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Direct Scan-Lines Mapping for Ultrasound 3D image Reconstruction

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Abstract

3D Ultrasound has recently been a routine imaging modality for medical diagnosing and in other bioscience fields.Compared to the conventional method where 2D images are used to represent a 3D anatomy, clinicians base upon theirexperience, build the 3D anatomy mentally. This approach has many short comings where 3D ultrasound has well addressed,but with high computational burden. Various approaches have been made to minimize the computational demand in 3Dultrasound image reconstructions. Discussed in this paper is an alternative method to achieve 3D ultrasound image.Experimental 3D ultrasound image reconstruction was done using simulated 3D RF data derived from standard simulatedphantom. The scan lines from each RF data were directly mapped to a target volume and then scan converted inside thevolume. For robustness and accuracy of the method, the acquired results were compared to the conventional method. Itdemonstrated that the proposed method reconstructed 3D ultrasound image with lesser time and memory requirements whilepreserving the quality of the image compared to the conventional methods. The proposed method is a reliable tool forachieving 3D ultrasound image.

Keywords

Scan lines, 3D ultrasound, 3D reconstruction, 3D scan conversion, pixel mapping

1. Introduction

Diagnostic 3D ultrasound is a widely used imaging modality, and the need for it in clinical and bioscience research iscontinuing to grow [1]. This new imaging approach is gaining importance because of the limitation of 2D viewing of 3Danatomy while using conversional ultrasound [2]. This occurs because: (a) Conventional ultrasound images are 2D, yet theanatomy is 3D, hence the diagnostician must integrate multiple images in his mind. This practice is inefficient, and may leadto variability and incorrect diagnoses. (b) The 2D ultrasound image represents a thin plane at some arbitrary angle in thebody. Therefore it is difficult to localize the image plane and reproduce it at a later time for reviews [3].

In addition, ultrasoundis much more comparative when considering the other imaging modalities especially computed tomography (CT) andmagnetic resonance imaging (MRI) [2]. Since the application of ultrasound is faster, no ionizing radiation applied and iseconomical [1]. Although 3D ultrasound has many advantages over the conventional 2D ultrasound, it is limited because of itshigh computational demand. Therefore it is of paramount need to tackle this problem using new approaches that would helpgain the full satisfaction of 3D ultrasound imaging.

2. Previous Work

3D ultrasound reconstruction is often a trade-off between performance and quality. Gobbi et al. [8] use the simple PNN method to enable high performance. Different approaches are described by Rohling et al. [9] and that fall into the function based category according the terminology of Solberg et al. [10]. Rohling et al [9] used splines to construct a volume from the input b-scans, and Sanches et al. used statistical methods to estimate a function for the interpolation. A recent voxel-based method is described by Coupe et al. that takes the probe trajectory into account to improve reconstruction quality, especially for sparse input where there is much space between the b-scans. A performance increasing scheme for fast slice selection is described by Wein et al. and benefits voxel-based reconstruction methods. Karamalis et al. describe a high performing hybrid reconstruction method partially implemented using GPU texture interpolation features. Huang et al. described a technique for utilizing the Fourier domain to take redundant frequency components into account, preserving the high frequencies and resulting in better resolutions. Another work done was to present a formative description of a system where optical tracking is used to orient a freehand ultrasound probe, and includes volume reconstruction by both a voxel-based and a pixel-based method. The most recent was described by U. Scheipers et al. a method for direct frame interpolation for reconstructing 3D ultrasound image [2].

3. Methodology

The overview of the approach described in this paper is illustrated in Figure 1.

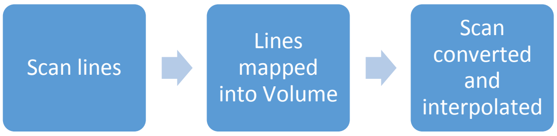
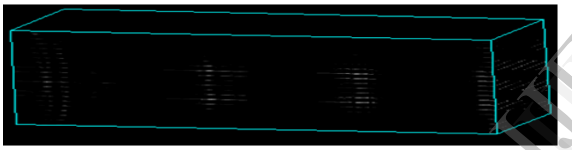


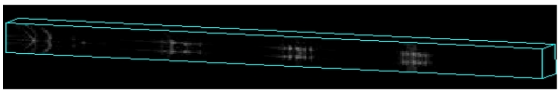
Figure 1. Illustrating the flow of the developed method

3.1 Scan lines Mapping

We used the standard 3D scattered dot phantom and simulated 75 RF data, each having 20 lines. It is better to think of the slices as 75 sets of 20 lines because of our approach. Figure 2 (a) illustrates the scan lines when placed inside the volume, to visualize clearly we padded zeros between the lines, while (b) is the volume with unpadded lines. We used math lab therefore padding did not alter the properties of the scan lines.



(a)



(b)

Figure 2. (a) Padded lines inside a volume. (b) Unpadded lines inside a volume.

The RF scan lines are processed at the dedicated processing units in the ultrasound pipeline to produce the B-mode image that is displayed on screen. Figure 3 below illustrates the main processing blocks in a typical ultrasound system and indicating where our method taps in.

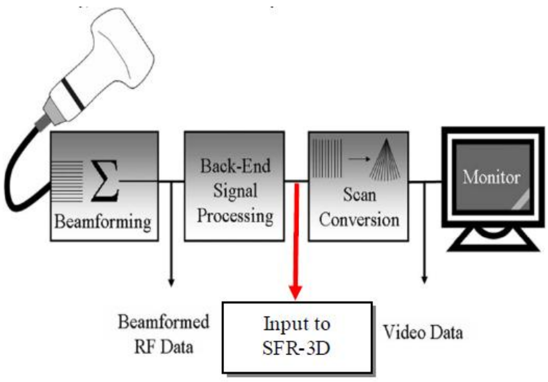


Figure 3. Illustration of the typical ultrasound system with our method incorporated.

The beamformed RF data is inputted to the signal processing unit where it is pre-processed, the scan lines are then interpolated and scan converted before displaying in the monitor as 2D B-mode image [7]. In the traditional method for 3D image reconstruction. The scan lines from a fan scan are taken in as parallel scan lines then interpolated to form a 2D image, and then are scan converted to fit the actual geometrical alignment. Finally the reconstructed 2D fan scan images are placed into the volume at their appropriate location to form a 3D fan scan image. Therefore the conventional approach does reconstruction from 1D (scan lines) to 2D (the scan converted and interpolated 2D images) and then 3D (build from 2D image slices). In our method, we picked up the scan lines before they are interpolated and scan converted to form a 2D B-mode image as indicated in Figure 3, by directly placing them into a volume at their appropriate location and performed scan conversion in 3D and then interpolated them into a full 3D image by using the standard interpolation methods.

3.2 Scan Conversion and Interpolation inside the volume.

The scan lines placed inside the volume as shown in Figure 2 where then scan converted and interpolated to a 3D fan scan ultrasound image. Figure 4 illustrates the basic parameters for achieving scan conversionin 3D. We used the conversional pixel nearest neighbor and bilinear interpolation methods and performed interpolation on the scan converted lines inside the volume.

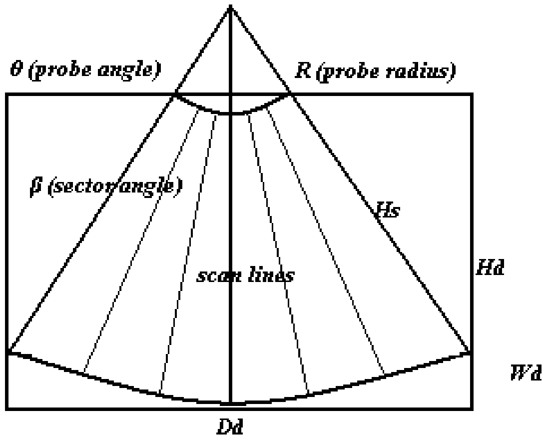


Figure 4. Schematic diagram of the main parameters for scan conversion inside a 3D volume.

The height of the destination image *Hd*is derived as expressed in (1), where θ is the half of the full probe angle.

$$Hd = R + Hs - R(\cos\theta)$$

(1)

As given in (2) the depth of the destination image *Dd* isderived by taking the sine of θ. While {*Wd* = 1, 2…n} as the width of the destination image determined by the (n) number of scan line sets inside the volume.

$$Dd = 2(R + Hs)\sin\theta$$

(2)

The sector angle β was used to determine *Ysrc* and *Xsrc*which are x and y component respectively of the source image, and were derived from the following expressions.

$$\beta = \tan^{-1}\sum_{j=1}^{Dd}\sum_{i=1}^{Hd}\left[(j-\frac{Dd}{2})\div(R\times\cos\theta+i)\right]$$

(3)

$$Ysrc = \sum_{j=1}^{Dd}((j-\frac{Dd}{2})\div\sin\beta)-R$$

(4)

In (4) taking sine of angle β,*Ysrc* was calculated while in (5)*Xsrc* was basically determined by taking the ratio of β and θ.

$$Xsrc = Ds(\frac{\beta}{\theta}) + \frac{Ds}{2}$$

(5)

After deriving the parameters, 3D scan conversion was performed then we used the two gold standard interpolation methods, pixel nearest neighbor (PNN) and bilinear to interpolate the scan converted lines into a full 3D fan scan image. The figure below displays the results after scan conversion inside the volume.

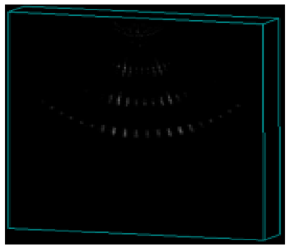
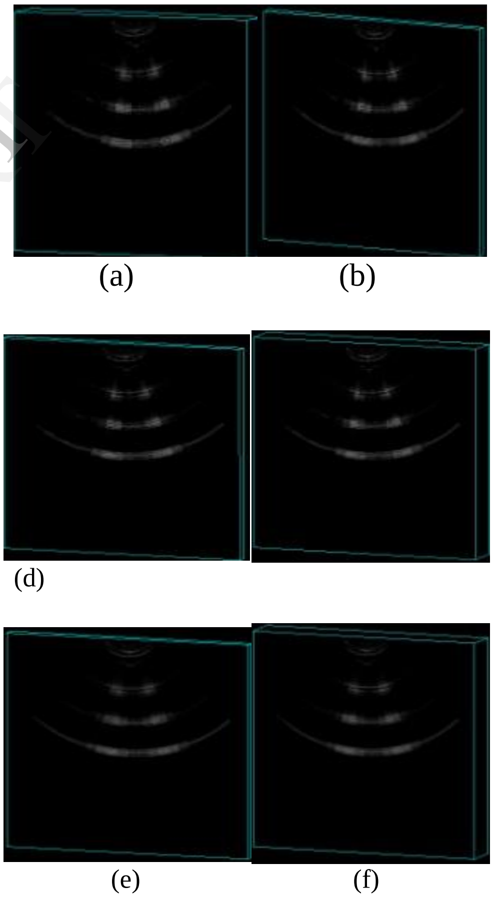
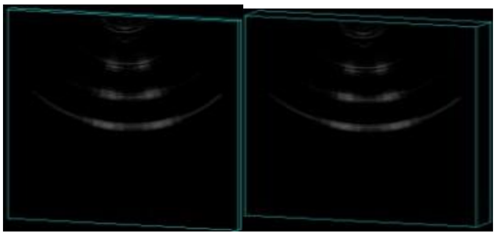


Figure 5. 3D reconstruction from padded lines





(g) (h)

Figure 5. (a) 20 slices & (b) 75 slices, 3D reconstruction using traditional method while applying PNN interpolation method, while (c) 20 sets of RF data& (d) 75 sets of RF data, 3D reconstruction from the proposed method applying PNN. And (e) 20slices & (f) 75 slices, reconstruction done with conventional method using bilinear interpolation method while (g) 20 sets of RF data& (h) 75 sets of RF data, 3D reconstructed from the proposed method using bilinear interpolation.

4. Results and Discussion

The proposed method was tested with 20 and 75 sets of RF data separately, of each set consisted of 20 RF scan lines and after 3D scan conversion of each set of lines, the converted lines were interpolated using the PNN and bilinear interpolation methods inside the volume into a full 3D fan scan image. For comparison the same data and interpolation method were used in conventional 3D reconstruction technique, with all coding done in Matlab. In each respective test we recorded the mean time in seconds (s) and memory usage in megabytes (mb). The observed outputs are depicted in the following table both for proposed method and the conventional method. From the results in Table1, not much time difference was noticed although there was about 2 % time and memory gain from the proposed method compared to the traditional method. In Table 2 clearer variations can be observed, when the number of reconstructed slices increased to 75, the proposed method was about 20% faster than the conventional method. The memory consumption was also more obvious with the increased slices, where about 10% of memory been preserved.

Table 1. Shows the mean time and memory usage for 3D ultrasound image reconstruction using conventional and our method. Tested with 20 RF data sets, each set of 20 scan lines.

	Conventional Method		SFR-3D	
Interpolation	PNN	Bilinear	PNN	Bilinear
Time (s)	2.5	5.2	2.3	4.8
Memory (mb)	4.0	4.0	3.8	3.8

Table 2. Shows the mean time and memory usage for 3D ultrasound image reconstruction using conventional and our method. Tested with 75 RF data sets, each set of 20 scan lines.

	Conventional Method		SFR-3D	
Interpolation	PNN	Bilinear	PNN	Bilinear
Time (s)	10.0	19.7	8.3	17.6
Memory (mb)	15.0	15.0	14.0	14.0

Considering the experimental results, we can see that much greater variation between the two methods can be observed, if the source images are taken from real or more complex data. Because our simulated RF data had only 20 scan lines that outputted approximately 5-6 kb per image slice compared to real data, which is normally around 256 kb per image slice. In addition, the quality of the 3D reconstructed images as shown in Figure 5, when visually judged had no differences detected between images from the proposed method compared with the conventional method.

5. Conclusion and Future Work

The method developed in this work is another method for achieving fast 3D ultrasound image reconstruction. Using our direct mapping technique, scan lines from a conventional 1D transducer can be mapped from their respective location from 1D to 3D volume. The main idea behind the proposed method is where one can achieve 3D ultrasound image without reconstructing the 2D image slices. The common practice of using the interpolated and scan converted 2D image slices to build a volume has been well avoided with the developed direct scan lines mapping to volume technique for 3D ultrasound image reconstruction. We have demonstrated that scan conversion can be done direct on the scan lines inside a volume, which is the real significant part of this method. The experimental approach was done using synthesize data, therefore the angle and geometrical information was not much of the concern. But we have proved that as long as the probe angle is known the other parameters can be calculated using the model given in Figure 4 to achieve proper mapping of the scan lines from a fan scan into the 3D volume.

The use of the gold standard interpolation methods was to interpolate the scan converted lines inside a volume to achieve a full 3D fan scan ultrasound image. The developed method as the following contributions:

- The computational time was competitive compared to traditional method
- There was a decrease in memory consumption
- While the image quality was been preserved.
- Need scan lines only for building a 3D image

Although the measured variables (time and memory) had little variation compared to the conversional methods, greater difference canbe achieved if more complex data was been used. The small variation was because of the fact that the data used for experiment was pretty simple since it was been synthesized, with only 20 scan lines per slice with a size of 5~6 kilobytes (kb) for each slice. Looking at that conclusion can be clearly made that much greater differences can be achieved if real data were being used, since a typical slice from real data is about 256 kb or 128 scan lines per slice.

Future work can be done to retest the proposed method with real data, and also try out 3D ultrasound reconstructions from scattered dots instead of scan lines. Although getting real RF scan lines is still a very complex task that needs extra effort and resources. But it worth doing since bigger ideas starts small. The idea used for developing the direct scan lines method can also be an excellent foundation for 3D reconstruction from other inputs rather than conventional approach of using 2D image slices.

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