

Review of the Software Used for 3D Volumetric Reconstruction of the Liver

P. Strakos, M. Jaros, T. Karasek, T. Kozubek, P. Vavra, T. Jonszta

Abstract—In medical imaging, segmentation of different areas of human body like bones, organs, tissues, etc. is an important issue. Image segmentation allows isolating the object of interest for further processing that can lead for example to 3D model reconstruction of whole organs. Difficulty of this procedure varies from trivial for bones to quite difficult for organs like liver. The liver is being considered as one of the most difficult human body organ to segment. It is mainly for its complexity, shape versatility and proximity of other organs and tissues. Due to this facts usually substantial user effort has to be applied to obtain satisfactory results of the image segmentation. Process of image segmentation then deteriorates from automatic or semi-automatic to fairly manual one. In this paper, overview of selected available software applications that can handle semi-automatic image segmentation with further 3D volume reconstruction of human liver is presented. The applications are being evaluated based on the segmentation results of several consecutive DICOM images covering the abdominal area of the human body.

Keywords—Image segmentation, semi-automatic, software, 3D volumetric reconstruction.

I. INTRODUCTION

IN medicine, digital image processing and analysis has its important place and it is extensively used especially in diagnostic medicine, where different imaging techniques are available. In this area of medicine, techniques like computed tomography (CT), magnetic resonance imaging (MRI) or positron emission tomography (PET) is very often used. Each of this technique brings enormous amount of data to process and offers wide source of information about the particular patient. Interpretation of the information and possibility of the post-processing of the obtained information can be very often of a low level. Usually the data are raw and for example to post-process them to serve surgical needs it can be time consuming. Using advanced techniques of image segmentation and volumetric model reconstruction of human organs can be highly beneficial. Such techniques could shorten the time between diagnosing a patient with a disease and planning a surgical intervention. Even more important fact here is that with the advanced techniques of image segmentation and model reconstruction risks of the planned operation can be minimized.

Great interest in the image segmentation and modelling of

the liver and its vessel system was observed recently. The reasons are obvious, since liver is one of the vital organs, any kind of disease affecting the liver can be fatal. The liver is also very complex and shape varying organ and thus very difficult to segment. Successful automatic segmentation of the liver is therefore a high challenge. Review of available methods for automatic liver segmentation can be found in [1], while the survey of methods for automatic and semi-automatic liver segmentation from CT images is written in [2].

In this paper attention is focused on already available software solutions directly intended for the image segmentation of the liver with the further 3D model reconstruction. More general software for image segmentation and 3D model reconstruction are considered as well. All of the selected software solutions are distributed either as an open-source or as a free to use for research purposes. Majority of the selected software uses widely known and popular image processing libraries ITK [3] and VTK [4]. In the paper, comparison of the considered software applications is made but the main importance of the paper is to show and describe the state-of-art of today's available solutions for segmentation and 3D modelling of the liver.

The paper is organized in the following manner: in the next section introduction of considered software solutions is made, while details of each selected software application are provided in its particular subsection. In the section to follow, evaluation method is described. Next section describes the selected data for segmentation. The following section brings the results and the last section comes with the conclusions.

II. SELECTION OF AVAILABLE SOFTWARE SOLUTIONS

For selection of the available software only open-source or free software solutions have been considered. All the software applications should either be specialized to image segmentation and model reconstruction of the liver or offer the image segmentation techniques with further model reconstruction in their general functionality. Based on these prerequisites five applications have been selected:

- A. Itk-Snap,
- B. GeoS,
- C. Lisa,
- D. 3D Slicer,
- E. Osirix.

A. Itk-Snap

Itk-Snap [5] is a software application used to segment structures in 3D medical images. It provides semi-automatic segmentation using active contour methods, as well as manual

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delineation and image navigation. In addition to these core functions, SNAP provides a number of supporting utilities.

Itk-Snap is free software, provided under the General Public License [6]. Its binaries are provided free of charge for academic or commercial use.

As already mentioned Itk-Snap uses semi-automatic segmentation method based on active contour [7], which uses the level set method. The object of interest which is going to be segmented is first pre-processed and then covered by an active contour of a ball shape in initialization phase. This contour then evolves to the shape of the segmented object.

The application offers import of several medical data format including DICOM [8]. The user interface is straight forward and consists of typical transversal, sagittal, coronal and 3D view. Application's user interface can be seen in Fig. 1.

Software is distributed for all major platforms; Windows, Linux and OS X. For the evaluation latest release Itk-Snap 3.2.0 has been used.

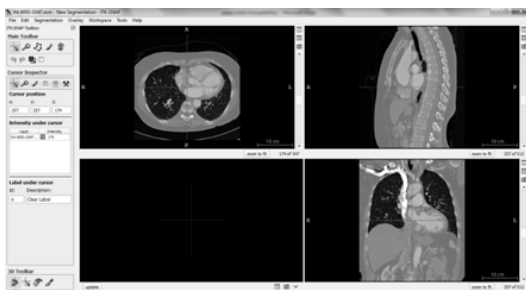


Fig. 1 Graphical user interface of Itk-Snap



Fig. 2 Graphical user interface of GeoS



Fig. 3 Graphical user interface of Lisa

B. GeoS

GeoS is software from Microsoft production, more specifically from division Microsoft Research. GeoS [9] is a

tool for the semi-automatic segmentation of 3D medical images such as CT or MRI scans.

Generally GeoS is free to use for non-commercial purposes. Specifically it is bounded by the license agreement [10].

GeoS is based on geodesic image segmentation, details about the algorithm can be found in [11]. The geodesic segmentation can work in automatic manner but in GeoS software it is used in interactive or semi-automatic way. User roughly marks in several slices the area of interest together with the area where segmentation should not extend. Then the automatic process segments the whole volume.

The application reads only the medical volume data in raw format. The user interface is straight forward and consists of transversal, sagittal and coronal view. Layout of the user interface is shown in Fig. 2. Calculated volume and its 3D representation can be shown separately.

Software is distributed only for Windows platform. Software version 2.3.6 has been used for the evaluation.

C. Lisa

Lisa is software developed by researchers of University of West Bohemia in Pilsen. Software is written in Python programming language. Based on [12] the present functions of Lisa include segmentation of the liver, vessels, and lesions from abdominal CT images, volumetry of the liver and liver lesions volumetry and their relation to the liver vascular tree.

Lisa is provided as free software if the following license terms are met [13].

As a segmentation algorithm graph-cut method [14] is used. The applied method works in Lisa in semi-automatic manner. For user it applies same principles as GeoS. User roughly marks in several slices the area of interest together with the area where segmentation should not extend. Then the automatic process segments the whole volume.

The application reads only the data in DICOM format. Beyond that image data in DICOM cannot be compressed, otherwise they will not be loaded. The user interface is straight forward and leads through separate steps to final segmented volume and its 3D representation. Initial screen of the application is shown in Fig. 3.

Software is distributed for Windows, Linux and OS X. For evaluation software version v1.3-9-g3c703b6 was used.

D. 3D Slicer

3D Slicer is a software package for visualization and image analysis [15]. It is not intended for clinical use but only for research purposes. Software is more of general purpose based on core modules and additional extending modules.

3D Slicer is provided as free, open source. Details of the license agreement can be found in [16].

For segmentation purposes grow cut method has been used. Grow cut segmentation is a competitive region growing algorithm using cellular automata [17]. The algorithm works by using a set of user input brush strokes for foreground and background. For N-class segmentation, the algorithm requires a set of brush strokes corresponding the N classes and a brush stroke for a don't care class. Then the calculation is performed

on the whole volume. Volumetric model is then created by using the Make model function and can be easily saved for example in STL format.

3D Slicer reads versatility of medical data including DICOM. The user interface is strongly user dependent but it can be organised in typical transversal, sagittal, coronal and 3D view. 3D Slicer includes a Python interpreter for direct interaction with Python language. Typical user interface of the application can be seen in Fig. 4.

Software distributions are available for all major platforms (Windows, Linux, OS X). Software version 4.3.1 has been used for evaluation.

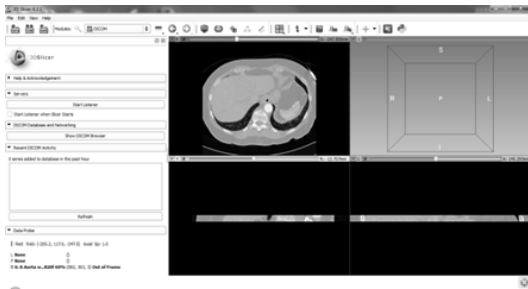


Fig. 4 Graphical user interface of 3D Slicer

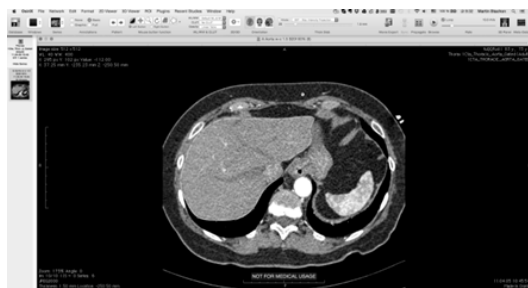


Fig. 5 Graphical user interface of Osirix

E. Osirix

Osirix is an image processing software. It is specially designed for images in DICOM format. Software can be used for navigation and visualization of multimodality and multidimensional images. It supports a complete plug-in architecture that allows one to expand the capabilities of Osirix for personal needs [18].

Software is provided as free, open-source under the GNU license [19]. This version is not certified as medical device and can be used only for research or teaching purposes. Authors also offer commercial software version, which is certified for clinical use.

For segmentation purposes region of interests (ROI) segmentation is available and have been used. It can be considered as semi-automatic method. User manually marks using the polygon function his region of interest in couple of slices. Software then automatically calculates missing ROIs in remaining slices. Generated ROIs can be manually adjusted for better match. After this operation software allows the user to calculate 3D model and its volume.

The user interface is user dependent. Its default version

offers one main view (transversal) with possibility to switch to sagittal or coronal view. User interface of the application can be seen in Fig. 5.

Software is available only for OS X operating system. Version 6.0 of the software has been used for evaluation.

III. EVALUATION METHOD

To compare evaluated software applications, reference volume of selected part of the liver was established. This has been done using manual segmentation of image series consisting of 10 consequent images followed by the 3D model reconstruction of the segmented volume. Only 10 images were segmented to reduce the complexity of manual segmentation. The volume reconstruction was based on the knowledge of the liver boundary in each slice and on the voxel size. The information about a voxel size is part of the DICOM metadata. Resulting volume was then obtained as a sum of all the voxels lying inside the liver boundary and through all the slices. The closer the reconstructed volume to reference volume the better ranking the evaluated software gets. Manual segmentation was done in 3D Slicer.

Technically speaking method of Relative Volume Difference (RVD) has been used for comparison [2]. The relative volume difference between two groups of voxels VR and VS is defined as in (1):

$$RVD = 100 \cdot \frac{(|VS| - |VR|)}{|VR|} \quad (1)$$

In (1) VS is the segmented volume produced by the particular evaluated software and VR is the reference volume obtained from the manual segmentation. The RVD value is stated in percentage. In (1), a value of 0 means that both voxel groups (VS, VR) have the same volume and in this sense they are identical. It has to be noted that this does not imply that VS and VR are identical, or overlap with each other. This is the drawback of the RVD method in comparison with for example VOE (Volumetric Overlap Error) that considers not only the resulting volume but also the degree of overlapping. The reason to use RVD method was mainly to have a fast tool to easily compare the different software in terms of their resulting 3D model volumes.

IV. SELECTED DATA FOR SEGMENTATION

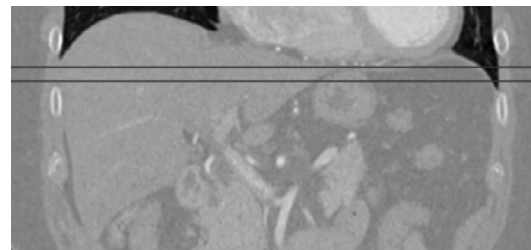


Fig. 6 Selected area for segmentation tests

As already mentioned 10 consecutive images capturing the upper part of the liver have been selected. As a source of

images DICOM database from [20] has been used. In Fig. 6, marked area of selected images from the whole liver area is shown.

V. SEGMENTATION RESULTS

Results in terms of relative volume differences are summarized in Table I. Beside the RVD values produced 3D models of all software applications are depicted in Table I.

The semi-automatic image segmentation of 3D Slicer led to the closest match with 3D model obtained by solely manual segmentation. On the other hand worst RVD value was achieved by GeoS. It is necessary to note that GeoS was not able to successfully segment input data and to create the 3D model with its volume and thus failed. It was probably caused by the nature of the used input data which are not the strictly convex set but only a convex set. If the GeoS was used to segment input data being a strictly convex set (whole liver), problem did not occur and the software worked correctly. Graphical representation of difference between convex and strictly convex set is shown in Fig. 7.

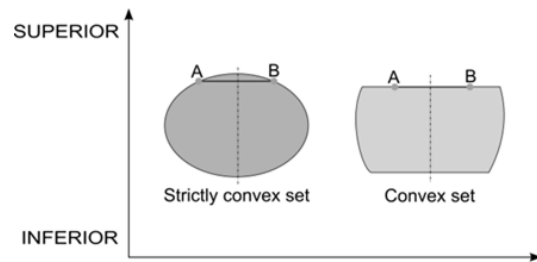



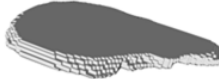

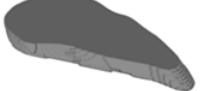


Fig. 7 Convex and strictly convex set

Except the RVD values the provided 3D models in Table I give an idea about the smoothness of the resulting models using the particular software and its segmentation technique. Finest results were performed by Osirix while coarsest by Itk-Snap. In case of Osirix software, it is due to the use of polygon regions of interest for segmentation. Itk-Snap on the other hand produces coarse model due to use of thresholding in pre-processing phase and lack of the dilate function over the segmented data.

TABLE I
EVALUATION RESULTS

Software	Resulting 3D model	Segmented volume VS [ml]	Reference volume VR [ml]	RVD [%]
3D Slicer (Manual segmentation)		137.024	137.024	0
Itk-Snap (Semi-automatic segmentation)		126.500	137.024	-7.680
GeoS		Failed	137.024	-
Lisa (Semi-automatic segmentation)		127.910	137.024	-6.651
3D Slicer (Semi-automatic segmentation)		130.290	137.024	-4.915
Osirix (Semi-automatic segmentation)		101.444	137.024	-25.966

VI. CONCLUSIONS

In this paper selected part of the liver is chosen and then reconstructed as a 3D model from DICOM images. This procedure is done in versatility of today's available medical imaging software. All of them are distributed as free or open-source for non-commercial or research purposes. As a measure of quality of the model reconstruction in each software RVD method is used. RVD compares model volume sizes with the volume of the model reconstructed by manual segmentation. All of the software applications use semi-automatic image segmentation to segment the liver part.

Since all segmentation techniques used in the reviewed software are highly user dependent, RVD results can be

considered as only approximate.

The important result of this review is that none of the software can work in fully automated manner to produce the liver model from the segmented input data images. Beyond that in case of liver segmentation reviewed software can easily diverge from semi-automatic segmentation to almost manual segmentation while difficult parts of the liver are being segmented.

To conclude, the problem of fast and precise liver image segmentation is still an open issue. Software for reliable automatic liver segmentation would be highly appreciated.

ACKNOWLEDGMENT

This paper has been elaborated in the framework of the project New creative teams in priorities of scientific research, reg. no. CZ.1.07/2.3.00/30.0055, supported by Operational Programme Education for Competitiveness and co-financed by the European Social Fund and the state budget of the Czech Republic.

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