Semi-automatic 3D Segmentation Tool for CT Data in DICOM Format Using MATLAB Lab work For Medical Image Analysis Master Computer Vision (CVR) Universite De Bourgogne

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1 Summary:

A GUI based application for segmenting prostrate and its regions from CT (Computed Tomography) was developed in this lab work, using MATLAB. The application expects CT slices encapsulated as DICOM files and allows the user to view several DICOM headers, anonymize the DICOM files in bulk by removing information in 2 tags, PatientName and PatientBirthDate, and convert DICOM images to JPEG as well as allowing conversion the other way.

The key feature is a semi-automatic segmentation system whereby the user can annotate the boundaries of a region of prostrate in one slice and the application propagates this annotation into specified preceding as well as proceeding slices and constructs a 3D isosurface representation, along with computing cross-sectional area and volume information. It is also possible to assign tags to annotations and save them.

2 Introduction:

3D information about internal organs, such as the prostrate, is often desirable through use of non-invasive techniques. This information can be used for planning a radiation therapy to selectively irradiate an organ [2], for planning minimally invasive surgeries (MIS), as well as designing custom implants and graspable 3D models of internal organs [1].

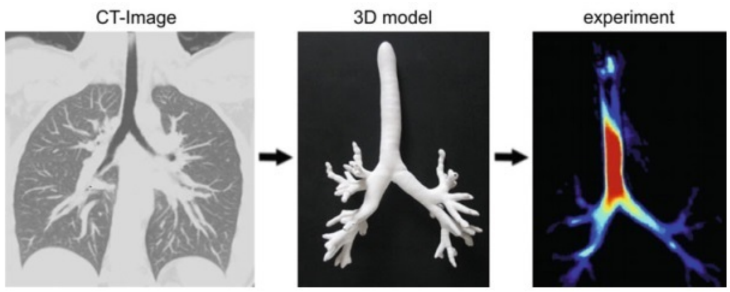


Fig. 3 Rapid prototyping can be used in medical research for creating 3D models of living organs. In this work, a CT image data set of the bronchial tree was processed for rapid prototyping. A 3D model of the human trachea and bronchial tree was produced. The model was then used as a flow phantom for gas flow experiments with hyperpolarised helium (3He) MRI to study the flow pattern through trachea and bronchial tree

From [1] : Rengier, Fabian, et al. "3D printing based on imaging data: review of medical applications." International journal of computer assisted radiology and surgery 5.4 (2010): 335-341.

Non-invasive imaging techniques such as CT and ultrasound acquire information corresponding to planes (or slices) in a body. To build volumetric (3D) representation of an organ of interest from such data, it is necessary to first segment the organ's cross-section in each slice, and second to construct a 3D representation from the segmentations. With gainful advances in reduction of slice thickness of CT, we now have HRCT (High Resolution

CT). This advance, however, requires segmentation of region of interest in a greater number of slices.

The volume reconstruction can be manual, whereby a trained personnel draws annotates on each slice the cross section of the organ of interest and a software creates 3D representation from these annotations, or it can be semi-automatic whereby the user provides some information for some slices like a seed-point, or automatic. [3]

The application presented here is a semi-automatic, and hence the 3D segmentation is interactive; the user is required to draw an annotation as a closed-shape delineating the cross-section of the organ of interest in a CT slice. The user can then specify the index of slices centered around the annotated slice that are to be used to construct a 3D representation of the organ by 'propagating' the provided annotation 'forward' and 'backward'.

3 Method:

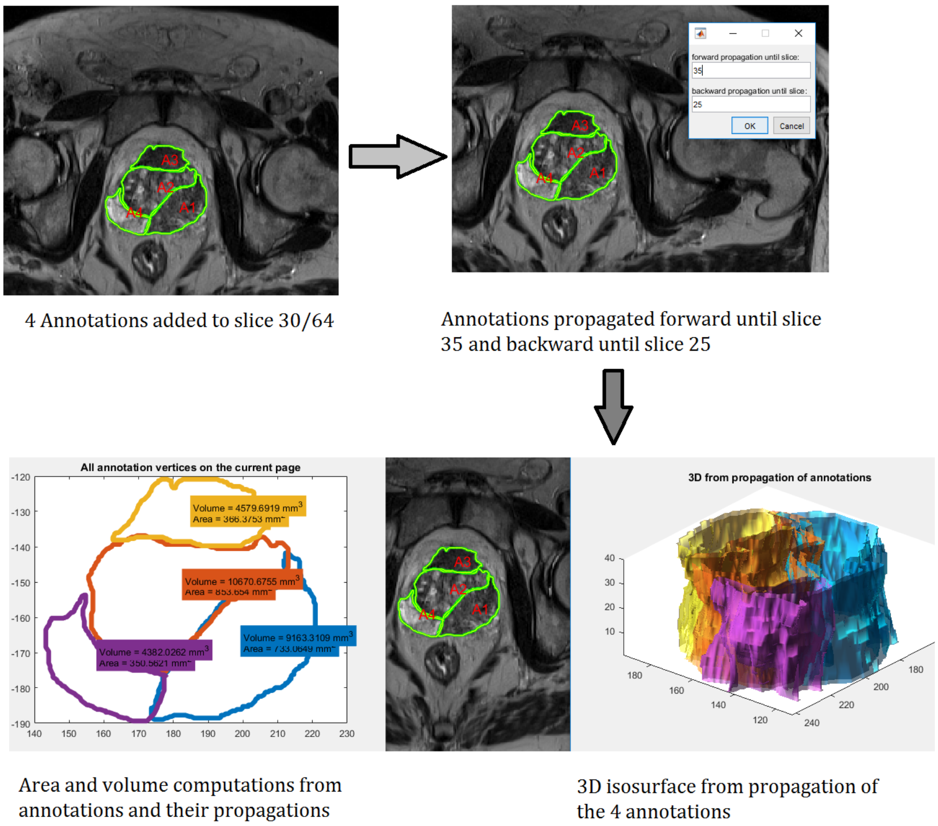


Figure 1: Steps in creating 3D isosurface from annotations on one CT slice using the presented application.

The user first uses the application to locate the CT slice on which the cross-sections of the volumes of interest are most clearly visible. The user then draws the annotation tool to draw a closed contour around each cross-section.

The user then asks the application to propagate the annotated contours on the current CT slice forward and backward until the slices s/he specifies upon which the application produces two figures, one containing the area and volume information associated with each contour, and the other containing the 3D isosurface representation obtained from propagating the current annotations.

3.1 Propagation of Annotations:

Every annotation on a CT slice S_n is represented as a set of (locations) ordered pairs, $\{(u_i, v_i)\}$. The propagation step is to find in neighbouring slices S_{n+1} (forward) and S_{n-1} (backward) the corresponding (locations) ordered pairs $\{(x_i, y_i)\}$.

In propagating the annotations forward, every (x_i, y_i) is first initialized as equal to (u_i, v_i). A search is then made in the region Ω^i_{n+1} of S_{n+1} in a neighbourhood centered around $(x_i, y_i) = (u_i, v_i)$; $\Omega^i_{n+1} = \{(x_k, y_k) : u_i - m/2 \leq x_k \leq u_i + m/2, v_i - m/2 \leq y_k \leq v_i + m/2\}$, and for every searched location (x_k, y_k), a distance measure is calculated:

$$d_k = \sum_{p=-m/2}^{m/2} \sum_{q=-m/2}^{m/2} (I^n(u_i + p, v_i + q) - I^{n+1}(x_k + p, y_k + q))^2$$

This is the sum of squares distance between the image intensities in square patch of width m centered at (u_i, v_i) in slice n, S_n, and (x_k, y_k) in slice $n + 1$, S_{n+1}. (x_i, y_i) is finally taken as that (x_k, y_k) which minimizes the distance measure, d_k. Propagated vertices in slice S_{n+1} are then used for propagating annotations to slice S_{n+2}, and so on.

The annotations are similarly propagated backwards.

Note: Refer Figure 2.

3.2 Creation of 3D volume:

The volume implied by the annotation of a cross-section in a slice is rendered as an isosurface whereby vertices of the annotation and those of its propagations define locations in 3D at which the isosurface assumes a certain (same) value [4]. In doing this, each slice is arbitrarily given a height (z coordinate). We note that this provides a representation that is not up to scale.

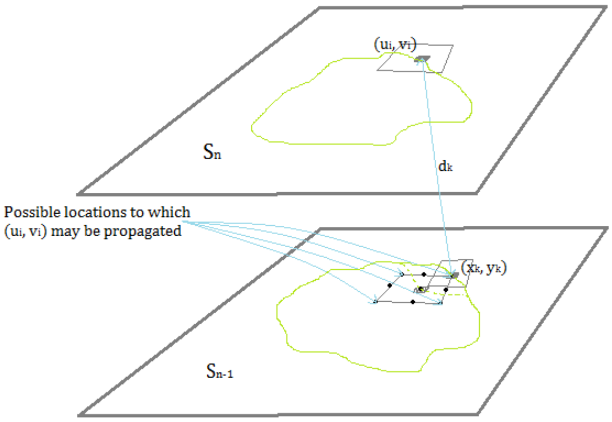


Figure 2: Backward propagation of vertex (u_i, v_i) to location (x_k, y_k), since it returns smallest distance d_k.

Obtaining a Smooth Isosurface: For obtaining a smooth contour in each slice, the propagated annotations $\{(x_i, y_i)\}$ are interpolated. The interpolation is done several times to obtain a good density of contour vertices.

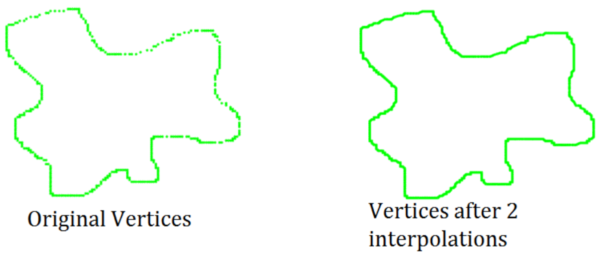


Figure 3: Gaps between vertices obtained from user's annotations are filled using interpolation.

Filling Holes: When isosurface representations were built using vertices after interpolation, surfaces with many holes were obtained. This is because interpolation was not enough in many cases to generate sufficient points between vertices that were far apart. Problems also arose due to slender local corners in contours. To address these problems, gaussian smoothing was applied to vertices in each slice.

Each slice was first created as a binary image with an 'isovalue at vertex locations and zeros elsewhere. A 3x3 gaussian filter with $\sigma = 0.5$ was then applied to this image and those locations which did not contain zeros upon filtering were assigned 'isovalue'. The results are illustrated below.

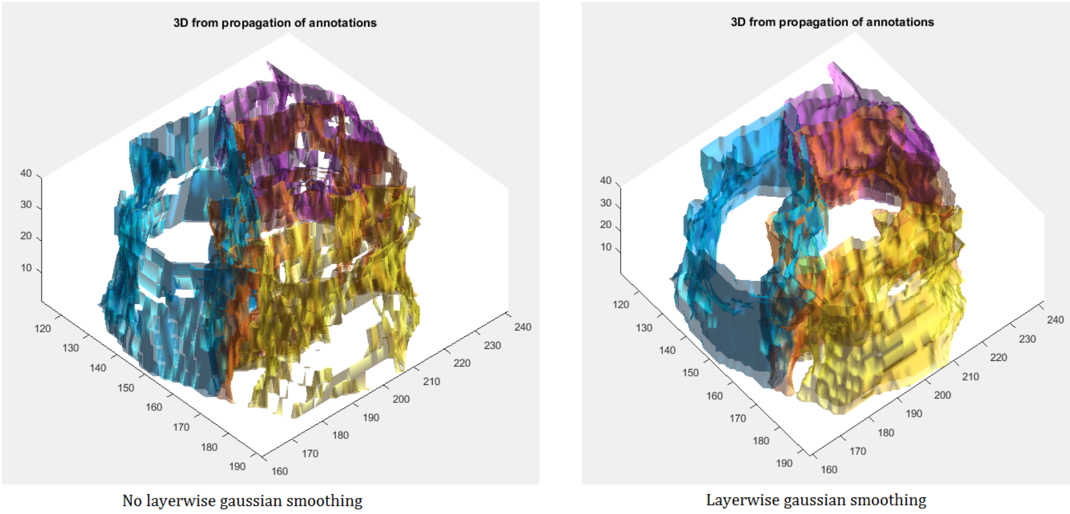


Figure 4: Isosurface created without and with layerwise Gaussian Smoothing. Smoothing helped to fill holes in the surface.

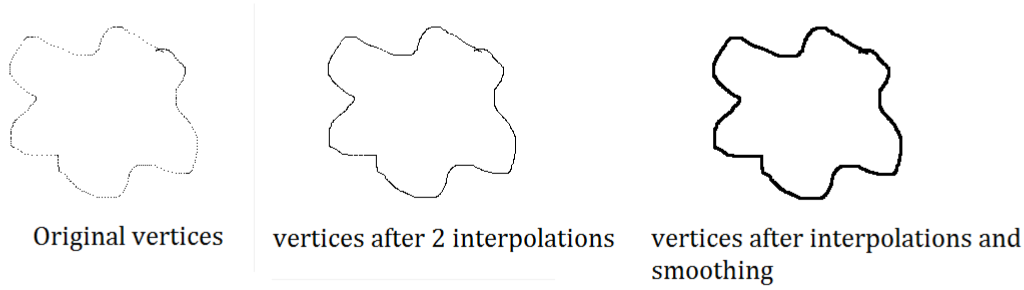


Figure 5: Effect of layerwise smoothing. Vertex locations become more dense.

Area and Volume: In order to calculate the area of the annotated cross-section, the area of the polygon defined by the annotation vertices is calculated using MATLAB's built-in function *polyarea*[5], and the resulting area is multiplied by the square of value in **PixelSpacing** in the corresponding DICOM header.

If N slices are being used for creating the 3D reconstruction, the volume is computed as the cross section area of the annotation multiplied with N times the value of **SliceThickness** field in the DICOM header.

4 Results:

The annotations of different regions of the prostrate were made on slice 30. The annotations were propagated forward until slice 35 and backward until slice 25.

The annotation for the whole prostrate was made on slice 31. It was then propagated forward until slice 38 and backward until slice 25. When 3D was created from the same annotation using slices 25 to 35, the volume of prostrate was calculated to be 29000 mm^3. This is within the normal range of volume for a healthy prostrate while the former is not. The application thus provides different estimates of volume when reconstruction is done from different number of slices. This must hence be chosen carefully.

5 Conclusions:

It is possible to extract 3D representation of internal organs from CT. However, since the data corresponds to cross-sections of the body, the volumetric representation has to be computed.

The computed representation may or may not be accurate. High accuracy can be obtained if the organ of interest is manually segmented (delineated) in each slice. However, when contouring is manually performed only in one slice and the annotated contour propagated automatically to the other slices, the reconstruction's accuracy depends on method of propagation as well as the quality of the 'seed' manual annotation.

In order to compute cross-sectional area and volumes of internal organs, the information present in DICOM headers, specially the tags PixelSpacing and SliceThickness, are very useful. CT images stored in the DICOM format are hence more valuable than those that are not.

6 References:

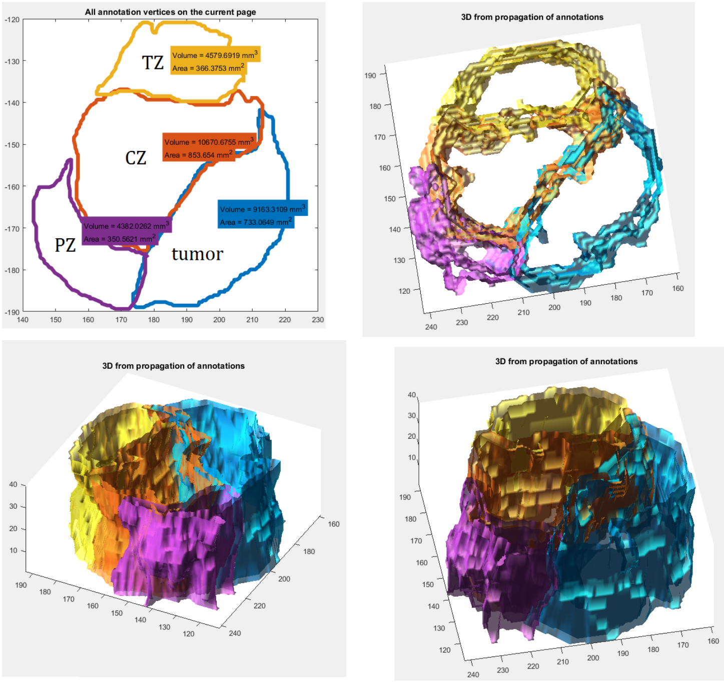
[1] Rengier, Fabian, et al. "3D printing based on imaging data: review of medical applications." International journal of computer assisted radiology and surgery 5.4 (2010): 335-341.

[2] MacManus, Michael, et al. "Use of PET and PET/CT for radiation therapy planning: IAEA expert report 2006–2007." Radiotherapy and oncology 91.1 (2009): 85-94.

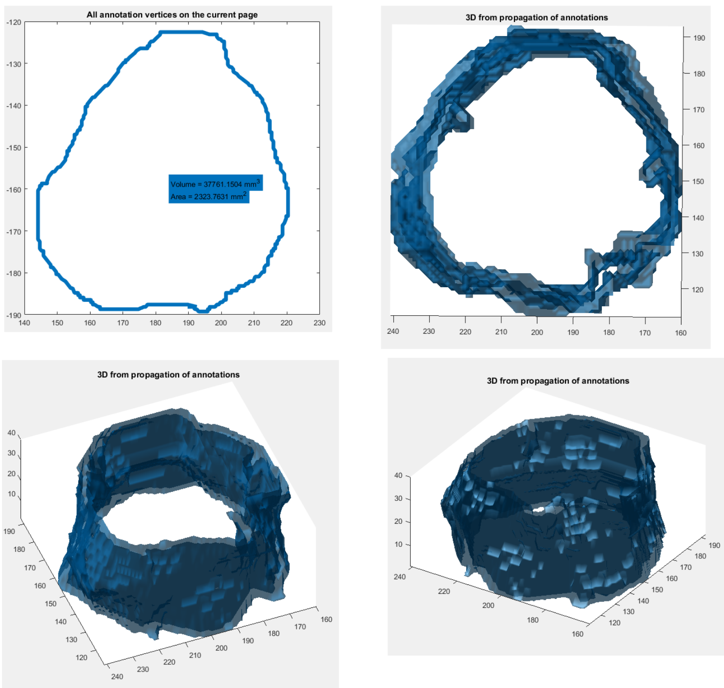
[3] Ma, Zhen, et al. "A review of algorithms for medical image segmentation and their applications to the female pelvic cavity." Computer Methods in Biomechanics and Biomedical Engineering 13.2 (2010): 235-246.

[4] Wikipedia contributors. "Isosurface." Wikipedia, The Free Encyclopedia. Wikipedia, The Free Encyclopedia, 20 Feb. 2017. Web. 8 May. 2017.

[5] MATLAB :: *polyarea*
https://fr.mathworks.com/help/matlab/ref/polyarea.html



(a) Different regions of the prostrate, tumor is the blue region



(b) The prostrate

Figure 6: (a) Area and volume of different regions of the prostrate and the tumor therein. Tz = Transition Zone, PZ = Peripheral Zone, CZ = Central zone. (b) The whole prostrate