A Hybrid Semi-Automatic Method for Liver Segmentation Based on Level-Set Methods Using Multiple Seed Points

Xiaopeng Yang¹, Younggeun Choi¹, Wonsup Lee¹, Heecheon You¹, Jihyeon Kim², Jaedo Yang², Hongpil Whang², Baojian Wang², Hee Chul Yu², and Baik Hwan Cho²

¹ Dept. of Industrial & Management Eng., POSTECH
² Dept. of Surgery, Chonbuk National Univ. Medical School
Agenda

- Introduction
  - State-of-the-Art
  - Objectives of the Study

- Hybrid Semi-Auto Liver Segmentation Method Development

- Evaluation

- Discussion
Necessity of Preoperative Liver Volume Measurement

- Important for prediction of hepatectomy safety
  - Serious hepatic dysfunction occurs if relative residual liver volume (%RLV) < 26.6% (Schindl et al., 2005)
  - Hepatectomy is safe if %RLV > 26.5% with healthy liver and %RLV > 31% for impaired liver (Ferrero et al., 2007)

<table>
<thead>
<tr>
<th>Recipient</th>
<th>Donor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too <strong>small graft</strong> ⇒ Posttransplant complications such as <strong>small-for-size</strong> syndrome</td>
<td>Too <strong>much loss of liver tissue</strong> ⇒ High risk of postoperative <strong>liver failure</strong></td>
</tr>
</tbody>
</table>
Regression Models for Liver Volume Estimation

- Explaining **statistical relationship** between liver volume and body dimensions such as height and weight

<table>
<thead>
<tr>
<th>Author</th>
<th>Regression models</th>
<th>Adjusted $R^2$</th>
<th>Errors*</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yu et al. (2004)</td>
<td>$LV = 21.585 \times BW^{0.732} \times BH^{0.225}$</td>
<td>0.590</td>
<td>Mean</td>
<td>Median</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27.96</td>
<td>27.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>275.4</td>
<td>275.8</td>
</tr>
<tr>
<td>Urata et al. (1995)</td>
<td>$LV = 2.4 + 706.2 \times BSA$</td>
<td>0.962†</td>
<td>Mean</td>
<td>Median</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>226.90</td>
<td>213.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>289.4</td>
<td>289.6</td>
</tr>
<tr>
<td>Heinemann et al. (1999)</td>
<td>$LV = -345.7 + 1072.8 \times BSA$</td>
<td>0.300†</td>
<td>Mean</td>
<td>Median</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30.64</td>
<td>29.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>281.5</td>
<td>281.7</td>
</tr>
</tbody>
</table>

* Differences between actual LV data and corresponding regression estimates
† Values reported by Heinemann et al. and Urata et al.
BW: body weight, BH: body height, BSA: body surface area

**Limitation:**

- **Accuracy sacrificed** in liver volume estimation
Liver segmentation from CT images by image processing methods. Then calculate volume of the reconstructed liver.

Liver segmentation methods
- Manual drawing
- Semi-automatic
- Fully automatic
Fully Automatic Liver Segmentation Methods

- No initialization such as seed points

<table>
<thead>
<tr>
<th>Source</th>
<th>Methods</th>
<th>Accuracy (Overlap ratio: %)</th>
<th>Time Efficiency (Processing time per data: min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jiang and Cheng, 2009</td>
<td><strong>Mathematical morphology</strong>: applied to separate the liver from others using the erosion and dilation operations</td>
<td>94.6</td>
<td>10.5</td>
</tr>
<tr>
<td>Massoptier and Casciaro, 2008</td>
<td><strong>Statistical analysis</strong> to separate the liver region from others since it has minimal S.D. in intensity compared to other regions</td>
<td>94.2</td>
<td>13.3</td>
</tr>
</tbody>
</table>
| Ruskó et al., 2007      | • **Automatic seed region identification** using histogram analysis  
                          • Region growing method used to extract the liver | 89.3                       | N/A                                           |

**Limitation:**

- Accuracy **sacrificed** since it is hard to separate the liver from others due to **intensity similarity** (Lee et al., 2007)
Semi-Automatic Liver Segmentation Methods

- Initialization needed such as seed points or seed regions

<table>
<thead>
<tr>
<th>Source</th>
<th>Methods</th>
<th>Accuracy (Overlap ratio: %)</th>
<th>Interaction Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dawant et al., 2007</td>
<td>• Delineation of initial liver contours</td>
<td>90.2</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>• Interpolation applied to extract other slices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hermoye et al., 2005</td>
<td>• Seed region (a circle) selection on each slice</td>
<td>N/A</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>• Geometric deformable models and level-set method used to extract the liver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pan and Dawant, 2007</td>
<td>• Seed region (a circle) selection on each slice</td>
<td>95.8</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>• Level-set method used to extract the liver</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Limitation:

- Long user interaction required to generate initial contours or seed regions

⇒ Cumbersome to use
Objectives of the Study

- Develop a hybrid semi-automatic liver segmentation method which has
  - Better accuracy and time efficiency
  - Minimum user interaction for initialization
- Evaluate the proposed method
Developed a five-step procedure for liver segmentation

- S1. Preprocessing of CT images
  - (1) Denoising

- S2. Selection of multiple seed points

- S3. Formation of initial liver regions

- S4. Liver extraction based on the initial liver regions

- S5. Post-processing of the extracted liver
  - (1) Liver surface smoothing
S1. Pre-Processing

- Reduce Noises of the CT images by an anisotropic diffusion filter (Perona and Malik, 1990)
S2. Multiple Seed Points Selection

- Select multiple seed points (20 ~ 30) from different CT slices (4 ~ 5)

Selection of 27 seed points from four slices with an interval of 40 for a CT volume of 184 slices (selection time: 30 sec)
S3. Initial Liver Region Identification

- Form an **optimal initial liver region** automatically from the selected seed points by a customized **fast-marching level-set method** (Sethian, 1996)

1. Calculate **image gradient magnitude**
2. Calculate **contour propagation speed**
3. Calculate **arrival time** of the propagating contour at each voxel
4. Extract the **initial liver region**
Liver segmentation from the initial liver region by a threshold-based level-set method (Hsu et al., 2010; Lefohn et al., 2003)
S5. Post-Processing

- Liver **surface smoothing by a binary median smoothing filter**
  (Nodes and Gallagher, 1982)
Evaluation: Compare to OsiriX 2D Region Growing Method

- Visual inspection of segmentation accuracy
  - **Proposed hybrid method** > OsiriX 2D region growing method

![Ground truth](manually segmented by a radiologist)

![Proposed hybrid method](OsiriX 2D region growing method)
### Segmentation Accuracy

<table>
<thead>
<tr>
<th></th>
<th>Hybrid</th>
<th>OsiriX 2D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Similarity index (%)</strong></td>
<td><img src="#" alt="97.6 ± 2.2" /></td>
<td><img src="#" alt="94.0 ± 5.3" /></td>
</tr>
<tr>
<td><strong>False positive error (%)</strong></td>
<td><img src="#" alt="2.2 ± 1.4" /></td>
<td><img src="#" alt="5.3 ± 6.7" /></td>
</tr>
<tr>
<td><strong>False negative error (%)</strong></td>
<td><img src="#" alt="2.5 ± 1.4" /></td>
<td><img src="#" alt="6.5 ± 6.7" /></td>
</tr>
<tr>
<td><strong>Average symmetric surface distance (mm)</strong></td>
<td><img src="#" alt="6.5 ± 1.4" /></td>
<td><img src="#" alt="6.7 ± 6.7" /></td>
</tr>
</tbody>
</table>

- **Similarity index (%)**: 
  - Hybrid: 97.6 ± 2.2
  - OsiriX 2D: 94.0 ± 5.3
  - ($t(16) = 6.92, p < .001$)

- **False positive error (%)**: 
  - Hybrid: 2.2 ± 1.4
  - OsiriX 2D: 5.3 ± 6.7
  - ($t(23) = –9.07, p < .001$)

- **False negative error (%)**: 
  - Hybrid: 2.5 ± 1.4
  - OsiriX 2D: 6.5 ± 6.7
  - ($t(15) = –4.19, p = .001$)

- **Average symmetric surface distance (mm)**: 
  - Hybrid: 1.4 ± 1.4
  - OsiriX 2D: 6.7 ± 6.7
  - ($t(14) = –5.35, p < .001$)
**Time Efficiency**

**Interaction time (sec)**

<table>
<thead>
<tr>
<th>Method</th>
<th>Interaction time (sec/CT dataset)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid</td>
<td>28</td>
</tr>
<tr>
<td>OsiriX 2D</td>
<td>484</td>
</tr>
</tbody>
</table>

\[ t(14) = -13.97, \, p < .001 \]

**Total liver segmentation time (sec)**

<table>
<thead>
<tr>
<th>Method</th>
<th>Total liver segmentation time (sec/CT dataset)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid</td>
<td>77</td>
</tr>
<tr>
<td>OsiriX 2D</td>
<td>575</td>
</tr>
</tbody>
</table>

\[ t(14) = -14.20, \, p < .001 \]
Effect of seed point selection on segmentation accuracy

- SI increased rapidly when the number of seed points increased from 5 to 15, slowed down from 15 to 30, and leveled off after 30.
Onsite Competition at SLIVER07 of MICCAI 2007 Workshop

- Evaluated using 10 onsite test data sets provided by MICCAI 2007 Workshop
- Evaluation score: 78.9; ranked as 11 among 72 submissions (http://sliver07.org/results.php)

Left to right: sagittal, coronal, and transversal slices; Top to bottom: easy (no lesion), middle (middle size lesion), and difficult cases (large size lesion)

Limitation of the ranking system
- Limited measures: similarity index, Average symmetric surface distance (FPE, FNE not considered)
- Time efficiency not considered
- Large vessel branches not excluded from the liver
Achievement of the Hybrid Semi-Automatic Liver Extraction Method

- **Published** at the Computer Methods and Programs in Biomedicine in January, 2014

A hybrid semi-automatic method for liver segmentation based on level-set methods using multiple seed points

Xiaopeng Yang, Hee Chul Yu, Younggeun Choi, Wonsup Lee, Baojian Wang, Jaejo Yang, Hongpi Huang, Ji Hyun Kim, Jisoo Song, Baik Hwan Cho, Heechoon You

*Pohang University of Science and Technology, Pohang 790-784, South Korea

*Chonbuk National University Medical School, Jeonju 561-713, South Korea

**Abstract**

The present study developed a hybrid semi-automatic method to extract the liver from abdominal computerized tomography (CT) images. The proposed hybrid method consists of a customized fast-marching level-set method for detection of an optimal initial liver region from multiple seed points selected by the user and a threshold-based level-set method for extraction of the actual liver region based on the initial liver region. The performance of the hybrid method was compared with those of the 2D region growing method implemented in OsiriX using abdominal CT datasets of 15 patients. The hybrid method showed a significantly higher accuracy in liver extraction (similarity index, SI = 97.6 ± 0.5%; false positive error, FPE = 2.2 ± 0.7%; false negative error, FNE = 2.5 ± 0.8%; average symmetric surface distance, ASD = 1.4 ± 0.5 mm) than the 2D SI = 94.0 ± 1.9%; FPE = 5.3 ± 1.1%; FNE = 6.5 ± 3.7%; ASD = 6.7 ± 3.8 mm) region growing method. The total liver extraction time per CT dataset of the hybrid method (77 ± 103s) is significantly less than the 2D region growing method (675 ± 136 s). The interaction time per CT dataset between the user and a computer of the hybrid method (28 ± 44 s) is significantly shorter than the 2D region growing method (484 ± 126 s). The proposed hybrid method was found preferred for liver segmentation in prospective virtual liver surgery planning.

Video Demo of Liver Extraction
Discussion

- The proposed hybrid semi-automatic method sequentially incorporates a customized fast-marching level-set method and a threshold-based level-set method to achieve better accuracy (SI = 97.6%) and time efficiency (77 sec/CT dataset) in liver extraction.

- The proposed method overcomes the weaknesses of 2D region growing method in terms of accuracy and user interaction time (< 30 sec).

- The proposed method is superior to most methods at the onsite competition SLIVER07 of MICCAI 2007 workshop.

- The proposed method is applicable to tumor segmentation in the liver.
Future Work

- Develop a **fully automatic seed point selection method** to change the proposed hybrid semi-automatic method into fully automatic
  - Automatic identification of ROI through histogram analysis of CT images
- Provide **multiple intermediate segmentation candidates** for users to select the best one

**Abdominal CT Histogram**
(Kumar & Moni, 2010)

**Multiple Segmentation Candidates**
Thank you for your attention