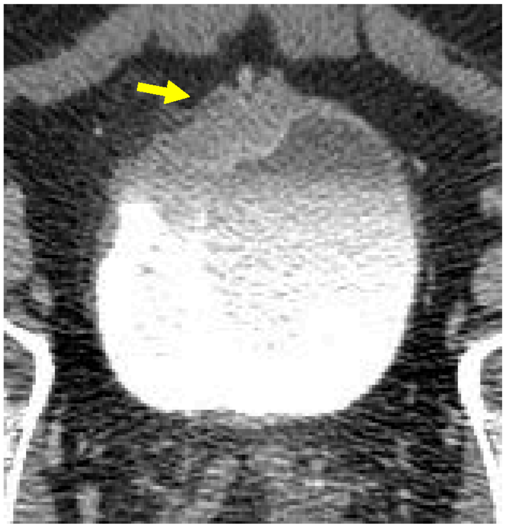

Figure 1. ROI containing a bladder partially filled with IV contrast material on an MDCT urography image. A malignant lesion is identified in the non-contrast part of the bladder (yellow arrow).

II. MATERIALS AND METHODS

A region of interest (ROI) on a CTU slice containing the bladder is shown in Fig. 1. The bladder is partially filled with IV contrast material. A lesion is present within the non-opacified upper part of the bladder.

A. Bladder segmentation using CLASS

A challenge for bladder segmentation is the presence of two distinct areas that have very different intensities: an area filled with IV contrast and an area without contrast (Fig. 1).

We are developing a new segmentation package, specifically designed based on the characteristics of bladder in CTU images. The package is referred to as the Conjoint Level set Analysis and Segmentation System (CLASS). CLASS consists of four stages: (1) preprocessing and initial segmentation, (2) 3D level set segmentation, (3) 2D level set segmentation, and (4) post-processing. The block diagram of CLASS is presented in Fig. 2.

In stage 1, preprocessing techniques are applied to the predefined volume of interest (VOI) (Fig. 2) in the original 3D volume to obtain a set of smoothed images and a set of gradient images. An edge image is obtained based on smoothing, anisotropic diffusion, gradient filters and the rank transform of the gradient magnitude. Then the number of pixels in the image for consideration are selected based on attenuation, gradient, and location [9], which results in a subset S of voxels that are relatively close to the center of the lesion and belong to smooth (low gradient) areas. S is used as a statistical sample of the full population of voxels in the object of interest. The mean μ and standard deviation σ of the voxel values from the smoothed image within S are computed. The object contour $\tilde{C}$ is obtained after thresholding and includes the set of all pixels falling within 3.0 standard deviations of the mean of the pixel values in the mask S and with values above -400 HU. A morphological dilation filter, 3D flood fill algorithm, and morphological erosion filter are applied to $\tilde{C}$ to connect neighboring components and extract an initial segmentation surface C.

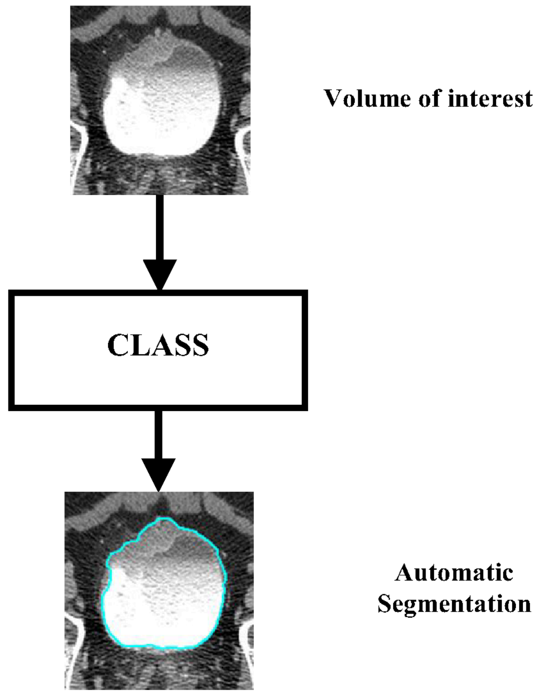

Figure 2. Conjoint Level set Analysis and Segmentation System (CLASS). Segmentation is performed in a 3D volume of interest. One slice is shown for illustration.

In stage 2, the initial segmentation surface C is propagated using a 3D level set method [9]. Three level sets with predefined sets of parameters are applied in series to the initial contour C in 3D. The first level set slightly expands and smoothens the initial contour. The second level set pulls the contour towards the sharp edges, but at the same time it expands slightly in regions of low gradient. The third level set further draws the contour towards sharp edges.

In stage 3, in order to correct the 3D contours at the top and the bottom of the object, a 2D level set is applied to every slice of the segmented object from the stage 2. The 2D level sets is allowed to propagate locally for a small number of time steps in order to maintain a degree of inter-slice cohesion.

In stage 4, an additional processing of the obtained contours is performed to combine the C and NC parts of the object contour to obtain the final contour.

In this study, CLASS used as input an approximate bounding box for the bladder. The bounding box was split into 2 boxes in case the bladder was partially filled with contrast material. One box was enclosing the non-contrast (NC) region of the bladder and the other was enclosing the contrast-filled (C) region of the bladder (Fig. 1). The NC and the C regions of the bladder were segmented separately in CLASS (Fig. 3 and 4, respectively). The final contour was obtained in the post-processing CLASS stage 4 by the union of the NC and C contours (Fig 5).

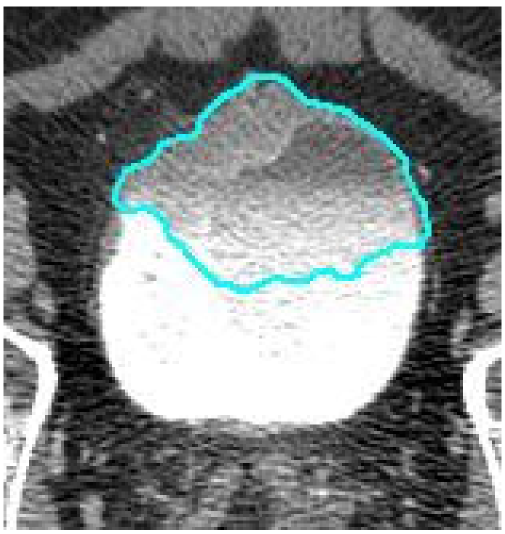

Figure 3. Bladder segmentation based on CLASS: Segmentation of the non-contrast (NC) part (blue contour) of the bladder in Fig. 1.

B. Data set

In this study, the cases were collected retrospectively from the Abdominal Imaging Division of the Department of Radiology at the University of Michigan with approval of the Institutional Review Board. A data set of 70 patients with biopsy proven bladder lesions was used. Of the 70 bladders, 31 bladders contained lesions (28 malignant and 3 benign), 24 bladders had wall thickening (19 malignant and 5 benign) and 15 were normal. Five bladders were completely filled with contrast material, 12 had no visible contrast material and 53 bladders were partially filled with contrast material. The bladder conspicuity was medium to high.

GE Healthcare LightSpeed MDCT scanners were used to acquire the MDCT urography scans. The images were acquired at an image interval and slice thickness of 1.25 mm using 120 kVp and 120–280 mA. The images were enhanced with IV contrast material administered at a rate of 3 mL/sec.

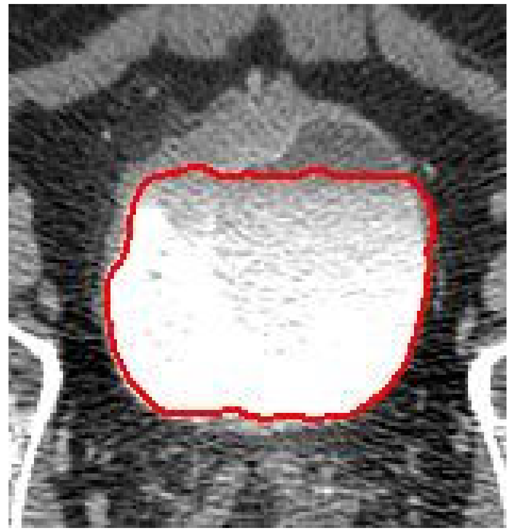

Figure 4. Bladder segmentation based on CLASS: Segmentation of the contrast (C) part (red contour) of the bladder in Fig. 1.

C. Evaluation methods

The performance of CLASS was assessed by rating the quality of the contours on a scale from 1 to 5 (1= “very poor”, 2= “poor”, 3= “fair”, 4= “good”, 5 = “excellent or perfect”). The scale represented the closeness of the segmentation to the visual bladder boundaries in 3D.

Figure 5. Bladder segmentation based on CLASS: Entire bladder segmentation (blue contour) based on union of the NC contour (Fig. 3) and C contour (Fig. 4). The bladder without the segmented contour is shown in Fig.1.

III. RESULTS

An example of the CLASS segmentation of a bladder is shown in Fig. 3 to Fig.5. For the 53 bladders partially filled with contrast material, the average quality rating for the 53 NC and 53 C contours was 4.0±0.7 and 4.0±1.0, respectively. For 87% (46/53) NC and 77% (41/53) C contours were given quality ratings of 4 or above, which is relatively large portion. Only 4% (2/53) NC and 9% (5/53) C were given a rating under 3 ("fair"). The average quality ratings for the 5 bladders completely filled with contrast (C) or 12 completely no contrast (NC) were 3.4±0.5 and 3.3±1.0, respectively. Only 3 NC contours were given a rating of 2. After combining the NC and C contours for each of the 70 bladders, 66% (46/70) had quality ratings of 4 or above (Fig. 6). Only 6% (4/70) had a rating under 3. The average quality rating was 3.8±0.7.

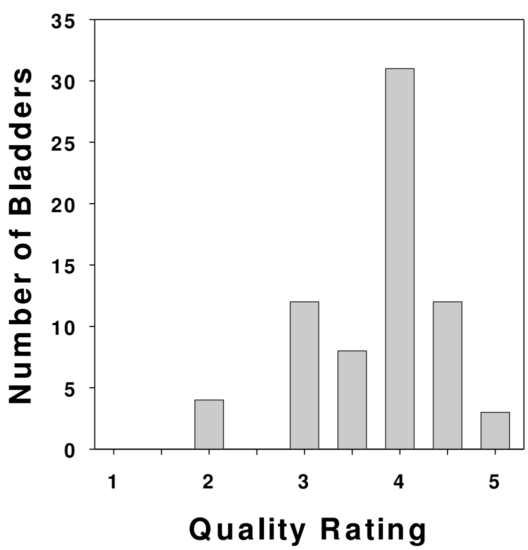

Figure 6. Histogram for the quality ratings of the automatically segmented contours for all 70 bladders. The summary quality ratings for the 53 bladders with NC and C parts are obtained by averaging the quality ratings for the NC and C parts. This resulted in ratings of 3.5 and 4.5. For example for a given bladder with NC contour rating of 5 and C contour rating of 4 the summary rating is 4.5.

IV. CONCLUSION

The preliminary results reported above demonstrate the feasibility of the segmentation system CLASS to segment the bladders on CTU scans. CLASS performs segmentation of the contrast and non-contrast filled regions of the bladder separately to overcome the large difference in the CT intensities of the two regions. It uses a combination of 3D and 2D Level Set to achieve initial segmentation and refinement. In a future study radiologists' manual segmentation of the bladders will be used as reference standard for quantitative evaluation of the segmentation accuracy of CLASS. Further study is underway to improve and evaluate the segmentation performance with a larger data set. This study is the first step towards the development of a reliable and efficient system for segmentation of bladders and detection of lesions in CT urography.

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