Instrument Segmentation in Hybrid 3-D Endoscopy using Multi-Sensor Super-Resolution

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Outline

● Motivation

● Multi-frame Super-Resolution

● Tool Segmentation

● Experiments
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Motivation for Tool Segmentation
Motivation for Tool Segmentation

Assistance systems:

- Collision avoidance
- Camera positioning
- Automated procedures
Hybrid 3-D Endoscopy

- Augment color with metric range information
- Rigid endoscope
- Time-of-Flight: 64×48 px
- Color: 640×480 px
Hybrid 3-D Endoscopy

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- Rigid endoscope
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![Diagram of Hybrid 3-D Endoscopy](image)
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Multi-frame Super-Resolution

- Simultaneously increase image quality and spatial resolution
- Exploit small movements of the endoscope (e.g. jitter)
Multi-frame Super-Resolution

- Simultaneously increase image quality and spatial resolution
- Exploit small movements of the endoscope (e.g. jitter)

- Calculate the transformation on the color images
- Scale transformation into the range domain
Multi-frame Super-Resolution [1]

Multi-frame Super-Resolution [1]


Results obtained from a hybrid 3-D endoscope: RGB image (top left), raw range data (top right), single-sensor super-resolution (bottom left), our proposed multi-sensor approach (bottom right)
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Tool Segmentation

Hybrid approach:

1. Segment tools in ToF data (tools are close to the sensor)

2. Segment tools in RGB data (tools are grayish → HSV)

3. Consolidate both results
Tool Segmentation

Range Data

Sensor Data Fusion

Optical Flow Estimation → Displacement Field Mapping → Range Correction → MAP Estimation

Super-Resolution

Segmentation → Consolidation → Segmentation

Final Output

Super-Resolved Range Data
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Experiments & Results

Ex-vivo experiments with two endoscopic tools in two scenarios with six frames each (→ 12 data sets) and expert labeled ground truth data.

<table>
<thead>
<tr>
<th></th>
<th>ToF</th>
<th>Color</th>
<th>ToF &amp; Color</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>0.93</td>
<td>0.91</td>
<td>0.85</td>
<td>(\frac{TP}{TP + FN})</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.67</td>
<td>0.80</td>
<td>0.91</td>
<td>(\frac{TN}{TN + FP})</td>
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<tr>
<td>F-Score</td>
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<td>0.61</td>
<td>0.73</td>
<td>(\frac{2 \times TP}{2 \times TP + FP + FN})</td>
</tr>
</tbody>
</table>
Experiments & Results

Input Data

ToF Mask

RGB Mask

Final Mask
Experiments & Results

- Improve the Super-Resolution framework
- Consider more complex segmentation techniques (e.g. k-means ..)
Thank you
Multi-frame Super-Resolution

- Simultaneously increase image quality and spatial resolution
- Exploit small movements of the sensor

1. Register all images
2. Set up a generative image model
   \[ y^{(k)} = W^{(k)} x + \epsilon^{(k)} \]
   \( W^{(k)} \) : System matrix of the \( k^{th} \) frame
3. Solve the equation system
   \[ \hat{x}_{MAP} = \arg\min_x \sum_{k=1}^{K} \left\| y^{(k)} - W^{(k)} x \right\|_2^2 + \lambda R(x) \]