Paper Review: Needle Detection in Ultrasound using the Spectral Properties of the Displacement Field: A Feasibility Study

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Project Description

- Goal: To detect and track tools during surgery
  (more specifically, needle tips)
- Our approach:
  - Use a combination of Ultrasound and 2-D photo images to locate the position of a needle tip with an acoustic element

Paper Selection

- " Needle detection in ultrasound using the spectral properties of the displacement field: a feasibility study ", *Proc. SPIE* 9415, Medical Imaging 2015: Image-Guided Procedures, Robotic Interventions, and Modeling, 94150U (March 18, 2015); doi:10.1117/12.2081723; http://dx.doi.org/10.1117/12.2081723

Problem Summary

- Ultrasound-guidance is the standard of care for needle procedures
- Clear needle visibility is an issue
- Increased by depth of needle and angles with ultrasound axial direction

Some Other Approaches

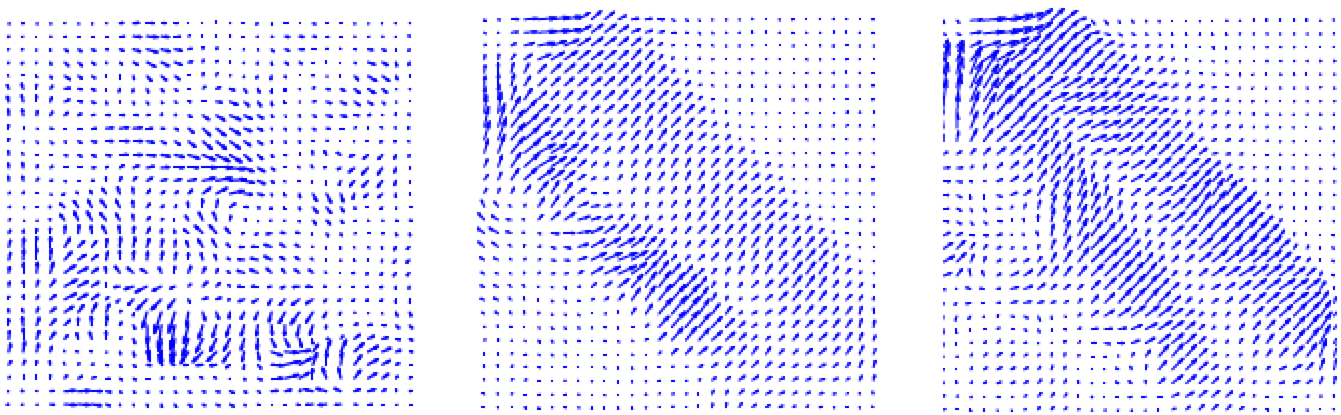
- Signal/Image post-processing techniques
- Physical Needle modifications to improve visibility
- Beam formation enhancements
- All require significant change

Methods

- Attempts to resolve needle visibility without any physical changes
- Combine 3 Techniques
  - Displacement Field Estimation
  - Block-based Motion Estimation
  - Spectral Coherency

Displacement Field Estimation

- Optical flow model based on Lucas-Kanade approach



Block-based Motion Estimation

- Motion estimation only done on smaller regions to save on computation

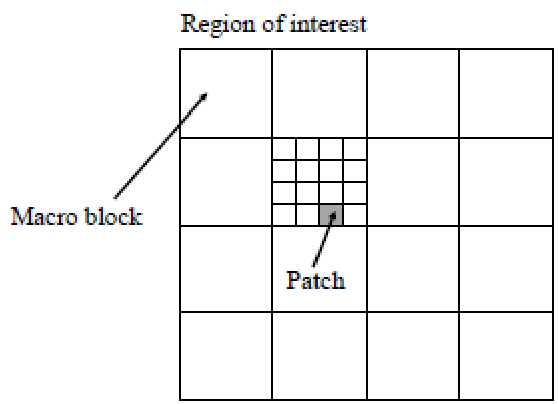


Figure 1: Macro blocks and patches in an ROI.

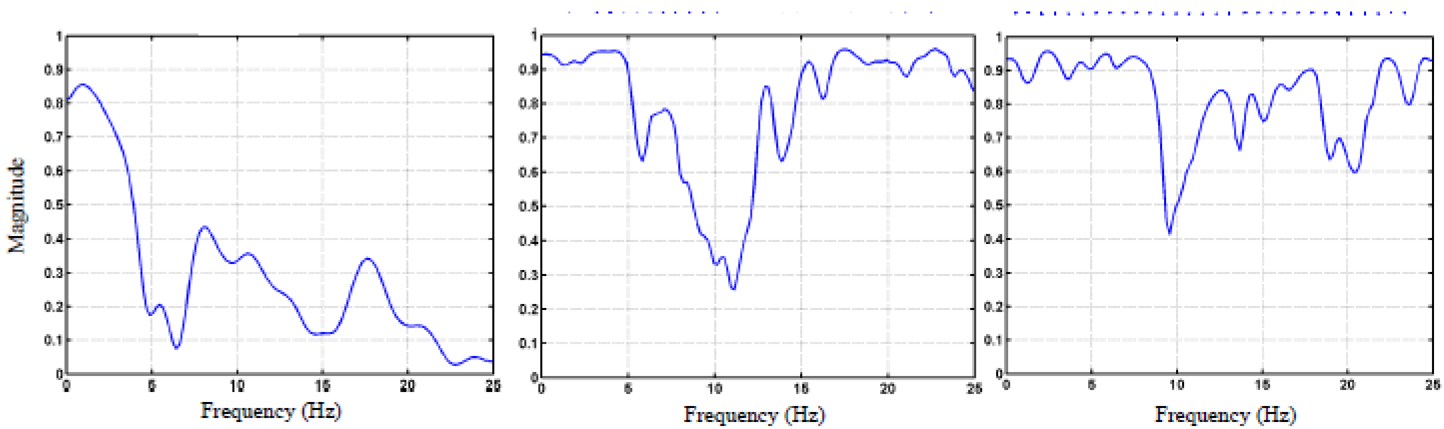
Spectral Coherency

- Reference block is chosen (tissue or needle)
- Intrinsic body motion produces coherent displacement with respect to reference block
- Intentional movements of the needle also produces coherent displacement with respect to reference block
- Cxy(f) is the magnitude squared spectral coherence
- Pxx, Pyy, and Pxy are the power spectral densities (PSD)

$$C_{xy}(f) = \frac{|\mathbf{P}_{xy}(f)|^2}{\mathbf{P}_{xx}(f)\mathbf{P}_{yy}(f)}$$

Spectral Coherency

- Needle movement coherent to needle block but not tissue block
- High spectral coherency at higher frequencies are needle regions



Experiment Setup

- iU22 ultrasound imaging system with a C5-1 (1-5 MHz) curved array transducer from Philips Ultrasound
- Standard 17 gauge Tuohy epidural needle
- Captured in vivo images of tissue around abdominal aorta for intrinsic body motion data
- Performed needle tracking in an agar based tissue-mimicking phantom

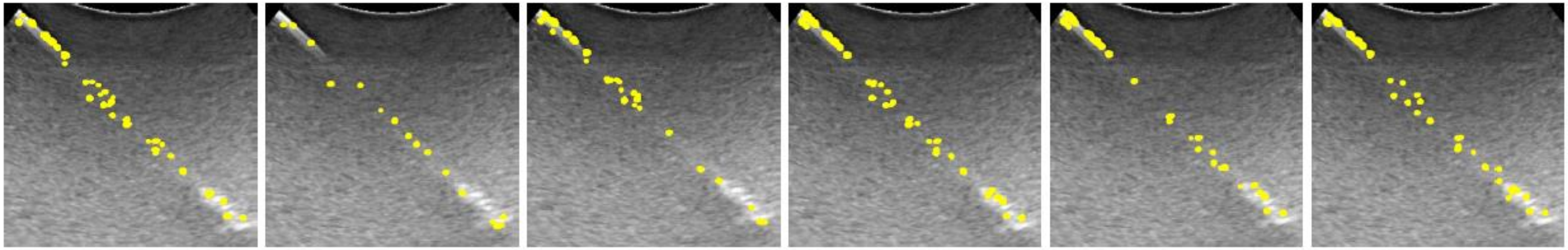
Experiment

- Want to differentiate intrinsic motion from heart beat from:
  - vibration of needle (approx. 1 mm)
  - rotation about the needle shaft (approx. 5 degrees)
  - hand tremor (holding the needle steady)
- Compare results with manual needle localization on B-mode images

Results

- Three motion types compared for a total of 30 images
- Needle shaft localization error for three different motion types captured from an agar phantom (below)

Motion Type	$\overline{\Delta l}$	$\sigma_{\Delta l}$	RMS(Δl)
Tremour	$0.9\ mm$	$0.5\ mm$	$1.0\ mm$
Vibration	$0.6\ mm$	$0.5\ mm$	$0.7\ mm$
Rotation	$0.5\ mm$	$0.3\ mm$	$0.5\ mm$



Relvance

- Attempts to solve the same issue that we want to solve
- Provides an alternative viable technique to locate a needle inside a patient during surgery

Assessment

Pros

- Does not require additional hardware modifications
- Detects segments of the needle unseen in ultrasound image by human perception
- Low error compared to manual localization

Cons

- Did not perform the needle tracking in the human body
- Small sample size
- Requires needle to be in the plane of the Ultrasound image
- Does not run in real time yet