Development and Usability Testing of Dr. Liver, a User-Centered Virtual Liver Surgery Planning System

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- Introduction
  - Background
  - Objectives of the Study
- Virtual Liver Surgery Planning System Development
- Usability Testing
- Discussion
Virtual Liver Surgery Planning System?

- A system which assists surgeons in preoperative planning for liver resection and transplantation

**Image Processing**
- 3D Reconstruction of the liver, vessels, and tumor(s) from CT volume dataset
- Liver segmentation

**Safe & Rational Surgery**
- Volumetry of the liver
- Volumetry of the remnant and/or graft

**Quantitative Analysis**

- Location & size of the tumor(s)
- Vascular structure
- Liver segments
- Resection plane

TFLV = 1237 ml
Remnant = 362 ml
%RLV = 30%
# Generic Virtual Surgery Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Rapidia (Infinitt)</th>
<th>Voxar 3D (Barco ⇒ Toshiba)</th>
<th>Syngo.via (Simense)</th>
<th>OsiriX (Freeware - Pixmeo)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="rapidia.png" alt="Image of Rapidia" /></td>
<td><img src="voxar3d.png" alt="Image of Voxar 3D" /></td>
<td><img src="syngovia.png" alt="Image of Syngo.via" /></td>
<td><img src="osirix.png" alt="Image of OsiriX" /></td>
</tr>
<tr>
<td><strong>Country</strong></td>
<td>Korea</td>
<td>Japan</td>
<td>Germany</td>
<td>Swiss</td>
</tr>
<tr>
<td><strong>System features</strong></td>
<td>3D visualization</td>
<td>3D visualization</td>
<td>Oncology</td>
<td>3D visualization</td>
</tr>
<tr>
<td></td>
<td>Measurement</td>
<td>Measurement</td>
<td>PET &amp; CT segmentation (extraction)</td>
<td>Measurement</td>
</tr>
<tr>
<td></td>
<td>Options</td>
<td>Options</td>
<td>CT Lung CAD</td>
<td>Options</td>
</tr>
<tr>
<td></td>
<td>Colon &amp; polyps</td>
<td>Colon</td>
<td>Colonography</td>
<td>Custom plugins</td>
</tr>
<tr>
<td></td>
<td>Cardiac Ca</td>
<td>Cardiac Ca</td>
<td></td>
<td>iPhone, iPad compatible</td>
</tr>
<tr>
<td></td>
<td>Vessel</td>
<td>Vessel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brain angio</td>
<td></td>
<td>Cardiology</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Vascular</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Cardiac</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ca Scoring</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Neurology</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PET evaluation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Perfusion CT</td>
<td></td>
</tr>
</tbody>
</table>

**System features**
- 3D visualization
- Measurement
- Options
- Colon & polyps
- Cardiac Ca
- Vessel
- Brain angio
- Oncology
- PET & CT segmentation (extraction)
- CT Lung CAD
- Colonography
- Cardiology
- Vascular
- Cardiac
- Ca Scoring
- Neurology
- PET evaluation
- Perfusion CT
- iPhone, iPad compatible
Generic Virtual Surgery Systems: Limitations

- Lack of functions specialized for liver surgery planning, such as liver segmentation and surgical resection simulation

- Liver extraction
  - Manual drawing
    - Liver contour manually traced slice by slice
    - Time demanding: more than 30 min for a CT dataset of 200 slices with a thickness of 1 mm
  - Semi-automatic
    - Simple region growing method provided
    - Heavy manual editing required due to false extraction

⇒ Cumbersome to users
## Specialized Virtual Liver Surgery Planning Systems

<table>
<thead>
<tr>
<th>System</th>
<th>MeVis Distant Service (MeVis)</th>
<th>Synapse Vincent (Fujifilm)</th>
<th>IQQA Liver (EDDA)</th>
<th>Mint Liver (Mint Medical &amp; German Cancer Research Center)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Country</strong></td>
<td>Germany</td>
<td>Japan</td>
<td>USA</td>
<td>China</td>
</tr>
</tbody>
</table>
| **System features** | • Segmentation of the liver, veins, biliary system, and tumors  
• Volumetric data for both remnant and/or graft  
• Vascular territory evaluation  
• Virtual resection options  | • Liver extraction  
• Vessel analysis  
• Segmentation  
• Volumetry  
• Surgery planning  | • Segmentation of the liver, lobes, vessels, and lesion  
• Volumetry  
• Calculation of 3D distances, margins, and diameters  
• Virtual knife control  | • Integration in the existing software platform  
• Automatic liver analysis  
✓ Visualization  
✓ Volumetry  
• Definition of resection strategies |
MeVis Distant Services

- Provided by MeVis Medical Solutions AG, Germany
- LiverAnalyzer & LiverViewer developed using MeVisLab
- Analysis services
  - Segmentation of the liver, veins, biliary system, and tumors
  - Volumetric data for both remnant and/or graft
  - Vascular territory evaluation
  - Virtual resection options

Limitation:
- LiverAnalyzer not for sale
Liver analysis report (viewed by LiverViewer)

Limitation:
- Difficult to cross-check the accuracy of the analysis results since CT images are not provided.
Synapse Vincent

- Developed by Fujifilm, Japan
- Functions provided
  - Liver extraction
  - Vessel analysis
  - Liver segmentation
  - Volumetry
  - Surgery planning

Limitations:
- Expensive
- More user-friendly UI needed
- Manual drawing of vessels required
  ⇒ Cumbersome to users
Research Objectives

Development and Usability Testing of Dr. Liver, a User-Centered Virtual Liver Surgery Planning System

1. Functions specialized to liver surgery
2. Decision support information
3. Intuitive, user-friendly interface
4. Acceptable processing time
Use Scenario Development

- A use scenario consisting of hierarchical tasks was developed based on:
  - Interviews with surgeons
  - Benchmarking of commercialized systems
  - Literature survey
  - Questionnaires

**Liver extraction**
- S1. Seed point selection
- S2. Liver extraction
- S3. Liver editing
- S4. Update & save
- S5. Update & save

**Vessel extraction**
- S1. Mask the liver
- S2. Seed point selection
- S3. Vessel extraction
- S4. Vessel editing

**Tumor diagnosis**
- S1. Seed point selection
- S2. Tumor extraction
- S3. Tumor editing
- S4. Update & save

**Liver segmentation**
- S1. Segmentation plane generation
- S2. Liver segment adjustment
- S4. Update & save

**Surgery planning**
- S1. File loading
- S2. Resection of tumor by a sphere
- S3. Volumetry

Entire processing time: **20 ~ 30 min**
Use Scenario: Liver Extraction Module

S1(M). Seed point selection
- Multiple seed points selection on the liver using the mouse

S2(A). Liver extraction
- Liver extraction using the proposed hybrid method
- Liver contour verification

S3(M). Liver Contour editing
- Liver contour editing using a scalable editing circle

S4(A). Update & save
- Update & save of the 3D liver

Total 3 ~ 5 min
A hierarchical and sequential user interface was designed based on the use scenario.

High level UI

Low level UI
- Procedure **status indication and color coding**
- Iterative execution **arrow**
User-Friendly UI Features (3/4)

- **3D view indication** and **resetting functions** for easier 3D object manipulation
Hot key menus on the 2D screen for easier accomplishment of various tasks such as seed point selection and CT image zooming in/out
Demo: Liver Extraction Module
Demo: Liver Surgery Planning – Sphere Mode
Usability Testing

- **Participants**
  - 3 medical doctors at Chonbuk National University Medical School
  - Age: 30 ~ 50 years

- **Patient dataset**
  - One dataset of abdominal CT images provided by Chonbuk National University Medical School, South Korea
  - Resolution: 512 × 512
  - Thickness: 1 mm
Test Design

1. **Pre-Test Session**
   - 1. Informed consent
   - 2. Introduction of usability testing
   - 3. Training of Dr. Liver

2. **Test Session**
   - Liver extraction
   - Vessel extraction
     - Portal vein
     - Hepatic artery
     - Hepatic vein
     - IVC
   - Tumor extraction
   - Liver segmentation
     - Plane
     - Sphere
   - Liver surgery planning
     - Plane
     - Segment
     - Sphere

3. **Post-Test Session**
   - Debriefing

(1 h)  
(1.5 h)  
(10 min)
<table>
<thead>
<tr>
<th>Measures</th>
<th>Liver Extraction</th>
<th>Vessel Extraction</th>
<th>Surgery Planning</th>
<th>Instrument/Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Performance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>Comparison to golden standard</td>
</tr>
<tr>
<td>(Similarity index, False positive error, and false negative error)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completion Time</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>Programming</td>
</tr>
<tr>
<td>Number of mouse clicks</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>Programming</td>
</tr>
<tr>
<td>Number of keystrokes</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>Programming</td>
</tr>
<tr>
<td><strong>Preference</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usefulness</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>Questionnaire with 7-point Likert Scales</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Learnability</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Informativeness</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Clarity</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Tolerance</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Satisfaction</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
</tbody>
</table>
### Assessment Questions: Liver Extraction (illustrated)

<table>
<thead>
<tr>
<th>Questions</th>
<th>Very Poor</th>
<th>Poor</th>
<th>Slightly Poor</th>
<th>Fair</th>
<th>Slightly Good</th>
<th>Good</th>
<th>Very Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>How <strong>useful</strong> is it for extracting the liver from DICOM images?</td>
<td>①</td>
<td>②</td>
<td>③</td>
<td>④</td>
<td>⑤</td>
<td>⑥</td>
<td>⑦</td>
</tr>
<tr>
<td>How <strong>easy</strong> is it to <strong>use</strong>?</td>
<td>①</td>
<td>②</td>
<td>③</td>
<td>④</td>
<td>⑤</td>
<td>⑥</td>
<td>⑦</td>
</tr>
<tr>
<td>How <strong>easy</strong> is it to <strong>learn</strong> the steps of liver extraction?</td>
<td>①</td>
<td>②</td>
<td>③</td>
<td>④</td>
<td>⑤</td>
<td>⑥</td>
<td>⑦</td>
</tr>
<tr>
<td>How <strong>adequate</strong> is the <strong>information</strong> provided?</td>
<td>①</td>
<td>②</td>
<td>③</td>
<td>④</td>
<td>⑤</td>
<td>⑥</td>
<td>⑦</td>
</tr>
<tr>
<td>How <strong>clear</strong> are the step names?</td>
<td>①</td>
<td>②</td>
<td>③</td>
<td>④</td>
<td>⑤</td>
<td>⑥</td>
<td>⑦</td>
</tr>
<tr>
<td>How <strong>adequate</strong> is the <strong>tolerance</strong> to allow you make mistakes?</td>
<td>①</td>
<td>②</td>
<td>③</td>
<td>④</td>
<td>⑤</td>
<td>⑥</td>
<td>⑦</td>
</tr>
</tbody>
</table>
# Quantitative Assessment Results (selected)

<table>
<thead>
<tr>
<th>Measures</th>
<th>Liver Extraction</th>
<th>Vessel Extraction</th>
<th>Surgery Planning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SI (%)</td>
<td>97.0 (0.3)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>FPE (%)</td>
<td>2.0 (0.2)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>FNE (%)</td>
<td>2.3 (0.4)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Time (min)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction</td>
<td>1.8 (0.5)</td>
<td>0.6 (0.1)</td>
<td>1.0 (0.2)</td>
</tr>
<tr>
<td>Auto processing</td>
<td>1.3 (0.2)</td>
<td>1.6 (0.3)</td>
<td>1.2 (0.4)</td>
</tr>
<tr>
<td><strong>Number of mouse clicks</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before editing</td>
<td>30 (8)</td>
<td>20 (5)</td>
<td>10 (7)</td>
</tr>
<tr>
<td>Editing</td>
<td>56 (10)</td>
<td>0 (0)</td>
<td>4 (2)</td>
</tr>
<tr>
<td><strong>Number of keystrokes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before editing</td>
<td>0 (0)</td>
<td>6 (4)</td>
<td>9 (3)</td>
</tr>
<tr>
<td>Editing</td>
<td>17 (10)</td>
<td>0 (0)</td>
<td>3 (2)</td>
</tr>
</tbody>
</table>
### Qualitative Assessment Results - Overall

<table>
<thead>
<tr>
<th>Module</th>
<th>Average</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver extraction</td>
<td>6.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Vessel extraction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portal vein</td>
<td>6.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Hepatic artery</td>
<td><strong>5.2</strong></td>
<td><strong>0.8</strong></td>
</tr>
<tr>
<td>Hepatic vein</td>
<td>6.7</td>
<td>0.5</td>
</tr>
<tr>
<td>IVC</td>
<td>7.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Tumor extraction</td>
<td>7.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Liver segmentation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plane</td>
<td>6.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Sphere</td>
<td>6.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Liver surgery planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plane</td>
<td>6.1</td>
<td><strong>1.1</strong></td>
</tr>
<tr>
<td>Segment</td>
<td>7.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Sphere</td>
<td>7.0</td>
<td>0.2</td>
</tr>
</tbody>
</table>

- **Low score:** Incomplete extraction of HA
- **Large variation:** high scores provided by young doctors, but a low score by a senior doctor
Discussion (1/3)

- Use scenario development based on interviews with surgeons, benchmarking of commercialized systems, literature survey, and questionnaires
  - User-centered
  - Clinically practical

<table>
<thead>
<tr>
<th>Liver extraction</th>
<th>Vessel extraction</th>
<th>Tumor diagnosis</th>
<th>Liver segmentation</th>
<th>Surgery planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1. Seed point selection</td>
<td>S1. Mask the liver</td>
<td>S1. Seed point selection</td>
<td>S1. Segmentation plane generation</td>
<td>S1. File loading</td>
</tr>
<tr>
<td>S2. Liver extraction</td>
<td>S2. Seed point selection</td>
<td>S2. Tumor extraction</td>
<td>S2. Resection of tumor by a sphere</td>
<td>S2. Resection of tumor</td>
</tr>
<tr>
<td>S3. Liver editing</td>
<td>S3. Vessel extraction</td>
<td>S3. Tumor Editing</td>
<td>S3. Volumetry</td>
<td>S3. Volumetry</td>
</tr>
</tbody>
</table>

Entire processing time: 20 ~ 30 min
Discussion (2/3)

- User-friendly UI design
  - Procedure-based and intuitive
  - Procedure status indication and color coding
  - 3D view indication box and resetting buttons for easier 3D object manipulation
  - Hot key menus on the screen to decrease cognitive workload
Discussion (3/3)

- Usability testing
  - Improvement needed: Connection function for discontinued extraction of HA branches
  - Usability testing at multiple centers
Liver Anatomy Workshop @ POSTECH
FEATURES

1 Clinical Decision Support for Safe and Rational Surgery
- Semi-automated extraction of the liver, vessels (PV, HV, HA, and IVC), and lesions
- Real-time, interactive boundary editing
- Customized liver segmentation based on PV and HV structures
- Volume of the liver, vessels, lesions, and liver segments
- Optimal surgery planning support based on risk analysis and resection strategies

2 User-Friendly Interface
- Procedure-based and hierarchical workflow
- Easy to learn and use
- Multi-modal (text, graphic, and voice) guidance

3 Time Efficiency in Surgery Planning
- Efficient workflows (20 min from liver extraction to surgery planning)

System Requirement

<table>
<thead>
<tr>
<th>Component</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>OS</td>
<td>Windows 7 64 bit or higher</td>
</tr>
<tr>
<td>HDD</td>
<td>2 GB or larger</td>
</tr>
<tr>
<td>CPU</td>
<td>i5 3.1 GHz or higher</td>
</tr>
<tr>
<td>RAM</td>
<td>8 GB or larger</td>
</tr>
<tr>
<td>VGA</td>
<td>GeForce GT 630 or higher</td>
</tr>
<tr>
<td>Monitor</td>
<td>Resolution 1920 x 1080 or higher</td>
</tr>
</tbody>
</table>

Retailer Information

Distributor: Humanopia Co., Ltd.
Address: 323 Main Building, Pohang Techno Park
334 Jigok-ro, Nam-gu
Pohang, Gyeongbuk, 790-834, South Korea
Tel: +82-54-223-2269-9
E-mail: eurham@hotmail.com
Webpage: www.humanopia.co.kr

Dr. Liver is a virtual liver surgery planning system to help surgeons plan liver surgery with high accuracy and ease of use in a reasonable time.

Dr. Liver pursues excellence in functionality for clinical decision support for safe and rational surgery and user-friendly interface.
The User-Friendly Virtual Liver Surgery Planning System

1. SLV Estimation
   The standard liver volume of a patient can be estimated based on the height and weight of the patient using three formulas (Yu et al., 2004; Urata et al., 1995; and Heinemann et al., 1999).

2. Liver Extraction
   The liver can be automatically extracted in 2 ~ 4 min using a sophisticated algorithm (termed as hybrid liver extraction method) once multiple seed points are selected on 5 ~ 6 slices by the user.

3. Vessel Extraction
   The PV, HA, HV, and IVC can be extracted in 2 min each using modified region growing methods, which use multiple seed points, masked CT images, and an optimal threshold interval identified by the K-means clustering method.

4. Tumor Extraction
   The tumor(s) can be extracted in 2 min by a threshold-based level-set method, which uses multiple seed points and an optimal initial threshold interval automatically identified by the K-Means clustering method.

5. Liver Segmentation
   The liver can be divided into segments in 1 ~ 3 min per segmentation according to Couinaud's classification method based on the PV and HV structures. Two modes (plane and sphere) are available for segmentation.

6. Liver Surgery Planning
   The resected area of the liver can be defined using one of three different modes (plane, segment, and sphere). The volumes of the liver and remnant/graft and the percentage of the remnant liver volume are provided.
Thank you for your attention!
IQQA Liver

- Developed by EDDA, USA

Limitations:
- Expensive and no specifications of the system provided
- No usability testing of the system provided

⇒ Not available for evaluation and close comparison