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

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ABSTRACT

Diagnosis of epithelial diseases is extremely dependent on a clinician's ability to identify suspicious masses or nodules on radiological images and obtain, via endoscopy, a representative tissue specimen for pathological analysis. Often, a potentially cancerous mass is so peripherally located or difficult to reach that the clinician decides to forego further examination. We have recently constructed an ultrathin catheterscope capable of reaching regions of the body that were previously inaccessible. However, navigating through a tortuous path to precisely locate and diagnose disease can be difficult. This is quite evident in bronchoscopy, where a clinician must maneuver through a complex series of branching airways to biopsy small nodules in the peripheral lung. In an attempt to improve diagnostic accuracy and assuage misguidance of the device, we have developed a user interface to merge both medical image data and a tracking system that records the position of the catheterscope tip in real-time. By tracking the catheterscope and tracing its movement on a virtual lung model, a clinician can be effectively guided to a precise point in the anatomy during a diagnostic procedure.

General terms: Design**,** Algorithms, Measurement

Keywords: Interface, medical, image, CT, endoscopy, endoscope, bronchoscopy, bronchoscope, ultrathin, surface, model, airway, lung, pathology

INTRODUCTION

On high-resolution computed tomography (HRCT) scans there is a high incidence of potentially cancerous masses appearing as radio-opaque nodules. "Screening" HRCT scans are now offered commercially to target patients at high risk for lung cancer. However, a majority of these lesions pose a difficult diagnostic problem because they are small and peripherally positioned in the lung, making them difficult to reach for tissue sampling. Whenever possible, bronchoscopy is the preferred method of extracting lung tissue for pathological analysis.

Bronchoscopy involves the insertion of a fiber-optic bundle or CCD camera into the trachea and lower lobes of the central airways. A small pair of forceps is then extended from the head of the bronchoscope to obtain a tissue sample. Though still invasive, this method is much safer and is not considered to have a traumatic effect. However, the large diameter of commercially available bronchoscopes restricts their entrance into small airways where nodules are common. We are developing an ultrathin fiber scanning catheterscope capable of accessing these small airways[1]. Our most recent prototype is 1.6 mm in diameter using a resonant fiber scanner at the distal tip. It possesses a maximum field of view of 70° and produces 500 line resolution, full-color images at a 15 Hertz frame rate. This device will afford clinicians a new view of pathology in the more peripheral airways and is predicted to improve diagnosis of disease through image-guided biopsy.

The lung is a series of bifurcating or branching airways ranging in diameter from 18 mm to 0.25 mm. Conventional fiber bundle bronchoscopes designed primarily for larger lumens are capable of reaching 5^{th} generation bronchioles amounting to a total of 2^5 or 32 separate airways. The ultrathin catheterscope is able to extend to the 8^{th} generation comprising a total of 2^8 or 256 distinct airways. The exponential increase in complexity underscores the need for some means of visually tracking the position of the catheterscope on a virtual model. A user interface has been designed, as part of a navigation system to assist in guiding the clinicians to one or many predetermined sites and monitoring the progress of the examination. Although designed for the lung, this interactive user interface can be applied to other branching organs and the cardiovascular system.

SYSTEM COMPONENTS

The key components of this navigation system are: 1) the ultrathin catheterscope; 2) an electromagnetic tracking system (EMT) that is used to track the position and orientation of the catheterscope tip; 3) a virtual surface model of the airways; 4) a virtual skeleton model of the airways; and 5) a 3D user interface that guides the clinician to a desired location in the anatomy.

The EMT is comprised of both a transmitter and a position sensor system (microBird, Ascension Technology). The location and orientation of the sensor is computed by measuring the current induced in the sensor by the electromagnetic field of the fixed transmitter. The sensor (1.3 mm O.D.) is encased in the distal tip of the catheterscope, and is tracked in 6 degrees of freedom in real-time, updated on the virtual model and displayed on the 3D graphical interface.

The virtual lung models (both surface and skeleton) are computed form directly from the CT scan itself. Prior to computing the model, the airway region is segmented from the CT image using previously developed algorithms[2].

From this data, a surface model is generated using the Insight Segmentation and Registration Toolkit (ITK), and a skeleton model is produced by medial axis thinning using a variation of the method in [3]. The surface model provides a realistic surface topography that is quite similar to the actual anatomy, allowing the clinician to more easily correlate virtual images with those obtained from the catheterscope. The skeleton model serves as a “roadmap” of the lungs; it contains segments, endpoints, and branch points and their connectivities so that the connection path between any two points is known.

INTERFACE DESIGN

The user interface as a tool reduces the level of geometrical complexity that a clinician must perceive to successfully navigate through the airways both quickly and efficiently. The application is sub-divided into three separate modes or tasks that facilitate information exchange with the operator. These three modes consist of pre-procedural planning, virtual navigation, and record keeping.

Pre-Procedural Planning

During pre-procedural planning, the user selects one or more regions of interest in the lung. To select a destination, the physician selects an identified pulmonary nodule or other region of interest by clicking on the CT scan. From this, adjacent branches in the airway skeleton are selected for inspection, and multiple routes that lead from the trachea to those branches are plotted as intended courses (Figure 1). The clinician can then watch a computer-generated virtual bronchoscopy session. In this session, a fly-through view of the virtual airway model is displayed and maneuvered from the trachea of the virtual model to the chosen destination. The clinician can then observe the virtual fly-through until sufficiently familiar himself with the proposed route to the destination.

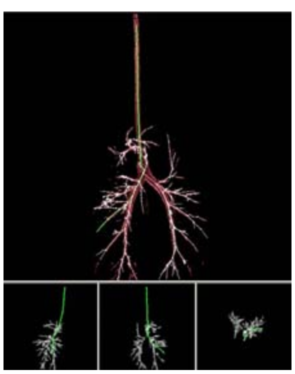

Figure 1: Interface displays a virtual surface model. The green line represents a path to a selected destination point. formed by segments of the virtual skeleton model.

Virtual Navigation

At the time of bronchoscopy, the clinician is equipped with both the ultrathin catheterscope providing images of the internal airway anatomy, and a virtual interface which provides a road map and directions to the destination. Before the procedure can begin, the coordinate system containing the virtual model must be aligned or registered to the real coordinate system in which the patient, catheterscope, and EMT reside. Fiducial points with known locations in the virtual model are located in real space with the EMT to determine the rigid transformation between these two coordinate systems. As the catheterscope is extended into the airways the user interface displays both the video from the catheterscope and the virtual manifestation at the location measured by the EMT system. The user interface indicates which path to take by means of a colored line segments. Way-finding through the main airways is helpful, but thorough inspection of a region through which multiple airways pass may require the clinician to diverge from the intended route in order to image or biopsy multiple sites surrounding a nodule. The interface can also display relevant information such as the distance from the nodule, and its direction relative to the current orientation of the catheterscope tip. The opacity of the surface model can also be reduced to allow the user to visualize relative distance from the region of interest, and sufficiently position the catheterscope or biopsy tool to various locations.

Record Keeping

Bronchoscopy relies on the clinician’s ability to mentally reconstruct the airway anatomy and keep tabs on where they have gone and where they need to go. This task is not all that daunting within the central lung where branching is less extensive, but as the catheterscope is extended further into the peripheral lung, structural complexity increases exponentially. The user interface provides an essential service by recording and visually indicating to the user those regions that have been explored, and those that have not. This reduces both the mental burden of memorizing the navigation “history” as well as minimizing the total procedure time and the tissue mass that is extracted from the patient. As well, the user interface can easily record a stream of position data from the tracking system to virtually re-inspect the airways following the examination. This navigation history can then be displayed on the surface model to give the user specific understanding of where the catheterscope was navigated, at what time it was at a given location, where biopsies were taken, what the clinical findings were, as well as retrieving the coinciding endoscopic images. This feature of the system is extremely useful given that it reduces time-cost while permitting post-review of the procedure for a follow-up examination or by another clinician at a later date.

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