MEASUREMENT ACCURACY IN 3D FREEHAND ULTRASOUND CALIBRATION

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ABSTRACT

In clinical applications 3D freehand ultrasound is finding its place and with higher fidelity of imaging is now partly applicable in common use. A positional sensor is attached to a conventional ultrasound probe, so that as B-scans are acquired they can be labeled with their relative positions and orientations. This allows 3D voxel array to be compounded from several B-scans. Such array can be visualized using plane slicing, volume rendering or surface rendering. A key requirement in freehand imaging is calibration. Determining the position and orientation of the B-scan with respect to the position sensor is necessary.

1 INTRODUCTION

Classical 2D diagnostic imaging uses a hand-held probe which transmits ultrasound pulses into the object of interest and receives the echoes. The magnitude and timing of the echoes are used to create 2D grey-level image (B-scan) of a cross-section of the object in the scan plane. 3D ultrasound extends this concept so that volumes of intensity data are created from pulse-echo information.

In a chain of data processing, which consists of data acquisition, reconstruction and visualization, calibration of ultrasound probe and position sensor is necessary. Accuracy of the whole process depends mostly on determining relative position and orientation between these. The more precisely distances and rotations are found the less spatial resolution in reconstructed volume is degraded.

For more basic information see Asterios Anagnostoudis paper in this proceedings.

2 CALIBRATION

Our ultrasound data was obtained with the Vingmed Five system (GE Vingmed ultrasound), positions were taken with the miniBIRD system (Ascension, magnetic field principle). All data was saved on a PC hard disk and computed in MathWorks Matlab.

In Fig. 1 aquarium filled with water and cross-wire phantom is shown. For B-scans **P** is the coordinate system. The y-axis is the beam direction, the x-axis is the lateral direction. **R** is the coordinate system of the position system's receiver and **T** is the coordinate system of the transmitter. The reconstruction volume, created from the set of acquired B-scans, takes the form of a 3D matrix **C** of volume elements (voxels). The origin of **C**'s coordinate system is at the corner of the reconstruction volume [1].

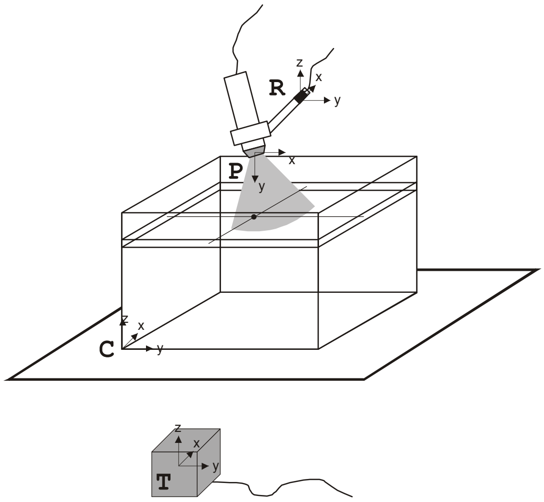

Fig. 1: *Calibration: Four coordinate systems with cross-wire phantom.*

In reconstruction process every pixel in every B-scan from **P** has to be located to the reconstruction volume **C**. The overall transformation can be expressed as the multiplication of homogenous transformation matrices [1]:

$$ {}^{C}x = {}^{C}T_{T}\,{}^{T}T_{R}\,{}^{R}T_{P}\,{}^{P}x \text{, where } {}^{P}x = \begin{pmatrix} s_x u & s_y v & 0 & 1 \end{pmatrix}^{T}. \qquad (1) $$

u and v are the column and row indices of the pixel in the image, s_x and s_y are scale factors with units of mm/pixel.

Standard notation for transformation from coordinate system I to coordinate system J is given as:

$$ {}^{J}T_{I}(x,y,z,\alpha,\beta,\gamma) = $$

$$ \begin{pmatrix} \cos\alpha\cos\beta & \cos\alpha\sin\beta\sin\gamma - \sin\alpha\cos\gamma & \cos\alpha\sin\beta\cos\gamma + \sin\alpha\sin\gamma & x \\ \sin\alpha\cos\beta & \sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma & \sin\alpha\sin\beta\cos\gamma - \cos\alpha\sin\gamma & y \\ -\sin\beta & \cos\beta\sin\gamma & \cos\beta\cos\gamma & z \\ 0 & 0 & 0 & 1 \end{pmatrix}, \qquad (2) $$

where (x,y,z) are three translations and (α,β,γ) are three rotations.

2.1 CROSS-WIRE PHANTOM

During calibration, a phantom of known geometric dimensions is scanned. The most common is the cross-wire phantom. Two intersecting wires are mounted in a water bath, with transmitter placed at some fixed location with respect to the wires, see Fig. 1.

The location, where the wires cross is scanned repeatedly from different directions, shows a detectable cross, see Fig. 2.

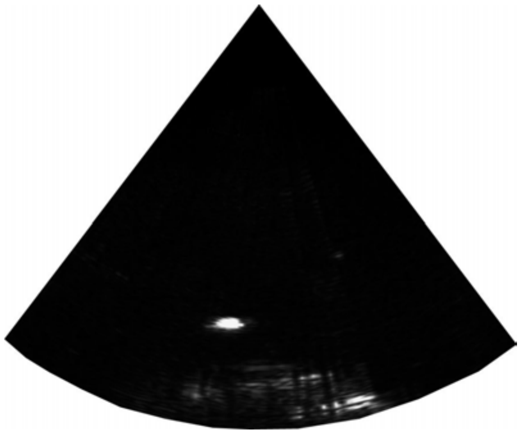

Fig. 2: *Two wires intersection on the ultrasound B-scan.*

The pixel at the center of the cross should satisfy [1]:

$$(0 \quad 0 \quad 0 \quad 1)^T = {}^C T_T \, {}^T T_R \, {}^R T_P \left(s_x u \quad s_y v \quad 0 \quad 1\right)^T . \qquad (3)$$

System (3) contains measured positions in ${}^T\mathbf{T}_R$, u and v, and unknowns ${}^R\mathbf{T}_P$, ${}^C\mathbf{T}_T$, s_x and s_y. If m B-scans were taken, then the equations produce a system of non-linear homogenous equations of size $3m$. The system can be solved using Newton or Levenberg-Marquardt algorithm [2].

2.2 CALIBRATION WITH A STICK

In this method a thin stick with attached position system receiver is used. On the one side the stick is ended with a sharp pin. In a distance of 200 or 300 millimeters from this point the position sensor is mounted. The calibration data is gathered up by moving the stick around the fixed point on the table and rotating around its axis, Fig. 3.

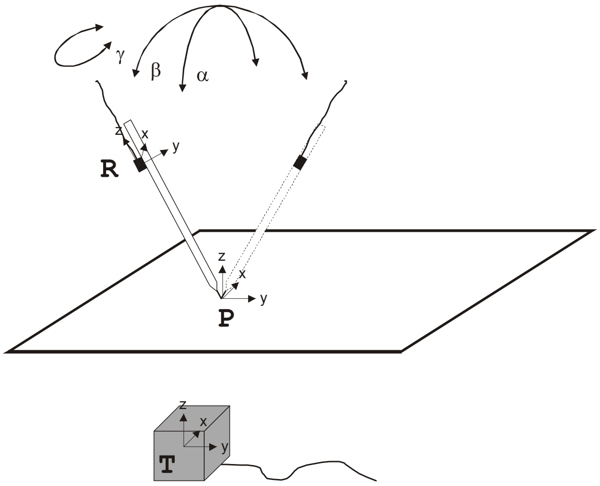

Fig. 3: *Calibration: Stick is fixed on the desk.*

In this case central point **P** should satisfy the simplified equation:

$$(0) = {}^C T_T \, {}^T T_R \, {}^R T_P . \qquad (4)$$

3 MEASUREMENTS

Whilst calibration with the ultrasound probe was taken manually, it was necessary to visually find the wires cross, only 30 B-scans and positions were taken. On the other hand position system provides data each 10ms, that is why a typical trial with a stick consists of 1000-1500 positions.

For estimation of the position system accuracy the method with the stick is used. In every computation 20 randomly chosen positions from the whole set (approx. 1000) were taken into each computation and computations were performed 10 times. Five different location of **P** with respect to the **T** were selected. This results in fifty values for sensor position estimation.

Average values (AVG) of computed distances for 200mm and 300mm stick (approximate value) are shown in Tab 1. Also standard deviations (STD) for each coordinates were computed.

Technical documentation of miniBIRD provides us with this accuracy: Positional resolution: 0.5 mm, Angular resolution: 0.1°.

	app. 200mm		app. 300mm	
	AVG	STD	AVG	STD
x	-1,724	0,1906	0,7773	0,2041
y	13,58	0,2617	9,216	0,2768
z	204,9	0,9359	307,7	1,795

Tab. 1: *Computed distances of position sensor* ***R*** *from fixed point* ***P***

4 CONCLUSIONS

An approach to 3D freehand ultrasound calibration was presented. Accuracy measurement with stick is very fast and can help with a calibration of the ultrasound probe. With good accuracy of magnetic position system and ultrasound system, 3D imaging can be useful in clinical and technical applications.

ACKNOWLEDGEMENTS

The paper has been prepared as a part of the solution of GAČR project No. 102/02/0890 and with the support of the research plan No. J22/98:262200011.

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