CIS II Paper Presentation Critical Summary

Project: **Synthetic Aperture Ultrasound Imaging with Robotic Tracking Technique**

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March 11, 2014

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"*Design and development of an ultrasound calibration phantom and system*", SPIE Medical Imaging, 2014, in press

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Paper Selection:

I selected this paper because the method proposed in this paper can be a strong reference for my project. The goal of my project is to achieve higher resolution in ultrasound imaging by combining tracking technique with synthetic aperture. Synthetic apertures improve the resolution of deep targets by expanding the aperture size and knowing the precise orientation and location of an ultrasound transducer can generate imaginary elements, which eventually expand the aperture size further. Accurate tracking of ultrasound images requires knowing the position of the tracking device attached to the ultrasound probe as well as the rigid-body relationship between the attached sensor and ultrasound image. The process to acquire the unknown rigid-body transformation is called ultrasound calibration. The strategy taken to get the transformation between the tracking device and image is solving the hand-eye calibration problem.

This paper describe the state-of-the art solution to do ultrasound calibration. The mathematical approach to obtain unknown transformation was solving AX=XB problem which can be a basement to apply into our project. Moreover, their experimental considerations are available to our project.

Technical Summary:

The main claim of this paper is its idea of new phantom design, but the technical background of the research is also described in the paper.

First, the basic of ultrasound calibration is discussed. Ultrasound calibration process is needed when one wants to use ultrasound to perform more advance forms of guidance. The tracked rigid body must be attached to the US transducer. This can be either an optical marker or an electromagnetic sensor. In our case, robotic tracking system will be used. The US calibration process finds the rigid body transformation between tracked rigid body to the ultrasound image. Once the transducer is calibrated, advanced uses of US system are possible, such as overlying the ultrasound image onto a video stream or actuating a tracked robotic actuator to the target. Actually our research is also based the application in a way that using robot to move transducer at specific direction and angle. There are several approaches to finally obtain the unknown transformation such as cross-wire, Z-fiducial, and AX = XB phantoms. Compared to these conventional phantoms, the advantage of the new phantom is that a lot of lines increase the opportunity to correct the error during segmentation (Fig. 2). Multiple Z-fiducial is combined in the phantom, and each position of Z-fiducial is considered to be able to be scanned from any directions. Moreover, the design is generated from CAD file, which means that the same structure can be easily printed repeatedly. Since it is not relying on specific material or process of construction, the easy access is a characteristic of the phantom.

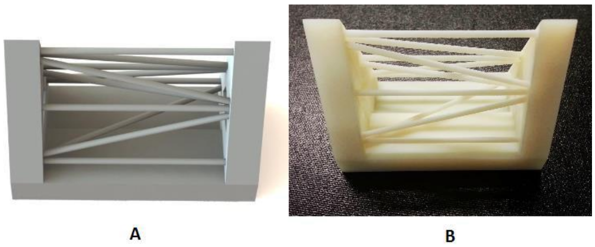


Figure 2. Calibration phantom model

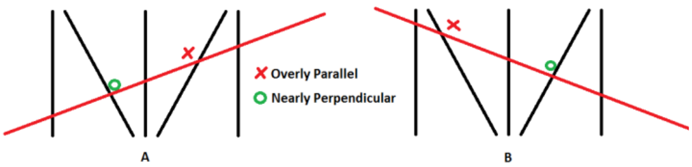
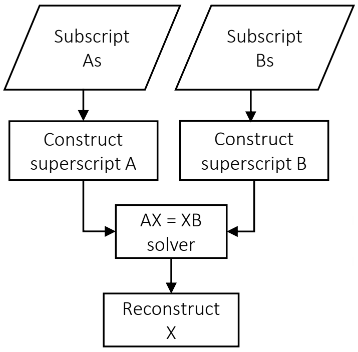


Figure 3. Z-fiducial orientations

Figure 1 shows the stream of ultrasound calibration. The mathematical derivation of the unknown transformation can be expressed as hand-eye calibration or AX = XB problem. Subscript B represents the transformation from tracking base to the tracker attached to the transducer, and subscript A represents the transformation from transducer to image (phantom). To construct superscript A and B, the relative transformation of each pose are calculated, and finally X is computed though Kronosolver by inputting As and Bs which come from multiple poses.



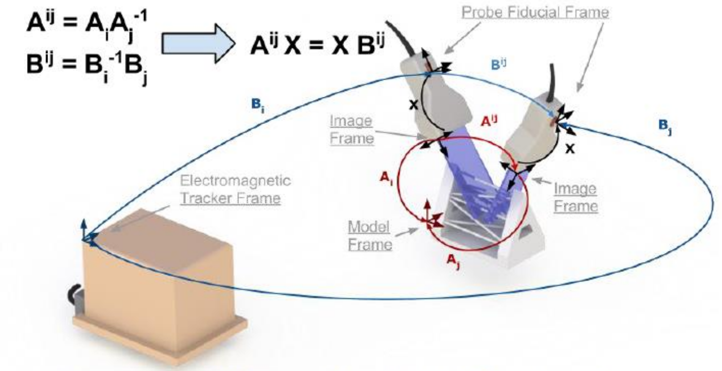


Figure 1. $AX = XB$ formulation with labeled coordinate frames

The data processing process is also discussed. Ultrasound calibration process has been discussed, so here I would like to look into automatic segmentation. The calibration itself can work by manually picking point from ultrasound images. However, this is really time consuming task, and it is also very human dependent. Therefore, automatic segmentation method is an objective and efficient implementation. After taking intensity threshold, only certain size and shape will be remained through filteration. Top most region will be found to take this point as the origin of the phantom. This process is important because if the transducer is tilted, it is possible to misunderstand the rotation of the unknown transformation. To improve the accurate point picking, hough transformation is used to find the most realistic line path through three side points and the ratio to the mid point tells us the unique rotation for subscript As. Since B can be obtained from tracking system, we can have enough information to solve AX = XB.

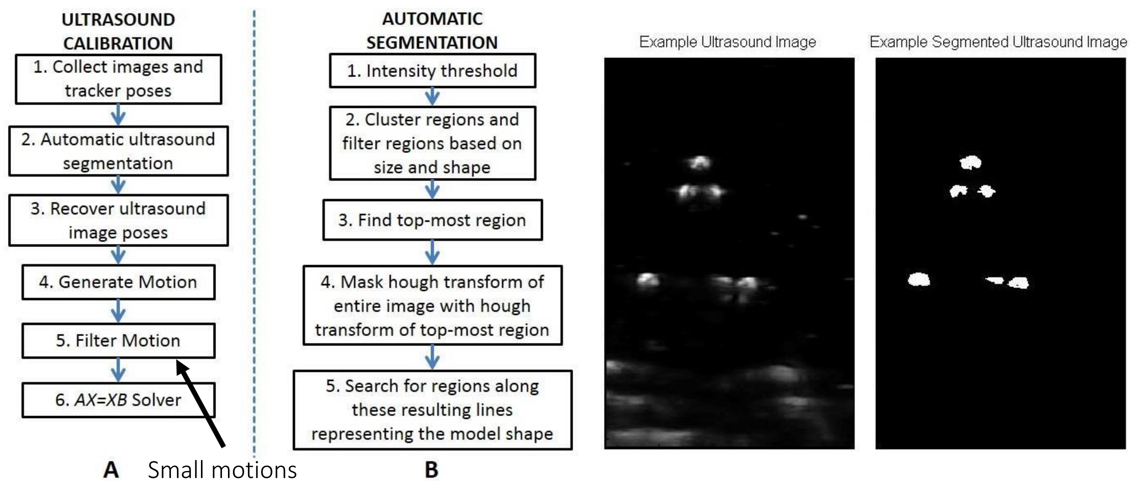


Figure 2. Workflows for A) the overall US calibration and B) the automatic segmentation algorithm

Finally, the experimental result is discussed. After calculating X using AX = XB solver, the point chosen from segmentation was put back to the three dimensional field to recover the structure of the phantom by calculating *BXp*. If the X is correct, the reconstructed points should construct the exact shape of the phantom built. The way to reconstruct error metric is not clearly described but probably the origin of the phantom coordinate is calculated. Two conditions are considered on the reconstruction processes. On one scenario, only relative poses were used to construct superscript As, and for the other scenario, we used all possible combinations of subscript As for all different poses. From table 1, it can be seen that the more number of combination we choose, the more reconstruction precision can be improved. Moreover, another idea to maximize the reconstruction accuracy, a filtration was implemented. The characteristic that the error which cause effect on AX = XB solver is depending on the amount of motion involved in reconstruction is considered, and small motion poses are cut out from the combination of superscript As. This filtration contribute to minimize the effect of error, and actually this condition results the best precision. The number of 1.56 mm is very high number compared to other reconstruction methods. For example the 1.78 mm accuracy was reported in other group using cross-wire based ultrasound calibration[1].

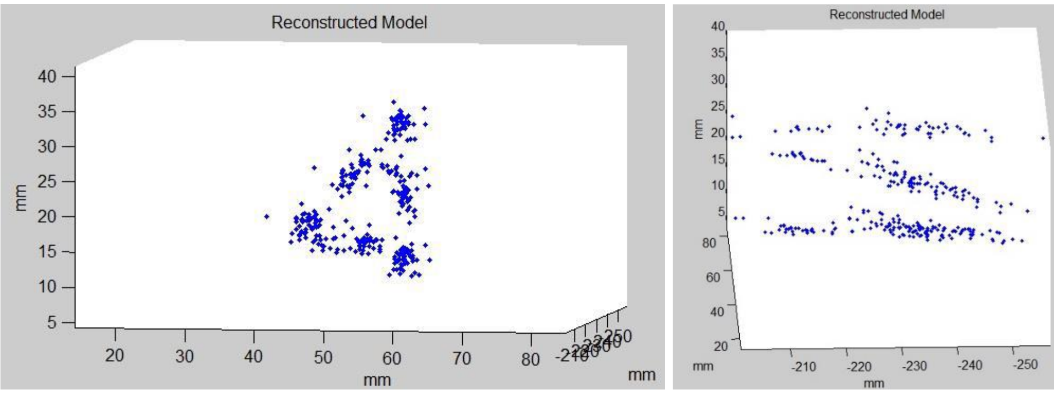


Table 1. Normalized error metric for different combinations of motion generation and filtering

Motion Generation	Filtering	Error Metric (mm)
A^i	Without	2.75 ± 1.67
A^i	With	1.74 ± 1.00
A^{ij}	Without	2.36 ± 1.49
A^{ij}	With	1.56 ± 1.02

Analysis:

The good point of this paper is that the proposed phantom is simple enough to be used and easy to be printed repeatedly. Moreover, the automated segmentation make the calibration process easier, which is really helpful to save time and close to the practical application. In cross-wire approach, the cross section has to be found for every point picking process, so that it is really time consuming. However, using this Z-fidutial based phantom, continuous data acquisition is possible.

On the other hand, the problem of this idea is the size of the diameter of line phantoms. It is somehow inevitable to make a phantom printable, but the wide diameter provide huge room to pick point in wrong way, and it is strongly depends on person who operate the calibration. Although the reconstructed result was good, still there is a room to be improved by arranging the shape of phantom or the way to process the data using the phantom.

References:

[1] Golafsoun Ameri ; John S. H. Baxter ; A. Jonathan McLeod ; Uditha L. Jayaranthe ; Elvis C. S. Chen ; Terry M. Peters, “Synthetic aperture imaging in ultrasound calibration”, SPIE Medical Imaging, 2014