Bofeng Zhang Paper Review

Paper citation:

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" 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

Project Overview for CIS Group 9

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 active piezoelectro (PZT) element

Paper Selection

The paper chosen for the review is *Needle Detection in Ultrasound using the Spectral Properties of the Displacement Field: A Feasibility Study*. This paper is chosen because it is another approach using ultrasound to locate a needle inside a solid body. It offers the group an understanding of other methods of needle detection. Furthermore, the approach described uses a conventional epidural needle to perform the localizations. This approach is different from our approach in that the needle needs to be in the plane of the ultrasound image. In addition, we require an active PZT element. Nevertheless, this paper deals with needle detection using ultrasound, which is the problem the group is working on. This will give the group members a better understanding of the possibilities and limitations with ultrasound image based needle tracking.

Problem Summary

The use of ultrasound-guidance is the standard of care for procedures involving needle incisions. Even though it is the standard, clear needle visibility is still an issue with ultrasound. The problem stems from physical challenges caused by the depth of penetration of the needle into the human body and by large angles formed by the needle relative to the axial direction of the ultrasound image. Some approaches that other groups have tried to use to improve ultrasound imaging-based needle tracking include signal and image post-processing techniques, physical needle modifications, ultrasound beam formation enhancements to improve the visibility of the needle in an ultrasound image. All of these methods, however, either require specialized equipment or significant changes to the current protocols.

Methods Overview

The paper combines three techniques post-image-collection to help locate the needle within a body. This means that improved needle visibility will come without the need of making any physical modifications to the system. The three techniques are named Displacement Field Estimation, Block-based Motion Estimation, and Spectral Coherency. For Displacement Field estimation, the Lucas-Kanade method is used along with a multi-scale affine optical flow model. The changes of intensity and displacement of intensity are used.

For Block-based Motion Estimation, a region close to the approximate site of insertion is chosen as the region of interest. Then the region of interest is split into macro blocks and the further into patches. The position of each patch is tracked for a number of frames to create a displacement map of the macro block. Average displacement in each (lateral and axial direction) is the computed for all the marc blocks in the region of interest.

For Spectral Coherency, it is hypothesized that intrinsic body movement has coherent displacement with respect to a reference block in the tissue. The same is hypothesized for intentional movement of the needle produces coherent displacement with respect to the reference block on the needle. These two, however, can be distinguished spectrally. Spectral coherence can be computed by:

$$C_{xy}(f) = \frac{\left|P_{xy}(f)\right|^2}{P_{xx}(f)P_{yy}(f)}$$

Where P is the power spectral density (PSD). The PSD describes how the power of the signal is distributed over different frequencies much like how a probability distribution function (PDF) describes a probability distribution. Pieces of the images that have high spectral coherency at higher frequencies are the needle.

Results Overview

The authors compared the needle shaft localization determined by their new method using the spectral properties of the displacement field against manual needle localization on the same B-mode ultrasound images. The results for 30 images were examined. The mean error for the Tremor, Vibration, and Rotation motion were 0.9mm, 0.6mm, and 0.5mm. The corresponding standard deviation of the error was, for the motions in the same order, 0.5mm, 0.5mm, and 0.3mm. The corresponding root mean square was, for the motions in the same order, 1.0mm, 0.7mm, and 0.5mm. These resulting are promising in that they are at least on par with other methods to improve needle localization using ultrasound imaging. In addition to the accuracy described by the table of results, they have showed the spectral method to be especially useful in detecting parts of the needle that is unseen in the ultrasound B-mode images to the naked eye.

Paper Evaluation

The paper was successfully able to detect the location of a needle using the spectral properties of the displacement field in the ultrasound image. In addition, it showed that using the spectral properties of the displacement field it is able to achieve similar accuracies with the localization of a needle using ultrasound-imaging techniques as techniques implemented by other groups to improve needle visibility for better localization accuracy. This technique is potentially very promising as it is able to achieve the measurements with no additional hardware or hardware modifications. It was also able to detect needle section unseen by manual localization of human perception using the same ultrasound images.

The paper, however, does have some shortcomings. There were only a total of 30 points images taken. This is a rather small sample size as each motion type only has 10 images. The paper also does not mention the number of different positions and depth that the needle were in. If all 30 images were taken with the needle in the same pose, then we do not know if the method with work with the needle in other poses and the limitations of its depth. In addition, the ground truth used in the experiment was needle localization using human perception. The accuracy and precision of the ground truth is unknown. If the whole point of needle localization is to improve accuracy and precision because the lack of both accuracy and precision with human perception in this task, then problem statement already rules out human perception as a valid ground truth to measure against. The paper also states that an agar phantom was used for the experiment. Even though human images of the aorta were used before the experiment to show that the tissue can be differentiated from the needle, the authors do not account possible unknowns of the flesh directly around the needle unless it is tested. One such possibility would be the flesh very close to the needle experience similar spectral coherence.

Ultimately, this paper still requires the needle to be in the plane of the ultrasound image, so it will only serve to provide the group with insight on how other methods solve the same problem that we are looking to solve. It seems that the group has problems imaging the needle due to reflectance of the needle. This will not be an issue in our approach, as the active PZT element at the tip of the needle will be transmitting the signal to the transducer.