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Virtual bronchoscopy method based on marching cubes and an efficient collision detection and resolution algorithm

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Abstract

A novel system for electromagnetic navigation in bronchoscopy (NaviCAD) to improve peripheral lesion targeting and diagnostic is currently under development. The virtual bronchoscopy module of this system, including the collision and resolution algorithm, together with some preliminary tests on a complex phantom are presented in this paper. The NaviCAD system consists of a planning and orientation software, a navigation forceps, and an electromagnetic tracking system connected to a computer running the NaviCAD software. NaviCAD can be used with any bronchoscopy system, it has a short set-up procedure time and learning curve. The system proves to be easy to use, accurate and useful for experienced users and novices, with precision in reaching targets in sub-segmental bronchi where a video-bronchoscope cannot reach.

Keywords: bronchoscopy; navigation; electromagnetic tracking; biopsy; lung diagnosis; virtual bronchoscopy.

1. Introduction

From the estimates of the International Agency for Research on Cancer regarding the worldwide incidence, mortality and prevalence of 26 types of cancer in the year 2012, it was shown that lung cancer was the most lethal one, causing 1.59 million deaths [1]. In order to diagnose lung cancer, medical doctors perform a trans-bronchial biopsy. First, this is planned by examining a number of Computed Tomography (CT) scan slices. Then, the procedure is performed by introducing a video bronchoscope into the bronchi as far as the diameter of the bronchoscope permits. With the bronchoscope, the doctor can see the larynx (voice box), trachea (windpipe), bronchi (large airways to the lungs), and bronchioles (smaller branches of the bronchi). Bronchoscopy can be combined with a procedure to collect pieces of lung tissue - the transbronchial lung biopsy. This procedure uses a flexible bronchoscope and biopsy forceps inserted through the bronchoscope working channel and is one of the easiest and safest methods in diagnosing such lesions. The success rate of the procedure is dependent on the size and location of the lesion and is lower in peripheral lesions and small lesions [2], compared with those of central and intermediate lesions. One of the reasons is that the forceps for transbronchial biopsy cannot reach small peripheral pulmonary lesions, due to the difficulty in maneuvering within the angles of the bronchi. Baaklini *et al.* [3] reported that lesions less than 2 cm in diameter had a diagnostic success of only 14% when located in the peripheral third, compared with 31% when located in the inner

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two thirds of the lung. When failure of the procedure occurs, pulmonologists must repeat the procedure or follow up with more invasive methods that have increased complication rates, such as CT-guided percutaneous (transthoracic) fine needle aspiration (FNA) or biopsy. Although the success rates of these techniques are very high, with 76-97% diagnostic accuracy [4], they have several shortcomings: they carry a risk of pneumothorax, or seeding the malignant cells along the biopsy path and into the pleural cavity. Shinagawa *et al.* used an ultrathin bronchoscope [2], but it has limited suction capability due to its extremely small working channel. Currently there are other technologies for guiding, like endobronchial ultrasound (EBUS) that is difficult to use for peripheral lesions due to dimension of the scope and x-ray fluoroscopy [2], [5] involving radiation for clinical personnel and patients.

More than 50% of lung targets are not accessible by conventional bronchoscopes due to the size of the constantly narrowing branches of the bronchial tree and due to orientation and maneuverability difficulties. Electromagnetic navigation bronchoscopy (ENB) is a guided bronchoscopic technique that allows accurate navigation to peripheral pulmonary lesions which cannot be reached by traditional bronchoscopy. The feasibility of electromagnetic navigation bronchoscopy (ENB) with a steerable instrument has been presented by Becker *et al.* [6] and Schwarz *et al.* [7].

A novel system called NaviCAD is currently being developed by the authors, for spatial guidance of a customized bronchoscopic forceps to reach peripheral targets within the bronchial tree, further than the diameter of the video bronchoscope permits. The technology uses preoperative CT images or other imaging techniques to create three-dimensional (3D) and virtual reconstructions of the region to be biopsied.

This paper describes the virtual bronchoscopy method from NaviCAD system, based on the Marching Cubes algorithm, used to calibrate and correct the path that the physician follows towards the lesions in the hard-to-reach periphery of the lung.

The preliminary tests of this procedure using a complex phantom prove that the system is easy to use and improves navigation through the bronchial tree. Further studies on phantom and large animals are planned to prove its efficacy for clinical and training usage.

2. General description of the system

NaviCAD is an image-guided navigation system including an electromagnetic tracking system (ETS) Aurora (NDI Inc., Canada) for spatial positioning and orientation tracking. Aurora is an electromagnetic spatial measurement system, which determines the location and orientation of objects that are embedded with sensor coils. When the object is placed inside a controlled, varying magnetic field, voltages are induced in the sensor coils. These induced voltages are used by the measurement system to calculate the position and orientation of the object. The magnetic fields are of a low field strength and can safely pass through human tissue [8].

The system is connected to a computer that runs a specific software application. It features also single-use navigation forceps for biopsy with electromagnetic sensor to determine its spatial position and orientation in the magnetic field. The NaviCAD software uses multiple technologies for anatomy 3D reconstruction, registration, manual calibration and navigation, with two main screens for user interface.

The system can compute the instantaneous position of biopsy forceps tip related to the patient and CT space. When the bronchoscope diameter is too big to advance in the sub-segmental bronchi, the user extends only the navigation forceps further to the peripheral target. The navigation is performed using the virtual bronchoscopy visualization in the NaviCAD system and the instantaneous position of the forceps tip overlaid on the 3D model. The biopsy using the forceps can be performed when the target is reached. Improved diagnosis is accomplished via enhanced navigation and targeting.

3. The virtual bronchoscopy procedure

In virtual bronchoscopy (VB), a computer simulation of the video bronchoscope image from the bronchoscope camera [9] is created from the 3D CT volume, with the same view angle and zoom setting. More precisely, the VB is the descriptive term given to an indirect or artificial (virtual) visualization of the bronchi and surrounding structures created from spatial information derived from imaging sources other than the bronchoscope itself (usually from CT) [9]. VB is valuable for procedure planning and during bronchoscopy; when the video display is not available due to e.g. reduction of eyesight by blocked camera from mucus or blood, reduced view by swelled tissue [10], or when navigation of tracked tools are outside