Open-source tool for 3D segmentation and rendering of abdominal CT scans

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***Abstract*—3D visualization of the size, shape, and location of the kidney stone as well as of the anatomical characteristics of the renal collecting system, surrounding tissue and blood vessels could significantly facilitate the surgeon's treatment planning for urolithiasis. Standard clinical Computed Tomography (CT) software does not offer the flexibility in the 3D display of individual or combined renal phases. In this paper we present a flexible and interactive open-source application for segmentation and 3D visualization of abdominal CT scans for the urolithiasis treatment planning. The usage of the new tool is demonstrated through the clinical examples and its advantages are explained in comparison with the output of the dedicated clinical software.**

***Index Terms*—abdominal CT, minimally invasive surgery, open-source, 3D rendering, 3D segmentation.**

I. Introduction

THE accurate diagnosis is a prerequisite for the effective treatment [1]. In the era of modern medicine, this assumption becomes more important, since the backbone of quality diagnostics consists of performing radiological procedures, primarily computed tomography (CT) imaging, but also radiography, ultrasound, magnetic resonance imaging (MRI), as well as interventional radiological procedures. Radiological procedures are associated with the patient's exposure to ionizing radiation, and therefore it is necessary to use these procedures rationally and optimally.

Low-dose abdominal CT imaging has high sensitivity, specificity, and accuracy for the detection of urolithiasis (kidney stone disease) [2]. Urolithiasis could be treated conservatively (by pain control, hydration, and medical expulsive therapy), surgically (endoscopic methods: ureteroscopy and percutaneous nephrolithotomy) or by extracorporeal shockwave lithotripsy (shockwaves applied outside the body to break the stone) [3,4]. The size, shape, localization, and structure of the kidney stone determine the decision about the treatment method.

The treatment of choice in case of large stones (>2 cm) or complex anatomic factors is percutaneous nephrolithotomy (PCNL) [5-7]. Each percutaneous (through the skin) path to the kidney and the stone implies the passing of instrument through the renal highly vascularized parenchyma, so the optimization of each puncture, even individual, and kidney access is an imperative for the minimization of potential complications. The prerequisite for the minimally invasive surgery is the detailed 3D visualization of the target organ and its anatomic environment [8].

A reliable anatomical 3D visualization is based on the quality segmentation process. One of the directions for abdominal segmentation is by using so called “atlas”, structures that combine the location and shape of anatomical structures and spatial relationships among them [9]. The main obstacle in “atlas” approaches is huge anatomical diversity. Recently, promising results in abdominal segmentation have been achieved using deep learning approaches [10-13], but these methods require large homogeny datasets. However, the greatest accuracy for abdominal organ segmentation has been obtained by multi-level hierarchical strategy combined with neural network approach [14], so in this paper we have used a hierarchical strategy for organ segmentation [15].

Dedicated clinical CT software usually presents independently stone scans, then the structure of the kidney itself, and finally the anatomy of the excretory system. These tools are not interactive, and they do not offer options for controlling the overall process of segmentation and 3D visualization. In this paper, we propose a flexible and interactive open-source tool, so called *3D Gastro CT tool*, for segmentation and 3D rendering of abdominal CT scans that could facilitate the urolithiasis treatment planning. In Section II we have presented the flowchart of the developed application, image preprocessing, segmentation and rendering methodology. Examples of the tool usage in patients with and without kidney stone are illustrated and compared with the output of the dedicated clinical software in Section III. Finally, the conclusion and plans for future work are given in Section IV.

II. The Method

3D Gastro CT tool was developed in Python language using the following libraries and toolkits: matplotlib [16], ndimage [17], SimpleITK (abstraction layer and wrapper around Insight Segmentation and Registration Toolkit, ITK) [18-20] and VTK (Visualization Toolkit) [21]. The graphical user interface (GUI) was developed using PyQt5 bindings for Qt v5 [22]. The code is available at Github link: https://github.com/milicevickatarina/3D-Gastro-CT.

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The flowchart of the developed application is shown in Fig. 1.

A. Data management

3D Gastro CT tool offers the option for reading and viewing a variety of 2D or 3D formats that are supported by SimpleITK reader (*Dicom*, *MetaImage* etc.). This allows the user to select the work directory with images and to explore available image files determining which files are appropriate for further processing.

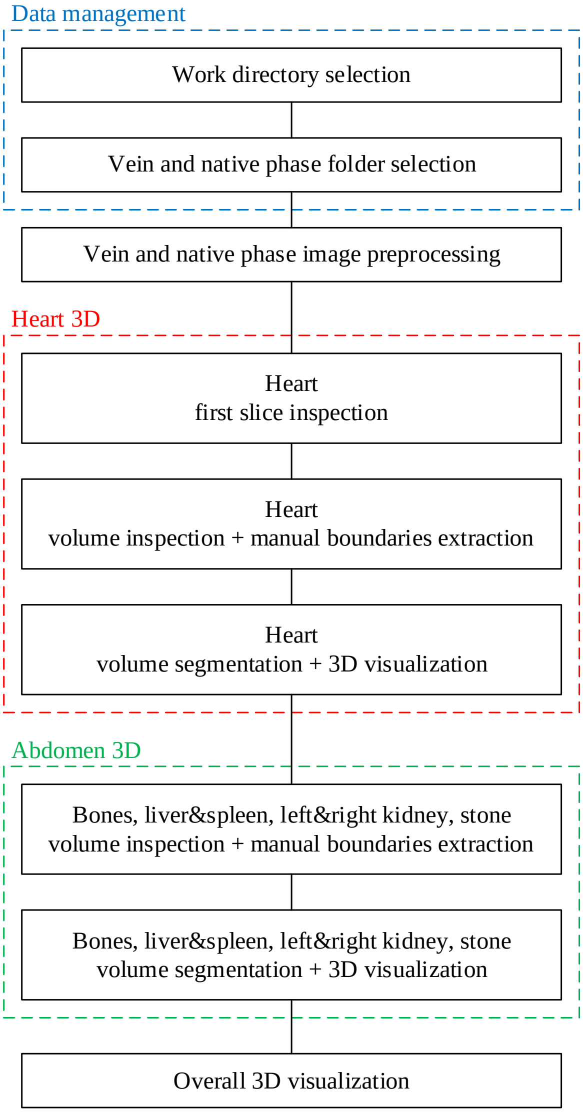

Fig. 1. Flowchart of the 3D Gastro CT tool

For the next step, “Image preprocessing”, the selection of folders with native phase images (abdominal images recorded before CT contrast injection) and vein phase images (abdominal images recorded 70-80 s after the CT contrast injection) is necessary. The reason of using these two phases is that grey levels differ well: 1) in vein phase for heart, abdominal organs (liver, spleen, kidney) and stone 2) in native phase for skeleton (unlike vein phase where it overlaps with the intensity of the blood vessels).

Once performed, all preprocessing, segmentation and 3D rendering results would be stored for the future image retrieval. Export option in .stl and .jpg formats of individual and merged rendering results is available.

3D Gastro CT tool was tested using the dataset available from the routine CT imaging (Aquilion Prime CT Scanner, Toshiba Medical Systems, USA) performed for patients with suspected urinary tract stones in the Clinical Center of Serbia. The resolution of CT scans was 512x512 pixels and 588 CT slices in axial projection were available.

B. Image preprocessing

The images from the vein and native phases are preprocessed completely automatically using the following steps: 1) linear intensity transfer function for the band [-548, 800] to [0,255], 2) resampling images from 512x512 resolution to 256x256 to reduce time and space resources in further steps, 3) median filtering for noise reduction. Native phase was coregistered with the vein phase using the *SimpleITK* class *ImageRegistrationMethod* (similarity metric: mutual information (Mattes MI), interpolator: sitkLinear, optimizer: gradient descent), [23].

C. 3D segmentation

The segmentation process is executed hierarchically, organ by organ, on the preprocessed images. The segmentation order is as follows: heart, bones, liver and spleen, kidneys and kidney stone. The segmentation of bones and kidney stone can be performed even if segmentation of previous organs is not finished. The result of individual organ segmentation is displayed rendered in the pop-up interactive window (rotation and zoom options enabled) so the user can decide to save or repeat the segmentation procedure.

C1. Heart 3D segmentation

Heart 3D segmentation performs on vein phases images. This procedure includes the following steps, Fig. 2:

- manual selection of heart rectangle region of interest (ROI) boundaries (left, right, upper, lower border) on the first CT slice, Fig. 2A
- fully automatic heart segmentation of the first CT slice using the following steps: 1) gaussian filtering (σ=2), Fig. 2B, 2) image binarization (threshold is set to 10 % of maximal pixel intensity), Fig. 2C, 3) the cross section between the heart rectangle ROI boundaries and the binary image, Fig. 2D, 4) filling holes and removing particles, Fig. 2E.
- fully automatic heart segmentation of the rest of CT slices containing heart using the following steps: 1) gaussian filtering (σ=2), 2) image binarization (threshold is set to 10 % of maximal pixel intensity), 3) the cross section of the binary image, heart rectangle ROI boundaries, and the dilated extracted heart ROI from the previous CT slice (dilation was used to compensate heart movements and different heart surface on successive CT slices)
- opening and closing of the extracted heart volume (cube structural element with the dimension 10).

C2. Other organs’ 3D segmentation

Bones 3D segmentation performs on native phases images. The procedure is the same as in case of liver&spleen and stone 3D segmentation. Liver&spleen and stone 3D segmentation performs on vein phases images. This procedure includes the following steps:

- histogram presentation for the whole CT volume
- manual selection of upper and lower threshold that correspond to the VOI intensity boundaries on the histogram for image binarization as it is defined in Fig. 3A, B, C (left)
- volume binarization performs on the volume where the heart and bones VOIs are removed for liver&spleen segmentation
- opening and closing of the extracted volume (cube structural element with the dimension 3).

Kidney 3D segmentation performs on vein phases images. This procedure includes the following steps, Fig. 3D:

- manual selection of kidney VOI boundaries (top and bottom slice number, left, right, upper, lower border) that cover the kidney VOI in all CT slices
- histogram presentation for the kidney VOI where bones and liver&spleen volumes are previously removed
- manual selection of upper and lower threshold that correspond to the kidney intensity boundaries on the histogram for volume binarization as it is defined in Fig. 3D (left)
- the cross section between the kidney VOI boundaries and the binary image
- opening and closing of the extracted kidney volume (cube structural element with the dimension 4).

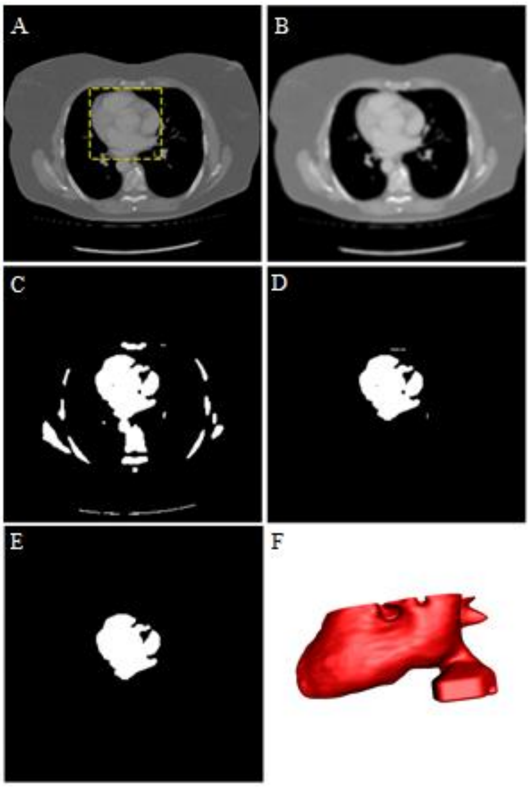

Fig. 2. Heart 3D segmentation process: A) manual selection of heart rectangle ROI boundaries, B) gaussian filtering, C) image binarization, D) cross section with rectangle ROI, E) filling holes and removing particles, F) 3D heart rendering result

D. *3D visualization*

3D rendering was performed using the *Marching Cubes* algorithm [24] using the implementation presented in [25]. Segmented images are archived in *.mhd* format compatible with the VTK reader. Individual segmentation results are merged to perform the overall 3D visualization.

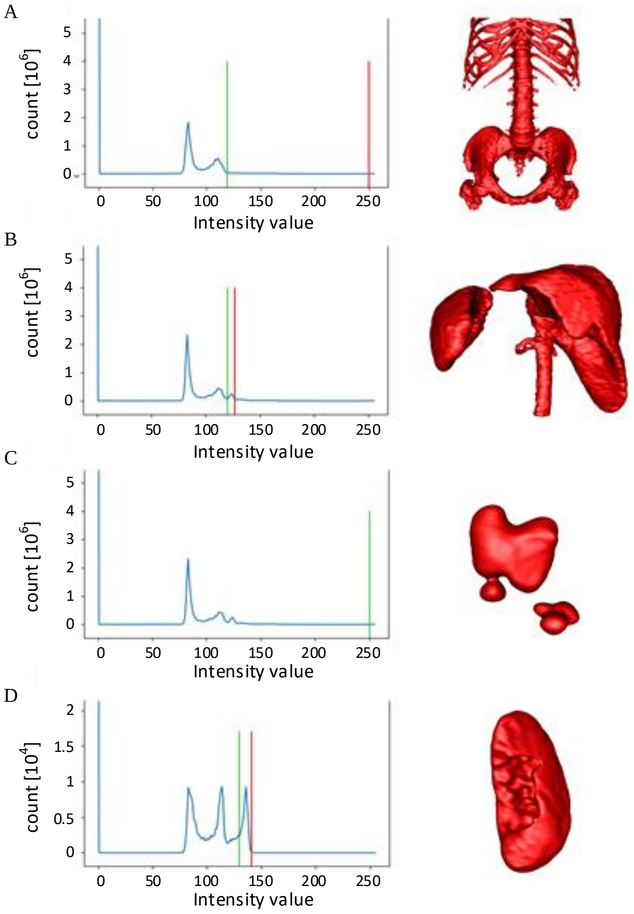

Fig. 3. Bones (A), liver&spleen (B), stone (C), and kidney (D) upper and lower threshold selection on corresponding histograms (left) and individual 3D rendering results (right)

III. Results

An example of the GUI for semi-automated left and right kidney segmentation is shown in Fig. 4. Numerical controls are used for setting values of VOI boundaries. Histogram display is used for determination of lower and upper thresholds. Pop-up windows are used for checking selected kidney boundaries and the display of individual kidney 3D rendering results.

Fig. 5 presents the comparison of the 3D visualization results from *3D Gastro CT tool* and dedicated clinical software for two subjects: the first one is without kidney stone and the second one is with the left kidney stone. For the second subject, the displays are without showing liver and spleen volumes. It could be observed that *3D Gastro CT tool* offers more selectivity in the display where disturbing blood vessels can be completely removed.

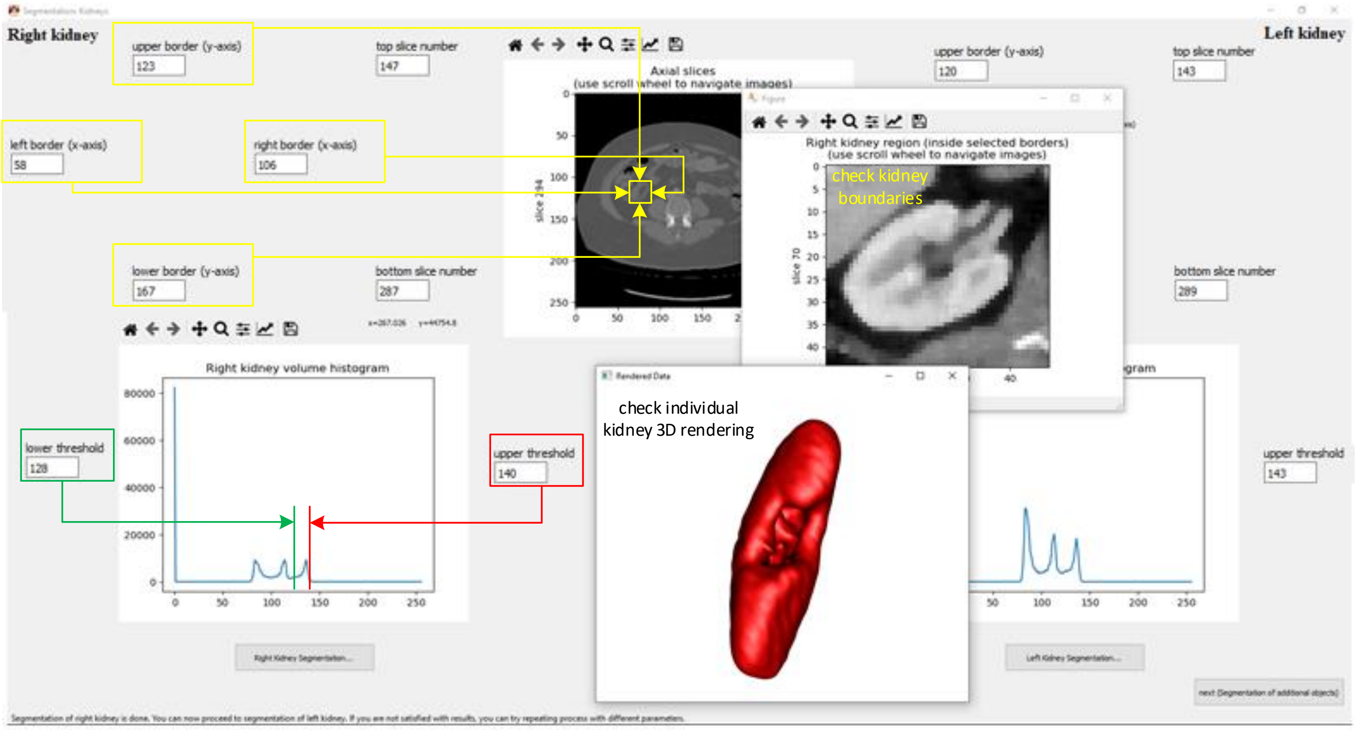

Fig. 4. An example of GUI for setting boundaries and thresholds for the left and right kidney segmentation process, checking boundaries and individual kidney 3D rendering

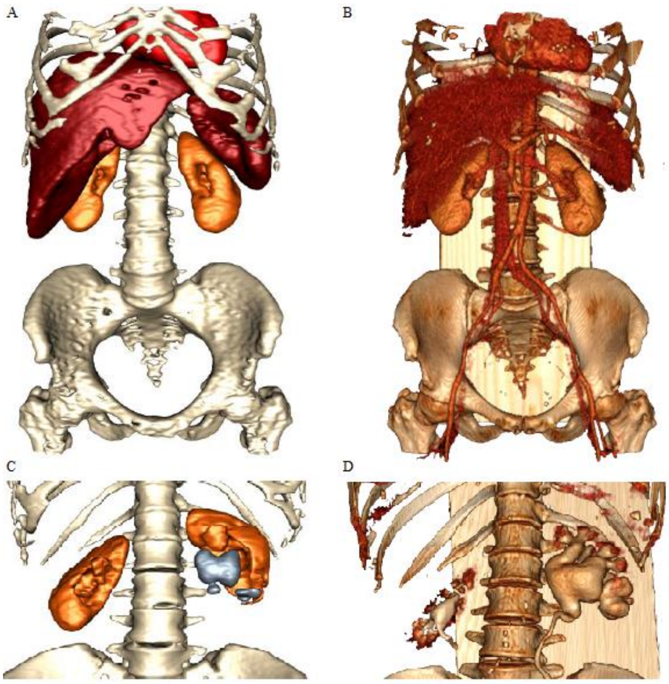

Fig. 5. The comparison of the 3D visualization results from *3D Gastro CT tool* (left) and dedicated clinical software (right) for the patient without (up) and with (down) kidney stone

IV. CONCLUSION

An open-source semi-automated solution for the visualization of abdomen in patients with urolithiasis is presented in the paper. The segmentation process of individual organs is sequential, and necessary inputs for the realized *3D Gastro CT tool* are native and vein phase CT slices of abdomen. The advantages of the developed tool are demonstrated through examples that are compared with the output from the dedicated clinical software. The usage of the tool is presented on the specific type of urologic CT study, but it is flexible to expand to a wider range of applications. Future work will be focused on testing of the tool on a larger clinical dataset and improving it by the completely automatic algorithm for segmentation.

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