Interactive 3D Interface for Guiding an Ultrathin Catheterscope in the Peripheral Lung

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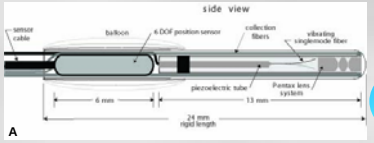
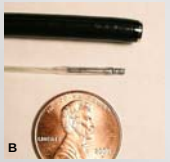
INTRODUCTION

Bronchoscopy involves the insertion of a fiber-optic bundle of CCD camera into the trachea and lower lobes of the central airways. This is the preferred method for visually inspecting the airway surface for irregularities or to biopsy suspicious masses identified on computed tomography (CT) scans. Because of the bronchoscope's large diameter, it is often restricted to airways that lie within the first 4 generations of branching yielding a total of 2^4 or 16 airways. Our lab is developing an ultrathin single-fiber scanning catheterscope[1] capable of extending into the peripheral lung where cancer often originates. The current prototype possesses an outer diameter of 1.6 mm, permitting its insertion into 8^{th} generation airways, totaling to 2^8 or 256 separate airways. This exponential increase in the number of airways now accessible to the bronchoscopist underscores the need for a navigation system that tracks the position of the bronchoscope tip and assists in guiding the bronchoscopist to a predefined region. We are developing a user-interface that allows the clinician to interact with a virtual surface model of the patient's airways. The software can be used to perform a virtual bronchoscopy through the airways, examine the radiological CT images, and to guide the user to specified location during an actual procedure by using a position sensor that is embedded within the scope's distal tip.

NAVIGATION SYSTEM

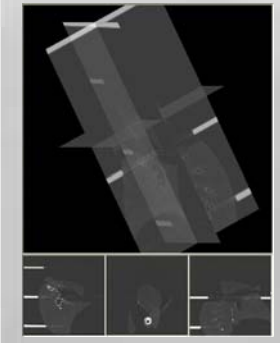
HARDWARE





The navigation system hardware is comprised of both the ultrathin catheterscope and an electromagnetic tracking system. A diagram of the catheterscope's distal end is presented (A) including the fiber, scan engine, lens system, and 6 degree of freedom (DOF) position sensor within a 1.6 mm outer diameter casing. The distal end of conventional bronchoscope and ultrathin catheterscope are shown relative to a U.S. penny (B). The tracking system (C) (microBIRD, Ascension Technology, Burlington, VT) includes a PC board, transmitter and two sensors.

CT SCAN



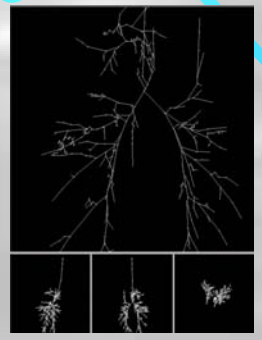
High resolution (512 x 512 x 300+) images provide detailed view of anatomy. The user interface allows the clinician to identify the position of a suspicious mass or select a specific region of interest by marching through slices within any of the three orthogonal axes. The images are scaled to present an accurate depiction of the volume dimensions. A CT scan of a dried sheep lung presented here has a transverse scan resolution of 0.68 mm, and an axial resolution of 1.25 mm. The small viewport windows display each slice from the sagittal, transverse, and coronal reconstructions.

DATA VISUALIZATION

VIRTUAL SURFACE

The virtual surface model is reconstructed from the CT data directly by segmenting the airways using previously developed image processing algorithms[2] and computing a triangulated surface mesh using the Insight Segmentation and Registration Toolkit (ITK). The surface model provides realistic virtual renderings of the anatomy so that a user can explore the airway space using the software or to generate a virtual "tip view" perspective using readings from the position sensor.

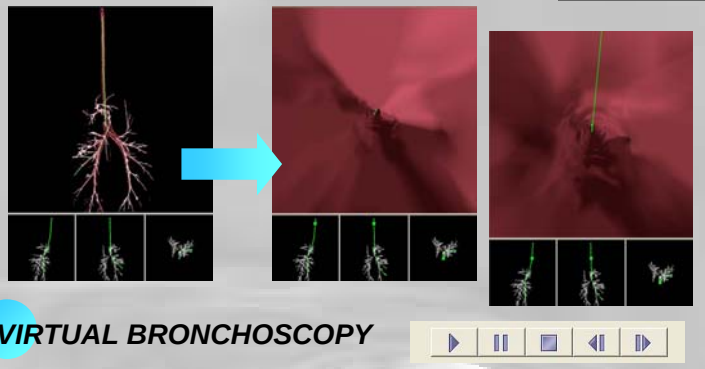
AIRWAY TREE



The airway tree is derived from the segmented airway volume via medial axis thinning using a variation of the method developed by [3] . The result is a 1-voxel thick component. The airway tree structure is subsequently computed by fitting B-spline curves to select voxels of each branch. The data structure also contains information on branch connectivity, where each branch has both a parent branch and a set of child branches.

INTERFACE FEATURES

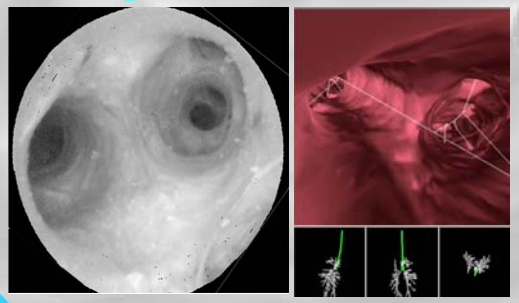
VIRTUAL BRONCHOSCOPY



The figure depicts virtual exploration of the trachea. A destination point is selected on the skeleton to construct a path through the model. Three subsequent frames depict virtual fly-through images of the trachea leading to the main carina. The position is displayed in green on the orthographic viewports

Virtual bronchoscopy is useful for pre-procedural planning during which the clinician can select single or multiple routes for obtaining biopsies. The path can be reviewed and altered while consulting the CT scan so that the clinician can come within close proximity of an identified mass. The software automatically defines the path required to navigate to the selected region from the trachea by using the branch connectivity information obtained within the airway tree data structure. The virtual view smoothly weaves its way through the virtual model by evaluating the spline curve equations that define each branch (see accompanying video) The virtual bronchoscopy can be played, stopped, stepped through, and paused, similar to a movie.

BRONCHOSCOPIC GUIDANCE



During bronchoscopic examination of the airways, the tracking system provides real-time measurements of the tip's position and orientation. Once the virtual model is registered to the subject in real space, the virtual and endoscopic views are aligned. The clinician can thus refer to the virtual model to be advised as to which path to take or to visualize the present position from an external view as presented in the bottom three viewports. The green path displays the intended navigation path, and the present position. Pictured above is an endoscopic view acquired from the ultrathin catheterscope and the corresponding virtual view.

RECORD KEEPING

During the examination, it can be difficult for the bronchoscopist to keep track of what regions have been explored, especially within the more peripheral lung where branch segments are small and densely distributed. The virtual model can be used to display the decision history of the examination, thereby optimizing the tissue sampling process and time cost associated with the procedure. The figure displays unexplored branches of the airway in white and those that have been explored in green.

REFERENCES

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3. Kiraly, A.P. *et al.* Three-dimensional path planning for virtual bronchoscopy. *IEEE Trans. Med. Imag.* 2004, 23 (9), 1365 - 1379

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