Toward Reliable Multi-generational Analysis of Anatomical Trees in 3D High-resolution CT Images

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Outline

- Introduction
- Methods: 3-Stage approach
- Experimental results
- Conclusion
Introduction

- High-resolution X-ray micro-CT scanner and Multi-detector helical CT scanner
  - High-resolution 3D digital images of various anatomical tree structures
    - Coronary or hepatic vasculature
    - Airway tree

- Sheer size and complexity of these trees
  - Essentially impossible to define them interactively

- Automatic Approaches
  - Principle pathway (Karau et al. 2001, Johnson et al. 2000)
  - High percentage of apparently correct branches

  - None of them, however, guarantee geometrically accurate tree structures
Output of Automatic Approaches: Imperfect Trees

- Branches are missed
- Branches break, creating overly short branches and forming new false branches
- Extra spurious branches arise, causing false bifurcations
- Anatomically implausible loops occur
Interactive System: Tree Analysis Module for Analyze 4.0

- Segmentation (Single Threshold)
- Image Projection (Rendering)
- Labeling
- Action
  - Group 1 (Rendering) - Rotate, Scale, Translate, Select
  - Group 2 (Tree Editing Tools) – Set Root, Combine Trees, Split Tree, Delete Branch, Delete Point, Add Point, Insert Point, and Move Point.

- Map

Rendering and Editing

Map
The goal of this paper

- Develop methods for defining accurate 3D tree structures and accompanied quantitative descriptions.

- Satisfy the following requirements to be useful
  - Reasonable amount of human interaction
  - Computationally efficient
  - Function effectively over a wide range of anatomical and data variations
Basic Philosophy

- Unrealistic to rely on improved scanning technology and automated algorithms for defining a tree

- But, automated techniques are vitally necessary

- Judicious human interaction is essential
Three-stage approach

- Stage 1 – Apply an automated technique to produce a segmented tree and an associated tree description
- Stage 2 – Analyze the automatically defined tree to identify possible errors
- Stage 3 – Use a series of interactive tools to examine and correct identified errors
Stage 1: Define the Raw Tree (Wan, TMI 9/2000)
Stage 2: Identify Possible Tree Errors using Tree Diagnostician

<table>
<thead>
<tr>
<th>Branches are missed</th>
<th>Short end branch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Branches break</td>
<td>Branches break in a same tree</td>
</tr>
<tr>
<td></td>
<td>Branches break between two trees</td>
</tr>
<tr>
<td>Small Trees</td>
<td>Short end branch</td>
</tr>
<tr>
<td>Spurious branches</td>
<td>Short end branch</td>
</tr>
<tr>
<td>Anatomically implausible loops occur</td>
<td>Loop</td>
</tr>
<tr>
<td></td>
<td>Close bifurcation</td>
</tr>
<tr>
<td></td>
<td>Trifurcation</td>
</tr>
</tbody>
</table>

The Tree Diagnostician interface shows various types of errors with corresponding measurements and options for selecting and marking.

List:
- Break (*): 2, Voxel(s): 0.04 mm
- Breaks btw 2 trees (*): 10, Voxel(s): 0.1 mm
- End to End Point: 2 Interior: 2 Interior
- Short End-branch (*): 1, Voxel(s): 0.02 mm
- Small Tree: 10, Voxel(s): 0.2 mm
- Close Bifurcation (*): 2, Voxel(s): 0.04 mm
- Loop: 1, Voxel(s): 0.02 mm
- Trifurcation/More (*): 1, Voxel(s): 0.04 mm
- Mark Point: 2, Segment: 2

Errors:
- Close bifurcation Trif: 3 (Length: 1.4124)
- Close bifurcation Trif: 3 (Length: 1.7306)
- Close bifurcation Trif: 3 (Length: 1.4124)
- Close bifurcation Trif: 3 (Length: 1.7306)
- Trifurcation/More Trif: 3 (Length: 1.4124)
- Trifurcation/More Trif: 3 (Length: 1.7306)
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- Trifurcation/More Trif: 3 (Length: 1.4124)
- Trifurcation/More Trif: 3 (Length: 1.7306)
- Short Tree Trif: 3 (Length: 99.3991)
- Short Tree Trif: 3 (Length: 2)
- Short Tree Trif: 3 (Length: 6.6698)
- Short Tree Trif: 3 (Length: 7.7007)
- Short Tree Trif: 3 (Length: 5.4041)
Stage 3: Examine and Correct Tree Errors

Tools built for interrogation/correction process:

- 3D rendering system
- Locator Tools
  - Skeleton Picker
  - 3D Site Locator – Shooter
  - Intersection-Center Locator
  - 3D Cursor
- Site Bounding Box
- Editing Tools
- 2D Tree Map
3D Rendering System

- Surface and skeleton displayed

- Rotate, transpose and zoom in/out using rendering control
Locator Tool 1 - Skeleton Picker
Four visualization modes for picker control
Locator Tool 2 - 3D Site Locator (Shooter)

Projected Site

Site

Center of Projection Plane

Shooter (Projected line)

Focal Point

Move/Rotate Camera
Locator Tool 3 - Intersection Center

The projection of the intersection center

Site is the center of intersection area of a projected line with segmented image

Projected line

First intersection area

Focal Point
Locator Tool 4 - 3D Cursor
Site Bounding Box
Tree Editing Tools

- Skeleton Editor – enables point and connection editing
- Point Editor – allows the addition or removal of specific skeletal points
- Connection Editor – line segments can be deleted or added
- Tree root selection and tree pruning
2D Tree Map
Zoom in/out and Detail-on-demand
Example of loop editing

(b) connected-branch case

(c) refined skeleton

(d) shared-branch case

(e) refined skeleton
Experimental Results - Control2 case (Hepatic vasculature)
A close look at Control2 case
Control2: Problems eliminated
(list in Tree Diagnostician)

- Took two hours of user interaction
- Number of generations increased from 14 (previous work) to 25

<table>
<thead>
<tr>
<th>Error</th>
<th>Number</th>
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<tr>
<td>Branch Breaks</td>
<td>60</td>
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<tr>
<td>Trifurcations</td>
<td>5</td>
</tr>
<tr>
<td>Loops</td>
<td>5</td>
</tr>
<tr>
<td>Small Trees</td>
<td>31</td>
</tr>
</tbody>
</table>
Experimental Results – H61 case

(a)  
(b)
H61: Problems eliminated  
(list in Tree Diagnostician)

- Took two more hours of user interaction
- Number of generations 15
- Computer identified extra branches at generations 12-15 that the human did not measure

<table>
<thead>
<tr>
<th>Error</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trifurcations</td>
<td>12</td>
</tr>
<tr>
<td>Loops</td>
<td>14</td>
</tr>
<tr>
<td>Small Trees</td>
<td>1</td>
</tr>
</tbody>
</table>
2D Tree Map of H61
Conclusion

- Complete procedure for defining correct branching-tree structure in large 3D CT image

- Graphical tools allow user to interrogate and fix tree defects

- Enable precise geometric tree definition, so that quantitative assessments can be made.

- A more systematic use of tools is required

- Semi-automatic tools are vital to speed up the interactive process

Acknowledgements

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