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A new procedure for automatic path planning in bronchoscopy

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Abstract

Virtual bronchoscopy is often used for planning a real bronchoscopy procedure. Software applications are developed for virtual bronchoscopy, involving usually segmentation of the tracheobronchial tree from the medical image scan, which is a difficult operation, both conceptually and from the computer implementation and running time point of view. That is why in this paper, a new method for bronchoscopy procedure planning that does not require such a segmentation is presented. The proposed procedure involves automatic path generation between the starting and ending points, skin removal, an algorithm for detection and resolution of collision with the airways walls and validation of the automatically created path. Results are presented for two datasets – one being the representation of a theoretical lungs model, with six levels of branches and the other one being the image scan of a real patient. Together with a system for tracking the bronchoscope during the real procedure, the proposed method can improve the diagnostic success rate of lung cancer using bronchoscopy and decrease the discomfort perceived by the patient.

Selection and/or Peer-review under responsibility of the Committee Members of 34th DANUBIA ADRIA SYMPOSIUM on Advances in Experimental Mechanics (DAS 2017).

Keywords: Lungs; Path planning; Virtual bronchoscopy; A* algorithm

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1. Introduction

Lung cancer can be diagnosed using a bronchoscopy procedure together with a biopsy from the affected area, performed using a forceps introduced through the working channel of the bronchoscope in order to obtain a tissue specimen from the prospective tumor location. Virtual bronchoscopy (VB) is a very useful tool that can be used for a proper planning of the real bronchoscopy or even to replace it if considered too invasive, for example in case of children [1]. VB is a term that describes software-based three-dimensional visualizations created from noninvasive medical imaging methods such as computed tomography (CT) or Magnetic Resonance Imaging (MRI) scans, with the goal of creating results similar to minimally invasive bronchoscopy procedures of the trachea and upper airways [2]. In virtual bronchoscopy, a computer simulation of the video bronchoscope image is created with similar view angle and zoom settings, making possible the study of the bronchial tree in a non-invasive manner with no additional radiation exposure relative to standard CT scan of the chest in patients with benign and malignant disease, even in patients where ordinary video bronchoscopy is too invasive or not possible [3]. Software applications for virtual bronchoscopy are usually based on the segmentation of the tracheobronchial tree from the medical image scan (usually multirow detector X-ray computerized tomography - MDCT). Stacks of CT slices, adequately reconstructed, now allow for high-resolution three-dimensional images of the thorax to be obtained [4]. Mayer *et al.* presented a segmentation tool SegoMeTex based on image data acquired by a multislice computed tomography scanner and which is used to segment the tracheobronchial tree by a hybrid system with minimal user action [5]. Using a 3D MDCT chest image as input, Kiraly *et al.* proposed a new quantitative method for the analysis of the major airways [6]. Their method involves three major steps: a. segmentation of the airway tree, b. extraction of the central-axis structure of the major airways, and c. a novel improvement on the standard full width half maximum approach for airway wall delineation. Measurements for all defined tree branches, including airway diameters and cross sectional area values are produced with this method. A virtual bronchoscopy system coupled with a customized electromagnetic (EM) tracking system for navigation in the lung is described in [7]. The proposed method has been implemented as an extension to the open-source platform, 3D Slicer and it creates a virtual reconstruction of the airways starting also from CT images for virtual navigation.

The segmentation obtained from CT images is usually a difficult operation, both conceptually and from the computer implementation and running time point of view. That is why in this paper, a simpler method for bronchoscopy procedure planning that does not require such a segmentation is presented. The procedure was built starting from CustusX, an open source image-guided therapy research platform dedicated to intraoperative navigation and ultrasound imaging [8].

2. Description of the method

The method is based on the discretization of the 3D reconstructed CT scan in voxels. A Hounsfield unit value corresponding to the gray scale from CT is assessed to each voxel. Airways tubes will be the voxels having the Hounsfield unit values of the air, taken in this research between -1100 and -850. Based on the 3D image volume discretization, two geometric methods are implemented: i. A "line" tool that enumerates the voxels intersected by a certain line segment between two points and ii. A "wave" tool that creates iteratively a certain wave surface centered on a fixed voxel and which enumerates the voxels of a specific wave generation.

In the set of 2D projections of the CT data (axial, sagittal and coronal planes), the user selects the starting point and the target point which will appear in the 3D image of the medical data. If, according to the Hounsfield value of the voxel containing the target point, this point is not inside the airways, it is projected using the wave tool iterator inside the "nearest" air tube. Then, a path is automatically generated through voxels containing Hounsfield values for air between the starting point and the projected target point using a modified version of the A* algorithm [9]. The user validates the generated path by manual navigation through the airways, based only on mouse gestures. During navigation, an algorithm for detection and resolution of the possible collision with the airways walls was conceived, with two steps: i. Collision detection - if the current navigation position is not inside a voxel with the Hounsfield value of air and ii. Collision resolution – using the line tool iterator. For the second phase, a line is drawn between the current navigation position (outside the airways) and the previous correct navigation position (inside the airways). The software finds, along this line, two adjacent voxels, one containing the air value and the other with the

Hounsfield value outside the air range. The common wall of these two airways is marked and the corrected position inside the voxel with air value is computed.

3. Skin removal

The colors of the 3D volumetric visualization are obtained from the Hounsfield units of each voxel, using transfer functions. Lung tissue has Hounsfield values around -400. The view of the lungs in the 3D reconstructed volume may be blocked by other body tissues that have similar Hounsfield value as the lungs, as it is shown in Fig. 1. These layers can be removed from each slice considering the cylindrical organization of the chest volume on layers: skin (outside layer) – fat tissue (middle layer) – lungs tissue (inside layer). A view of the slices after skin removal is shown in Fig. 2.

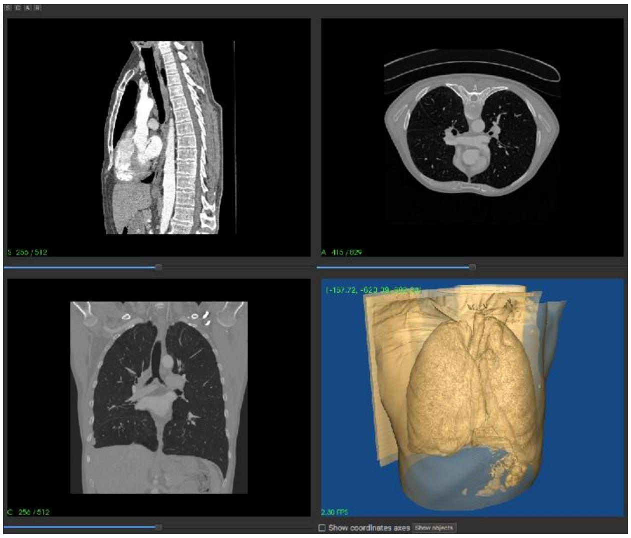


Fig. 1. The 3D volumetric visualization of lungs using transfer functions; tissues with similar Hounsfield value as lungs can be noticed in the right lower image

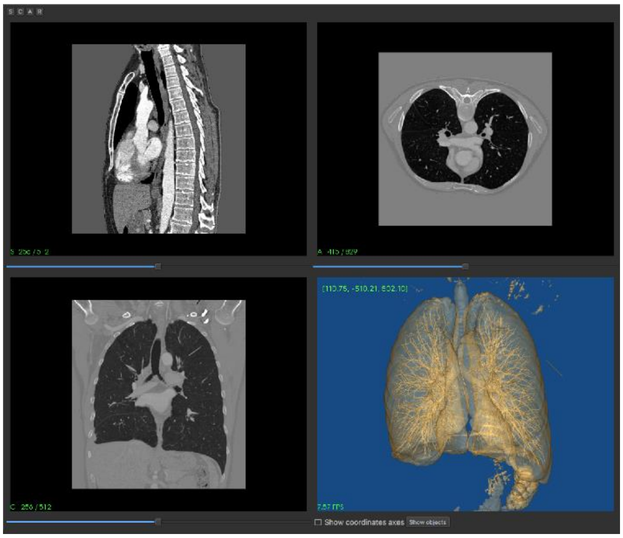
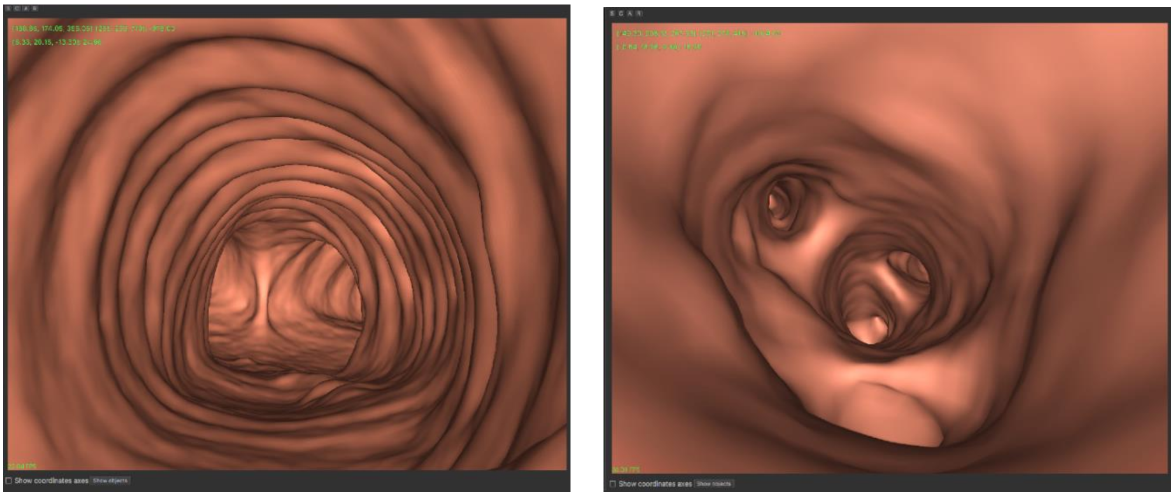


Fig. 2. Axial, sagittal, coronal slices and lungs 3D view after applying the skin removal algorithm; the lung tissue can be clearly viewed in the right lower image.

4. Virtual navigation and collision detection

In this method, virtual navigation through the lungs and airways can be undertaken using a computer mouse with three buttons. The 3D visualization camera is rotated around its own axes with mouse drag operations, through quaternion computations that implement a method known as “arc ball” rotation. Once a mouse click and drag operation is started, the camera is rotated in such manner that the point in 3D space perceived under the mouse position when the operation is started will remain in the same position during dragging. Translations are done along the 3D axes perpendicular to the screen, and rotations can be performed around the same axes to better simulate the bronchoscope rotations. The camera view angle and other view parameters can be modified from the software application interface.

In order to constrain the visualization camera to remain always inside the airways, an algorithm for collisions detection and resolution is used. The algorithm is adapted from the one presented in [10], with the main improvement that, in the new one, there is no segmentation of the airways. Only the Hounsfield values for the voxels and the “line” tool iterator are used to detect the collision and to find the position where the camera trajectory intersects the lungs tissue. For the collision resolution, the gradient in the collision place is used to move camera back “inside” the airways tube. Two views obtained inside the airways tree during virtual navigation are shown in Fig. 3.



a. b.

Fig. 3. Views inside the airways tree during virtual bronchoscopy navigation: a. view from the trachea; b. view deep inside the airways tree

5. The A* algorithm and automatic path

The path between the starting point (usually in the trachea) and final point chosen by the user can be automatically created using the A* search algorithm which tries to find the shortest path from a starting voxel to a destination voxel, iterating from one neighbor voxel to another until the destination is reached. The algorithm uses two scores to evaluate the distance from the search current position to the destination:

$$F\_Score[current] = G\_Score[current] + H[current, destination]$$

where G_Score is the distance along the partially constructed path from the starting point to the current search position and H is a heuristic that approximates the distance from the current search position to the destination. For H, the standard Euclidian distance between two points in the 3D space is used. F_Score is used to select the voxels intersected by the path from a set of candidates. In the case of virtual bronchoscopy, it is important find the airways that form a path from the trachea to the area of interest. That is why the search algorithm was adapted for speed, using the Euclidian distance as the heuristic score H with a a reduced set of candidates prescribed by the A* algorithm in the vicinity of the current search position at certain steps. The procedure generates any path very fast, even for destinations deep inside the airways tree.

6. Results

The procedure described above was applied on two data sets. The first data set is a representation of a theoretical lungs model, with six levels of branches, generated using an algorithm proposed by the authors and used to test the virtual bronchoscopy procedure implemented in an innovative system for bronchoscopy with electromagnetically tracked and steerable biopsy forceps [11]. The second data set is the CT scan of a real patient. In both sets, the starting point, the selected target, the projected target, the automatic path and the validated path are visualized and the area of interested is chosen deep inside the airways tree. The results (automatic path and manual validation) are shown in Fig. 4 and Fig. 5.

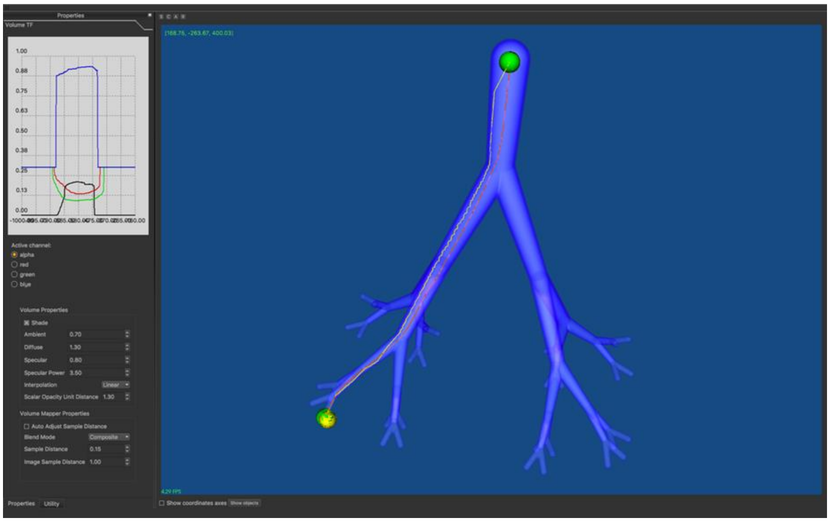


Fig. 4. The starting point and target (green dots), automatic generated path (yellow) and manual validation with virtual bronchoscopy (red) for a theoretical airways model

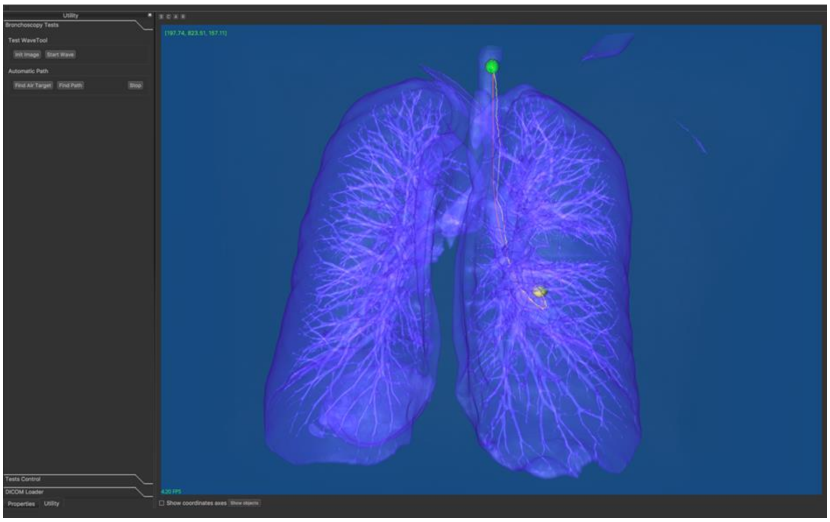


Fig. 5. The starting point and target (green dots), the automatic generated path (yellow) and manual validation with virtual bronchoscopy (red) for a real patient dataset

7. Conclusions

In this paper, a method for path planning in bronchoscopy interventions is described. The method has the advantage that it does not need segmentation of the tracheobronchial tree from the medical image scan. The procedure is very easy to use and navigation through airways can be performed using only the computer mouse. The algorithms can be improved using geometric iterators (line and wave tools) to approximate the airways center and diameter locally in a certain position, allowing a better procedure planning and indicating to the clinician the type and size of the medical instruments that could be used along the planned path. A new tool that can estimate the diameter of the airways tube around a chosen area is intended to be developed during the future research.

Together with a system for tracking the bronchoscope during the real procedure, this method can improve the diagnostic success rate and decrease the discomfort perceived by the patient.

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