A novel fusion imaging guiding system for bronchoscopy

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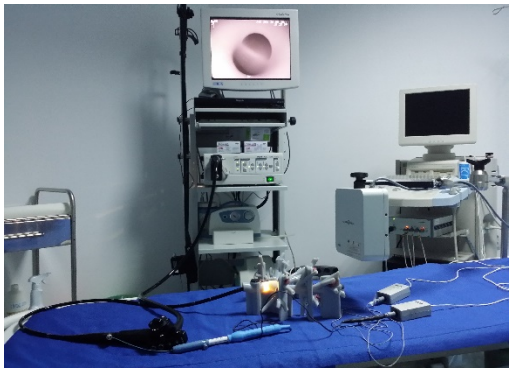
Background

Lung cancer is the most deadly cancer being responsible for 28% of all cancer deaths and causing 1.3 million deaths worldwide every year [1]. Currently, to diagnose lung cancer, pulmonologists plan the transbronchial biopsy procedure by examining a number of Computed Tomography (CT) scan slices before the procedure. Then they manipulate a video bronchoscope into segmental and sub-segmental bronchi as far as the diameter of the bronchoscope permits. Finally, they insert a biopsy forceps through the working channel of the bronchoscope, and, often (if the lesion is beyond the visual reach of the scope), blindly perform the biopsy. The diagnostic success rate is dependent on the size and location of the lesion. Consequently, a large percentage of the procedures fail to reach peripheral targets. When these failures occur, pulmonologists must repeat the procedure or follow up with more invasive methods that have increased complication rates, such as CT-guided percutaneous needle biopsy with increased level of radiation for surgeon and patient or surgical biopsy with high stress for patient.

At present there are other technologies for guiding like endobronchial ultrasound (EBUS) but they are still difficult to use for peripheral lesions and computed tomography fluoroscopy involving radiation for surgeon and patient [2]. The feasibility of electromagnetic navigation bronchoscopy (ENB) with a steerable instrument has been previously presented [3].

In the present study we developed a new fusion imaging system (FIS) for spatial guidance of a bronchoscopic forceps to reach peripheral targets within bronchial tree, outside the range than the video bronchoscope can reach. We tested the FIS for ease of use and improvement of navigation time on a bench top phantom, which simulates the bronchial tree.



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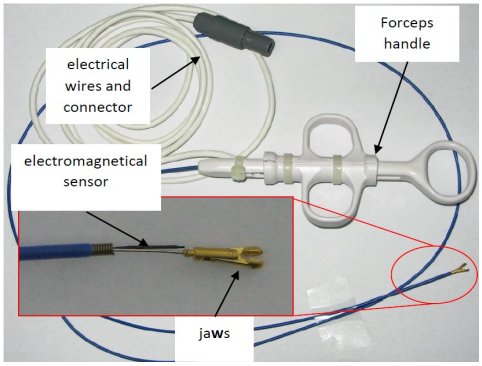

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Figure 1. A. The GI room setup for EUS procedure using Transbite system. B. The navigation forceps for biopsy.

Methods

The FIS includes an electromagnetical tracking system (ETS) AURORA (Northern Digital Inc., Ontario, Canada) for spatial positioning connected to a computer that runs a proprietary navigation software application, a disposable navigation forceps for biopsy, and an active marker placed on the patient's skin. For a bronchoscopy procedure using FIS, the patient is moved from CT/MRI procedure to the interventional room where a specific set-up is necessary (Figure 1). The personal computer is connected to the video bronchoscope and the ETS system. The magnetic field generator is mounted on the bronchoscopy bed close to the patient, and the active marker (with positioning EM sensor) is placed on the patient's xiphoid bone. The navigation forceps is introduced in the bronchoscope's working channel and connected to the ETS. The navigation forceps is similar to a biopsy forceps for bronchoscopy and includes a 6DOF electromagnetic sensor at its tip to determine its spatial position and orientation in the AURORA magnetic field.

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The FIS assisted bronchoscopy procedure starts by launching the software and loading the patient's CT data. The navigation software uses multiple technologies for anatomy three-dimensional reconstruction, image-to-patient registration, manual calibration and navigation. The user loads the sagittal, coronal and transverse CT planes. The system automatically develops airways segmentation, semi-automated lung nodule segmentation, multiple targets selection (eight maximum), virtual bronchoscopy visualization and geodesic minimal path extraction and displayed it in the first screen window.

While navigating through the CT planes, the user finds the place of the active marker on patient's skin to be used for the initial registration. Next the user indicates on the virtual bronchoscopy or CT windows the entry point of the procedure and the anatomical target and then selects a pathway between the two points by picking several points along airways to create a median line between them.

The FIS can compute the instantaneous position of its tip relative to the patient and CT space and continuously overlaying it on the 3D model. Following the path to the target lesion in the bronchial tree, the user visually compares the live and virtual images of the bronchoscope video and can correct the registration by translating and rotating the virtual bronchoscopy while keeping the bronchoscope still, until the two images are similar.

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 image and the instantaneous position of the forceps tip overlaid on the 3D model. The user is also able to investigate surrounding tissues using the virtual CT section. The biopsy using the forceps can be performed when the target is reached.

The navigation software modules are developed using ITK, VTK and IGSTK open source libraries, to co-register the information from two imaging modalities (http://www.igstk.org/) [4, 5]. The virtual bronchoscopy was developed based on a GPU implementation of the Marching Cubes algorithm for extracting surfaces from volumes using OpenCL and OpenGL. This algorithm has 6 stages:

1. Data storage as a 3D texture on a NVidia Quadro 6000 model GPU.
2. Base level construction of the histogram pyramids.
3. Histogram pyramid construction on a set of ND Range kernel calls in OpenCL.
4. Memory allocation on the graphics card (VBO) for all vertices and nodes needed to store the surface.
5. Histogram pyramid traversal when the memory is filled with the output of the Marching Cubes algorithm by running a ND Range kernel of the same size as the total sum of triangles.
6. Render. The vertices and normal are stored in the VBO made in the previous step.

For the FIS feasibility testing, a complex shape phantom of lung airways is used. A 3D CAD model was designed using SolidWorks by segmentation and surface reconstruction using a patient's CT scans. The phantom was created on a precision Objet260 Connex 3D printer from a rigid material VeroGray RGD850. Seven tumor models from ceramic powder, with diameters between 10-25mm were placed 110-254 mm deep inside the bronchial branches.

As active marker for this tests was used an Aurora 6DOF Reference, 25 mm disc from NDI (part number 610066) and the exact position and orientation of the tumors on the phantom were measured using the Aurora system by touching every target with a 6DOF Probe, Straight Tip, Standard (part number 610065). A check between CAD model and phantom model was performed using measured data, using the marker as reference and the tumors were located on the CAD model with a precision under 1 mm. The phantom and CAD model are used to test the navigation utility and accuracy, by steering the forceps in the tumor closest proximity, for locations where bronchial diameter is to small for bronchoscope.

Results

The feasibility tests were performed by three engineers and two experienced pulmonologists with instructions from the developer (LGG). An Olympus Bronchoscope was used in a bronchoscopy procedure room, at the Emergency Hospital from Craiova, Romania. There were seven "tumor" targets that the users had to reach at different depths inside the airway tract phantom. The absolute error (distance from the bronchoscope tip to the target) and the procedure time were measured. The engineers reached the targets in 79.5±2.7 sec with the FIS (8.3±0.5 mm error) vs. 204.2±3.7 sec with the bronchoscope alone (28.7±5.5 mm error). In comparison, the pulmonologists reached the targets in 71.3±7.9 sec with FIS (8.4±1.8 mm error) and 74.3±7.1 sec with the bronchoscope alone (16.2±3.3 mm error).

Interpretation

The preliminary tests using a complex phantom proved the FIS is easy to use and improves navigation through the bronchial tree in both unexperienced and experienced operators. Further studies on phantom and large animals are planned to prove its efficacy for clinical and training use. In addition, in the NAVICAD project (EEA grant), we will further automize some of the steps for navigated bronchoscopy. This research was supported in part by ANCS-CNDI-UEFISCDI from "PNII - Joint Applied Research Projects" program, contract number 87/2012, and code PN-II-PT-PCCA-2011-3.2-0482; and the EEA Financial Mechanism 2009-2014, project contract no. 3SEE/30.06.2014.

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