Computer Aided Liver Surgery Planning:
An Augmented Reality Approach

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Liver Tumor

HCC
CT image

Resection may be the only curative treatment
Resection Types

- Anatomical resection
- Atypical resection

Virtual Liver Surgery Planning

VISION

support radiologists and surgeons in planning liver tumor resections

Traditional planning in 2D  Surgery planning in VR
Liver Resection Planning Support Requirements

- Intuitive/interactive for surgeons
-Provide information and interactive tools for surgeons required for pre-operative planning:
  - Consistent data representation
  - Partitioning tools (healthy/diseased)
  - Quantitative analysis tools
  - Surgical resection planning tools
Virtual Liver Surgery Planning

Highly automated liver/tumor segmentation

Vessel extraction

Virtual Reality-based 3D interaction

Interactive segmentation verification/editing

Simulation of surgical resections

Surgical plan Quantitative indices

Liver Segmentation in CT
Diaphragm Segmentation

Solution: Sequential Segmentation

1. Middle lobe of right lung
2. Quadrate lobe of liver
3. Left lobe of liver
4. Diaphragm
5. Heart
6. Upper lobe of the left lung
3D Shape Representation

Axial reference plane

Elevation image

3D Shape: 2D Reference Curve

2D reference curve
Key landmark point
Landmark point
3D Appearance Representation

- Warping all layers to the mean reference curve shape and sample them into vectors
- Concatenating all the vectors into one intensity vector

Building a 3D AAM

Concatenating appearance and shape models

\[
b = \begin{bmatrix} W_x b_x \\ W_h b_h \\ b_g \end{bmatrix} = \begin{bmatrix} W_x p_x^T(x - \bar{x}) \\ W_h p_h^T(h - \bar{h}) \\ p_g^T(g - \bar{g}) \end{bmatrix}
\]

Complete 3D AAM: \( b = P_c \mathbf{c} \)
Diaphragm Segmentation - AAM

Liver and Tumor Segmentation

- Relatively easy once diaphragm segmented
- Fast marching / fuzzy connectivity / region growing work well
- Ribcage surface detection may further improve occasional leaking between ribs
- Tumor – combination of classification and region growing
Virtual Liver Surgery Planning

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Liver Segment Partitioning

- Skeletonization
- Segment-feeding vessels
- Nearest Neighbor partitioning

Eight segment defined by portal veins

First stage of recursive partitioning
Segmented liver

Portal vein segmentation – vessel mining

Formal tree representation

Labeling of segment-feeding portal vessels

Nearest Neighbor based liver segment approximation

Approximated liver segments

Branch Labeling

corrosion cast model
Virtual Liver Surgery Planning

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- Surgical plan
  Quantitative indices

Augmented Reality System

1. Tracking target
2. HMD (see-through)
3. Tracking camera
4. Tracked PEN
5. PIP
   Personal Interaction Panel
Augmented Reality

Visual Inspection
Free Deformation

Virtual Liver Surgery Planning

- Highly automated liver/tumor segmentation
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- Quantitative indices
Planning Tools

- **Interactive** quantitative measurements
  - Volume calculations
  - Distance measurements

- Resection proposal generation
  - Segment-oriented liver resections

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5-Step Planning Approach

1. Binary vessel (V)
2. Graph model (G)
3. Branch model (BM)
4. Binary tumor (T)
5. Labeled vessel (LV)
6. Labeled skeleton (LS)
7. Liver segments (LS)
8. Resection proposal
Interactive Branch Labeling

Security Margin
Resection Planning

Required Partitioning Tools

- **Plane** \textit{analytical}
  - Simple/fast and straight

- **Sphere** \textit{geometrical}
  - Wedge resections

- **Deformable plane**
  - More complex resections
Surgical Planning Workflow

Data exploration → Segment approximation → Inspection of liver segments → Resection strategy

Resection plan → Atypical resection → Safety margin adjustment → Anatomical resection

3D Quantitative Analysis

- Volume measurement
- Distance measurement
- Angular
- Measurement jug
- Ruler
Evaluation

A) Quantitative measurement tools
   - Comparing 2D and VR measurement tools

B) Resection tools
   - Planning in 4 patient datasets
   - 1 surgeon (Dr. Werkgartner, LKH Graz)

Evaluation

- 2 conditions 2D / 3D
- 20 subjects (12m/8f)
- 3 datasets
- Tasks
  - Volume
    - estimation & measurement
  - Distance
    - estimation & measurement
  - Angle estimation
**Task completion time**

<table>
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<tr>
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<th>2D</th>
<th>VR</th>
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<tbody>
<tr>
<td>Volume estimation</td>
<td>83.15±48.74</td>
<td>27.70±18.34</td>
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<tr>
<td>Volume measurement</td>
<td>34.58±10.43</td>
<td>9.80±9.11</td>
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<tr>
<td>Distance estimation</td>
<td>84.84±50.46</td>
<td>16.95±10.56</td>
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<tr>
<td>Distance measurement</td>
<td>45.65±31.37</td>
<td>22.80±18.26</td>
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<tr>
<td>Angular estimation</td>
<td>77.65±55.87</td>
<td>18.45±10.35</td>
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Timing in seconds

ANOVA testing, p < 0.05

**User Preferences**

![User Preferences Chart](chart.png)
Four Virtual Liver Planning Cases
so far …

Timing

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<th>c014</th>
<th>c006</th>
<th>d048</th>
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<tr>
<td>Σ time (min)</td>
<td>30</td>
<td>20</td>
<td>15</td>
<td>28</td>
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<tr>
<td>average: ~23 min</td>
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Surgeons’ Evaluations

- better spatial perception
- safety margin visualization is instructive
- shorter intervention time
- better approximation of volumetry
- best suited for difficult cases
- surgeons want to plan in 3D
- saves time ...

Conclusions

- Highly automated image analysis is a prerequisite to virtual surgical planning
- AR-based planning tools facilitate interactive and collaborative planning that includes objective evaluation of competing planning options
- Benefits
  - Intuitive visualization & interaction
  - Improved visual perception
- Successfully applied to 4 surgical planning cases