

Technician-free system for image-guided bronchoscopy

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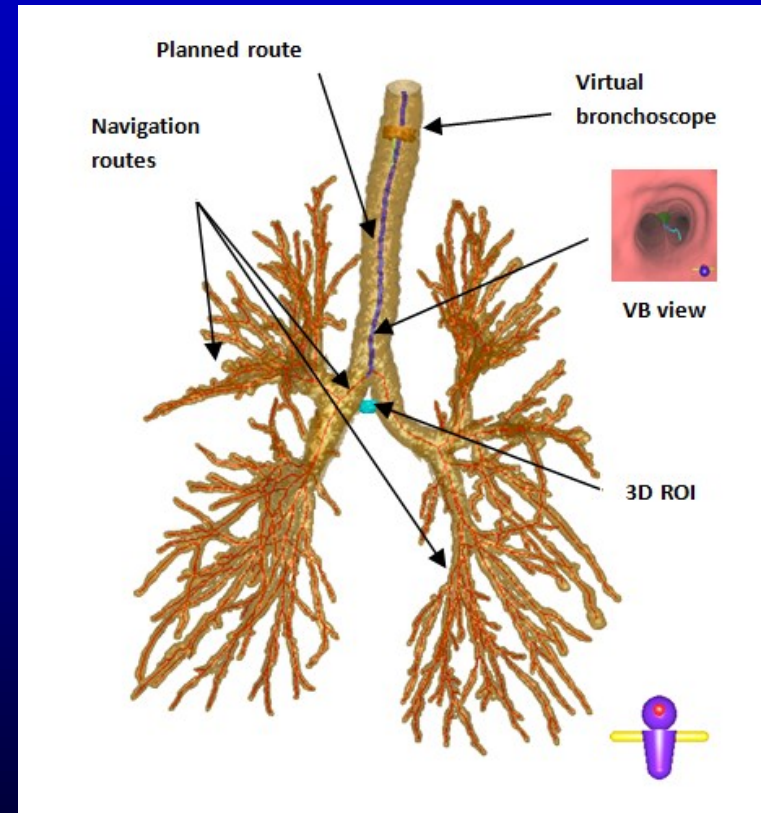
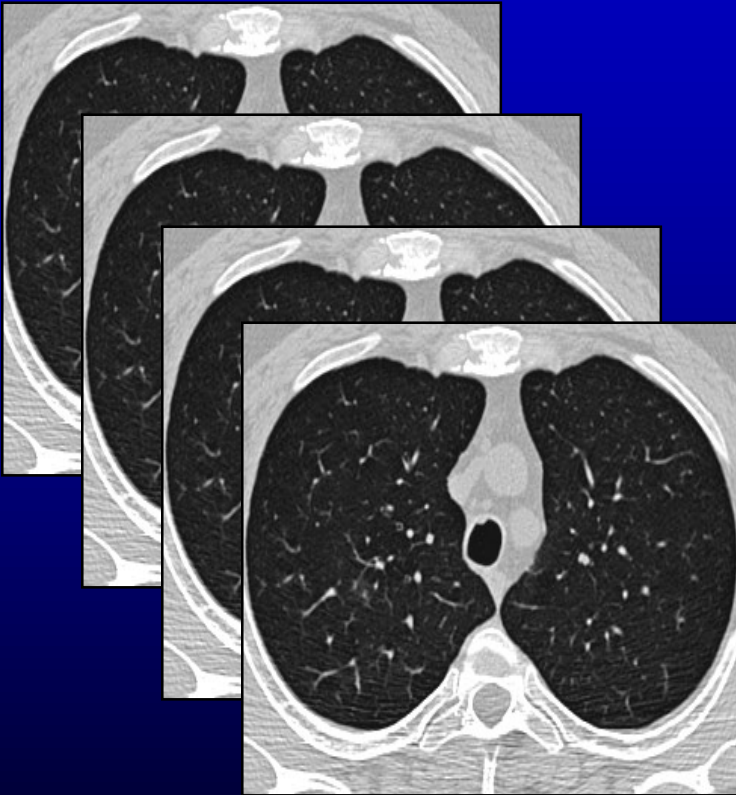
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*SPIE Medical Imaging 2013:
Image-Guided Procedures, Robotic Interventions and Modeling
Orlando, FL, 12 Feb. 2013.*

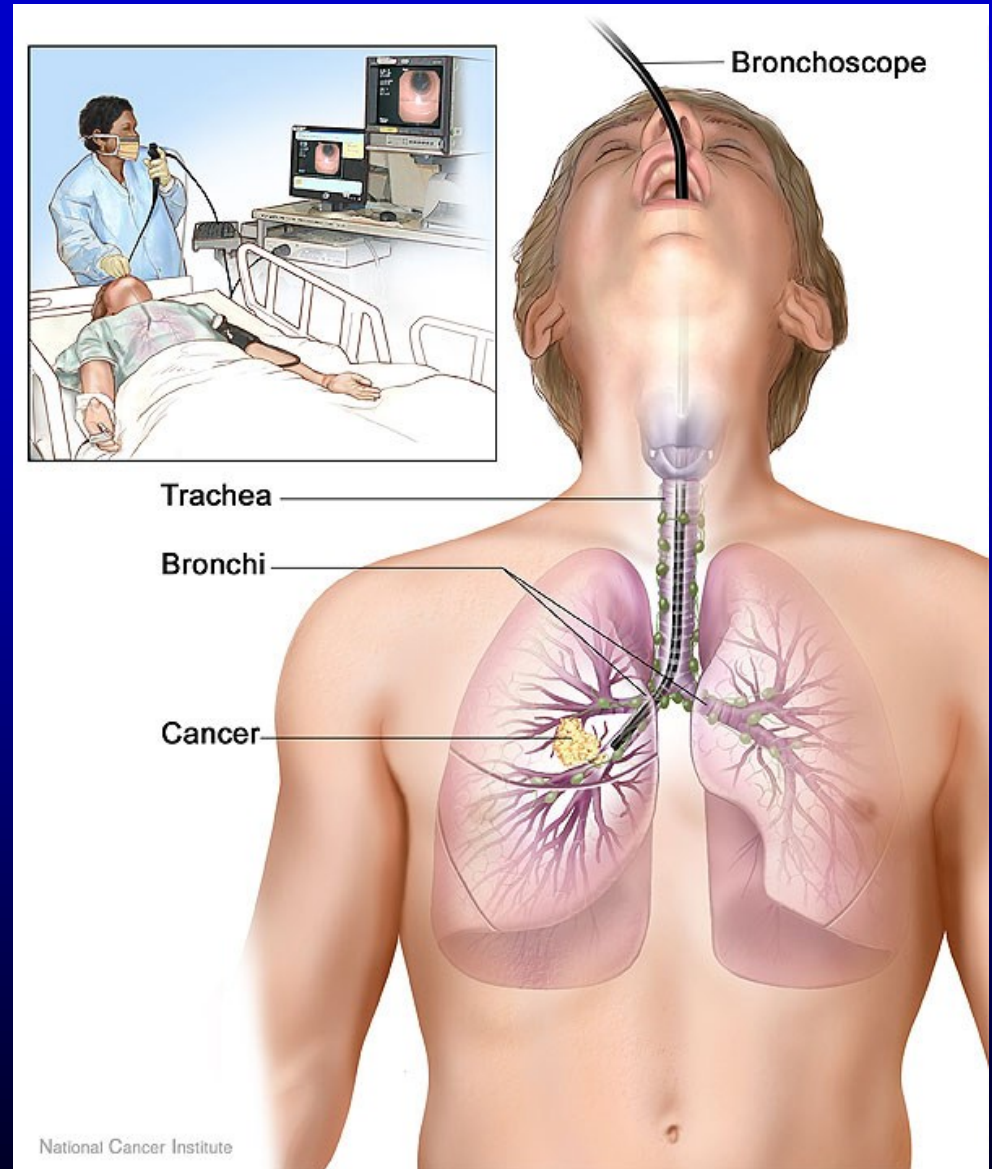
Lung Cancer Assessment

1. 3D MDCT image-based planning



Lung Cancer Assessment

1. 3D MDCT image-based planning
2. Follow-on diagnostic bronchoscopy



Bronchoscopy Guidance Systems

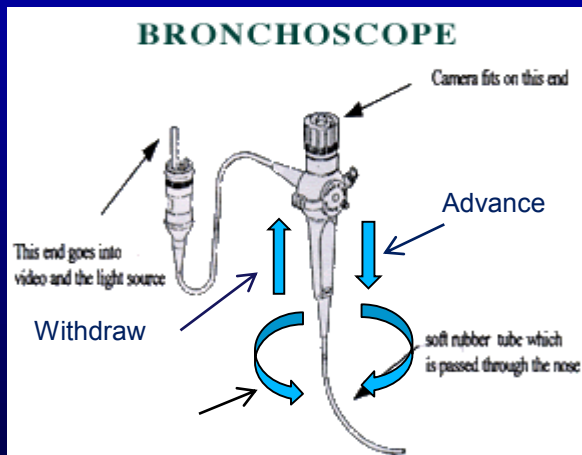
- “Manual” lung cancer assessment is HARD!!
- EM-, image-, and sensor-based bronchoscopy guidance systems mitigate difficulty, but
 - Need an attending technician
 - Need extra hardware
 - Unable to detect faulty maneuvers
 - Lengthy re-synchronization after adverse events

Our Approach to Image-Guided Bronchoscopy

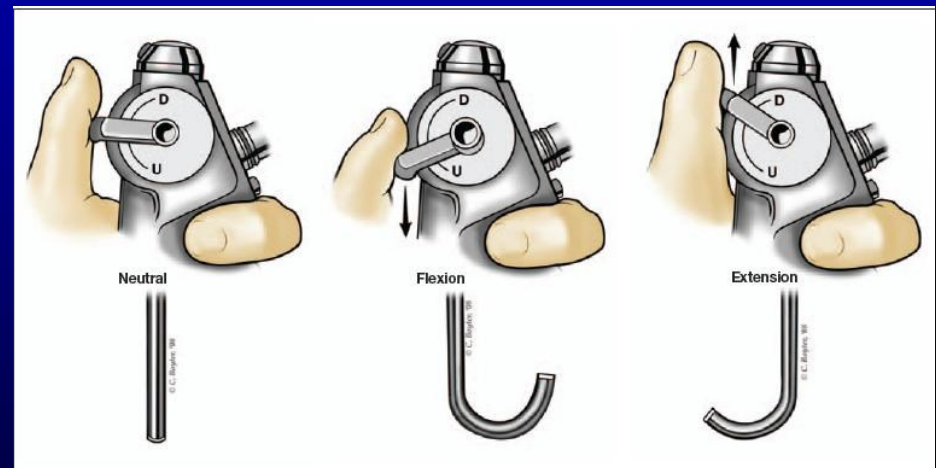
1. Pre-procedure planning – *Khare SPIE MI 2011*
 - Compute natural bronchoscope navigation maneuvers
2. Bronchoscopy navigation – *Khare SPIE MI 2010 & 2012*
 - Technician-free guidance
 - Enable bronchoscope position verification
via global registration

Precompute Guidance Paths using standard bronchoscope maneuvers

1. **Rotate** bronchoscope to left or right
2. **Flex** bronchoscope tip
3. **Advance / withdraw** bronchoscope

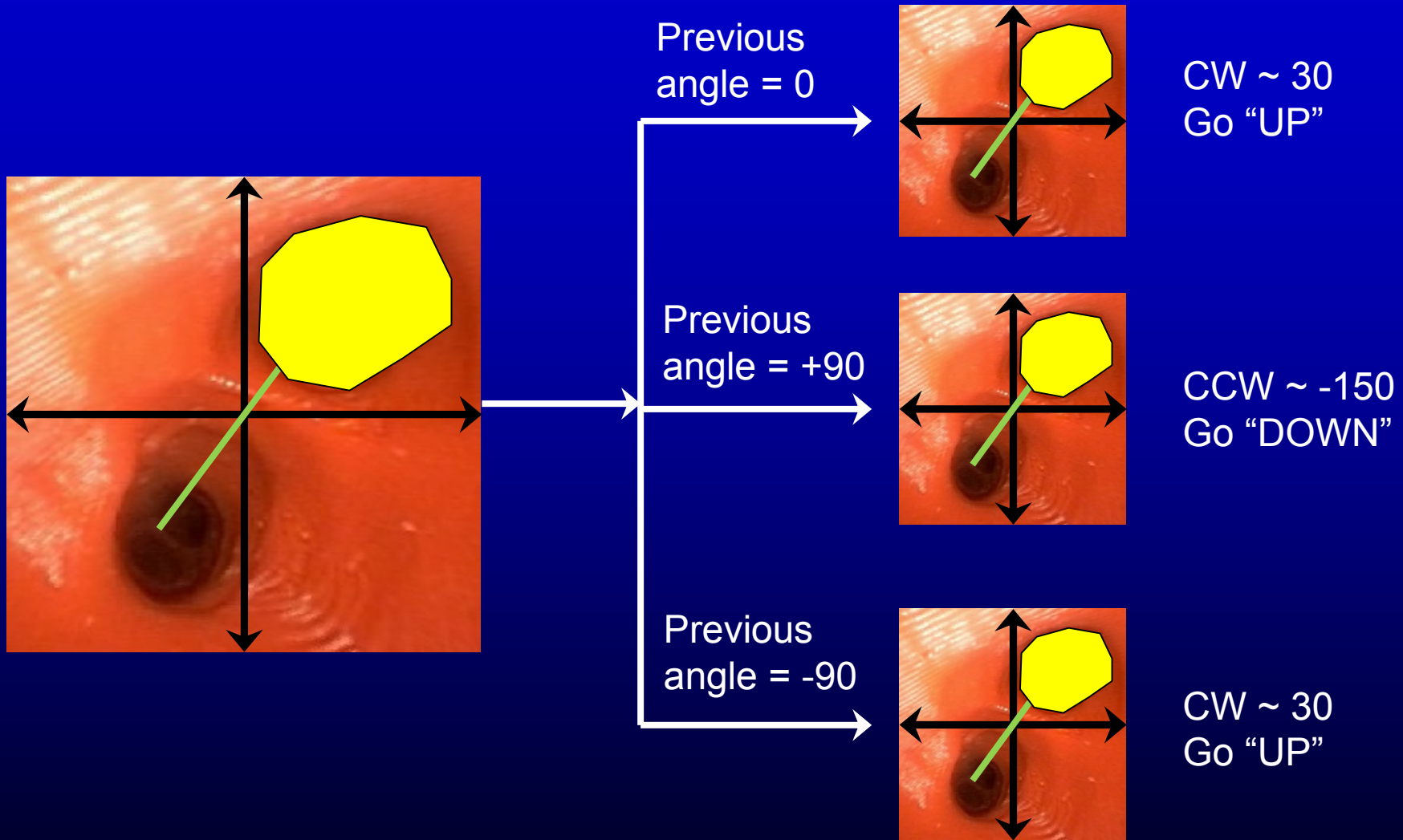


Source: <http://cfccenter.stanford.edu/education/Bronchoscopy.html>



Source: J. Respiratory diseases, 29(11), "The technique of adult flexible bronchoscopy: Part 1," K. Y. YONEDA, B. M. MORRISSEY

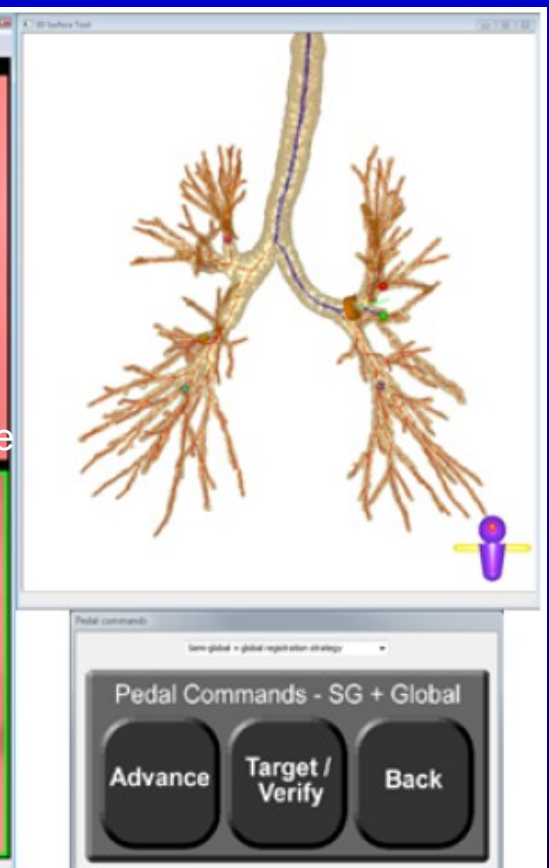
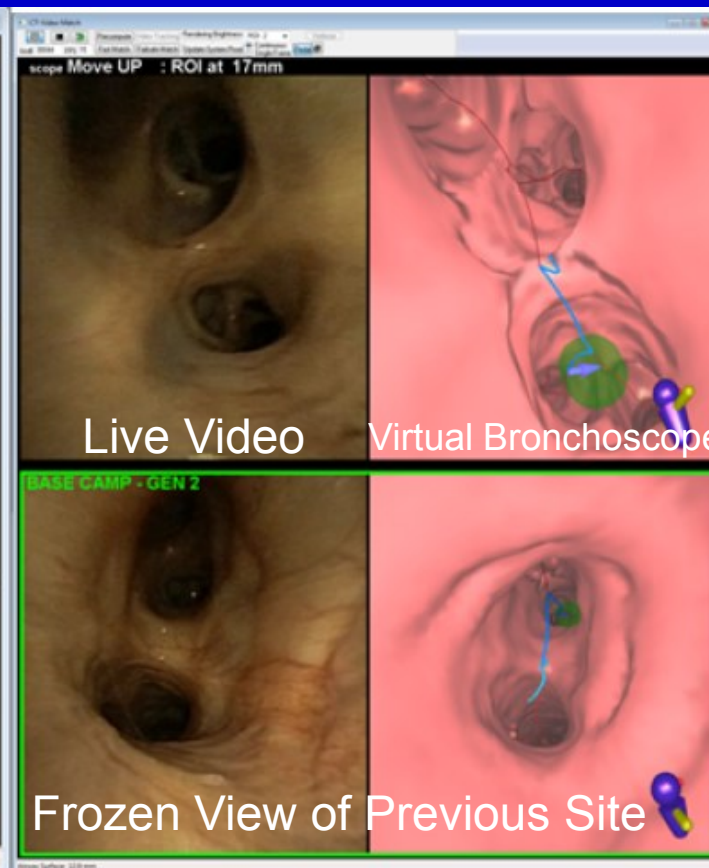
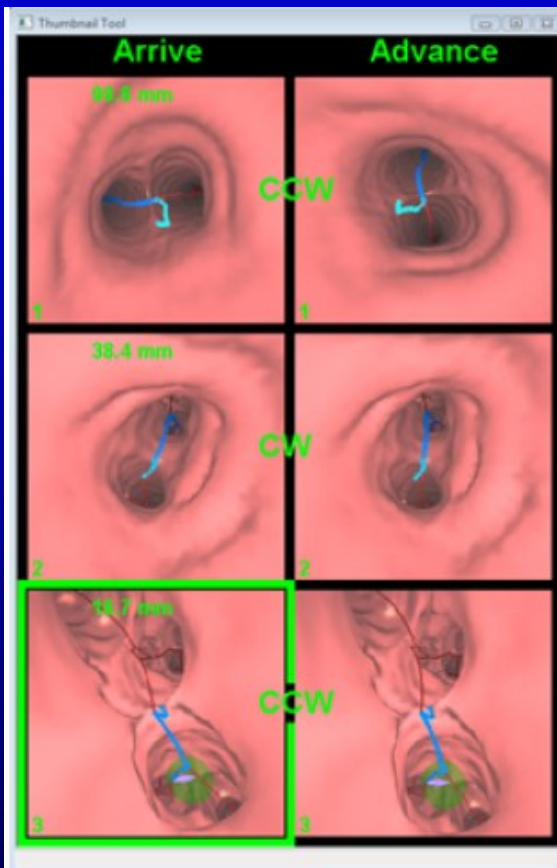
Pre-Procedure Planning



Positive angle: CW rotation
Negative angle: CCW rotation

Guidance Computer Set-up

3D Surface Tool

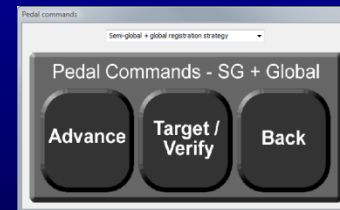
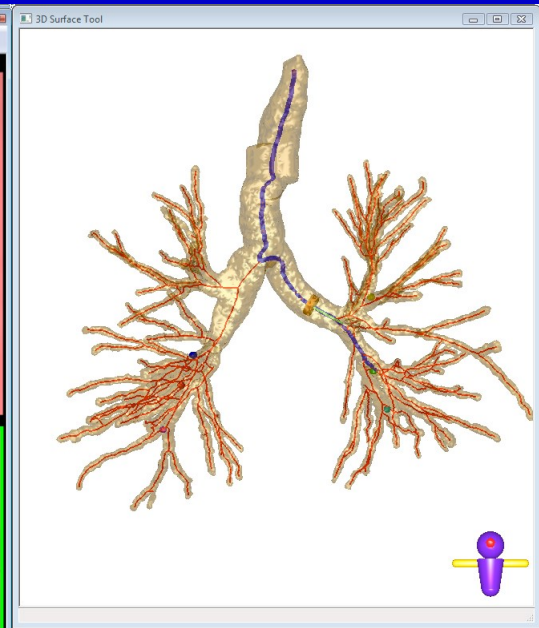
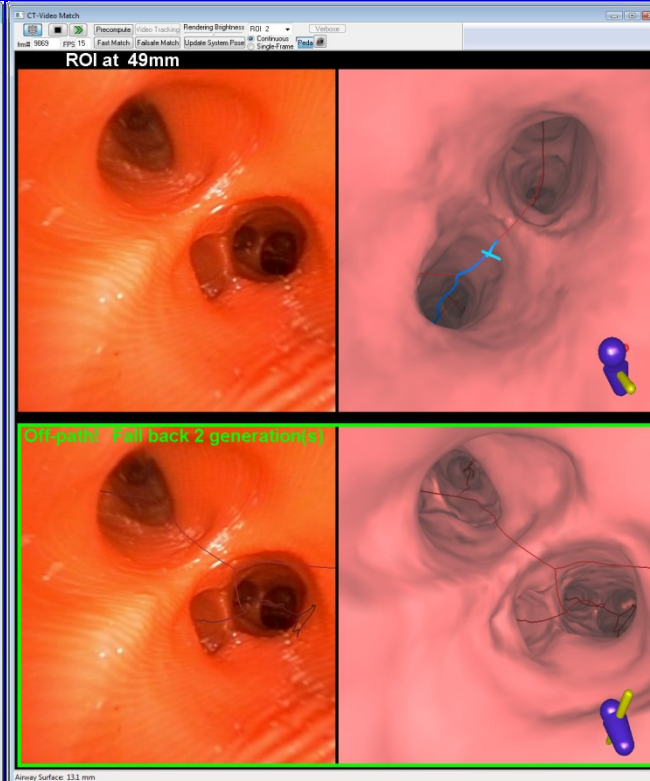
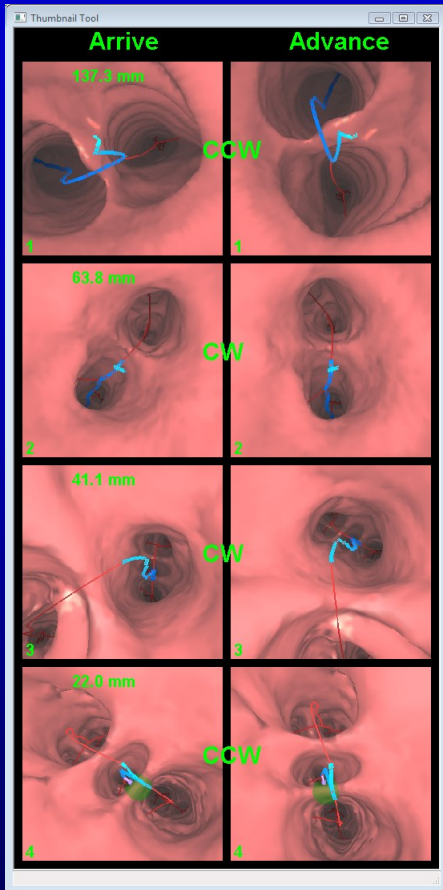


Thumbnail Plan Tool

CT-Video Guidance Tool

Foot pedal Commands

Guidance Strategy

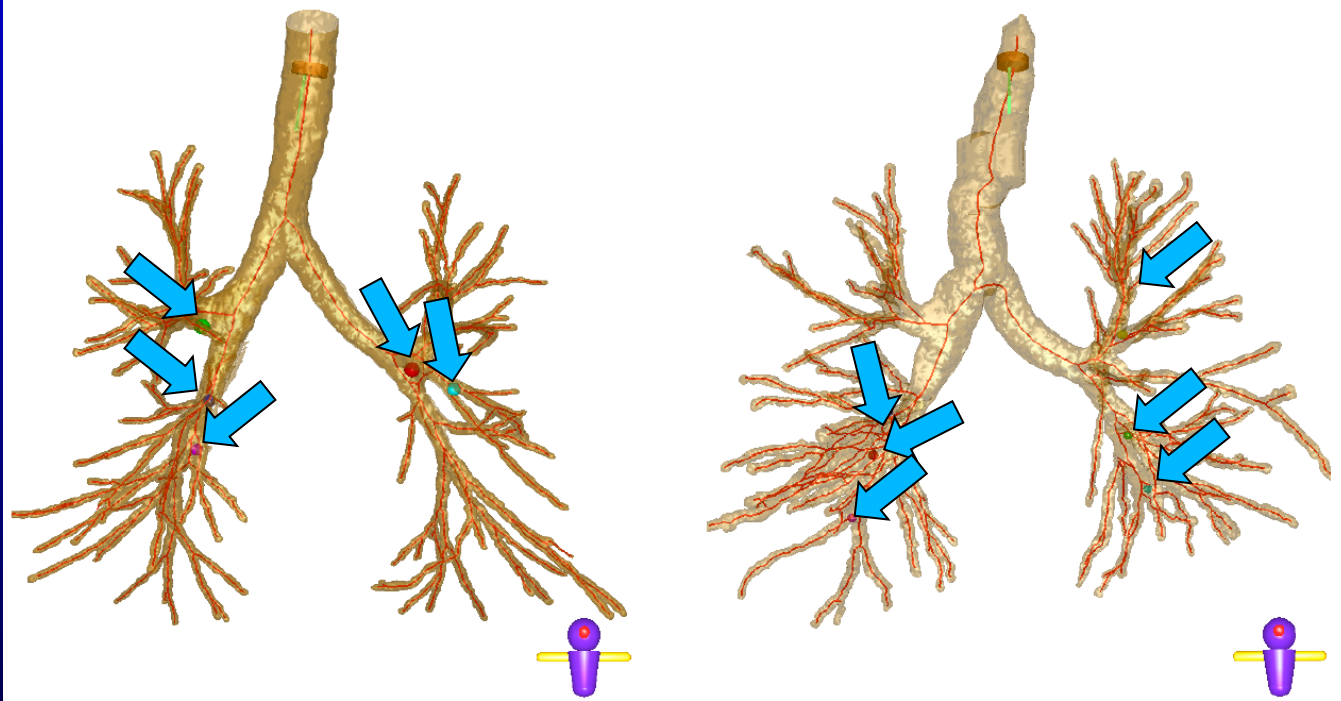


- 1. Real and virtual bronchoscopes positioned at manubria.
- 2. Established a path by the operator's best judgment for minimizes global registration.

1) Phantom Study Results

Table 1. Phantom case study specifications.

Phantom #	Scanner	Image Dimensions (X×Y×Z)	Resolution ($\Delta x, \Delta y, \Delta z$) in mm
21405.3a	Siemens Sensation-16	512×512×706	0.67,0.67,0.5
20349.3.48	Phillips Gemini True Flight	512×512×373	0.7,0.7,0.8



Phantom 1: 5 ROIs

Phantom 2: 6 ROIs

Phantom Study Results

- Successful guidance to ALL ROIs
 - “success” = reach final airway
- Bronchoscope navigation as deep as airway generation 12
- ROIs 4, 5 for 21405.3a: penultimate airway generation reached

Phantom #	ROI #	Location	Airway generation	Route length (mm)	Guidance time (secs)
21405.3a	1	LMB	2	144	28.1
	2	RMB	2	121	33.5
	3	RLL	3	143	31.4
	4	RLL	5	165	50.9*
	5	LUL	5	167	41.4*
20349.3.48	1	RLL	8	214	79.9
	2	LLL	6	233	54.5
	3	RML	5	199	43.6
	4	RLL	12	264	88.1
	5	LLL	9	274	77.3
	6	LUL	5	213	45.5

* Indicates bronchoscope unable to reach last airway generation

Phantom Study video (earlier system version)

The screenshot displays a software interface for "CT-Video Match". The main window is split into two panels showing a video sequence of a phantom study. The left panel shows a close-up of a circular structure, and the right panel shows a similar view with a blue hand-drawn arrow pointing to a specific feature. A small 3D model of a sphere with a red dot and a green line is visible in the bottom right corner of the right panel. The text "Dist to ROI= 138mm (Air: 14.6, Length: NA)" is displayed at the top of the main window. Below the main window, the text "Airway Surface: 14.6 mm" is visible.

The "Guidance Dialog" window on the right contains the following information:

- Guidance information:
 - Rotate RIGHT
 - Move DOWN
- Past registration information:
 - No History
- Current status:
 - Mode: Segment

The "Thumbnail Tool" window at the bottom shows a grid of 10 thumbnails, arranged in two rows of five. Each thumbnail is labeled "Gen 1" through "Gen 5" in green text at the bottom. The thumbnails show a sequence of frames from the video, with a blue hand-drawn arrow in each frame pointing to the same feature as in the main window. The first thumbnail in the top row is highlighted with a green border.

2) Human Pilot Study: Results

- 9 consented patients; 39 total ROIs
- Bronchoscopes used: Olympus BF 1T180 (6 mm) or BF P180 (4.9 mm)
- Physician underwent multiple training sessions during study
- Physician previewed preplanned routes before each procedure

Case #	Scanner	Image Dimensions (X×Y×Z)	Resolution ($\Delta x, \Delta y, \Delta z$) in mm
20349.3.65	Siemens Sensation 40	512×512×274	0.62,0.62,0.8
20349.3.66	Siemens Definition	512×512×381	0.66,0.66,0.5
20349.3.67	Siemens Sensation 40	512×512×652	0.74,0.74,0.5
20349.3.68	Siemens Sensation 40	512×512×655	0.62,0.62,0.5
20349.3.69	Siemens Definition	512×512×519	0.69,0.69,0.5
20349.3.71	Siemens Sensation 40	512×512×562	0.70,0.70,0.5
20349.3.73	Siemens Sensation 40	512×512×760	0.67,0.67,0.5
20349.3.74	Siemens Sensation 40	512×512×727	0.69,0.69,0.5
20349.3.75	Siemens Sensation 40	512×512×601	0.66,0.66,0.5

Usage during a Human Study



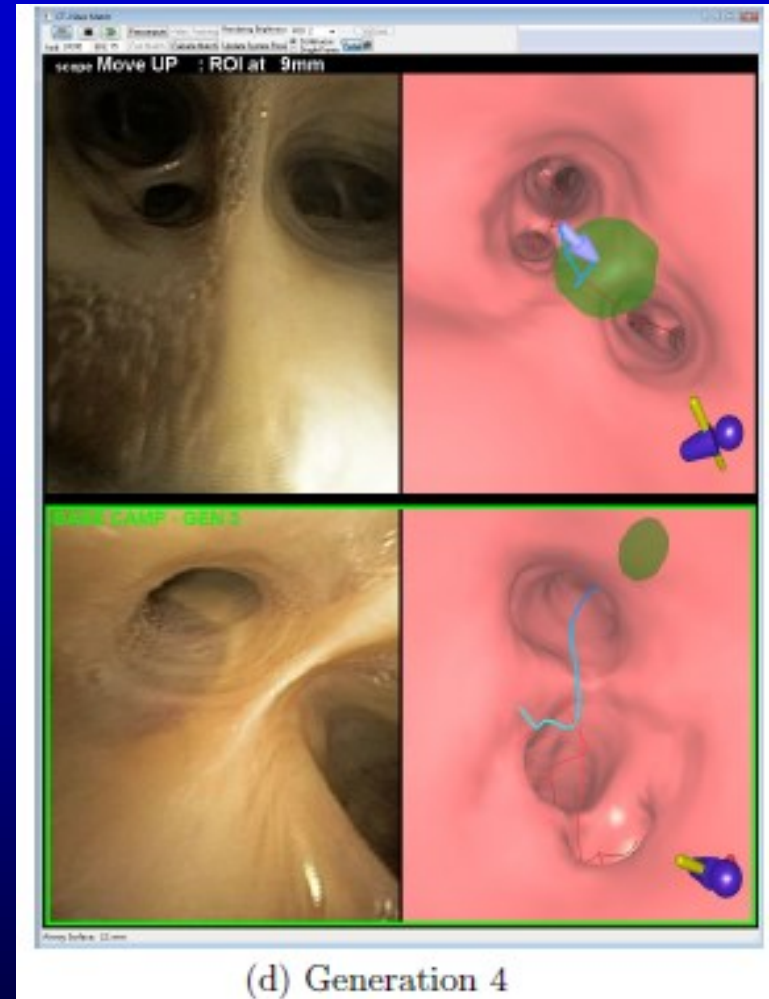
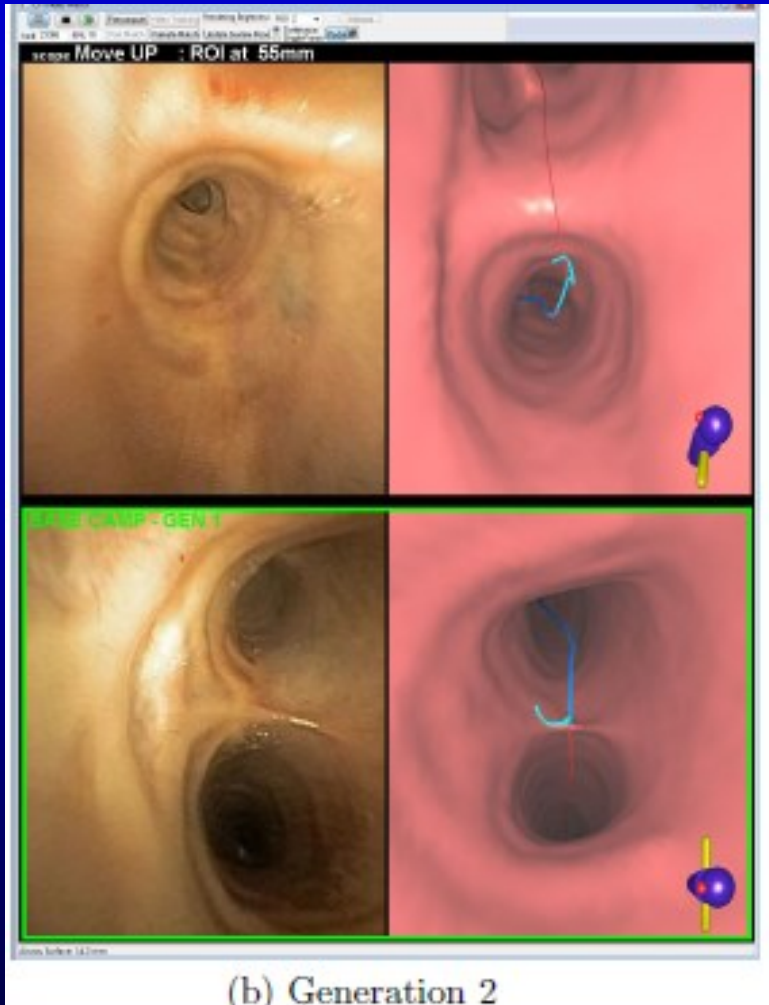
guidance
monitor

foot pedal

Human Study Results

- 97% Success rate (38/39 ROIs)
- Navigated as deep as airway generation 10
- Failure occurred during first pilot case
 - System suggested a wrong maneuver (a bug!)
 - We upgraded the system after this case!
- Tumor prevented complete approach to 2 ROIs, but guidance succeeded

Sample Frozen Views for a Human Study



ROI 2 for case 20349.3.65

Human Studies: video for 20349.3.65

The screenshot displays a medical software interface for motion tracking in a bronchoscopic procedure. The interface is divided into several windows:

- CT-Video Match - Global:** This window shows a "ROI at 86mm" with two side-by-side views of the airway. The left view is a real-time video feed, and the right view is a corresponding CT scan. A blue line traces the airway path, and a purple and yellow marker is visible in the bottom right corner. Below the views, it indicates "Airway Surface: 35.8 mm".
- 3D Surface Tool:** This window shows a 3D reconstruction of the airway tree. A blue line traces the path through the airway, and a purple and yellow marker is visible in the bottom right corner.
- Pedal Commands - Motion Tracking:** This panel at the bottom right contains three buttons: "Start Tracking / Re-align", "Freeze View", and "Go To Main Carina".

On the left side of the interface, there is a grid of four pairs of images labeled "Arrive" and "Advance". Each pair shows a different distance from the airway surface:

- 88.1 mm (labeled "CW")
- 86.8 mm (labeled "CCW")
- 79.0 mm (labeled "CCW")
- 8.1 mm (labeled "CCW")

Each image in the grid shows a different view of the airway, with a blue line tracing the path and a purple and yellow marker. The "Arrive" and "Advance" labels are in green text.

Conclusion

- Technician-free bronchoscopy guidance system
- Relies on natural bronchoscope movements
- Nearly perfect navigation success: phantoms, humans

Acknowledgments

National Cancer Institute of the NIH

- Grants #R01-CA074325 and #R01-CA151433



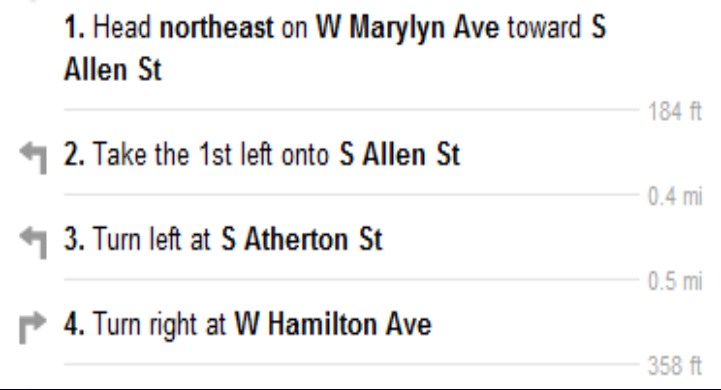
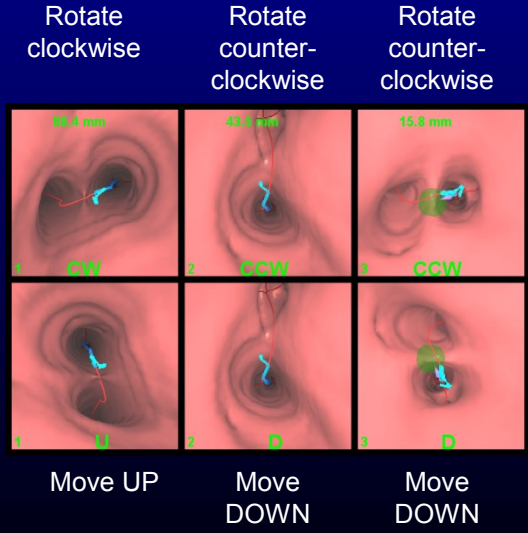
The Multidimensional Image Processing Lab
at Penn State



Conflict of Interest Statement

Drs. Higgins and Bascom have an identified conflict of interest related to grant R01-CA151433, which is under management by Penn State and has been reported to the NIH.

Planning/Navigation Strategy

<p>Device</p>		<p>3D airway tree</p> 
<p>Maneuvers</p>	<p>Left or right</p>	<p>Rotate - Flex - Advance</p>
<p>Directions</p>		

Guidance Strategy: System-Level Algorithm

Algorithm 1 — Guidance strategy during image-guided bronchoscopy.

```
1: for each ROI route  $R_i$  do
2:   Position the virtual and real bronchoscopes at the first bifurcation along ROI route.
3:   repeat
4:     Advance the virtual bronchoscope — the system view undergoes the rotation maneuver.
5:     Copy the rotation maneuver using the real bronchoscope so that the real and virtual bronchoscopes
     are synchronized.
6:     Advance the virtual bronchoscope — the system view moves to the next bifurcation along the ROI
     route.
7:     Replicate the maneuver using the real bronchoscope so that the real and virtual views look similar.
8:     if bronchoscope position needs to be verified or an adverse event occurs then
9:       if adverse event occurs then
10:        Hold the bronchoscope steady until the adverse event passes.
11:        Move the bronchoscope to a nearby bifurcation.
12:       repeat
13:         Verify the bronchoscope position by first invoking the targetting circles.
14:         Position the real bronchoscope so that the extent of the lumen region of the current bifur-
           cation lies within the two targetting circles.
15:         Invoke global registration.
16:         The system displays the results of the global registration and corresponding maneuvers.
17:       until Global registration gives a correct result.
18:   until ROI vicinity is reached
19:   Local registration is invoked to synchronize the real and virtual bronchoscopes and present ROI localization
     information to the physician.
```

Human Studies

Case #	ROI #	Location	Airway generation	Route length (mm)	Procedure time (secs)
20349.3.65	1**	RUL	5	135	-
	2	RML	5	151	45.7
	3	RLL	7	156	fail
	4	LUL	4	154	23.4
	5	LLL	4	159	23.7
	6*	RLL	10	175	-
20349.3.66	1	LUL	4	179	62.5
	2	LUL	4	178	25.5
	3*	LLL	3	169	-
	4	LLL	4	180	50.9
	5*	RML	4	168	-
	6*	RLL	5	165	-
	7*	RLL	5	161	-
	8	RLL	7	177	88.7
	9*	RUL	3	139	-
20349.3.67	1	LLL	4	201	44.2
	2	LUL	4	199	42.8
	3	RUL	3	166	43.1
	4*	LUL	11	263	-
	5*	LUL	11	251	-
	6	RLL	3	180	8.7
20349.3.68	1	RML	4	156	51.5
	2	RUL	3	130	36.5
	3	LLL	3	150	36.7
	4	LUL	3	151	33.1
20349.3.69	1	LUL	7	193	56.6
	2	LUL	4	184	41.6
	3	LLL	6	205	79.8
	4	RUL	4	151	38.9
	5	RLL	8	202	89.8
	6	RML	4	180	69.5
	7*	RLL	5	176	-
20349.3.71	1	LUL	4	153	97.2
	2	LLL	5	159	43.3
	3	RUL	5	124	60.5
	4	RML	4	154	62.2
	5	RLL	6	150	85.1
20349.3.73	1	LUL	4	181	24.2
	2	LLL	4	185	21.6
	3	RUL	5	155	45.7
	4	RLL	5	179	17.5
	5	RLL	8	202	58.3
20349.3.74	1	LUL	3	207	@
	2	LLL	4	212	@
	3	RUL	6	180	46.4
	4	RML	6	199	55.4
	5	RLL	10	245	67.5
20349.3.75	1	LUL	4	150	64.4
	2	LLL	5	163	107.4
	3	RUL	5	128	38.6
	4	RLL	8	145	74.8

Failure ROI

Tumor ROIs

