METHOD FOR COMPILATION OF 3D ULTRASONIC DATA BASED ON IMAGE MATCHING TECHNIQUE

Ing. Jiří ZAČAL, Doctoral Degree Programme (2)
Dept. of Biomedical Engineering, FEEC, BUT
E-mail: zacal@feec.vutbr.cz

Supervised by: Prof. Jiří Jan

ABSTRACT

In free-hand 3D ultrasound, a position sensor is attached to the probe of a 2D ultrasound scanner. The resulting 3D data should permit flexible visualization and more accurate volume measurement than can be achieved using 2D B-scans alone; however the use of the position sensor can be inconvenient for the clinician but the main disadvantage is that these position sensors are not accurate enough and calibration of this is too complicated. The objective is thus to replace the sensor with a technique for estimating the probe trajectory based on the B-scan images themselves. Some publications on such techniques exist, based on a speckle correlation algorithm, e.g. [5]-[6]. In this paper we propose a method of this kind to accurate positioning using speckle correlation based algorithm, including possible modification.

1 INTRODUCTION

The 3D ultrasound data resulting as a data block compiled from multiple 2D scans should permit flexible visualization and more accurate volume measurement than can be achieved using 2D B-scans alone. 3D ultrasound data can be reconstructed from standard 2D ultrasound images if the position and orientation of each 2D image is known. Mechanical systems have been used to acquire the position and orientation information [1,2], but these limit which images can be acquired. Remote localization systems, such as with electromagnetic sensors, allow freedom in image acquisition, resulting in the desired field of view and good insonification of the structure of interest. Previous studies using a magnetic sensor system have demonstrated the feasibility of reconstructing 3D images from 2D slices [3,4].

However, the use of the position sensor can be inconvenient for the clinician, but the main disadvantage is that these position sensors are not accurate enough and calibration of this is too complicated. A possible solution is the speckle correlation algorithm [5]-[6]. Speckle is formed by the coherent scattering particles. For the statistical properties of speckle, the intensity autocorrelation acting on the speckle region follows those of the complex Gaussian with respect to the frame position. When the correlation function is used to estimate the frame spacing, the transducer must move steadily and slowly enough to ensure that each consecutive frames is correlated. Given a series of image slices, the correlation function is calculated and Gaussian curve is used to fit the correlation function, than we can back calculate the space of each two frames.

The speckle correlation algorithm still has some problems; that is, there exist some coefficients we need to know before performing the Gaussian curve fit, such as the ultrasound wavelength at its central frequency, a distance from the transducer to the ultrasound field point, and the height of linear array of transducer. In this paper, we propose a method to accurately position using speckle correlation without these coefficients; instead, we use a reference image to match the position.

2 METHOD

Tuthill et al. propose an automated 3D US frame positioning system [5], where B-scan images are collected by means of a handheld transducer moving in the elevational direction and frame spacing is computed with a speckle-correlation algorithm, without additional positioning hardware. Here the elevation direction means the direction perpendicular to the scan plane. The concept of this method is that we can monitor and evaluate the scan plane motion via changes in the speckle correlation in the elevational direction. It has been found that the intensity autocorrelation can be written as a Gaussian function with respect to the frame spacing.

Since the correlation algorithm holds true only the speckle regions, we need a speckle detector to find the speckle region. For the fully developed speckle, the intensity image should have an exponential distribution and a constant ration of mean to standard deviation (SD) of 1.0. In [5], a detector based on first-order statistic was developed. When the ratio of mean intensity to SD for a region with moving 3D volume was between 0.9 and 1.1, the region is classified as a speckle region. Another possible method to detect the speckle region using the statistics of a homodyned *k*-distribution we can find in [7].

Only the pixels in the speckle regions are used to form the correlation function. The autocovariance function is used to represent the correlation function. The autocorrelation (R_A) for positions r_1 and r_2 is defined as

$$R_A(r_1,r_2)=\langle A(r_1)A(r_2)\rangle,$$

and the autocovariance (C_A) is

$$C_A(r_1,r_2)=R_A(r_1,r_2)-\langle A(r_1)\rangle\langle A^*(r_2)\rangle, \tag{1}$$

where $\langle\ \rangle$ means the expected value and A means the intensity function.

The normalized intensity correlation function can be fitted by a Gaussian function [5]

$$C(\Delta y)\approx \exp[-2a_0(\Delta y)^2], \tag{2}$$

where Δy is a displacement in the elevation direction, $a_0 \propto 1/(\lambda_0 z)^2$, λ_0 is the ultrasound wavelength at its central frequency. z is a distance from the transducer to the ultrasound field point. These coefficients are determined by the transducer properties. By fitting the correlation function for a set of consecutive frames to a Gaussian curve, the average frame spacing can be back calculated.

3 THE PROPOSED REALIZATION

In our modification we use a technique based on image matching to estimate approximate position of each frame without a need to know any coefficients. In fact, we need a reference frame, which we obtain by scanning one frame in the direction perpendicular to the scan plane. The relationship between a reference image and the 3D dataset is depicted in Fig. 1. Than we can find the intersection lines of the images with the reference frame and frame spacing can be directly computed from the distances of these lines.

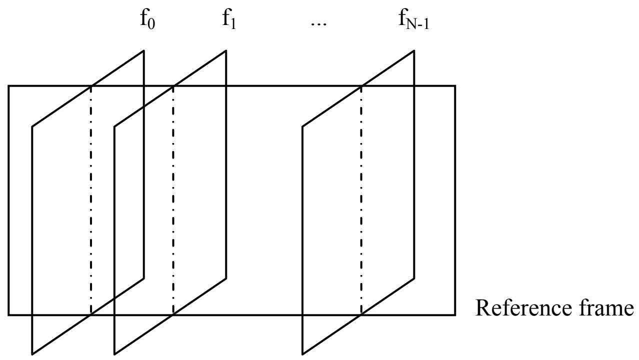

Fig. 1: *The relationship of the frames in the 3-D dataset and the reference frame.*

3.1 MATCHING FUNCTION

The similarity of any two pixels in the spatial domain can be computed from the difference of its intensity instinctively. The smaller of the difference, the more similar of these two pixels. Simply extended this ideal when we match the two lines, the matching function ($match\_line$) of these two lines is the sum of the difference of the corresponding pixels in these two lines,

$$match\_line(i,j) = \sum_{k=0}^{H-1} \left| f(i,k) - r(j,k) \right|, \tag{3}$$

where i and j are line numbers, f and r are the intensity functions, and H is the height of region of interest (ROI). Because the noise and speckle structure of the ultrasonic data, the changes of any consecutive lines of an ultrasonic images are usually very small. If the resolution of an image is not high enough, the result of the line matching will not be very clear. So we increase the number of match lines to reduce the error.

$$\begin{aligned} match\_3lines(i,j) = {} & match\_line(i-1, j-1) + match\_line(i,j) + \\ & + match\_line(i+1, j+1)\,. \end{aligned} \tag{4}$$

In the freehand scanned system, there exist some errors in the up and down directions when the transducer move along the elevation direction. Thus when any two lines perform line matching, we must moderately interlace these two lines in order to find best matching point. Thus equations (3) and (4) can be rewritten as:

$$match\_line(i,j,s)=\sum_{k=0}^{H-1}\left|f(i,k)-r(j,k+s)\right|,$$

and

$$\begin{aligned}match\_3lines(i,j,s) = {} & match\_line(i-1,j-1,s)+match\_line(i,j,s)+\\ & +match\_line(i+1,j+1,s),\end{aligned} \tag{5}$$

where s is the number of interlaced pixels. Take an example by $s \le 2$, we find the minimum of $match\_3lines$ function for $s=0$, $s=1$ and $s=2$, and the matching function of these two lines is set to the minimum value we found.

The procedure of finding all the intersection lines is based on some assumptions. First, the transducer must be moved forward unidirectionally and cannot reverse the scanning direction. Second, the transducer must be moved almost along a straight line.

3.2 SPECKLE CORRELATION FOR THE RATIO OF FRAME SPACING¨

Ratio of the frame spacing can be derived from equation

$$\frac{D(j,i)}{D(k,j)}=\sqrt{\frac{\ln(C(i,j))}{\ln(C(j,k))}}, \tag{6}$$

where i, j, k are the frames in the 3D dataset, D is the distance function of the two frames, and C is the correlation function of the two frames. From this equation, the ratio of the frame spacing can be calculated based on the correlation function without additional parameters. Here, we can get the ratio of all the frame spacing in the 3D dataset from equation (6). First, extract three frames (f_0, f_1, f_2) and get the ratio of the $D(f_0, f_1)$ and $D(f_1, f_2)$. Then extract three frames (f_1, f_2, f_3) and get the ratio of the $D(f_1, f_2)$ and $D(f_2, f_3)$ in the same way. Repeatedly using this method, the ratio of all the frame spacing in the 3-D dataset can be calculated.

4 EXPERIMENTAL DATA

The image dataset of B-scans for our experiments was captured by VingMed System FiVe Echocardiography System (GE Medical System) with a 2-D transducer (phased array with adjustable resonance frequency from 2.5 MHz up to 5 MHz), mounted on the special holder together with the position sensor. The position and orientation information were obtained via MiniBird System (Ascension Technology Corporation). In fact, the information from the position system will be used just to subsequently compare our results with the other methods that make use of additional positional systems.

The dataset was captured via movement in two directions, the transversal direction and the longitudinal direction. In fact, only one direction is needed to reconstruct the 3-D volume and the other direction is used as the reference direction for reconstructing the 3-D volume. We need only a single frame along the reference direction and this frame is used as the reference frame for image matching. We assume that the transducer is translated parallel to the body surface and resulting in axis-aligned images. The rotation of the transducer is not allowed so far so that each frame should be parallel to the other frame.

5 CONCLUSIONS

We have proposed a method which combines the speckle correlation algorithm and the image matching technique. This system is supposed to accurately compile the 3-D ultrasonic dataset from the 2-D scans acquired by free-hand scanning without any additional positioning hardware; in fact, just a reference frame is needed additionally for the compilation. In the present, the work is focused on implementation and verification of this approach.

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