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Interactive Virtual Surgery Simulation System for Bronchoscopy

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***Abstract*—Virtual bronchoscopy is an important application in modern medicine. The aim of this work is to establish a virtual bronchoscopy system that can examine the entire lung and assist physicians in detecting polygons inside the lung. It is separated two parts: preprocessing phase that used to construct human organ model based on the principal of CT medical imaging data, the run-time phase that used to simulate the several functions that can show the different procedure of surgery. The simulation results show that these key technologies can not only improve the computational performance, but also ensure the computing convergence and model integrity. It can satisfy the requirements between clinical, accuracy and realism of virtual surgery simulation. With the further development, it will widely applied clinic medical, assistant diagnoses and other fields.**

Keywords-virtual surgery simulation, virtual bronchoscopy, soft tissue modeling, virtual navigation

I. INTRODUCTION

Bronchoscopy is a common diagnostic and surgical technique performed in hospital for visual or to get the sample of suspicious region of interest (ROI). In practice, ROIs may be solitary pulmonary nodules or diffuse masses situated several airway generations beyond the trachea. Often, the ROIs are located outside the airway tree or deeply, making direct visual inspection impossible[1,2]. With the development of the virtual endoscopy technology, the disadvantages of the traditional optical endoscopy which it needs to put into human body are overcome. The object of virtual endoscopy system research is to provide trusty means for medical diagnoses, and to spread the new application fields as assistant diagnoses, surgery planning and training.

Numerous surgical simulators have been developed over the last decade for colonoscopy[3], ossicles in the middle ear[4], trache-bronchial[5], cardio vascular[6] and so on. Limitations of current virtual endoscopy systems include high cost, lack of visual aids beyond simulated endoscopic views, difficulty in performing interactive anatomic exploration, such as cutting, tearing, suturing and so on.

In order to improve the interactive of the virtual surgery simulation system, we need to build more powerful and realism system that can be useful in the simulation of different procedures. Therefore, a new virtual surgery simulation system is developed that involves many generic surgical gestures (visual, deformation, grasping, cutting, suturing).

II. METHODS

The virtual bronchoscopy system is presented in figure 1. The system is separated two parts: preprocessing phase and run time phase. It shows the different functional parts of virtual surgery interact with each other. OpenGL and VC++ are adapted to develop our software. In the first phase, a surface and tetrahedral model is created to represent the human organ model. In the second phase, it can be used to real-time simulate the procedure the surgery. These two parts construct the overall virtual bronchoscopy system, but the two phases are not independent of each other because the first phase provides the geometric data of human organ model for the second phase and the second phase feedback the simulation information to the first phase. This system not only shows the structure of modeling, but also simulate the physically characters of human organs.

The overall system flow consist image segmentation, geometry modeling, physical modeling, computation modeling, collision detection, virtual navigation, force feedback, cutting and realistic rendering, etc. Geometry modeling is the foundation of virtual surgery that constructs geometry model which segmented from medical image dataset. Physical modeling adds physical property to geometry model, and lets the model can behave more like that of the real surgery. Combining the geometry and physical model, computation modeling provides the method of deformation computation. In a virtual surgery system, the precondition of object deformation and object topology change is the collision between virtual instruction and virtual organ, so the collision detection is an important subject. Virtual navigation is required to provide camera positions and orientations to view the inside of organ. Cutting method decides the topology change algorithm after the cutting condition is meeting. Realistic rendering can strengthen the operator's sense of immersion in the simulation process, aims to present more realistic images of human organ and tissue, or other phenomena in real surgery, such as blood. The force feedback device is attached to 3D graphics simulation and provides the main user-interface to the simulation. The device captures the movement of the flexible endoscopy and tools. In addition, it provides passive force feedback to the user. The following sections will discuss the core techniques of system.

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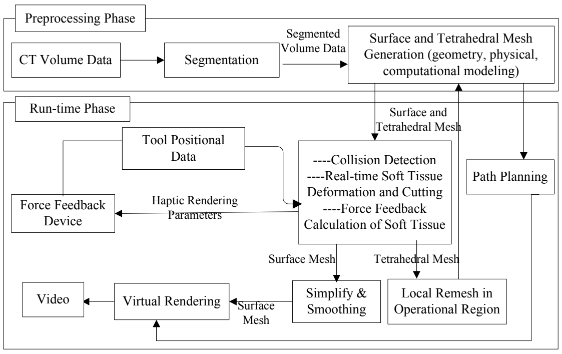

Figure 1. System architecture of the virtual bronchoscopy

A. *Soft tissue geometry modeling*

The geometry model in virtual surgery can be divided into two types: surface and volumetric model. The choice between surface and volume model is governed by computer efficiency and physical accuracy. Surface models are advantageous because they have fewer vertexes than volumetric models for representing the same shapes, but the volumetric models may take into account physical inhomogeneities. Moreover, volumetric models are better suited to the simulation of cutting or suturing operation. Therefore, the surface and volumetric model are all used for different function in this surgery simulation system. The major steps to create the patient's anatomy model for surgical simulation are as follows:

Import of medical image data(DICOM);

Image filtering for the reduction of the noise;

Segmentation of different tissue regions using dynamic region-growing algorithm;

Generation of a surface model with correct topology by Marching Cubes algorithm;

Surface simplification and optimization with regard to the triangular shape;

Generation of an unstructured tetrahedral model on basis of the surface model;

Simplification and optimization of the tetrahedral model according to the finite element method.

To extract the shape of the lung from this dataset, we used the CT slices, which give a better contrast between the lung and the surrounding organs. The dataset concerning the lung can be reduced to about 80 slices. After contrast enhancement, we apply a dynamic region-growing algorithm to extract the contours of the image, and then using a simple threshold technique to retain the stronger ones as the figure 2. After segmentation, the surface contours are segmented from a set of 2D segmented medical images (see figure 3). Then, marching cubes algorithm is used to get the surface of the lung model. However, the number of triangles generated is too large for further processing. Moreover, a smoothing of the surface is necessary to avoid staircase effects (see figure 4). The lung model is composed of 123124 triangles and 62120 points, but the simplification model is composed of only 64260 triangles and 32688 points. Finally, an unstructured tetrahedral model on basis of the surface model is build which consist 36212 points and 118526 tetrahedral (see figure 5).

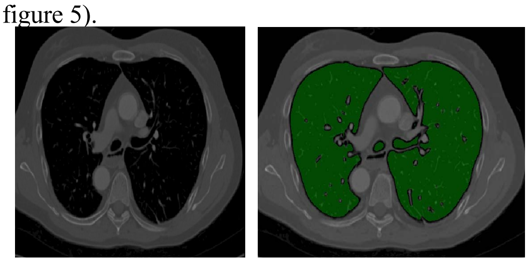

Figure 2. Segmentation of the lung slice by slice.

The initial data (left) is original CT-scan images of an anatomical slice of the abdomen. The binary image (middle) corresponds to the segmented lung cross-section.

Figure 3. After segmentation, the surface contours are segmented from a set of 2D segmented medical images.

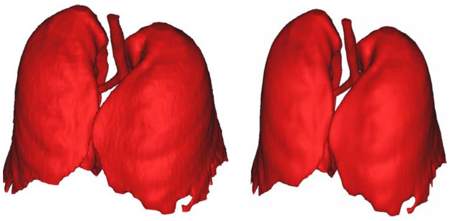

Figure 4. The lung surface model (left) is extracted using the marching cubes algorithm. The right is the smoothed model that reduced the step-effect.

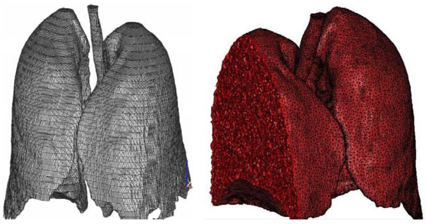

Figure 5. Well shaped tetrahedral model is build based on the Delaunay tetrahedralization theory as the radius-edge ratio equal to 2.0.

B. *Physical and computation modeling*

Most of medical simulation systems are based on geometric representations of anatomical structures that did not take account of their physical features. Representing physical phenomena and, more specifically the realistic modeling of soft tissue will not only improve current medical simulation systems but will considerably enlarge the application and the credibility of medical simulation. For a given surgical simulation, soft tissue deformation accuracy and computation time are the two main constraints for the modeling of soft tissue.

So far many simulations of deformation have been implemented using simple models: Mass-Spring[7], linear elastic FEM[8], centerline[9], MM-Model[10], Tensor-Mass models[11], quasi-static pre-computed linear elastic model and so on. These methods work well for simulations of very small strains and local deformations, but have poor accuracy for large global deformation modeling, and it do not suite for the simulation of tissue cutting. The dynamic linear elastic finite element models are able to address with the limitation of the previous model, but they have lower convergence speed.

Therefore, this soft tissue modeling deformation simulation method combine with these two approaches according to the characteristics of quasi-static and dynamic linear elastic models. As long as the force applied to the scalpel is smaller than a threshold value, the soft tissue models do not modify its topology structure, only modify its displacement, it would be natural to choose the proposed quasi-static linear elastic model for these soft tissue. Otherwise, the topology structure of model are modified and removed and updated the tetrahedron which contact with scalpel. We would use the modified dynamic linear elastic model. These properties improve the realism of the deformations and solve the problems related to the shortcomings of linear elasticity.

C. *Virtual navigation*

In fly-through navigation, it is crucial to generation an optimal camera path for efficient lung brochonoscopy screening. Our virtual navigation system includes four main steps: (1) extracting objects of interest, (2) segment the airway tree, (3)extract the medial axes(centerlines) of the airways, (4) determine an appropriate route to the destination. An each of the planning components should be validated on a wide variety of patients and across a range of images generated by numerous MDCT scanners.

Step 1： Define the target is the first step during bronchoscopy. To minimize the time and improve the efficiency, 3D livewire method[12] is utilized to segment the region of interest(Fig 6).

Step 2： Effective bronchoscopic procedure planning requires an accurate 3D airway tree. The airway tree is generated by the system of Graham[13], which automatically extracts the vast majority of the lumen voxels within 2 to 4 min, generally producing segmentations containing hundreds of airway branches.

Step 3：The centerline analysis method is mainly used to extracts the central axes of the airway tree. These centerlines define virtual bronchoscopic trajectories through the polygonal airway surfaces.

Step 4： According to the geometry of both the bronchoscope and the airway tree, an appropriate route is computed to ensure that the bronchoscope can fit along the entire route.

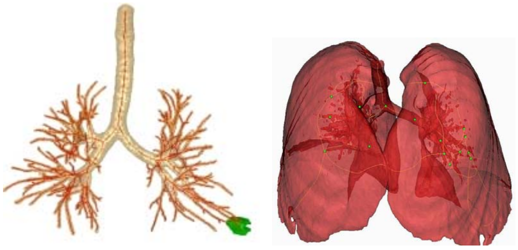

Figure 6. The 3D Surface Tool (left) provides a global view of the airway tree, centerlines (red), ROIs (green). The right shows the surface model of lung and its path planning.

III. EXPERIMENTAL RESULTS

In this thesis the standard graphics platform OpenGL has been used for visualization and implementation runs on a standard desktop computer with a standard monitor. A dataset provided by the National Library of Medicine is used for modeling the lung with anatomical details. This dataset consist of axial MRI images of the head and neck and longitudinal sections of the rest of the body. The CT data consists of axial scans of the entire body taken at 1mm intervals. The axial anatomical images are scanned pictures of cryogenic slices of the body. They are 24 bit color images of size 2028 by 1216 pixels. These anatomical slices are also at 1mm interval and coincide with the CT axial images. There are 1879 cross section for each modality.

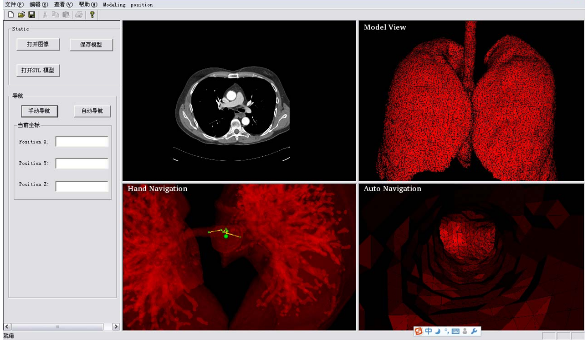

Figure 7. The layout of the virtual bronchoscopy system

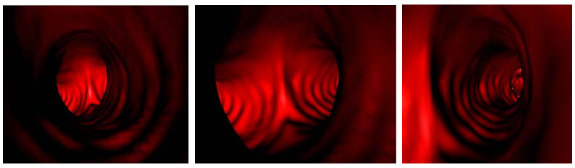

Figure 8. The virtual navigation of the surface model of lung.

The virtual bronchoscopy system is developed, which involves the global two-dimensional section images view, volume-rendered view, virtual endoscopic views (manual navigation and automatic navigation) as Fig 7 shows. The global two-dimensional section images view shows the human organ CT slice images, and you can change it between each slice from frame 0 to 80 using our keyboard. Volume render view shows the three dimensional organ model based on the CT images. Manual navigation view can see anywhere of human organ through the mouse and keyboard control, but automatic navigation view just see the target along the planning route in Fig 8.

IV. CONCLUSION

In this paper, we have constructed a main framework in virtual bronchoscopy system, and discussed several key techniques such as geometry modeling, physical modeling, computational modeling, collision detection, virtual navigation and so on. The experimental result shows that this system can not only show the anatomical structures of organ, but also reflect the physical properties. Although a virtual bronchoscope offers a unique opportunity for exploration and quantitation, it cannot replace a real bronchoscope.

REFERENCES

[1] Jeong YJ, Yi CA, Lee KS: Solitary pulmonary nodules: detection, characterization, and guidance for further diagnostic workup and treatment. AJR Am J Roentgenol, 2007, 188(1):57-68

[2] McAdams HP, Goodman PC, Kussin P: Visual bronchoscopy for directing transbronchial needle aspiration of hilar and mediastinal lymph nodes: a pilot study. AJR Am J Roentgenol, 1998, 170(5):1361-1364

[3] Tong-Yee Lee, Ping-Hsien Lin, et.al. Interactive 3-D virtual colonoscopy system. IEEE Transaction on Information Technology in Biomedicine. 1999, 3(2):139-150

[4] Tatsuhiko Nakasato, Makoto Sasaki, et.al. Virtual CT endoscopy of ossicles in the middle ear. Journal of Clinical Imaging. 2001, 25:171-177

[5] D. Buthiau, E. Antoine, et.al. Virtual tracheo-tronchial endoscopy: educational and diagnostic value. Surgical Radiologic Anatomy. 1996, 18:125-131

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