3D Human Airway Segmentation for Virtual Bronchoscopy

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Outline

1. Introduction
2. Method
3. Segmentation Results
4. Virtual Bronchoscopy Applications
Introduction

• New 3D CT Images can be large: 512 X 512 X 400
  – Partial volume effects
  – Reconstruction artifacts
  – Patient breathing artifacts

• Airway segmentation necessary for Virtual Bronchoscopy
  – Path planning, rendering, quantitative analysis

* Manual segmentation not an option
Previous Research

1. Knowledge-based

2. Central-axis analysis

3. 3D Region growing (RG) → not robust
   - K. Mori et al., *13th ICPR*, 1996

4. Mathematical morphology → too slow
Proposed Hybrid Approach

- Combines 3D RG and Morphology based methods
- Use filtering to improve robustness of both methods
- Use results of 3D RG to reduce application area of the larger operators in the Morphology method
- Order of magnitude improvement in execution time
3D Airway Segmentation Overview

3D image $I$ → Optional Filter → Modified 3D Region Growing

Optional Filter → Lung Region Definition

Lung Region Definition → Morphology

Morphology → 2D Candidate Labeling

2D Candidate Labeling → 3D Reconstruction

3D Reconstruction → Airway Segmentation $I_S$
3D Airway Segmentation Overview

3D image $I$ → Lung Region Definition → Modified 3D Region Growing

- Morphology
- 2D Candidate Labeling
- 3D Reconstruction

Airway Segmentation $I_S$

$W_i \in \{1, \ldots, Z\text{size}\}$
Optional Pre-Filtering of the Data

PURPOSE:

1. 3D RG can successfully complete without parenchymal leakage
2. Can help reduce false candidates in morphology method

COST:

Lose some peripheral branches

METHODS:

4-connected or 3 X 3 Median filter applied to each slice on 2D basis
3D Airway Segmentation Overview

3D image $I$  

Optional Filter

Lung Region Definition

Morphology

2D Candidate Labeling

3D Reconstruction

Airway Segmentation $I_S$

$W_{\mathcal{L}}$

$W_i \forall i \in \{1, \ldots, \text{Zsize}\}$
Modified Adaptive 3D Region Growing

3D Region Growing
Seed = s
Threshold = T

Volume < Explosion

If Yes, go to Post Processing
If No,

T = T - 1

3D Region Growing

T = T + 1
Post Processing

PURPOSE:

1. RG result contains cavities due to noisy data
2. Edges of segmentation can be very rough

METHOD:

Cavity deletion and binary closing of RG segmentation
3D Airway Segmentation Overview

3D image $I$ → Optional Filter → Modified 3D Region Growing

Optional Filter

Morphology

2D Candidate Labeling

3D Reconstruction

Airway Segmentation $I_S$

$W_{\perp}$

$W_i^\perp, i \in \{1, \ldots, Z_{\text{size}}\}$
3D Airway Segmentation Overview

3D image $I$ → Optional Filter → Modified 3D Region Growing

- Lung Region Definition
- Optional Filter
- $W_L$
- $W^i_R \ i \in \{1, \ldots, \text{Zsize}\}$
- Airway Segmentation $I_S$
Morphology-Based Segmentation

Two-Step Process

1. 2D Candidate Labeling
   - Identify potential airways on a 2D basis
   - Uses gray-scale reconstruction with different operators

2. 3D Reconstruction

HYBRID:

Use results of 3D RG and Lung Region Definition to limit application area of step 1
2D Candidate Labeling

Basis Operator

\[ B_4^1 \]

\[ B_4^b = bB_4 = B_4 \oplus B_4 \oplus \cdots \oplus B_4 \]

(b−1) dilations

b^{th} order homothetic operators
2D Candidate Labeling

1. Sample and threshold slice \( z \) from Image \( I \)

\[
S(x, y) = I(x, y, z) \text{ if } I(x, y, z) \leq 0 \quad \text{else} \quad 0
\]
2D Candidate Labeling

2 Perform gray-scale closing with operator of size $b$

$$J^b_1 = S \bullet B^b_4 = (S \oplus B^b_4) \ominus B^b_4$$

3 Erode image and take maximum with original

$$J^b_{k+1} = \max(J^b_k \ominus B^1_4, S)$$

4 Repeat above step until max no longer involves $S$
2D Candidate Labeling

5. Threshold result into binary image $C$

$$C^b(x, y) = 1 \text{ if } J^b(x, y) - S \geq \text{Threshold}, 0 \text{ otherwise}$$

6. Union of results for all $b$ determines candidate locations

$$C(x, y) = \bigcup_{b=1}^{M} C^b(x, y)$$
3D Airway Segmentation Overview

3D image $I$ → Optional Filter → Modified 3D Region Growing → Lung Region Definition → Morphology → 2D Candidate Labeling → Airway Segmentation $I_S$

- Optional Filter
- Lung Region Definition
- Morphology
- 2D Candidate Labeling
- Airway Segmentation $I_S$

$W_L$ and $W_{iR}$, $i \in \{1, \ldots, Z\text{size}\}$
3D Reconstruction

• PURPOSE: Determine valid candidates to form final result

• METHOD:
  • Closed space dilation with unit kernel radius
  • 3D 6-connected region growing
Results: case h006

- Morphology method failed
- Different branches segmented
- No filtering used

Case h006: 512X512X574 287MB (0.72mm X 0.72mm X 0.60mm)
Results: case h007

- 4-connected median filter
- 3D RG and Morphology methods show leakage

Case h007: 512X512X488 244MB (0.65mm X 0.65mm X 0.60mm)

Case h007_512_85, root site=(266,221,0), segre=(RegGrow,star median,explode at T=50000)
Results: case h007

Tree Renderings

- 4-connected median filter
- 3D RG and Morphology methods show leakage

Case h007: 512X512X488 244MB (0.65mm X 0.65mm X 0.60mm)

Case h007_512_85, root site=(266,221,0), seger=(RegGrow,star median,explode at T=50000)
Results: case h008

- Only hybrid method succeeded
- No filtering used

Case h008: 512X512X389 194MB (0.59mm X 0.59mm X 0.06mm)
## Segmentation Time Results

<table>
<thead>
<tr>
<th>Method</th>
<th>Labelingseconds</th>
<th>Reconstructionseconds</th>
<th>Totalseconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D RG</td>
<td>N.A.</td>
<td>N.A.</td>
<td>64</td>
</tr>
<tr>
<td>Hybrid</td>
<td>1700</td>
<td>1580</td>
<td>3280</td>
</tr>
<tr>
<td>Morphology</td>
<td>15380</td>
<td>3200</td>
<td>18580</td>
</tr>
</tbody>
</table>

Hybrid demonstrates 10X improvement in labeling time
Edge Localization

- Segmented by both RG and Hybrid methods
- Segmented by Hybrid method only

Hybrid method demonstrates better edge localization
H012 case: papilloma

Hybrid and Morphology method fail in capturing papilloma
Virtual Bronchoscopy Applications

1. Airway Analysis
2. Peripheral Nodule Biopsy
3. Mediastinal Lymph-Node Biopsy

Use the Virtual Navigator.

- Sherbondy et al., SPIE Medical Imaging 2000, vol. 3978
- Helferty et al., SPIE Medical Imaging 2001, vol. 4321
- Helferty et al., ICIP 2002
Virtual Navigator: architecture

**Data Sources**

**Image Processing Analysis**

**HTML Multimedia Case Report**

**Stage 1: 3D CT Assessment**
- Identify Target ROI Sites
- Segment Airway Tree
- Calculate Centerline Paths
- Virtual Endoluminal Movies
- Cross-Section Area Calculations
- Volume Slices, Slabs, Projections

**Stage 2: Live Bronchoscopy**
- Capture Endoscope Video
- Correct Barrel Distortion
- Interactive Virtual Views
- Register Virtual CT to Video
- Draw Target Regions on Video

**Outputs**
- ROI List
- Segmented Airway Tree
- Centerline Paths
- Screen Snapshots
- Recorded Movies
- Physician Notes
The system resides on a standard Windows-based PC. A Matrox video card serves as the interface between the PC and the videobronchoscope. The main software system, written in Visual C++, can run on an inexpensive laptop computer.
Airway Analysis (work in progress)

Case h16_512_85, root site=(263,233,45), seger=(RegGrow, star median, explode at T=50000)
Peripheral Nodule Biopsy (work in progress)
VB-Guided Mediastinal Lymph-Node Biopsy

1. Human Study underway

2. 29 cases to date (2/2002)

3. VB-Guided approach being compared to standard approach which uses CT film.
Mediastinal Lymph-Node Biopsy (study underway progress)
Conclusion

• Hybrid method
  – Clinically feasible
  – Similar results to Morphology

• No method superior
  – No method consistently recovered more airways
  – Hybrid and Morphology methods localize edges better
  – Only Region Growing succeeded in papilloma case

• Integrated segmentation tool-kit used for VB