3D FREEHAND ULTRASOUND IMAGING SYSTEM

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ABSTRACT

Conventional diagnostic ultrasound imaging is widely used in medicine because it allows dynamic analysis of moving tissues. It is non-invasive, relatively cheap and portable equipment. On other hand, the quality of ultrasound images is quite poor. The ultrasound 2D image is performed with hand-held probe which transmit ultrasound pulses into the body and receives echoes. These echoes are used to create a 2D grey-level image (B-scan) of across-section of the body in the scan plane. 3D ultrasound imaging extends this concept about volume information.

In this contribution is a 3D position sensor attached to the conventional probe. This system enables 3D reconstruction of examined volume, because each B-scan can be labelled with their relative positions and orientations.

1 3D ULTRASOUND SYSTEM

Our 3D freehand US system is shown on Fig.1. It consists of conventional US imaging system with 2D probe and 3D position sensor (with 6 degrees of freedom) that is attached to the probe. The set of obtained B-scans with position information is stored in the memory for consequential processing. The B-scans were measured with 2D transducer (phased array with tuning resonance frequency from 2.5 MHz up to 5 MHz), mounted on the special holder together with the position sensor. The position system was connected with the computer that served as a data collector and as a synchronization unit.

The *Vingmed, System 5* (GE Medical System) was used for US imaging. This system enables to measure raw US data (according to Vingmed specification) that are 8-bits envelope detected radiofrequency data before scan conversion. A number of transmitter-receiver position systems have been used to measure location in space. We used *MiniBird* system (Ascension Technology Corporation) with accuracy 1.8 mm and resolution 0.5 mm in translation and accuracy 0.5 degree and resolution 0.1 degree in orientation.

The synchronization marks placed partly in image sequence and partly in position data providing correct assigning position to each image.

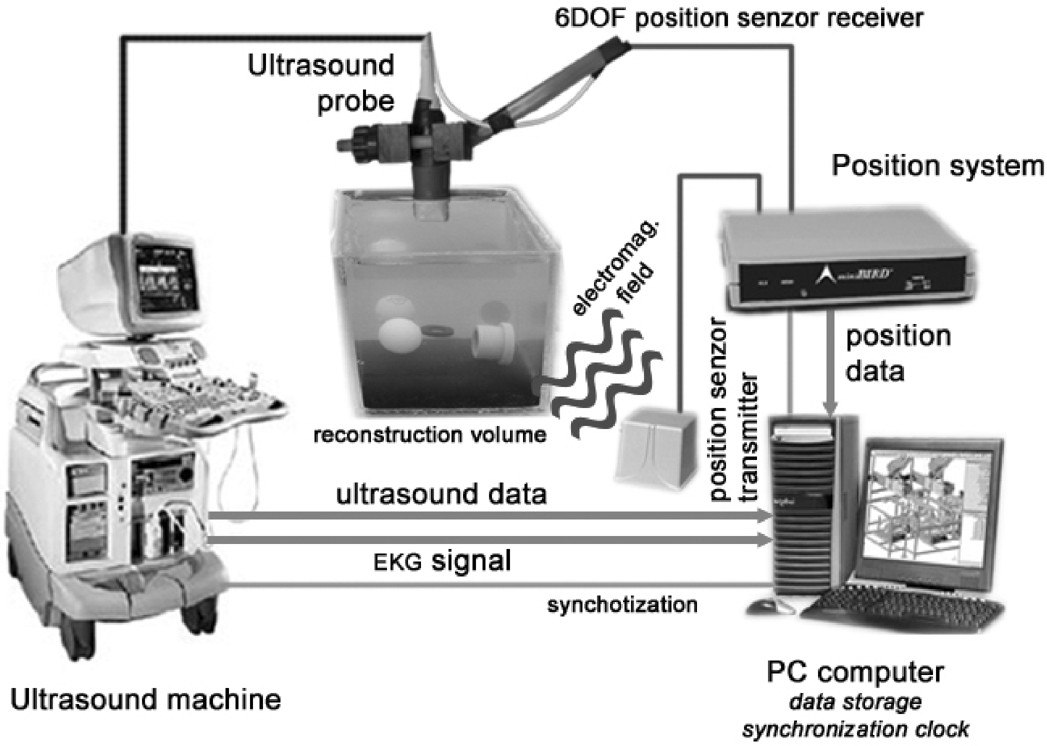

Fig. 1: *3D Ultrasound system.*

2 RECONSTRUCTION VOLUME

The reconstruction volume, created from the set of acquired B-scans, takes the form of a 3D voxel array *C*. Each pixel's location $P_{\underline{X}}$ is transformed first to the coordinate system of the receiver *R*, then to the transmitter *T* and finally to the reconstruction volume *C*. The overall transformation can be expressed as the multiplication of homogenous transformations matrices,

$$C_{\underline{X}} = {}^{C}T_{T} \quad {}^{T}T_{R} \quad {}^{R}T_{P} \,, \tag{1}$$

where ${}^{J}T_{I}$ means transformation from coordinate system *I* to coordinate system *J*. $C_{\underline{X}}$ is the pixel's location in the coordinate system *C*.

A transformation between two 3D coordinate systems has six degrees of freedom. Three rotational (θ,ω,ϕ) and three translational (x,y,z). The rotation between tow coordinate systems is effected by first rotating through θ around the *x*-axis, then through ω around *y*-axis, finally through ϕ around *z*-axis. There is the homogeneous matrix [2] describing the transformation.

$$\begin{bmatrix} \cos(\theta)\cos(\omega) & \cos(\theta)\sin(\omega)\sin(\phi)-\sin(\theta)\cos(\phi) & \cos(\theta)\sin(\omega)\cos(\phi)+\sin(\theta)\sin(\phi) & x \\ \sin(\theta)\cos(\omega) & \cos(\theta)\sin(\omega)\sin(\phi)+\cos(\theta)\cos(\phi) & \sin(\theta)\sin(\omega)\cos(\phi)-\cos(\theta)\sin(\phi) & y \\ -\sin(\omega) & \cos(\omega)\sin(\phi) & \cos(\omega)\cos(\phi) & z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

3 RECONSTRUCTION METHODS

B-scans can be at any relative position and orientation. B-scan elements called pixels lie at irregular locations in the array of volume elements called voxels. This means the reconstruction problem can be classified as an unstructured or scattered data interpolation [3]. There are number of different methods for 3-D ultrasound data reconstruction. Most of these methods are designed to minimize the time and memory. These methods take a few second and are preferred for visualization 3-D data sets immediately after acquisition. Details of the reconstruction are generally unpublished. Nevertheless, the methods that have been published can be classified into following categories: Voxel nearest neighbour interpolation, Pixels nearest neighbour interpolation and Distance-Weighted interpolation.

Voxel nearest neighbour (VNN) interpolation is very simple. Each voxel is assigned the value of the nearest pixels. This reconstruction method has advantage of avoid gaps in the voxel array [3], but reconstruction artefacts can be observed in slices.

Pixel nearest neighbour (PNN) interpolation consists of two stages. In the first stage, the algorithm runs through each pixel in every B-scan and fills the nearest voxel with value of actual pixel. The second stage fills these remaining gaps in the voxel array. The final image may show the boundary between the highly detailed voxels (first stage) and the smoothed voxels (second stage).

Distance-Weighed (DW) interpolation proceeds voxel with assigned a value to each voxel based on a weighed average of some set of pixels from nearby B-scans. Parameters to set are weight function and the size and shape of the neighbourhood. A naive implementation considers a fixed spherical neighbourhood of radius R, centred about each voxel [1] – [3]. All pixels in this neighbourhood are weighed by the inverse distance to the voxel and than averaged.

More advanced DW interpolation method uses a non-uniformly shaped neighbourhood to account for the asymmetric shape of the point spread function of the ultrasound beam [4].

4 RESULTS AND CONCLUSION

The 3D ultrasound imaging system has been developed. This system utilizes current 2D US imaging system and 3D position sensor that is easily available and low cost. The data processing and visualization are therefore performed off-line, which is the limitation of this system. Gained ultrasound data was transformed to reconstruction volume. PNN interpolation method was used to reconstruct this volume. For visualization of the 3D positions obtained B-scans was used the matlab algorithm, result is shown on Fig. 2a. Volume rendering method was used to visualize the reconstruction volume. Result is shown on Fig. 2b. There is ping-pong ball on the Fig. 2b. No special calibration measurement of position sensor and ultrasound probe was made, therefore ping-pong ball is a little warped.

Better calibration measurement of position sensor and more sophisticated interpolation method are the most serious problems. Therefore we have been focusing on these procedures more deeply in order to obtain better results.

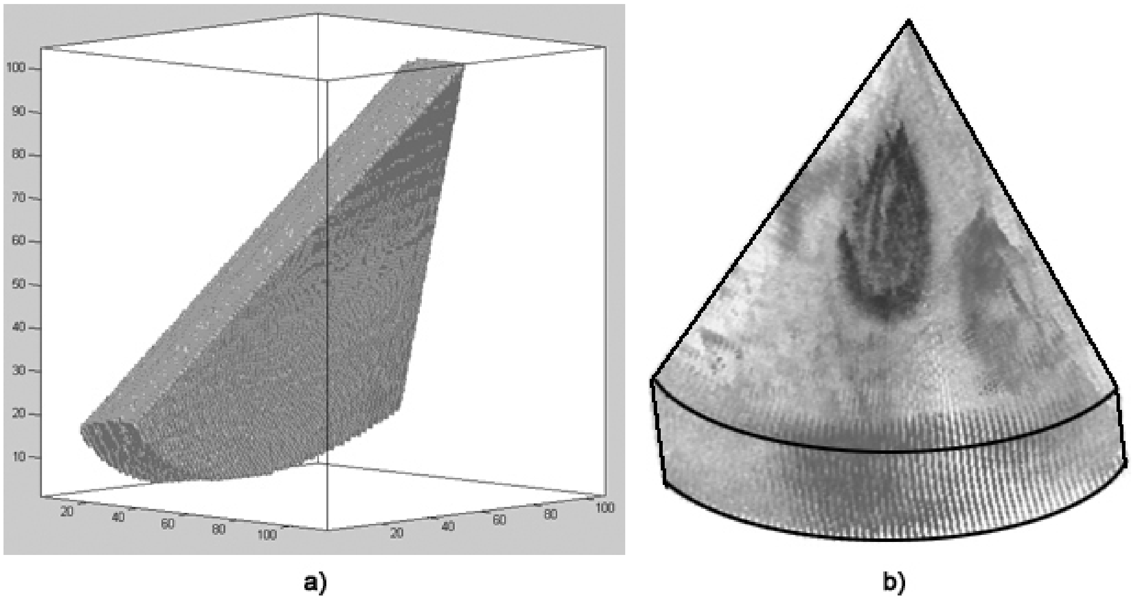

Fig. 2: *a) Visualization of the 3D positions obtained B-scans, b) Sample of ultrasound reconstructed volume obtained by SR method.*

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