

# Development of 3D Image Reconstruction Based on Untracked 2D Fetal Phantom Ultrasound Images using VTK

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*Abstract:* - Three dimensional (3D) ultrasound image reconstruction based on two dimensional (2D) images has become a famous method for analyzing some anatomy related to abnormalities. 3D ultrasound image reconstruction system is required in order to view the specific part of the object and so that it can be used for analysis purpose. In this paper, 2D images of fetal phantom were taken by using untracked free-hand ultrasound system. Few sets of 2D images were taken with different number of slices and after some basic 2D image processing, 3D reconstruction is done by using surface rendering techniques by implementing contour filtering and marching cubes algorithm in Visual C++ 6.0 with Visualization Toolkit (VTK) toolbox. From the experiment, we can conclude that in order to reconstruct a better 3D image, the aid of tracking sensor is important. Besides, image processing need to be performed thoroughly by adding other detailed processing techniques so that noises can be fully removed. From the result also, it can be concluded that the marching cube algorithm can give a better result compare to contour filtering where marching cubes algorithm can generate higher intensity 3D image which can make user easy to detect inner part and edges of 3D images. The number of slices should also be increased to improve the accuracy of the 3D image constructed.

*Key-Words:* - 2D ultrasound, 3D ultrasound, marching cubes, contour filtering, visualization toolkit (VTK)

## 1 Introduction

Medical imaging is the technique used to create images of the human body for clinical purposes especially for analyzing some anatomy related to abnormalities. Some of the commonly used imaging techniques are ultrasound, CT, and MRI [1-2]. However, the major difference between the other medical imaging equipment and ultrasound is that it is safer, low cost, non-invasive and non-traumatic. This made the diagnostic ultrasound machine become more popular than the other diagnostic tools [3]. Diagnostic ultrasound is applied for obtaining images of almost the entire range of internal organs in the abdomen including genitourinary system which consists of kidneys, urinary bladder, urethra and reproductive system of male and female [4, 44 - 47].

However, conventional 2D ultrasound imaging has limitations in quantifying the volume of structures of interest in the body, because only a two dimensional frame is produced at a given time. Volume quantification is important in assessing the progression of disease and tracking progression of response to treatment. Thus, 3D ultrasound imaging has drawn great attention in recent years especially in high quality hospitals and medical centers [5-6].

The 3D ultrasound systems can be classified as tracked free-hand, untracked free-hand, mechanical assemblies, and 2D arrays [7-8]. In tracked free-hand

systems, the operator holds an assembly composed of the transducer and an attachment, and manipulates it over the anatomy and 2D images are digitized as the transducer is moved. For untracked free-hand systems approach, the operator moves the transducer in a steady and regular motion while 2D images are digitized and in order to reconstruct a 3D image, a linear or angular spacing between digitized images is assumed. In mechanical localizers, the transducer is translated or rotated mechanically, while 2D ultrasound images are digitized at predefined spatial or angular intervals while 2D arrays generates a pyramidal pulse of ultrasound and processes the echoes to generate 3D information in real-time [9-12].

The 3D reconstruction process refers to the generation of a 3D image from a digitized set of 2D images and two approaches can be used which is either 3D surface model or voxel-based volume. Besides, the ability to visualize information in the 3D image depends critically on the rendering technique. Three basic types being used are surface-based viewing techniques, multi-plane viewing techniques and volume-based rendering techniques [13-14].

In this paper, 2D images were taken by using untracked free-hand system. Few sets of 2D images were taken with different number of slices and after some 2D image processing, 3D reconstruction is done

by using surface rendering techniques by implementing contour filtering and marching cubes algorithm in Visual C++ 6.0 with Visualization Toolkit (VTK) toolbox.

## 2 Material and Methods

In this experiment, the images were taken by using the untracked free-hand 2D ultrasound. The 2D images of fetal phantom are taken using Portable Ultrasound Diagnostic Scanner NeuCrystal C40 by Landwind and store into laptop by using TV grabber as a connector. The ultrasound images of fetal phantom are scanned from the head until the legs of the fetus. This can ensure the images of the whole body of fetus stack in a good arrangement condition. Since the images is taken using free hand without any tracking system or tool, some position or degree for taking the images will be slightly different from one image to another.

After the 2D ultrasound image acquisition step, the images were then undergoing some image processing techniques in order to enhance the images and remove noises in the images. Then, 3D image is reconstructed by using contour filtering and marching cubes algorithms. Figure 1 shows the block diagram of experiment setup and figure 2 shows the flow chart of the experiment.

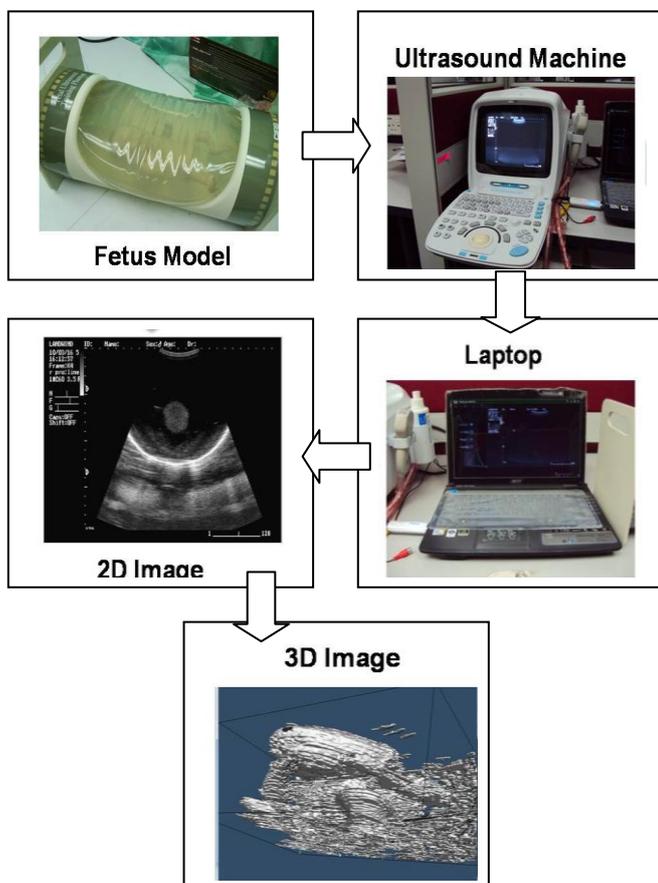


Fig.1 Block diagram of experiment setup

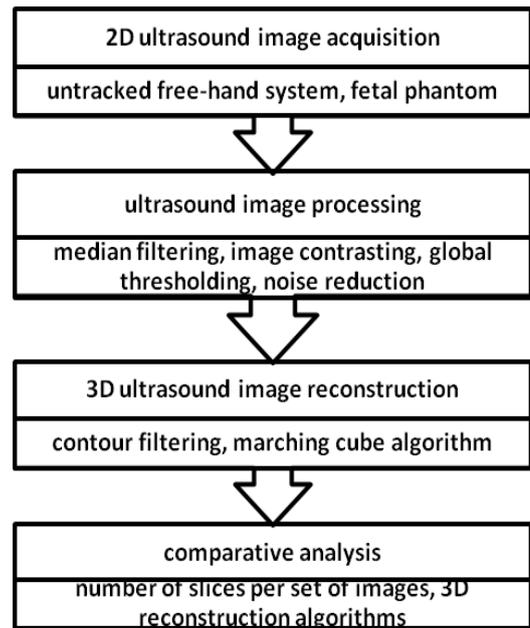


Fig.2 Flow chart of experiment

### 2.1 2D Ultrasound Image Acquisition

When creating a 3D image from a set of 2D images, the relative locations and orientations of the individual image frames must be known to create an accurate reconstruction. In order to develop a more accurate approach for volume quantification, many approaches of 3D ultrasound image reconstruction have been developed. One of the current practices involves a 2D ultrasound machine and a position sensor attached to the ultrasound scanner probe. The 2D ultrasound machine provides slices of images through the structure of interest while the position sensor provides the relative position of these slices in space [15].

Many research have been conducted in order to find the most accurate and convenient technique in this kind of systems. Richard JH et al propose the use of alternative position sensor, the Xsens MT9-B, which is relatively unobtrusive but measures orientation only [16]. A. M. Goldsmith et al propose 5 Degree of Freedom, low cost, integrated tracking device for quantitative, freehand, 3D ultrasound where it uses a combination of optical and inertial sensors to track the position and orientation of the ultrasound probe during 3D scan [17].

However, if the medical doctors use the untracked free-hand 2D/3D ultrasound, some problem will occur because, without the aid of an external sensing device, the doctors have the challenging task to maintain constant scan rate and transducer attitude and cannot employ the angle variation for better and complete image visualization.

## 2.2 Image processing

Analysis of the images cover the image acquisition, image formation, image enhancement, image segmentation, image compression and storage, image matching, motion tracking, measurement of parameters, and image-based visualization [18, 39 - 43]. In this experiment, after the images have been stored into laptop, the process of generate region of interest (ROI) will start. The ROI of the images will make the resolution of the image become smaller and take less time in running image processing step. The gray scale image of ROI is generated using manual crop function in image processing toolbox. The output resolution of is 237 x d 174.

Then, these 2D images have to go through some enhancement process. Image enhancement is needed in order to reduce the noise and increase the contract of image. Flemming F et al [19] use volumetric image processing techniques for reducing noise and speckle while retaining tissue structures in 3-dimensional (3D) gray scale ultrasound imaging while S. Sudha et al [20] propose wavelet-based thresholding scheme for noise suppression in ultrasound images.

In this experiment, few steps of image processing have been done consist of median filtering, image contrasting, global thresholding and noise reduction. Figure 3 shows the flow chart of image processing.

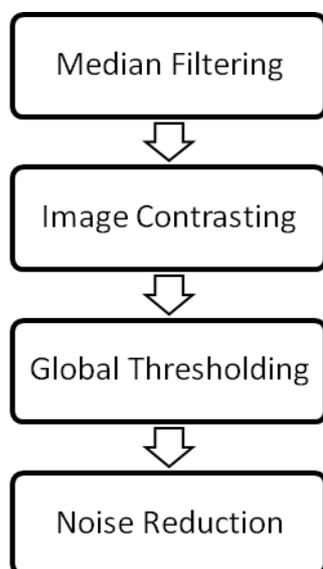


Fig.3 Flow chart of image enhancement process

### 2.2.1 Median Filtering

The median filtering is applied to the images for smoothing purpose. Median filters are quite popular because, for certain types of random noise, they provide excellent noise-reduction capabilities, with considerably less blurring than linear smoothing filters of similar size

[21]. This technique eliminates impulsive noise or the salt-and-pepper type of noise quite well.

123	125	126	130	140
122	124	126	127	135
118	120	150	125	134
119	115	119	123	133
111	116	110	120	130

**Neighborhood values:**  
115, 119, 123,  
125, 127, 126,  
124, 120, 150  
**Median values:**  
124

Fig.4 Calculating the median value of a pixel neighborhood

The median filter considers each pixel in the image in turn and looks at its nearby neighbors to decide whether or not it is representative of its surroundings. The median is calculated by first sorting all the pixel values from the surrounding neighborhood into numerical order and then replacing the pixel being considered with the middle pixel value. Figure 4 illustrates an example calculation.

### 2.2.2 Image Contrasting

Contrast within an image is depends on the brightness or darkness of a pixel in relation to other pixels. Therefore, by modifying the contrast among neighboring pixels can enhance the ability to extract information from the image. Operations such as noise removal and smoothing decrease contrast and make neighboring pixel values more similar while other operations such as scaling pixel values, edge detection and sharpening increase contrast to highlight specific image features [22-23].

In this experiment, image contrasting is used to sharpened the images. Sharpening an image increases the contrast between bright and dark regions to bring out features. The sharpening process is basically the application of a high pass filter to an image. The following array is a kernel for a common high pass filter used to sharpen an image:

$$HPF = \begin{bmatrix} -1/9 & -1/9 & -1/9 \\ -1/9 & 1 & -1/9 \\ -1/9 & -1/9 & -1/9 \end{bmatrix} \quad (1)$$

### 2.2.3 Global Thresholding

Global thresholding is used for generating the binary image. Binary image is the image only consists of 1 bit pixel value. There is only one threshold value needed to be set in order to differentiate the object and background of the image. Thresholding creates binary images from grey-level ones by turning all pixels below some threshold to zero and all pixels about that threshold to one [24]. Figure 5 shows the image of the histogram of global thersholding.

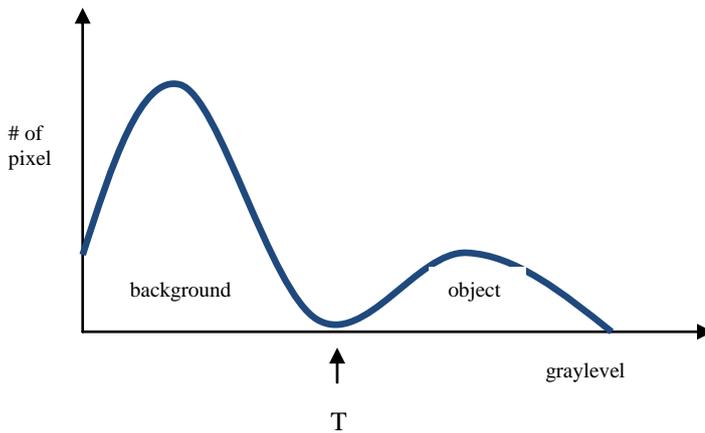


Fig.5 Image histogram of global thresholding

If  $g(x, y)$  is a thresholded version of  $f(x, y)$  at some global threshold  $T$ ,

$$g(x, y) = \begin{cases} 1 & \text{if } f(x, y) \geq T \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

### 2.2.4 Noise Reduction

Noise reduction is the process of removing noise from a signal or image. The key to noise reduction is to reduce or eliminate the noise without deteriorating other aspects of the image. Filtering is one of the common methods used for noise reduction and this time, the filter used will removes small and unwanted image [25].

## 2.3 3D Surface Constructions

Visualization is the process of comprehending the structure of the object system. There are some methods that can be use to reconstruct the 3D image by visualization. The method that is used in this paper is only surface rendering technique. Surface rendering is the process of improvement of interpretation of data sets through generating a set of polygons that represent the surface and display three dimensional models. The surface consist points which have the same intensity on the every slice.

### 2.3.1 Contour Filtering

The contour filtering is one of the method for generate the 3D image in this project. It attempts to generate a surface by connecting the vertices of adjacent contours in order to produce a mesh that passes through all contours. These approaches generally need to address the correspondence (how to connect vertices between contours), tiling (how to create meshes from these edges) and branching (how to cope with slices with different numbers of contours) problems.

Keppel and Fuchs et al. described the first algorithms for creating polygonal meshes from a series of contours and the Fuchs work defines the best reconstructed surface as the one with minimal surface area [26-27]. Later, many other researches have made improvements to these initial algorithms. Several solutions to the correspondence problem have been proposed, including those based on parameterization of the contours, contour decomposition, Minimum Spanning Trees, Angular Bisector Networks, medial axes and partial curve matching algorithms [28-33]. Figure 6 shows the steps for contour filtering.

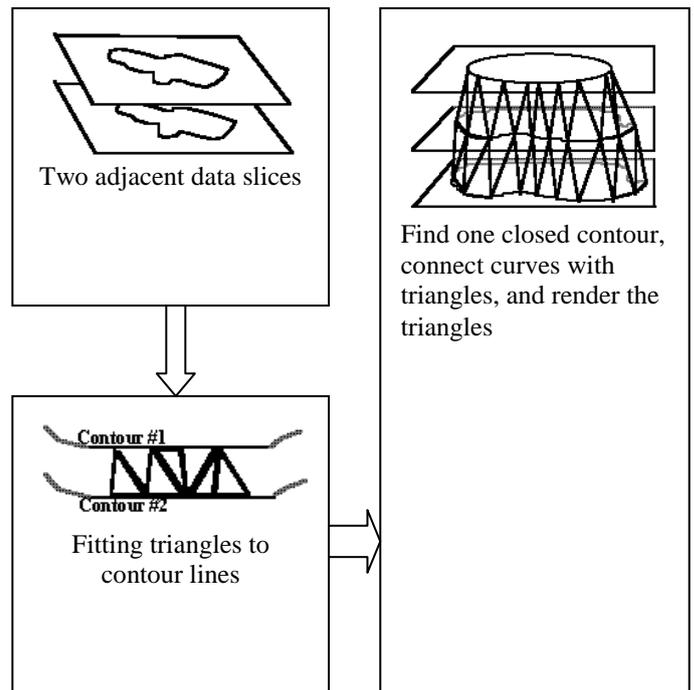


Fig.6 Step for contour filtering

### 2.3.2 Marching Cube Algorithm

One of the famous algorithm of surface rendering is marching cube algorithm. Marching cubes is one of the latest algorithms of surface construction used for viewing 3D data. This algorithm produces a triangle mesh by computing iso surfaces from discrete data. By connecting the patches from all cubes on the iso-surface boundary, we get a surface representation. Marching

Cubes (MC) algorithm is a 3D reconstruction method developed by W. Lorensen in 1987. Because of its merits of simple, easy to achieve, it has been widely used, is considered as one of the most popular algorithms for display [34-38].

This algorithm will take the eight neighbor locations when pass through the images and determining the polygon needed to represent the iso surface. The polygons will treat each of the eight scalars as 8-bit integer. The value will set inside the surface if the scalar value is higher than iso-value and vice versa. The figure 7 shows the 15 unique cube configurations or patterns of polygons generated by Marching Cubes algorithm.

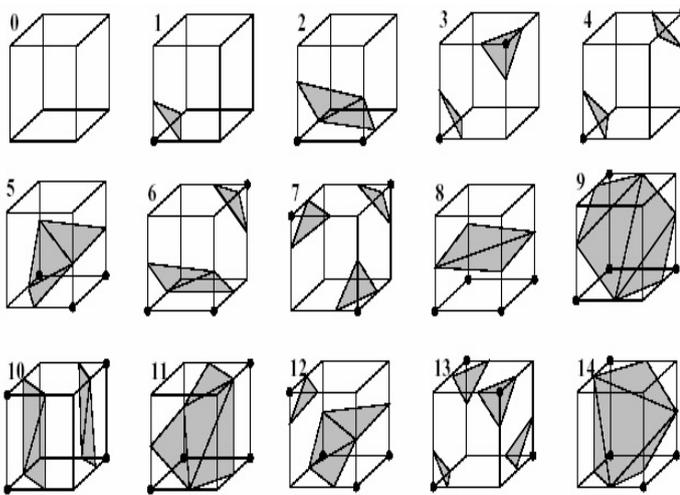


Fig.7 15 Unique Cube Configurations generated by Marching Cubes Algorithm

**2.3.2 Visualization Toolkit**

VTK is an open source, object-oriented software system for computer graphics, visualization, and image processing, and visualization used by thousands of researchers and developers around the world.

In this experiment, all of the slices of images need to be read as a volume into the system by using the function vtkJPEGReader in VTK. As the data input become volume, contour filtering and marching cubes algorithm can be applied for reconstruction of 3D image.

For contour filtering, after the function vtkJPEGReader, vtkContourFilter act as the main role to extract the iso-surface of the volume. The iso-surface value then needs to be process by vtkPolyDataNormals to generate the normal point of the iso- surface. Next, the vtkPolyDataMapper use to generate the mapping to rendering from poly data. The vtkActor is used as an entity for rendering purpose. It is act like a connector between renderer and the input data. Besides that, it also represents the object which is geometry or poly data to be render. Last, the render will generate the 3D image by

controlling the process of converting the geometry, light, camera view of the image.

The process of surface rendering using marching cubes algorithm is follow the pipeline of function vtkJPEGReader, vtkMarchingCubes, vtkPolyDataMapper, vtkActor and renderer. vtkMarchingCubes is used to extract the iso surface of the volume based on the identical intensity of each images. It will also generate many triangles of iso surface. vtkPolyDataMapper is used to generate the mapping to rendering from poly data while vtkActor is used as an entity for rendering purpose.

Figure 8 and Figure 9 show the flow chart of the contour filtering and marching cube algorithm implemented in VTK respectively.

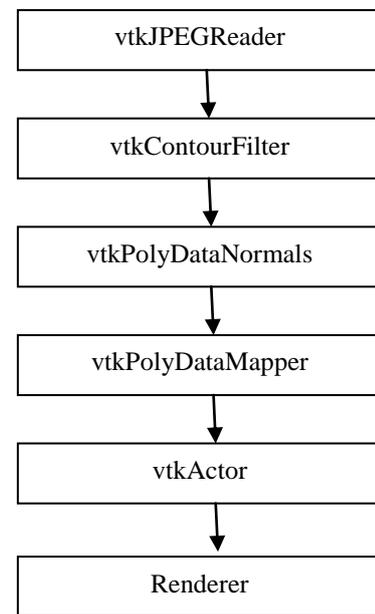


Fig.8 Flow chart of contour filtering implemented in VTK

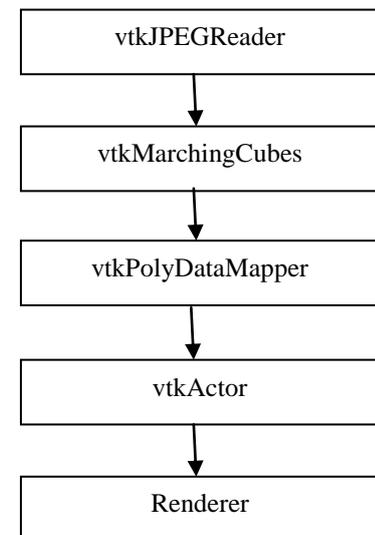


Fig.9 Flow chart of marching cube algorithm implemented in VTK

### 3 Result and Analysis

The fetus model is scanned by ultrasound machine and connects it to laptop with TV grabber. The images are stored in the laptop for 2D image processing and visualization process. The 2D image is taken using freehand with ruler as guideline for every image at constant distance of one millimeter. Several set of ultrasound image with different number of slices were taken for comparison purposes.

Figure 10 shows the result after the image processing consists of median filtering, image contrasting, global thresholding and noise reduction.

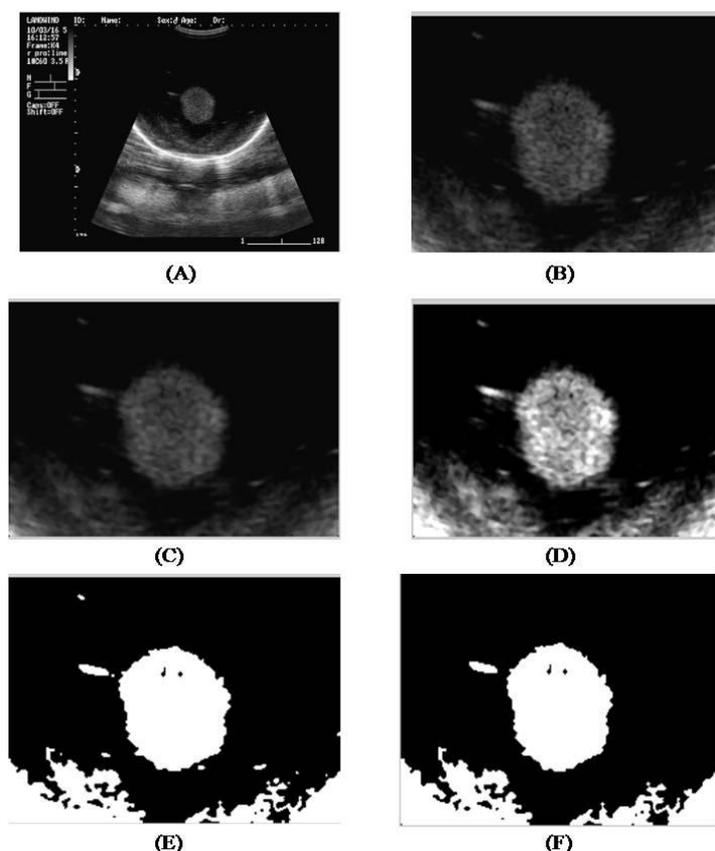


Fig.10 2D image processing A) Original Ultrasound image B) ROI C) Image after median filtering D) Image after contrasting E) Image after global thresholding F) Image after noise removing

Figure 11 and figure 12 show the result of 3D reconstruction of contour filtering and marching cubes algorithm. Based on the results, we can see that the 3D image of the fetal phantom is successfully reconstructed. However, the result is not smooth due to the noise unfiltered in the enhancement process. This result shows that the currently used image enhancement methods were not good enough to obtain a good result. Therefore, in order to overcome this problem, we should choose and added better image enhancement methods. The result also shows that the surface of the image is also not

smooth because we use the untracked free-hand system which may lead to inconsistency of scan rate and angle.

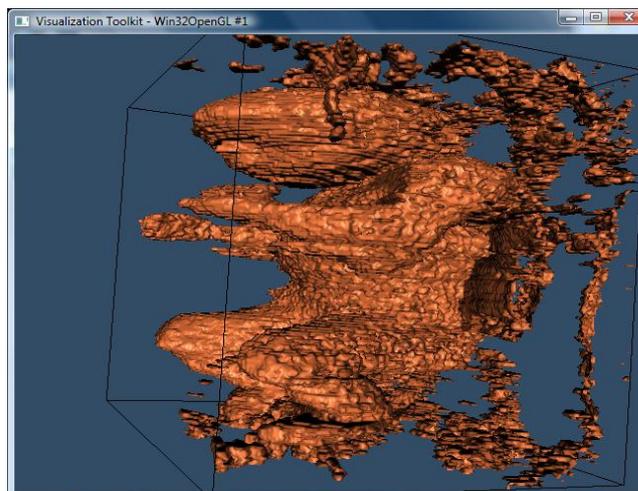


Fig.11 3D reconstruction using contour filtering

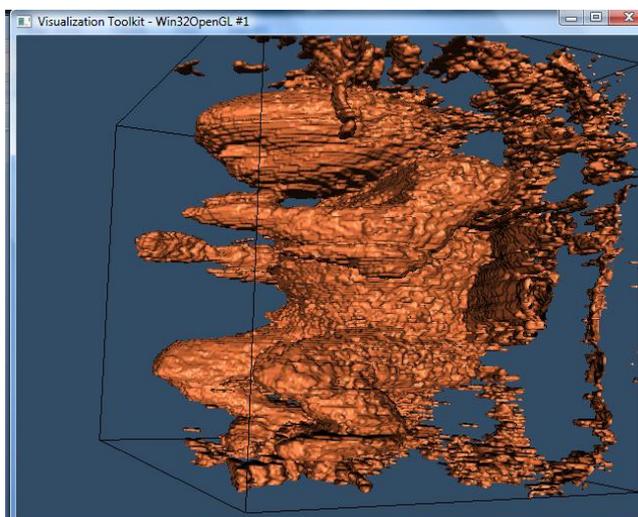


Fig.12 3D reconstruction using marching cubes algorithm

The result is analyzed by comparing the images based on certain criteria such as:

1. Analysis A: Comparing the 3D ultrasound image reconstructed with the real fetal phantom
2. Analysis B: Comparing the 3D ultrasound image based on reconstruction techniques (contour filtering and marching cubes algorithm)
3. Analysis C: Comparing the 3D ultrasound image reconstructed based on different set of 2D ultrasound images with different number of slices (103 slices, 155 slices and 183 slices).

### 3.1 Analysis A

In analysis A, the real fetal phantom has been compared with the 3D image reconstruct to ensure the image is matched with the real object. Figure 13 shows the correct match of head, hand and leg between 3D image and real fetal phantom. The result proved that 3D image has successfully been reconstructed as we can directly identify certain part of the fetal body. Even though the 3D image reconstructed is not good, we still can visually differentiate head, hands and legs of fetal phantom.

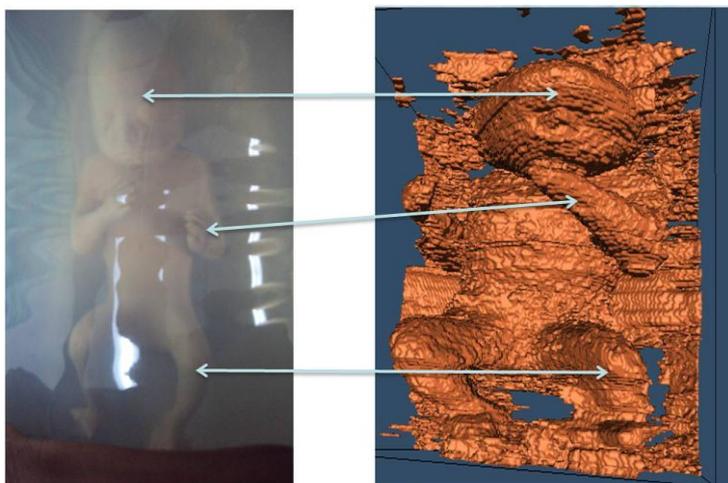


Fig.13 Comparison between real fetal phantom and 3D fetus image

### 3.2 Analysis B

Besides comparing the result with the real phantom, the result is also compared between those two techniques used for 3D reconstruction which is the contour filtering and marching cubes algorithm. Based on the figure below, we can see that the marching cubes algorithm can produce the sharper image compare to contour filtering. This is due to the different algorithm when reconstruct the 3D image.

The 3D image reconstructed by marching cubes algorithm has higher intensity which can help us easily to detect the edges and inner part of the object. Since the 3D result using the marching cube algorithm is better than contour filtering, the marching cubes algorithm is more suggested for 3D reconstruction of the images. Figure 14 shows the comparison of top view of different 3D visualization methods which are contour filtering and marching cube respectively.

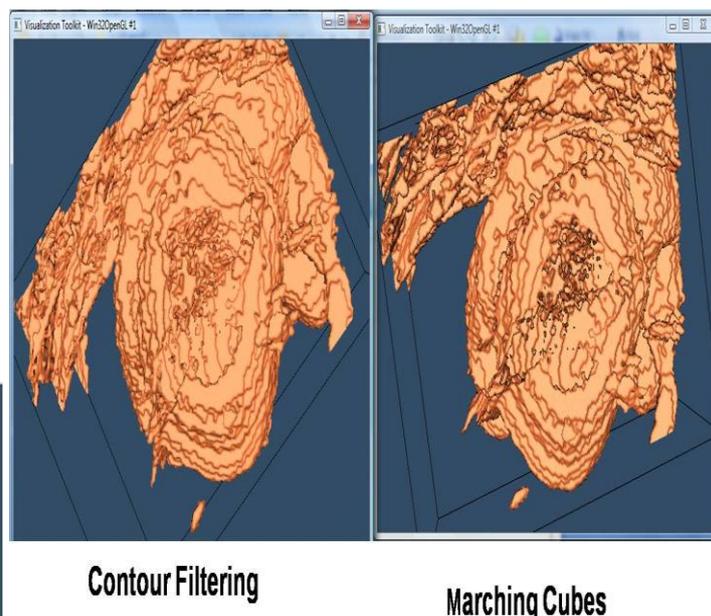


Fig.14 Comparison of top view of different 3D visualization methods

### 3.3 Analysis C

In order to generate a good 3D image, the minimum amount of slices taken need to be set and taken from the object. In this experiment, three set of images with different slices (103 slices, 155 slices and 183 slices) were taken and reconstructed. Figure 7 shows the comparison between three different amounts of slices for reconstruct 3D image. Based on the result, we can see that the 183 slices of images can produce a better look and similar image when compared to the real object. Therefore, in order to reconstruct a better 3D image, we need to increase the amount of slices in a set.

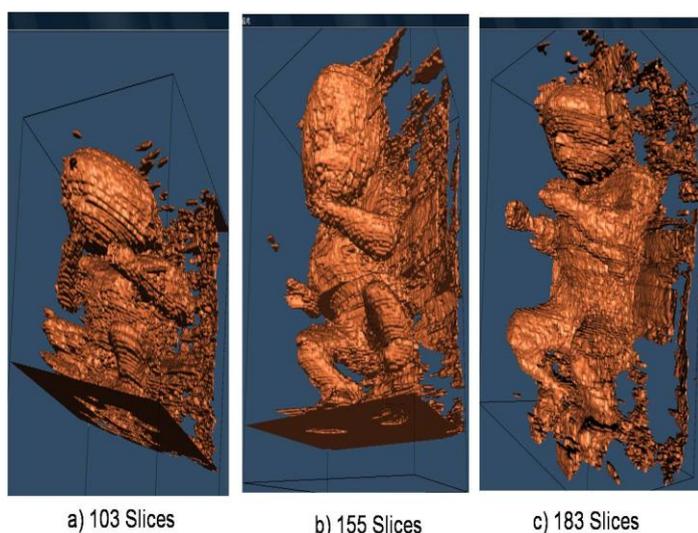


Fig.15 Comparison between different amounts of slices for reconstruct 3D image

## 4 Conclusion

The 3D reconstruction of fetal phantom has been developed using contour filtering and marching cube algorithm by implementing in Visual C++ 6.0 with Visualization Toolkit (VTK). From the experiment, we can conclude that in order to reconstruct a smooth and better 3D image, we need to use ultrasound machine together with tracking sensor to maintain constant scan rate rather than just using the untracked freehand 2D ultrasound which leads to inconsistency of the scanning rate and angle. Besides, for a set of ultrasound image from a low cost machine, image processing need to be performed thoroughly by adding other detailed processing techniques so that noises can be fully removed. From the result also, it can be concluded that the marching cube algorithm can give a better result compare to contour filtering where marching cubes algorithm can generate higher intensity 3D image which can make user easy to detect inner part and edges of 3D images. The number of slices should also be increased to improve the accuracy of the 3D image constructed. The higher the number of slices in a set of images, the better the 3D image reconstructed.

For future work, some recommendations have been made based on the problems and inaccuracy occurred during the experiment. Firstly, the quality and accuracy of the 3D result is determined by the position of taking the 2D image from the object. Therefore, it is suggested that the use of tracking device is important and crucial. Besides, higher quality of ultrasound machine should be used in order to get a higher quality of 2D images. This can ensure that the object scanned from the transducer have higher intensity and less noise. Lastly, in order to have a more concrete result and analysis, further experiment should be made by trying different 3D reconstruction algorithm and using some other different object as subject.

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