academicJournals

Vol. 8(31), pp. 1487-1494, 18 August, 2013
DOI 10.5897/SRE11.1071
ISSN 1992-2248 © 2013 Academic Journals
http://www.academicjournals.org/SRE

Scientific Research and Essays

Full Length Research Paper

Open sources three-dimensional ultrasound volumetric rendering in object oriented approach

Lai Khin Wee[1,2]*, Hum Yan Chai[3] and EkoSupriyanto[4]

[1]Institute of Biomedical Engineering and Informatics, Technische Universi tatIlmenau, 98693, Ilmenau, Germany.
[2]Department of Clinical Science and Engineering, Universiti Teknologi Malaysia, Skudai UTM, Malaysia.
[3]Center for Biomedical Engineering, Universiti Teknologi Malaysia, Skudai UTM, Malaysia.
[4]Department of Clinical Science and Engineering, Universiti Teknologi Malaysia, Skudai UTM, Malaysia.

Accepted 30 May, 2013

On account of the advanced technology in recent years, the increasing demand for an effective medical imaging system has addressed its significance in diagnosis especially in the development of three-dimensional medical image reconstruction. Based on literature revise on various computational investigated, none of them show efficiency in terms of cost and computing performance. Owing to this fact, a method of 3D ultrasound volume reconstruction and rendering using Visualization Toolkit (VTK) has been proposed in this paper. The 3D reconstruction has been achieved through a series of computerized processes includes DICOM sources manipulation, grey interpolations, ray casting and volume rendering. Volunteered subject scanned on carotid arteries were collected. Experimental simulations were taking place on a maximum 256 numbers of two dimensional ultrasonic slices in DICOM storage. The result obtained indicates that VTK is an efficient open source library in performing 3D restoration especially in the matter of volume rendering. Internal structure of carotid arteries can be examined explicitly in any orientation. Within several virtual slicing features, such as slider, double side slider and box widget, it allows certain region-of-interest (ROI) visualization. The method proposed has shown its future utilities in clinical application especially in CT, MRI and Ultrasound images, in order to provide a more informative view for hospital personnel performing a more significant diagnosis.

Key words: Three dimensional, reconstruction, visualization toolkit (VTK), volume, rendering, medical imaging, ultrasound, open sources

INTRODUCTION

With the rapid development of advanced technology in the current health care environment, requirements in diagnosis technology are becoming tremendously demanding. Especially while MRI, CT and other large equipment (Ali et al., 2010; Abu Baker et al., 2007; Ouadfel and Batouche, 2007; Selvan et al., 2010) which are widely used in the medical environment, image-based diagnosis and processing (Lai et al., 2010; Lai and Too, 2010; Lai and Eko, 2010) has been developing from the traditional two-dimensional diagnostic imaging X-ray film in reading digitized DR-chip technology to the current development of the three-dimensional diagnostic imaging technology (Rahmat et al., 2010).

Since the American College of Radiology (ACR), and the National Electronics Manufacturers Association (NEMA) proposed the standardized and uniform information exchange for the DICOM 3.0 in medical image (Ghrare et al., 2009), the obstacles and difficulties where different imaging devices have different image formats in image exchange has been solved and can now been further processed with the standardized layout.

Currently, in many large-scaled hospitals, DICOM images are embedded in three-dimensional reconstruct-tion software which is similar to a class of large-scale

*Corresponding author. E-mail: khin-wee.lai@tu-ilmenau.de.

image processing workstation system or treatment planning system. A major drawback of the work station system is the great consumption of computing processing and thus demanding hardware configuration is needed to perform the task. Therefore, prices are usually very high and consequently the establishment of such workstation is not affordable for many other small-scaled hospitals. Obviously, the software is not cost effective, moreover, only the related companies who developed the software are able to carry out the routine maintenance and this has created many difficulties and inconvenience.

Therefore, the development of smaller and efficient standard DICOM 3.0 medical image reconstruction system can be utilized to overcome the limitations mentioned above, at the same time, medium and small hospitals will own three-dimensional diagnostic imaging standards themselves (Selvaraj, 2010). This implementation can surely enhance the accuracy of the current diagnostic imaging system and perform further improved treatment for patients.

The main concept of volume rendering is to assign each individual voxel element with its Opacity, with the consideration of its light transmission, emission and reflection for every single voxels (Barillot, 1993; Byeonghun Lee, 2010; Herman, 1990; Treinish and Goettsche, 1991; Yemez and Schmitt, 2004). Transmission of light depends on the opacity of voxels; where light emission depends on the objectness, the greater degree of substance, the stronger the emitted light; and lastly, light reflection depends on the angle of surface and the voxel. In principle, volume rendering steps can be divided into projection, blanking, rendering and compositing. It can handle three-dimensional regular data and irregular data field of volume rendering (Rani and Nathan, 2009). The irregular data field can also refers to the structured data and unstructured data irregularities, such as finite element analysis and computational fluid dynamics data generally fall into this category, where in this type of data, the body elements of shapes variability and sizes variability reducing the algorithms efficiency.

So far, the research and development of irregular three-dimensional volume data is still remained a difficulty to be solved. On the other hand, the techniques for regular data field of volume rendering is more promising, it has four commonly used algorithms: Ray casting, Splatting, Shear-Warp and 3D Texture-Mapping Hardware. The basic idea of the three algorithms and features are elaborated below.

Ray casting

Ray casting has sparked a lot of research literature in volume rendering algorithm (Knoll et al., 2009; Qin, 2008; Ray et al., 1999; Silva and Mitchell, 1997). The basic theory is based on the principle of visual imagery to construct an ideal physical visual model where each voxel can be seen as the transmission, emission and reflection of light particles, then base on its lightness model, according to the pixel properties like color and opacity, and the direction along the line of observation sight, finally, it forms a translucent images on the surface.

As shown in Figure 1, ray casting involves generating color and opacity values for each element in the data set and combining the values along the path of an imaginary ray fired through the data set. These values of color and opacity are then used to produce the pixel value for the final image.

Splatting

This technique was specific developed to enhance the speed of volume rendering computing such as ray casting (Mueller et al., 1998; Neophytou and Mueller, 2005; Nichols and Wyman, 2010). However, the quality of the rendered image is affected. It differs from ray casting in the projection method. The projection is in iterated operations on the vowel depending on the opacity and the color of the voxel. A Footprint function is calculated for each voxel projection and the intensity distributed with a Gaussian function, thus calculating the overall contribution of its image and to synthesize to form the final image. This method mimics the way snowball was thrown onto the wall leaving traces of a diffusion-like phenomenon, hence the name "splatting." it has the advantage that the volume data storage in accordance with the order to access the object, and only voxels associated with the image projection are displayed, this has greatly reduced the number of physical data access, and thus the algorithm suitable for parallel operation.

In theory, the reconstruction functions using the same weights, splatting and the ray casting algorithm can generate the same quality of images. However, in practice, due to its difficulty of weight calculation, many approximation algorithms are used during computing and hence the image quality will decline.

Shear wrap

Shear-Warp is currently considered as the fastest volume rendering algorithms (Basso and Dal SassoFreitas, 1998; Jürgen and Ulrich, 2003; Lai et al., 2011). It uses a voxel and images based on coding scheme. While traversing in image voxel, opaque and transparent areas of the image voxel are excluded. During the pre-processing, the voxel is classified according to the degree of opacity. Then go into the Run-Length Encoded, RLE stage. It follows by the implementation method similar to ray projection to render the image. The rendering process can be simplified as appropriate coded by cutting out the ray orthogonal voxel to the voxel layer in all, using the bilinear interpolation in traversing the voxel layer to get their samples, and then converted to the screen image.

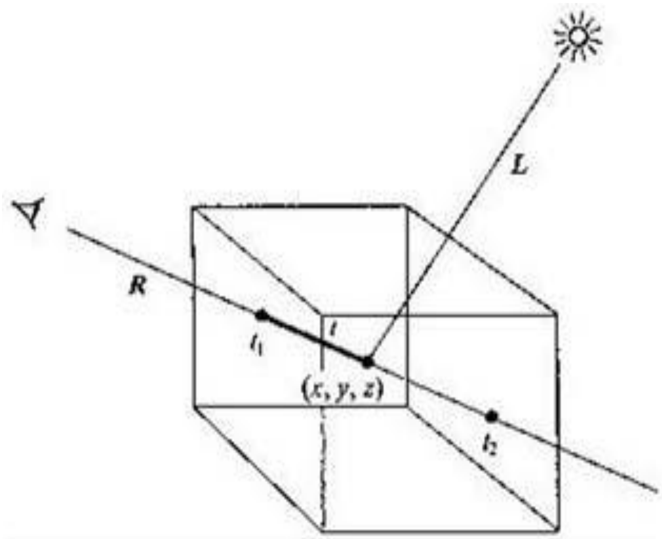

Figure 1. Concept of ray casting.

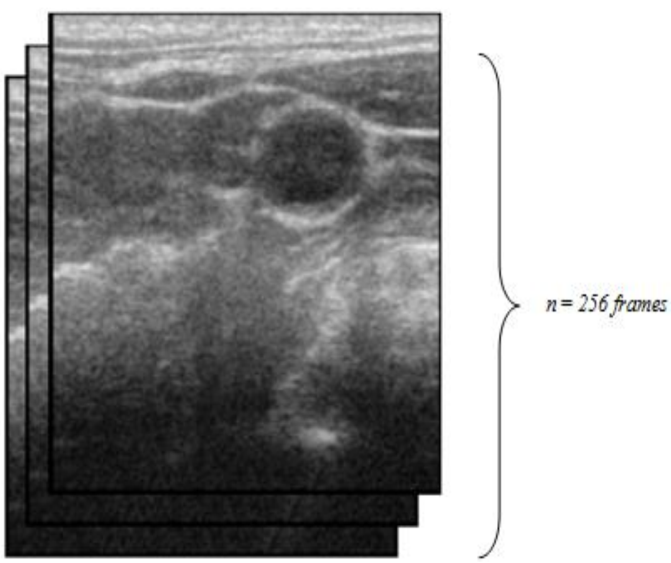

Figure 2. Multiples slices of two dimensional ultrasound images arranged in order.

METHODOLOGY

In this project, multi frames of DICOM ultrasound data were collected for three dimensional volume reconstructions. DICOM is also known as Digital Imaging and Communications in Medicine, which is specially used for medical digital imaging and communications. DICOM standard is jointly developed by the American College of Radiology (American College of Radiology, ACR) and the National Electrical Manufacturers Association (National Electrical Manufacturers Association, NEMA). The collected DICOM file is stored in 8 bit, and digital unsigned characteristic with the grey scale value between 0 and 255. The maximum numbers of frames stored are 256 frames, as shown in Figure 2. The order of these 256 ultrasound images need to be arranged according to their priority in advanced. The scanned subject in the present studies is carotid arteries, with the resolution 641 x 598 using trans-abdominal 3.5 MHz ultrasound transducer with freeze capability.

Architecture of visualization toolkit (VTK) pipeline design

Visualization toolkit is specially designed for use in pipeline mechanism, it can process almost all the structure type of data, and provides a various type of data conversion or processing for a number of the corresponding classes. According to the type of raw data, different algorithm is used to achieve the results. Design and visual process can be built by user where different class of data conversion processing can be chosen and link to each other through the data channel. Converting raw data into an algorithm module so that the data types can be processed directly and obtain desired visualization result ultimately.

In the present project, vtkSource class object create a data source; then, vtkFilter class or its derived class process the data source object. It follows by vtkMapper class or its derived classes mapped pixel data, and then the vtkActor class or a derived class represents a drawing entity. Finally, the image is rendered by the vtkRenderer. By using VTK for three dimensional reconstruction developments, the main aim is to design appropriate lines, and set the parameters to meet the program needs. The Figure 3 shows the flow chart of VTK pipeline connection.

Volume rendering computing design

The raw data used in volume rendering is the DICOM format (Barillot, 1993; Jin and Jong, 2003; Tae et al., 2001). In general, volume rendering is similar to the basic flow chart as shown in Figure 4, but it is slightly more complicated than the surface rendering. The main difficulty of the proposed method is to place different transparency and color for each different grey value of image voxel. Currently, VTK making uses the class *PiecewiseFunction* to situate the transparency; such method can be achieved by using *Add Point* (grey value, transparency) algorithms, so that the 3D visualization effects can shows discrete grey values boundaries continuously. Nevertheless, to know the exact grey value of different organ structures is far from straight forward task, in other words, skin, bone, artery's boundaries and others having various discrete block of grey values.Therefore, it requires thorough fine-tuning to find suitable range of grey values.

In VTK, the class*Color Transfer Function* is used to set the color, which in fact provides a grey value to the RGB values of the map. It is used to add color to voxel with different grey scale value for visual effect enhancement. Last but not least, VTK volume rendering method is implemented by the *VolumeRayCastFunction*.

Imaging interpolation with voxel concepts

Voxel is the basic unit in three-dimensional where it can be formed by four points in each corresponding slices into a cube (Schroeder et al., 2006). It has the shape of a hexahedron on each side of the orthogonal axes; voxel uses the defined points to coordinate the direction of gradually increasing order, as shown in Figure 5.

In general, image data slices obtained by medical imaging equipment always contains a gap in space direction, the gap is much larger than the distance between the pixels extends. For example, slice CT, the layer pixel pitch is usually between 0.5 ~ 2 mm, while the spacing between the range of 1 ~ 15 mm. Therefore, we need to generate new sections by interpolation between the layers when we performed 3D image reconstruction. In the present ultrasound image experimental studies, the value is place to 3.57,

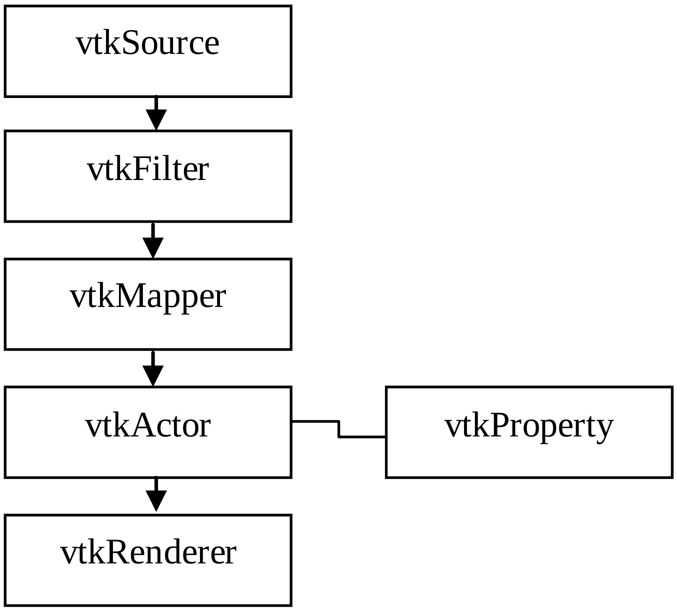

Figure 3. Classical VTK pipeline mechanism for three dimensional rendering.

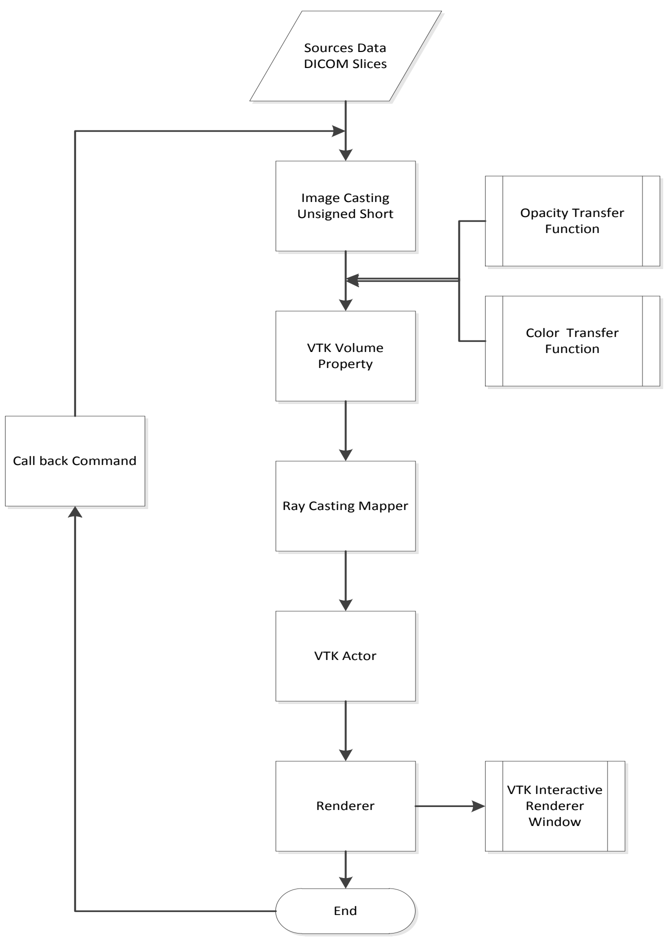

Figure 4. Flow chart of proposed computing pipeline for three dimensional volume rendering.

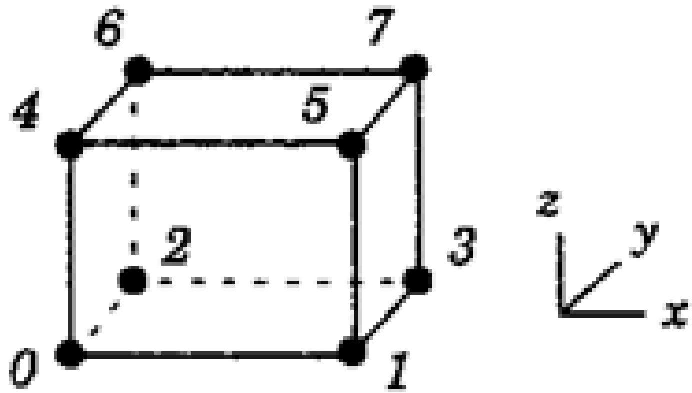

Figure 5. Definition of voxel in three dimensional.

where it complies with the ultrasound machine's setting for imaging output generation.

Interpolation methods are mainly divided into two sorts (Basso and Dal SassoFreitas, 1998; Scheipers et al., 2010) the first type are based on image grey value interpolation methods, such as neighbouring method, linear interpolation (Muthaiah and NeelaKantan, 2008), spline interpolation (Al Bayati et al., 2009; Asamwar et al., 2010; Youness and Hassan, 2008) and others. Another kind is based on matching interpolation method. These methods are essentially for the gap which contains images from the adjacent common feature extraction. Image interpolation based on grey-based interpolation is implemented in the present studies. The advantage of this interpolation is conservative, accelerative computing and less demand on computing loading.

Grey interpolation

The terminology of grey interpolation is to add a number of "missing" slice images in original tomography images sequences (Grevera et al., 1996; Higgins et al., 1996). Existing interpolation methods are mainly grey neighbour interpolation, linear interpolation and high order nonlinear interpolation. Linear interpolation is often assumed the grey value in the Z direction changes linearly through two adjacent sections, corresponding to the pixel interpolation intercropping to estimate the corresponding point on the new gap grey. Identification of a new grey value of pixel images needs to use information of corresponding points on several layers of grey level.

Suppose the known tomography image V (x_i, y_j, z_k) and V (x_i, y_j, $z_k +1$) interpolation between them out in a new layer of the image V (x_i, y_j, z). Interpolation algorithm using Nearest Neighbour, the new image V (x_i, y_j, z) of the grey scale value:

$$V(x_i, y_j, z) = \begin{cases} V(x_i, y_j, z_k) & d \leq 0. \\ V(x_i, y_j, z_{k+1}) & otherw \end{cases} \quad (1)$$

Where $d = z - z_k$as the distance between point (x_i, y_j, z) to V (x_i, y_j, z_k).

RESULTS

The usefulness of two-dimensional image plane often depends on the physical structure for the region of interest

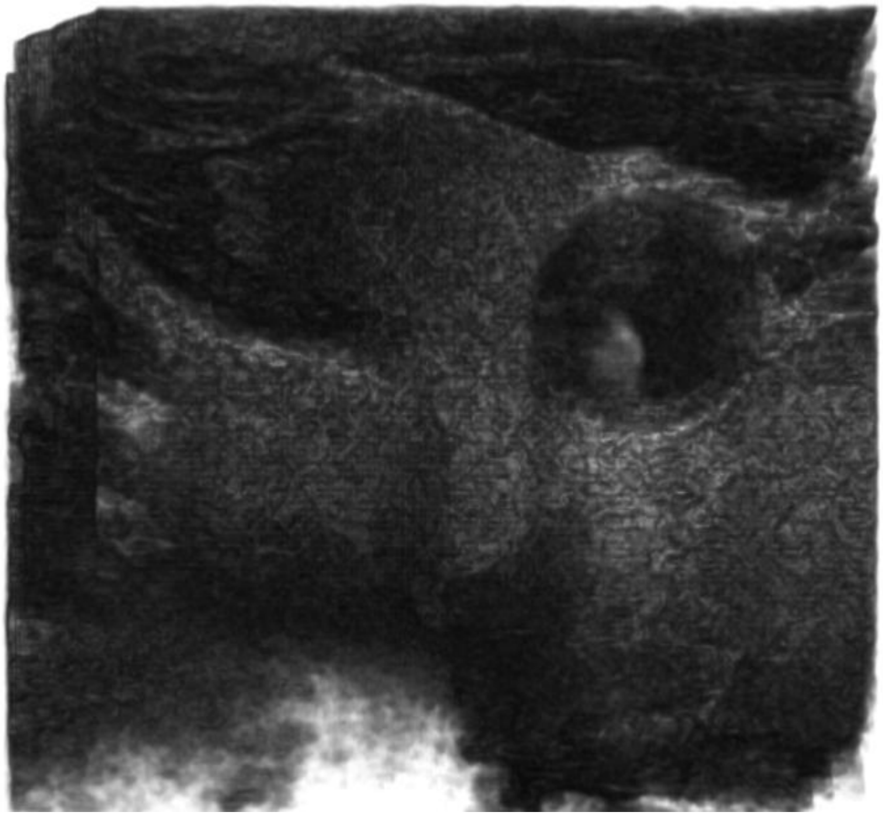

Figure 6. Three-dimensional volumes rendering with default values.

approach. However, for most of the existing medical imaging systems, it is difficult to generate the best spatial orientation two-dimensional image directly. This is because the structures of positioning and scanning orientation are generally subject to the structure and other physical limitations. Therefore, three dimensional imaging have higher value for the clinical application. In many occasions, it is crucial to identify and display the best two dimensional image plane from the three dimensional model.

Figure 6 shows the resultant three dimensional volumes rendering without interpolation. Therefore it can be observed that the results are poor in quality especially in the matter of z dimensional or space direction. The area of carotid arteries, which is the region of interest in this case are hardly to distinguish from the three dimensional model. Nevertheless, within appropriate parameters adjustment using the sub-library *OpacityTransferFunction*, and *Color TransferFunction*, it can be greatly improved and the internal image areas of carotid arteries are shown clearly, as shown in Figure 7.

When the whole volume image data are stored in the computer's memory, the image reorganization can be achieved interactively with some others external library such as the function of *vtkImplicitPlane*, which provide great three dimensional features like the cutting slider as shown in Figures 8, 9 and 10.

Figure 11 shows the function of *vtkBoxWidget*, which allows the users to change the view of the reconstructed three dimensional models. The users can also using it to select the region of interest, for close view, analysis and measurement.

DISCUSSION

The complexity of volume rendering algorithm are including large amount of data storage and slow computation time. It is always a difficult problem for three-dimensional visualization. In the present project, the focus of the volume rendering synthesis is to define the different grey value of image voxel with different transparency setting. Within different transparency settings, the effect of final displayed image is different.

Conclusion

In summary, we have proposed a three dimensional reconstruction for volume rendering using VTK library. The volume rendering is applicable to multiple organ with CT, MR, or ultrasound scan image reconstruction, it is

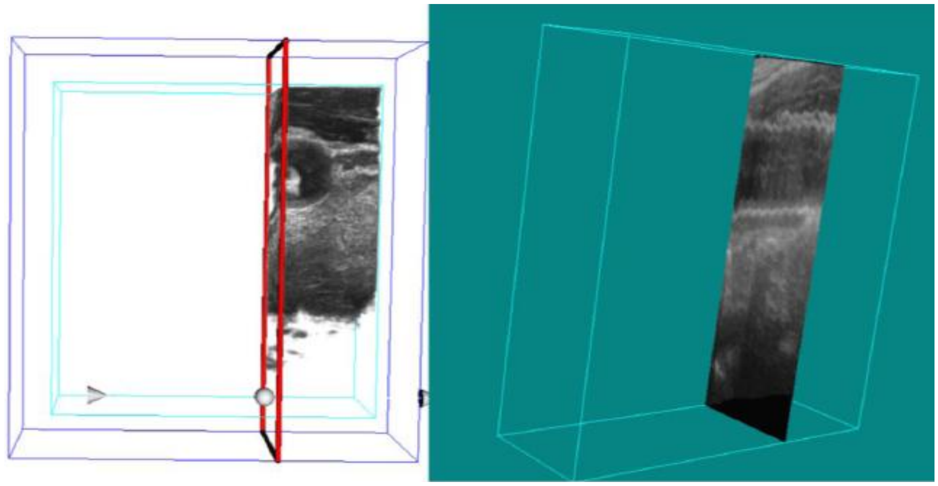

Figure 7. Three dimensional volumes rendering after adjusting specific volume property, however, the round area of carotid area still contains background cloud.

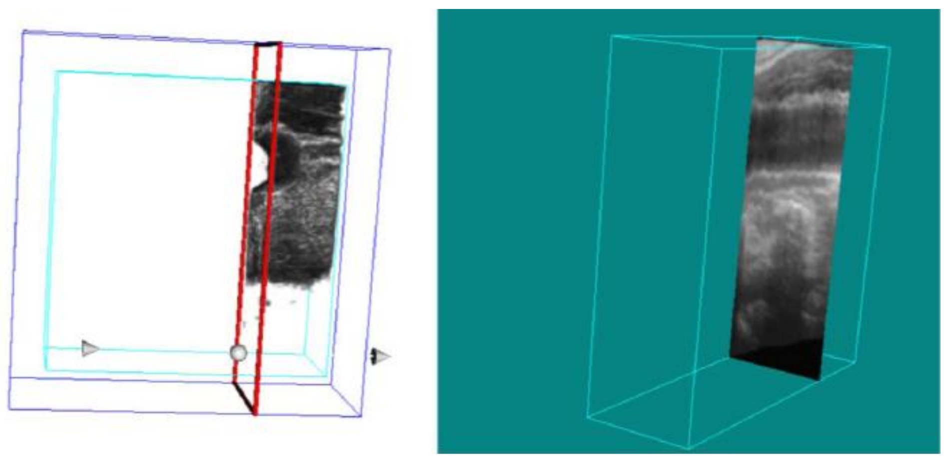

Figure 8. The background cloud can be removed by tuning additional filter, 3D anisotropic diffusion.

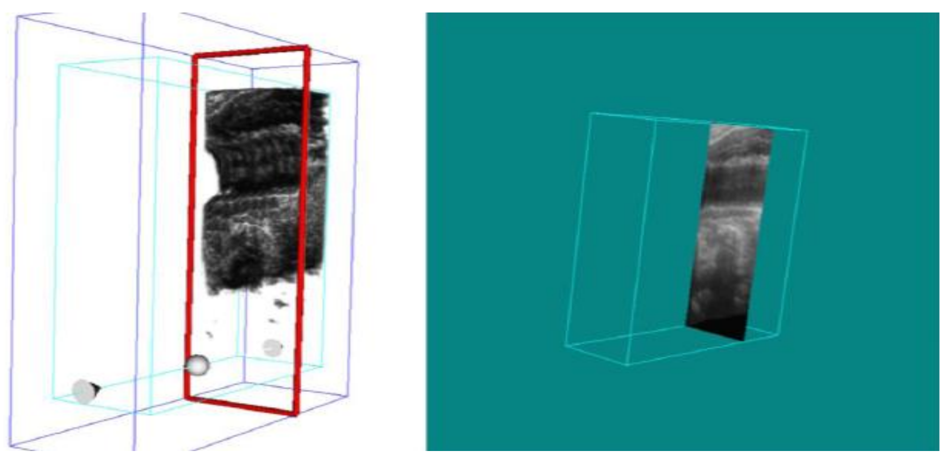

Figure 9. Front view from the cutting slider, perfect view for measurement on three dimensional carotid arteries.

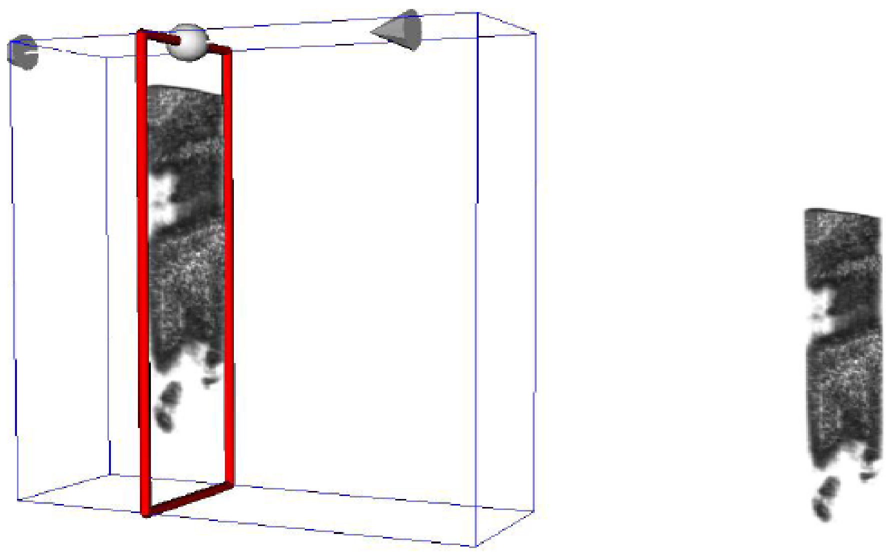

Figure 10. Double side cutting slider, allow user to view from both angle (left and right) direction.

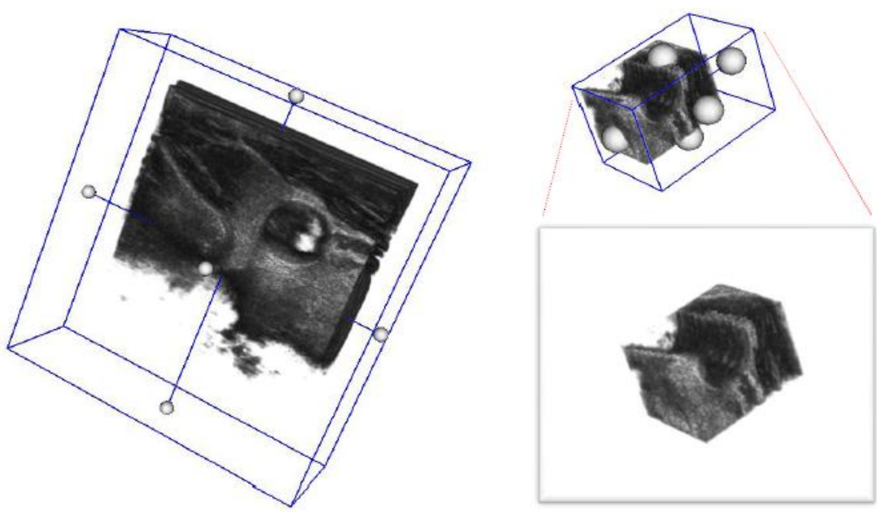

Figure 11. Box widget allows for ROI visualization.

more beneficial to observe the lesion and the normal organ or tissue between the spatial relationships, and it have a greater significance in practical clinical applications. Findings showed that the system is able to produce promising results.

ACKNOWLEDGEMENTS

The researchers are so indebted and would like to express our thankfulness to Prof. Dr. -Ing. habil. Jens Haueisen and Dr. rer. nat. Uwe Graichen for their supporting, comments and guidance throughout the project. We would also like to thank DAAD – Deutscher Akademischer Austausch Dienst for the financial support to the student who conducted the project at TU-Ilmenau, Germany. Our appreciation also goes to all the members of BMTI, Technische Universitat Ilmenau, Germany, for their ideas and support to the project.

REFERENCES

Ali AD, Swami PD, Singhai J (2010). Modified curvelet thresholding algorithm for image denoising. J. Comput. Sci. 6:18-23.

Abu Baker AA, Qahwaji RS, Aqel MJ, Al-Osta H, Saleh MH (2007). Efficient pre-processing of USF and MIAS mammogram images. J. Comput. 3:67-75.

Al Bayati AY, Saeed RK, Hama-Salh FK (2009). The existence, uniqueness and error bounds of approximation splines interpolation

for solving second-order initial value problems. J. Math. Stat. 5:123-129.
Asamwar RS, Bhurchandi K, Gandhi AS (2010). Successive image interpolation using lifting scheme approach. J. Comput. Sci. 6:968-978.
Barillot C (1993). Surface and volume rendering techniques to display 3-D data. IEEE Engr. Med. Biol. Mag. 12:111-119.
Byeonghun L, Yun J, Jinwook S, Byonghyo S, Yeong-Gil S, Bohyoung K (2010). Fast high-quality volume ray casting with virtual samplings.IEEE Trans. Visual. Comput. Graphics 16:1525-1532.
Basso K, Dal SassoFreitas CM (1998). Visualization of geological prospecting data. Proc. Int. Symp. Comput. Graphics Image Process. Vision pp. 142-149.
Barillot C (1993). Surface and volume rendering techniques to display 3-D data. IEEE Engr. Med. Biol. Mag. 12:111-119.
Ghrare SE, Ali MAM, Jumari K, Ismail M (2009). An efficient low complexity lossless coding algorithm for medical images. Am. J. Appl. Sci. 9:1502-1508.
Grevera GJ, Udupa JK (1996). Shape-based interpolation of multidimensional grey-level images. IEEE Trans. Med. Imag. 15:881-892.
Higgins WE, Orlick CJ, Ledell BE (1996). Nonlinear filtering approach to 3-D gray-scale image interpolation. IEEE Trans. Med. Imag. 15:580-587.
Herman GT (1990). A survey of 3D medical imaging technologies. IEEE Engr. Med. Biol. Mag. 9:15-17.
Jürgen PS, Ulrich L (2003). The parallelized perspective shear-warp algorithm for volume rendering. Parallel Comput. 29:339-354.
Knoll A, Hijazi Y, Westerteiger R, Schott M, Hansen C, Hagen H (2009). Volume ray casting with peak finding and differential sampling. IEEE Trans. Visual. Comp. Graphics 15:1571-1578.
Wee LK, Adeela A, Eko S (2010). Computerized automatic nasal bone detection based on ultrasound fetal images using cross correlation techniques. WSEAS Trans. Inf. Sci. Appl. 7:1068-1077.
Wee LK, Too YM, Adeelav A, Eko S (2010). Nuchal translucency marker detection based on artificial neural network and measurement via bidirectional iteration forward propagation. WSEAS Trans. Inf. Sci. Appl. 7:1025-1036.
Wee LK, Eko S (2010). Automatic detection of fetal nasal bone in 2 dimensional ultrasound image using map matching.12th WSEAS Int. Conf. Autom. Control Model. Simul. pp. 305-309.
Wee LK, Hum YC, Eko S (2011). Surface rendering of three dimensional ultrasound images using VTK. J. Sci. Ind. Res. 70:421-426.
Mueller K, Torsten M, Edward JS II, Roger C, Naeem S, Roni Y (1998). Splatting errors and antialiasing. IEEE Trans. Visual. Comput. Graphics 4:178-191.
Muthaiah R, NeelaKantan K, Sharma V, Arora A (2008). Image compression and reconstruction using cubic spline interpolation technique. Am. J. Appl. Sci. 5:1562-1565.
Neophytou N, Mueller K (2005). GPU accelerated image aligned splatting. Fourth Int. Workshop Vol. Graphics pp. 197-242.
Nichols G, Wyman C (2010). Interactive indirect illumination using adaptive multi resolution splatting. IEEE Trans. Visual. Comput. Graphics 16:729-741.
Ouadfel S, Batouche M (2007). An efficient ant algorithm for swarm-based image clustering. J. Comput. Sci. 3:162-167.
Qin W, JaJa J (2008). Interactive high-resolution isosurface ray casting on multicore processors. IEEE Trans. Visual. Comp. Graphics 14:603-614.
Rahmat MF, Isa MD, Jusoff K, Hussin TA, Rozali SM (2010). Image reconstruction algorithm for electrical charge tomography system. Am. J. Appl. Sci. 7:1254-1263.
Rani NS, Nathan VV (2009). An “Expert System” for stereoscopic 3d visualization (without the application of conventional attachments to the eyes) of computer acquired and computer generated stereopairs. J. Comput. Sci. 5:1048-1054.
Ray H, Pfister H, Silver D, Cook TA (1999). Ray casting architectures for volume visualization. IEEE Trans. Visual. Comp. Graphics 5:210-223.
Selvan S, Kavitha M, Shenbagadevi S, Suresh S (2009). Feature extraction for characterization of breast lesions in ultrasound echography and elastography. J. Comput. Sci. 6:67-74.
Selvaraj K (2010). Data extraction from computer acquired images of a given 3-d environment for enhanced computer vision and its applications in kinematic design of robos. J. Comput. Sci. 6:425-427.
Silva CT, Mitchell JSB (1997). The lazy sweep ray casting algorithm for rendering irregular grids. IEEE Trans. Visual. Comput. Graphics 3:142-157.
Schroeder WJ, Bertel F, Malaterre M, Thompson D, Pébay PP, O'Bara R, Tendulkar S (2006). Methods and framework for visualizing higher-order finite elements. IEEE Trans. Visual. Comput. Graphics 12:446-460.
Scheipers U, Koptenko S, Remlinger R, Falco T, Lachaine M (2010). 3-D ultrasound volume reconstruction using the direct frame interpolation method. IEEE Trans. Ultrason. Ferroelectrics Freq. Control 57:2460-2470.
Treinish LA, Goettsche C (1991). Correlative visualization techniques for multidimensional data. IBM J. Res. Dev. 35:184-204.
Tae YK, Yeong GS (2001). Fast volume rendering with interactive classification. Comput. Graphics 25:819-831.
Yemez Y, Schmitt F (2004). 3D reconstruction of real objects with high resolution shape and texture. Image Vision Comput. 22:1137-1153.
Youness EA, Hassan SZ, El-Rewaily YA (2008). Quadratic interpolation algorithm for minimizing tabulated function. J. Math. Stat. 4:217-221.