Improving N-Wire Phantom-based Freehand Ultrasound Calibration

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Purpose

Freehand tracked ultrasound imaging is an inexpensive, safe and non-invasive technique for guided interventions, such as needle insertions, biopsies and ablations. This technique requires spatial calibration between the tracker and the ultrasound image plane, usually achieved with the use of a precision-machined structure called a phantom which contains predefined geometrical motifs that are imaged with ultrasound. The motifs are segmented and registered with the known object, yielding the transformation between the tracking sensor and ultrasound. Several phantoms use N-wires that are convenient for automatic processing, as the segmentation of fiducials in the images and the localization of the middle wires in space are straightforward and can be performed in real time [1]. The calibration procedures reported in the literature consider only the spatial position of the middle wires. We investigated whether more accurate and consistent calibration results can be achieved when information from all wires is equally taken into account. We compared the precision and accuracy of the proposed computational optimization with other methods published in the literature.

Methods

The probe calibration problem using an N-wire phantom [1] is expressed mathematically as

$$ {}^{\mathbf{P}}_{\mathbf{U}}\mathbf{T}\,{}^{\mathbf{U}}\mathbf{X} = {}^{\mathbf{P}}\mathbf{X} \quad (1)$$

where the columns of the matrix ${}^{\mathbf{U}}\mathbf{X}$ are the homogeneous coordinates of all the segmented middle wires in the ultrasound image reference frame (z coordinate is considered as zero in the image plane) and the columns of ${}^{\mathbf{P}}\mathbf{X}$ are the coordinates of the corresponding computed middle wires points in the probe reference frame. Chen [1] resolved this problem using a straightforward implementation of least mean squares.

We propose to compute the solution as described by Chen [1] and then perform an additional optimization step to minimize an appropriate cost function while ensuring orthogonality of ${}^{\mathbf{P}}_{\mathbf{U}}\mathbf{T}$.

We consider an in-plane-error (IPE) cost function for the minimization:

$$ IPE = \sum_{i=1}^{N_i}\sum_{j=1}^{N_w}\sum_{k=1}^{3}\left\| x_{ijk} - w_{ijk} \right\|^2 \quad (2)$$

where x_{ijk} is the intersection between the *k-th* wire of the *j-th* N-wire with the *i-th* US image and w_{ijk} is the intersection of the *k-th* wire of the *j-th* N-wire with the computed image plane (see Fig.1). N_i and N_w are the number of images taken and the number of N-wires in the phantom respectively. The cost function was minimized by using Levenberg Marquard iterative non-linear optimization algorithm, using the closed form solution proposed by Chen [1] as an initial value.

Results

Mean calibration precision achieved with the N-wire phantom was about 0.7 mm using a shallow probe and mean accuracy was around 1.2 mm. Precision was about 2.0 mm using a deep probe. Improvements in the computational methodology of N-wire based US calibration improved accuracy by 10% and precision by 8%. Based on our experiments the performance of N-wire based method is comparable to previously reported alternative calibration methods [2].

Conclusions

The favorable performance and simplicity of fabricating and using the calibration phantom makes the N-wire based method a preferable calibration option. The implementation of the proposed computational method was made freely available as part of the Public Library for Ultrasound (PLUS) research toolkit [3]. The PLUS toolkit contains all components necessary for calibration, such as data acquisition software and printing-ready CAD model. The PLUS toolkit is open-source and usable without any restriction under BSD license.

References

[1] Chen T.K., Thurston A.D., Ellis R.E., and Abolmaesumi P. (2009) A real-time freehand ultrasound calibration system with automatic accuracy feedback and control. Ultrasound in medicine & biology, 35(1):79–93,

[2] Hsu P-W., Prager R. W., Gee A. H., and Treece G. M. (2007) Freehand 3d ultrasound calibration: A review. Technical report, University of Cambridge.

[3] Lasso A., Heffter T., Pinter C., Ungi T., Chen T., Boucharin A. and Fichtinger G. (2012) Plus: An open-source toolkit for ultrasound guided intervention systems development. Imaging Network of Ontario Symposium, Toronto, Canada.

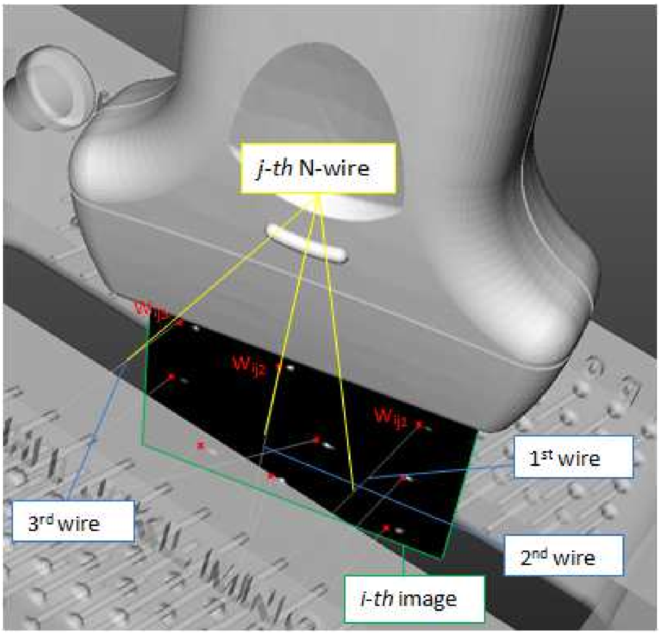

Fig. 1. The distance between the intersection of the wires with the computed image plane (red dots) and their respective segmented points in the image (white dots) is minimized

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