Physician-Controlled System for Image-Guided Bronchoscopy

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1. Background

The standard unguided approach to navigating the bronchoscope through the airway tree is very challenging, resulting in navigation errors as early as the 2nd–generation airways.[1] While image-guided intervention (IGI) systems have proven to be effective for bronchoscope navigation, they typically require two people to operate: the bronchoscopist and an attending technician.[2,3,4] This limits the practicality of such systems for more routine use. We present an IGI system that enables direct control by the bronchoscopist.

2. Materials and Methods

The system operates over two stages, as summarized by Figures 1-2.

Stage 1: Procedure planning

The bronchoscopist identifies lesions of interest using the patient's 3D multidetector computed-tomography (MDCT) chest scan. Automatic computer-based methods drawing upon the MDCT scan then derive navigation routes through the airways leading to each lesion. Given these data, follow-on automatic processing computes a set of navigation directions for each route, where the directions suggest how to navigate the bronchoscope toward a lesion along its preplanned navigation route. With reference to Figure 2, CCW = rotate the bronchoscope counterclockwise; CW = rotate the bronchoscope clockwise. After these preplanning operations, the bronchoscopist previews the navigation routes and directions on a tablet computer.

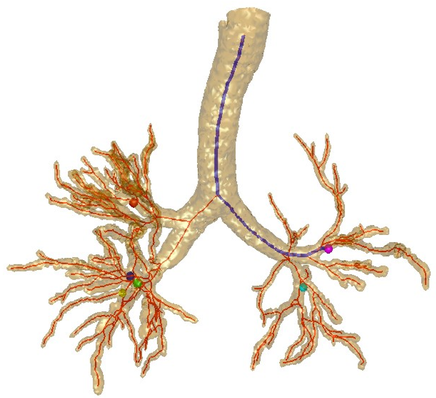


Figure 1. After the bronchoscopist identifies lesions of interest (colored spheres), the system automatically extracts the 3D airway tree, airway centerlines (red), and specific navigation routes for all lesions. The blue line indicates the navigation route for the magenta-colored lesion (case 20349.3.65).

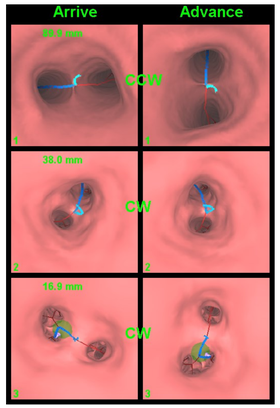
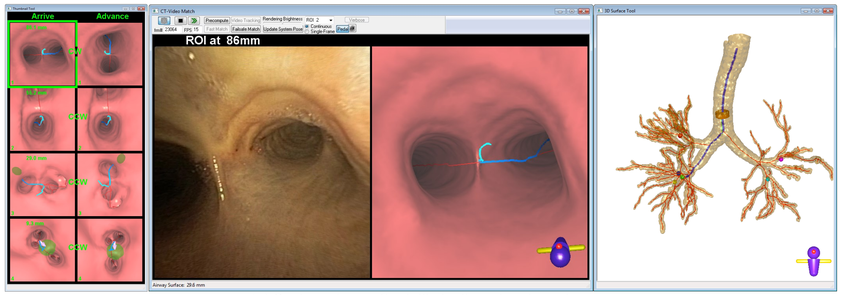


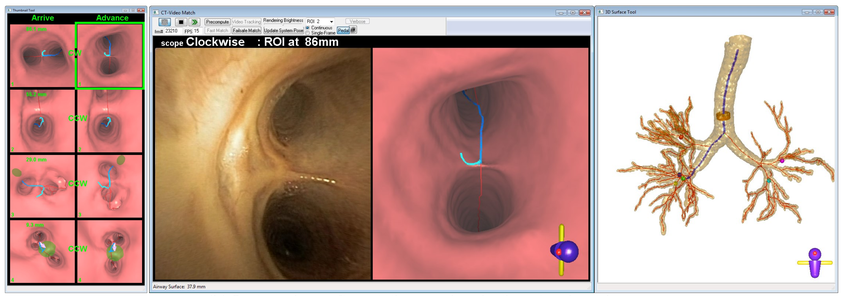
Figure 2. The system computes specific bronchoscope navigation directions for each lesion, as shown above for a specific lesion. Each row presents the bronchoscope movements to make at each bifurcation. The left view depicts the desired view upon arriving at a bifurcation, while the right view shows the bifurcation after performing the desired bronchoscope rotation (middle) .

Stage 2: Image-guided bronchoscopy

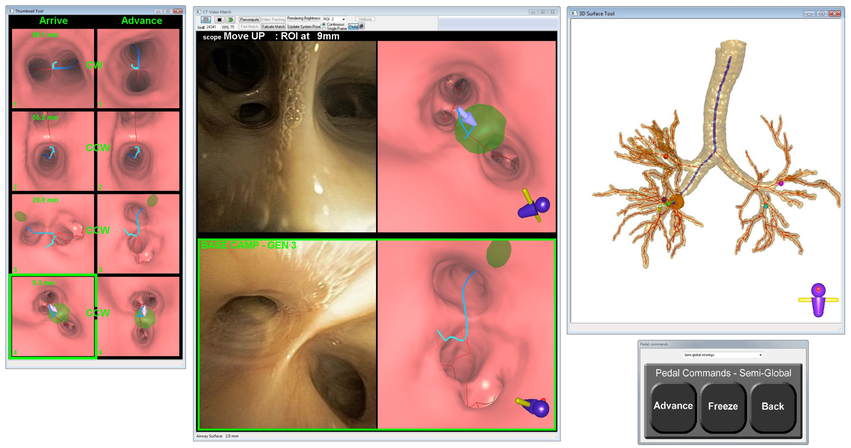
Before bronchoscopy, we channel the bronchoscope's video output into the IGI system and initialize the system's guidance display as shown in Figure 3. During bronchoscopy, the bronchoscopist controls the system through a 3-pedal foot switch. Switch commands (advance, freeze, back) trigger updates to the system's guidance display. For example, activation of the advance command moves the guidance display distally one bifurcation as the bronchoscopist follows along directly, referring to the navigation directions as needed.



(a) System views after initialization at main carina



(b) System views after rotation synchronization at main carina



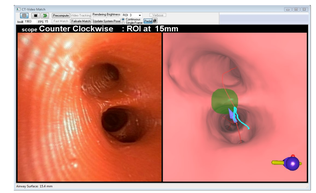
(c) System views after arrival at lesion site

Figure 3. IGI system views at three of the sites along the lesion route during live bronchoscopy (20349.3.65). The above figure shows the three visualization tools used to guide the bronchoscopist. The Thumbnail tool is the left-most tool and is described in Figure 2. The CT-Video Match tool is the tool in the center. This tool depicts the bronchoscopic video side-by-side with the virtual views. Lesion localization information is also presented in this tool as shown in (c). Views from the previous bifurcation are "frozen" at the bottom of the tool for the bronchoscopist's reference. The 3D Surface tool is the right-most tool and shows the global position of the bronchoscope in the airway tree. The dialog at the bottom-right shows the commands (advance, freeze and back) associated with each of the three foot-pedals used by the bronchoscopist. In (a), the system is initialized at the main carina. A green rectangle highlights the corresponding virtual view in the Thumbnail tool. The bronchoscopist then uses the foot-pedal to advance the system position. The system carries out the precomputed rotation and in the Thumbnail tool, the green rectangle advances to the rotated view. The bronchoscopist then follows this rotation and the synchronized virtual and bronchoscopic views are shown in (b). This process continues with the system leading and guiding the bronchoscopist until the lesion is reached, as shown in (c).

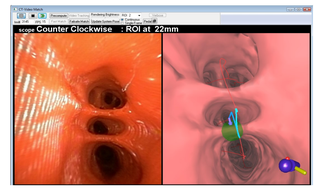
3. Results and Discussion

We first tested the system using two MDCT-based human airway-tree phantoms with lesions as summarized below. Using the IGI system, we successfully guided the bronchoscope to all sites, with no assistance from a technician, using the precomputed bronchoscope maneuvers associated with the planned routes. Figure 4 shows final sampling sites for two of the lesions in the two phantoms.

Case	# of lesions	Route Depth (airway generations)	Route Length (mm)
20349.3.48	4	6 ±1.4 (range: 5-8; median = 5.5)	215±14 (range: 198-233; median = 214)
21405.3a	5	4.2±1.3 (range: 3-6; median = 4)	148±19 (range: 121-167; median = 144)



(a) Lesion at right intermediate bronchus



(b) Lesion at left lower lobe bronchus

Figure 4. Figures (a-b) show the CT-Video Match tool at final sampling site for lesions of the two airway phantoms. Left image: lesion in airway phantom 21405.3a. Right image: lesion in airway phantom 20349.3.48.

We next performed a human study to test system safety and feasibility in clinical conditions. Image guidance was successful in all cases, with the terminal route branch being reached for 5 of 8 sites; for 3 sites, the bronchoscope's diameter exceeded more distal airway diameters. A summary of the results is presented below. Sample IGI system views along one of the lesion routes are shown in Figure 3. A preliminary pilot study involving four additional human subjects indicated that the system performed smoothly in all cases.

Case	# of lesions	Route Depth (airway generations)	Route Length (mm)	Navigation Time (secs)
20349.3.65	8	6.5±2.0 (range: 5-11; median = 6)	154±11 (range: 135-175; median = 154)	39±15 (range: 21-58; median = 35)

4. Conclusion

The self-guided IGI system has considerable potential for bronchoscope navigation and proved to be safe and feasible in a clinical environment. We believe this development could greatly improve the practicality of such systems for more routine use. The system's navigation directions could also help coach novice bronchoscopists and can adapt to the preferences of a bronchoscopist.

References

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Acknowledgments

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