A SIMPLE AND ACCURATE CALIBRATION METHOD FOR 3D FREEHAND ULTRASOUND

B. Brendel[1], S. Winter[2], H. Ermert[1]

[1]Institute of High Frequency Engineering, Ruhr-University Bochum, Bochum
[2]Institut of Neuroinformatics, Ruhr-University Bochum, Bochum
Ruhr Center of Excellence for Medical Engineering (KMR)

bernhard.brendel@rub.de

Abstract— *The accurate calibration of ultrasound transducers is essential for the recording of 3D-datasets with conventional 2D ultrasound systems. For the calibration, a phantom with a known geometry is scanned, and the content of the images is analyzed.*
We present a calibration phantom which combines simple construction with high calibration accuracy and moderate calibration time. The phantom consists of a sphere which is scanned from different views. The ultrasound images are semi-automatically processed to determine center and radius of the imaged circles. These measures are used to calculate the calibration matrix. The deviation of these matrices for 10 repetitions of the calibration is 0.66 mm, indicating a high accuracy of the method.

Keywords— *3D, freehand, ultrasound, transducer, calibration*

Introduction

For the recording of 3D ultrasound datasets with conventional 2D ultrasound systems, the ultrasound transducer has to be moved to receive specially distributed ultrasound images. To reconstruct a volume dataset of the ultrasound images, the position of the transducer has to be tracked during its movement. For this purpose, a reference base is mounted to the transducer, whose position and orientation is determined by a tracking system. Initially, the spatial relation between the reference base and the ultrasound imaging plane is unknown, and must be determined by a calibration process. The result of this calibration process is a transformation matrix between reference base and imaging plane.
For the calibration, phantoms with a given geometry are scanned. These phantoms image single points (e.g. cross wire phantom [1]), straight lines (e.g. three-wire phantom [2]) or planes (e.g. Cambridge phantom [3]).
The phantom presented here, uses a single point in space for calibration. Unlike the cross wire phantom, this point is not represented by two crossing filaments, but by a sphere. Such a phantom has the advantage, that it combines a simple construction with high calibration accuracy.

Materials

The following properties of the sphere are important for an accurate calibration: First, the sphere should have only slight deviations from a perfect sphere. Second, the part of the sphere that can be imaged with ultrasound should be as large as possible (i.e. the hull of the sphere should transmit sound). For our phantom a high-quality, liquid filled table tennis ball was used, which fulfills the aforementioned conditions.
Furthermore, the sound velocity of the phantom within and outside the sphere must accord with the sound velocity of 1540 m/s (which is assumed by ultrasound systems) to avoid geometrical deformations in the ultrasound images. At room temperature water has a significantly lower sound velocity of approx. 1490 m/s [4]. Aqueous solutions of NaCl have higher sound velocities, depending on mass concentration of NaCl, temperature of the solution and ambient pressure [5]. Thus, our phantom is filled with an adequate solution taking into account the temperature of the water.

Methods

If this phantom is scanned with an ultrasound transducer, the resulting ultrasound images intersecting the sphere visualize circles. For the calibration, radius and center of these circles must be known. For the determination of these parameters, a semiautomatic algorithm is used. First, a region of interest (ROI) is selected manually. In this ROI, center and radius of the circle are determined automatically, using the Hough-transformation. The Hough-transformation is a method to segment contours with a known shape, which must be mathematically describable [6]. An example for a segmentation result is given in figure 1. The white circle visualizes the segmentation result.

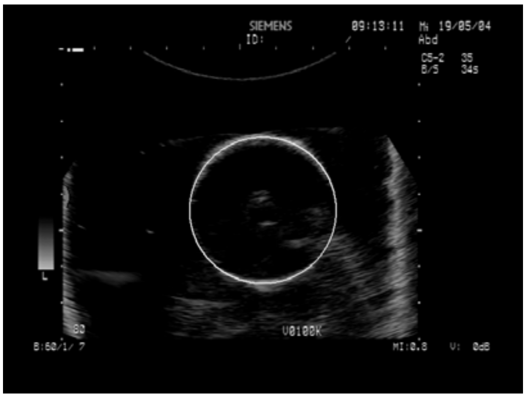

Figure 1: Segmentation of a circle in an ultrasound image with Hough-transformation

Knowing the positions of the reference base at the transducer, the positions of the reference base at the calibration phantom as well as the radii and centers of the circles in the ultrasound images, the calibration matrix can be determined.

Results

The implemented calibration phantom consists of a box with two acoustically transparent membranes. A reference base is mounted to the box and a table tennis ball (approx. 40 mm diameter) with two small holes, which allow inflow of water, is positioned inside the box (figure 2). The membranes are necessary to visualize the ball from different points of view with ultrasound.
The phantom and the ball are filled with an aqueous solution of NaCl, which has a sound velocity of 1540 m/s.

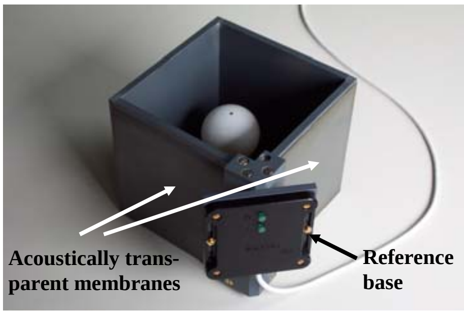

Figure 2: The calibration phantom

The ultrasound images are recorded using a Siemens Sonoline Omnia®. A computer with a frame grabber is used to store the ultrasound images via the SVHS interface of the ultrasound machine. Synchronously, the position data of transducer and phantom are recorded, using the optical tracking system NDI Polaris®.
The sphere is recorded from 15 different views through the two membranes and the top of the box. Approximately 100 images with slightly differing position are acquired per view. Thus approx. 1500 ultrasound images are used for calibration. The whole calibration process (i.e. recording of the data, segmentation of the circles and calculation of the transformation matrix) takes less than 15 minutes.
The calibration was tested with a 3.5 MHz curved array (C5-2). The result of the calibration is the transformation matrix between reference base and ultrasound imaging plane. Furthermore, position and radius of the sphere can be estimated with the equations with high accuracy.
From these results, the theoretical centers and radii of the circles in the ultrasound images can be determined. The deviation between these theoretical and the measured values define an estimation error for the calibration. The RMS-deviation is about 0.32 mm for the centers and 0.14 mm for the radii of a typical calibration.
The calibration was repeated several times to test the reproducibility of the procedure. The maximal distance between two estimated positions of the sphere was found to be 0.25 mm and the estimated radii of the sphere ranged from 19.66 mm to 19.71 mm. To quantify the error of the transformation matrix, the edge points of an ultrasound image with an imaging depth of 10 cm are transformed in the coordinate system of the reference base with each transformation. The maximal distance between the transformed edge points is 1.14 mm. This value is more than 4 times lower than the values reported for other calibration phantoms in [7].
The maximal distance of the transformed edge points with respect to the transformed vertexes of the averaged transform (assumed as reference) is 0.66 mm.

Discussion

The calibration phantom presented here combines very high accuracy of the calibration with simple construction of the phantom and moderate time needed for the calibration. Thus, it is predominant to conventional calibration phantoms.

Acknowledgements

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