Improving N-Wire Phantom-based Freehand Ultrasound Calibration

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Introduction

Background

Freehand tracked ultrasound (US)

- Inexpensive, safe, non-invasive technique used in several guided interventions.
- requires spatial calibration between the tracker and the ultrasound beam.

Ultrasound probe calibration

- Procedure used to relate points in the ultrasound image plane with points in the global coordinate system, ${}^{P}_{U}T$ in Fig.1.

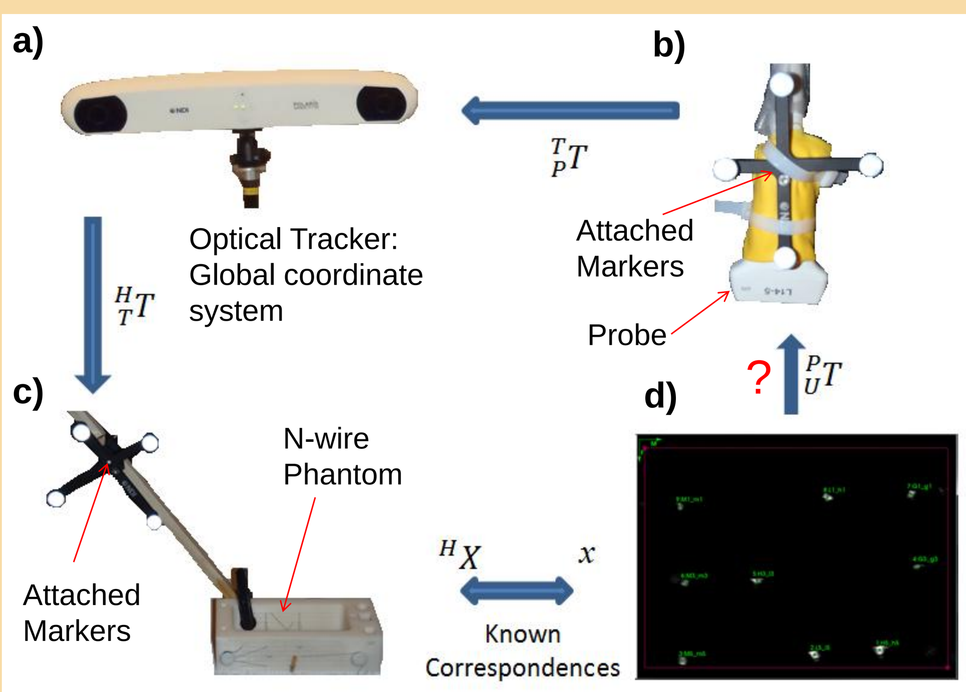

Fig.1
a) The optical tracker monitors the position of the markers
b) Position of the image with respect to the markers must be determined
c) Position of the wires with respect to the tracker is known
d) Wires in the US image are automatically segmented

N-wire phantoms

- Calibration devices that use multiple parallel N-wires
- Segmentation of fiducials in the images and the spatial localization of the middle wires are straightforward.

Methods

The procedures reported in literature consider only the spatial position of the middle wires.

Spatial intersection of a middle wire with the image plane is computed using

- Phantom geometry (Fig.2a)
- Segmented image points (Fig.2b)

as

$$X_2 = A + \frac{\|x_1 - x_2\|}{\|x_1 - x_3\|}(D - A)$$

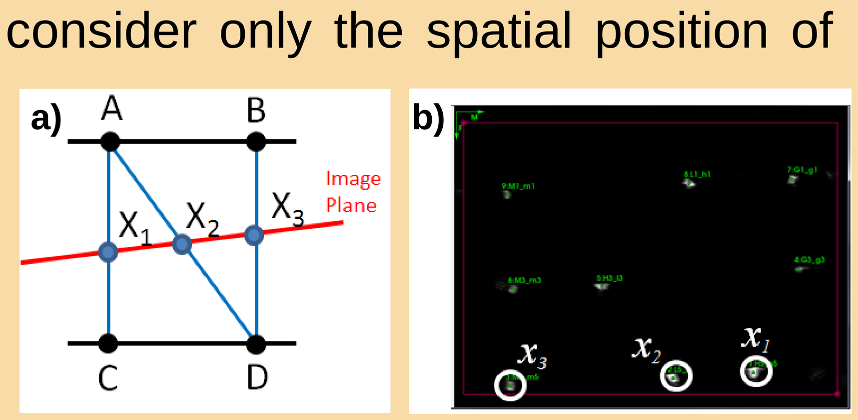

Fig.2 a) N-wire in the phantom reference frame **b)** N-wire segmented in the US image

Calibration can be performed using X_2 and $x_2$correspondences.

We propose an iterative non-linear optimization

- Initial value of the optimization is computed with a closed-form strategy based on the middle wires as in [1].
- Cost function is based on **2D errors** and it uses **all the wires** (see Fig.3).
- Estimated calibration transform = Rigid transform + Scaling transform
- Isotropic and anisotropic scaling is considered.

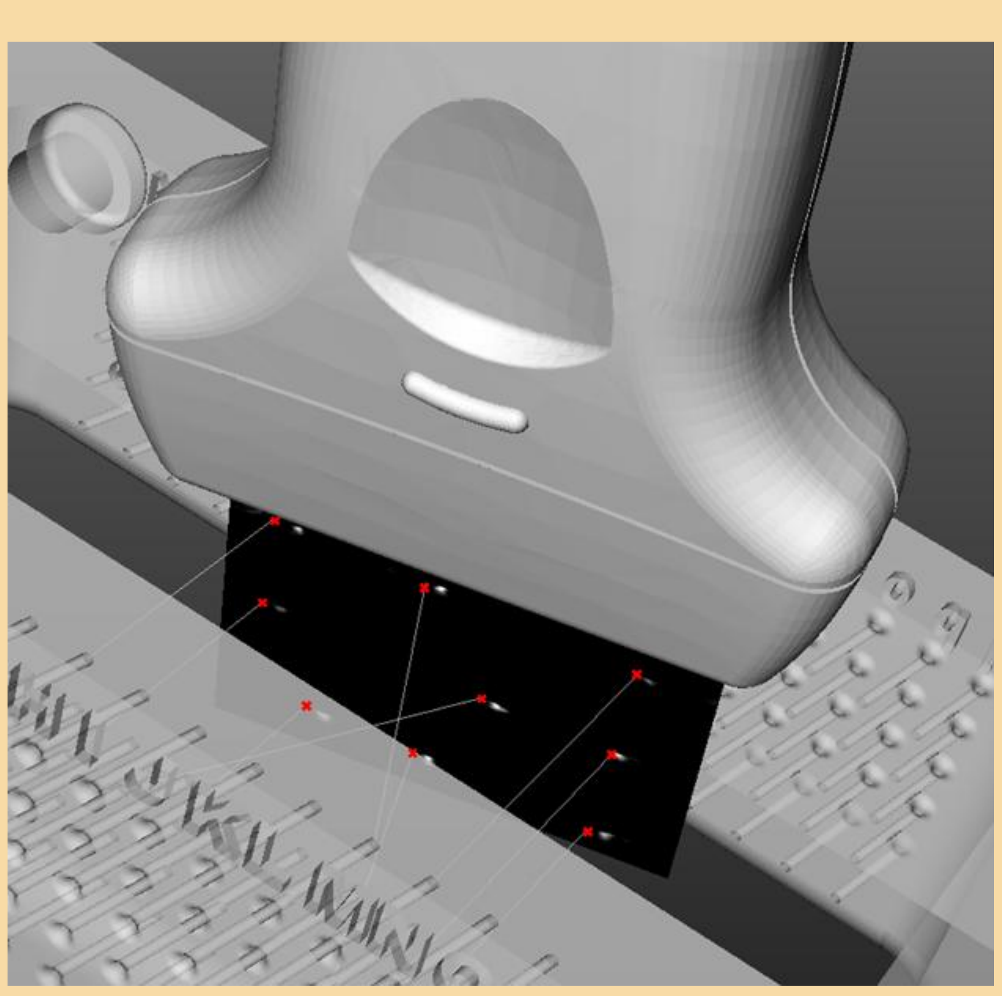

Fig.3 Distance between the intersection of the middle wires with the computed image plane (red points) and their respective segmented points in the image (white points) is minimized

Experiments and Results

- A curvilinear probe with 15 cm depth was calibrated using the methods described in Table 1.
- For each method, 15 calibration were performed using an **incremental number of frames.**
- **Precision** was estimated using the center and the corners of the image.
- Results are shown in Table1. In Fig.4 is shown the influence of the number of frames in the precision.

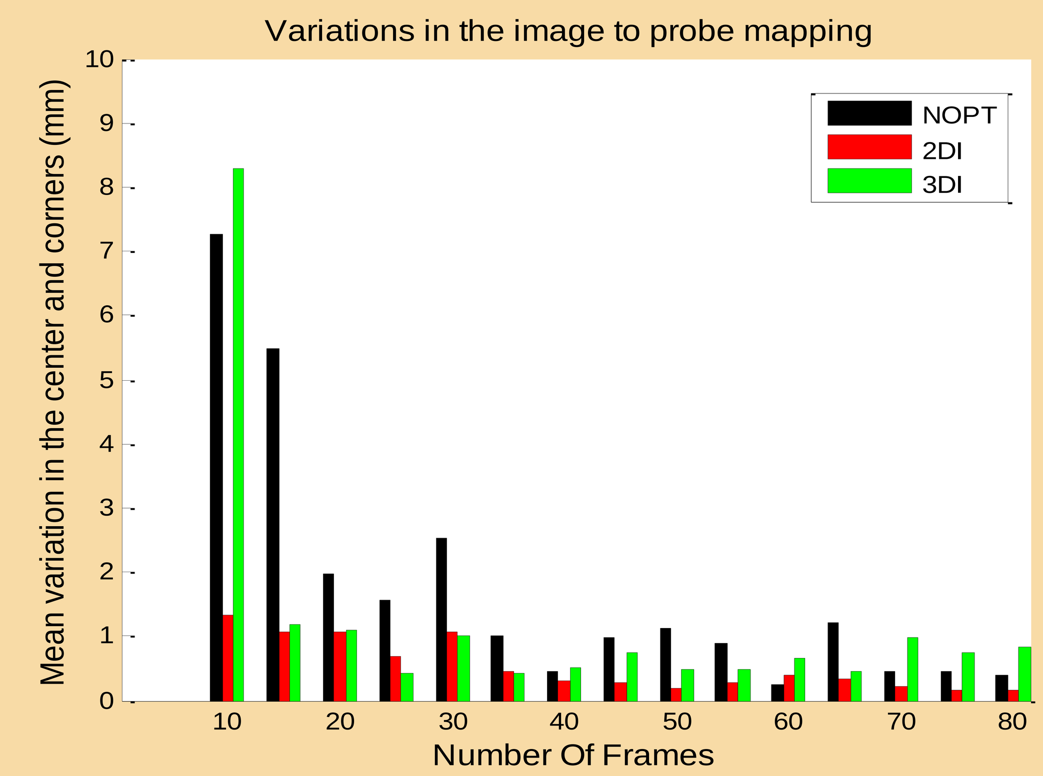

Fig.4 Deviation form the mean center and mean corners of the image

Table 1

Method	Precision (mm)
No optimization (NOPT)	1.73
2D error minimization and isotropic scaling (2DI)	0.53
2D error minimization and anisotropic scaling (2DA)	0.96
3D error minimization and isotropic scaling (3DI)	1.22
3D error minimization and anisotropic scaling (3DA)	2.24

Discussion

- **35 frames are enough to get a precision below to 0.5 mm when 2DI or 2DA is used**
- Isotropic scaling is preferred with both, 2D and 3D error minimization
- 3DI and 3DA do not improve the precision of the calibration with respect to NOPT
- Consistency of 2DI and 2DA can also be observed in the estimation of the parameters. In Fig.5 is shown the scale as an example

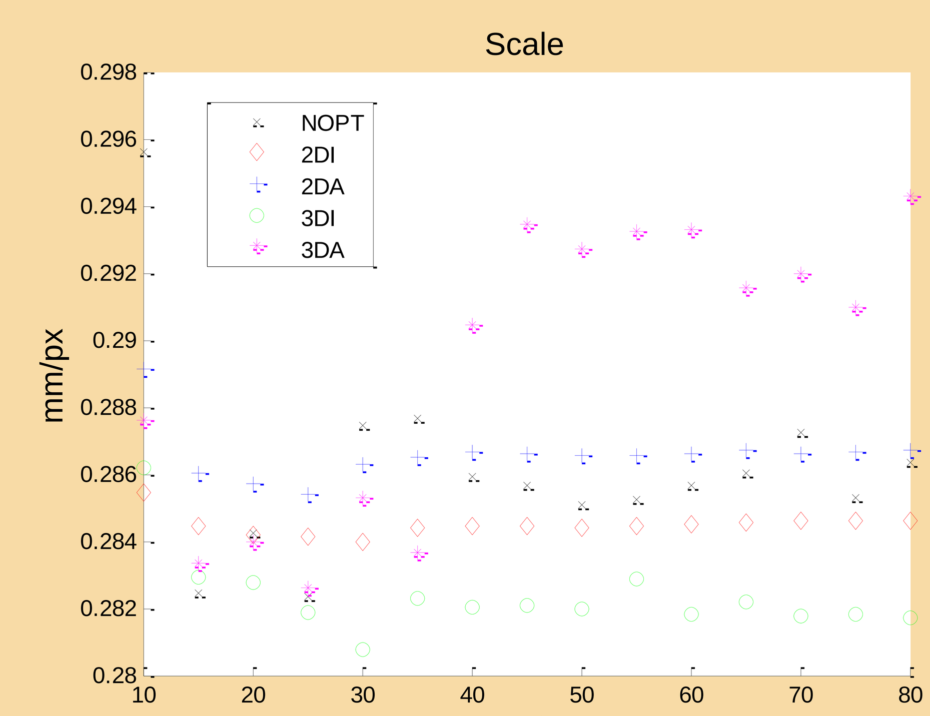

Fig.5 Scale factor in the horizontal direction.

Conclusion

Preliminary results suggest that US calibration using N-wires can be done more consistently and with a smaller range of probe movement if a 2D cost function is used for all the wires instead of a 3D cost function for only the middle wire to optimize calibration parameters.

Reference

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

Acknowledgement

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