Localizing dexterous surgical tools in X-ray for image-based navigation

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Background

- Continuous dexterous manipulators (snake-like robot) for orthopedic surgery\textsuperscript{[1]}
- Applications: osteolysis, femoroplasty, osteonecrosis, etc.

\textsuperscript{[2]} https://www.goudelis.gr/en/content/femoral-head-osteonecrosis-avascular-necrosis
Background

- X-ray images commonly used in orthopedic procedures → fast & accurate
- X-ray image-based tool navigation
Challenges

Snake navigation and shape estimation

Sensor based:

- Optical tracking system: limited workspace
- Fiber Bragg Grating (FBG) based shape sensing\(^3\): inaccurate results when touching obstacles

Image based:

- X-ray image-based 2D-3D registration: small capture range, requires automatic and robust initialization

Our solution

Image-based initialization for 2D-3D registration by concurrent segmentation and localization of the snake in X-ray images

Simulation DRR → Detection result → Initialization for 2D-3D registration
Segmentation and landmark detection

Segmentation mask:
- Region of 26 alternating notches which discerns the snake from other surgical tools

Localization landmarks:
- Middle of the 2 conjunction points between the first notch and the base
- Center of the distal plane of the last notch
Simulate X-ray images via DeepDRR[4]

CT data → Snake model → DeepDRR

Method

Data augmentation

*all uniform random sampling

• Source rotation:
  ➢ LAO/RAO ∈ [0°, 360°]
  ➢ CRAN/CAUD ∈ [75°, 105°]
• Source-to-isocenter ∈ [400, 500] mm
• Volume translation ∈ [−20, 20] mm in all axes

Snake shape:
• Control point angles ∈ [−7.9°, 7.9°]
Concurrent segmentation and landmark detection

- $\text{Conv2d} + \text{ReLU}$
- $(\text{Conv2d} + \text{ReLU}) \times 2 + \text{MaxPooling}$
- $\text{ConvTranspose2d} + (\text{Conv2d} + \text{ReLU}) \times 2$
Experiment

Real X-ray evaluation

• 87 *ex vivo* X-ray images acquired during curved drilling experiment of femur

• Manually annotated mask and landmarks for evaluation
## Result

<table>
<thead>
<tr>
<th></th>
<th>Segmentation Dice Score</th>
<th>Landmark Mean L2 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Synthetic</strong></td>
<td>0.996 ± 0.001</td>
<td>0.365 ± 0.345</td>
</tr>
<tr>
<td><strong>Real</strong></td>
<td>0.915 ± 0.063</td>
<td>2.54 ± 0.95</td>
</tr>
</tbody>
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**Sim:**

**Real:**
Application to Registration

Input

FBG data

Shape Estimation

X-ray Projection

Segmentation & Landmark Detection

Curve-based 2D-3D Registration

Intensity-based 2D-3D Registration
Conclusion

- **Automatic image-based initialization for 2D-3D registration**
  - yield overlapping structures by design

- **Learning-based localization pipeline**
  - simultaneously localize and segment snake in X-ray images

- **Further investigation of framework robustness**
  - generalize to real X-ray images
Future Work

- Train our ConvNet on a more exhaustive dataset
- Translate to other real data
- Reliably and robustly initialize image-based 2D-3D registration
Thank you!

Welcome to see our poster LA-1