Volume Measurement in Sequential Freehand 3-D Ultrasound

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Abstract. It has previously been demonstrated that using 3-D rather than 2-D ultrasound can increase the accuracy of volume measurements. Unfortunately, the time required to produce them is also increased. While *freehand* 3-D ultrasound allows complete freedom of movement during scanning, the resulting B-scans are generally resampled onto a low resolution, regular voxel array before subsequent processing — increasing the time even further. In contrast, *sequential* freehand 3-D ultrasound does not require a voxel array, and hence both the data resolution and the processing times are improved. Such a system is presented here, incorporating three novel algorithms, each operating directly on non-parallel B-scans. Volume is measured using *Cubic planimetry*, which requires fewer planes than step-section planimetry for a given accuracy. *Maximal disc guided interpolation* can be used to interpolate non-parallel cross-sections. *Regularised marching tetrahedra* can then be used to provide a regular triangulation of the zero iso-surface of the interpolated data. The first of these algorithms is presented in detail in this paper.

1 Introduction

There has been much research in the last two decades on systems which allow the construction and visualisation of three dimensional (3-D) images from medical ultrasound data. One of the more compelling applications where 3-D ultrasound can provide a real benefit is in the accurate measurement of volume. This is important in several anatomical areas, for instance the heart [7], foetus [5], placenta [8], kidney [6], prostate [1], bladder and eye [11]. Measurements have traditionally been made with 2-D ultrasound, but it is generally accepted that 3-D ultrasound can provide much greater accuracy.

Freehand 3-D ultrasound allows the clinician unrestricted movement of the ultrasound probe. The ultrasound images (B-scans) are digitised and stored in a computer. In addition, the position and orientation of the probe is measured and recorded with each B-scan. The various 3-D ultrasound systems are reviewed in [5]. One of the disadvantages of freehand scanning is that the recorded B-scans

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are not parallel — this makes processing of the data more complex, hence most systems interpolate this data to a regular 3-D voxel array, or *cuberille*. However, this can take considerable time and generate potentially misleading artifacts.

By contrast, in *sequential* freehand 3-D ultrasound, the original B-scan data, and the order of acquisition of the B-scans, are maintained throughout the subsequent processing. This reduces the time from scanning to display, at a cost of a slight increase in processing time for *each* display. Moreover, any sequential method which does not require human interaction[1] has the potential to be performed *during scanning*, greatly decreasing the residual (post scanning) processing time.

It has already been demonstrated that re-slice displays (i.e. 2-D displays in new orientations) and panoramic displays (i.e. 2-D displays with extended coverage) can be performed efficiently by sequential methods [14]. Resampling is only performed once, rather than once to the cuberille and once again to the viewing plane, which leads to increased quality displays. This paper demonstrates that volume measurements and organ surfaces can also be efficiently estimated in a sequential manner. Segmentation remains the most complex and time consuming step in this process. In view of this, the proposed algorithms are designed for *sparse cross-sections*, to limit the time spent segmenting, in *non-parallel planes*, so the segmentation can be performed in the original B-scans (which do not suffer from interpolation artifacts). Reducing total organ volume measurement time is particularly important in a clinical setting.

2 Volume Measurement Using Ultrasound

2.1 Sequential Volume Measurement from Scan Plane Data

Volume measurement using conventional 2-D ultrasound is achieved by approximating the organ of interest as an ellipsoid, or some other simple shape, and estimating the main dimensions from appropriate B-scans. A correction is then made to the result, dependent on the organ, the age and sex of the patient and other factors. There are many formulations for the resulting equations [8,16].

Ellipsoid formulae are easy to use, but they make geometrical assumptions about the shape of a given organ, leading to errors in the volume measurement which can be greater than 20%. *Planimetry* is an alternative approach, made possible with 3-D ultrasound, in which object cross-sections are outlined on each scan plane, and the volume is calculated from the cross-sectional areas and plane positions. The most common implementation of this is step-section planimetry, which assumes that the cross-sections are parallel.

There are numerous reports which indicate that step-section planimetry is much more accurate than ellipsoid or other geometrical formulae [1,13,15]. In one exception, planimetry was compared with 16 equations for measuring prostatic volume and $\frac{\pi}{6}(\textit{transverse diameter})^2(\textit{anteroposterior diameter})$ was found to be

[1] All the algorithms presented here are fully automatic, save segmentation.