International Journal of the Physical Sciences Vol. 6(23), pp. 5520-5527, 9 October, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.1101
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Interactive computing and measurement in three dimensional ultrasound fetal volumetric reconstruction using visualization toolkit

Lai Khin Wee[1,2]*, Hum Yan Chai[2] and Eko Supriyanto[2]

[1]Biomedical Engineering Group, Institute of Biomedical Engineering and Informatics, Faculty of Computer Science and Automation, Technische Universitat Ilmenau, POB 100565 98684, Ilmenau, Germany.
[2]Department of Clinical Science and Engineering, Faculty of Health Science and Biomedical Engineering, Universiti Teknologi Malaysia, Skudai, 81310 Johor, Malaysia.

Accepted 26 July, 2011

We have proposed the generic computing of 3D ultrasound volumetric reconstruction and measurement using visualization toolkit (VTK) open source computing approach. In present research, we have investigated the extent of voxel conversion from two dimensional image pixels to three dimension volume spacing. This is essentially important to analyze that the measurement on 3D volumetric possesses higher impact and accuracy vis-*à*-vis 2D image measurement. For that reason, we have developed measurement algorithm in 3D spaces via the expansion of Euclidean equation. Simulated results on ultrasound fetal training phantom indicate that the measurements are promising and consistent.

Key words: Ultrasound, three dimension, volumetric, rendering, measurement, Euclidean, distance, Visualization toolkit (VTK).

INTRODUCTION

Fetal abnormalities can be detected through the study of particular ultrasound markers for example like nuchal translucency (NT), nasal bone, length of femur and ductus venous (Nicolaides et al., 1992; Snijders et al., 1998; Zosmer et al., 1999). Recent studies showed that these ultrasound markers can be used for identification of incidence chromosomal abnormalities, such as Trisomy 21 (Hyett et al., 1995; Souka et al., 2001). Trisomy 21 (British Down's syndrome) is a genetic condition in which extra copy of 21st chromosome results in abnormalities of fetus development. It will, consequently, deviate the development of normal physical body structure, functions, and often leads to mental retardation. Other examples of Trisomy include Trisomy 18 and Trisomy 13 (Tul et al., 1999; Celentano et al., 2003); Trisomy 18 or Trisomy 13 is a chromosomal abnormality: three copies of the 18th chromosome (or of the 13th chromosome) present in each cell of the body in stead of the usual pair. Trisomy 21 or Down's syndrome, perhaps, is one of the most frequent congenital causes of severe mental retardation with an incidence at birthrate of 1.3 per 1000 (Hulten et al., 2010).

Ultrasound screening in first trimester of pregnancy provides the most effective way of chromosomal abnormalities screening above. Previous researches showed that assessment of particular ultrasound markers offers promising non-invasive method for fetal abnormalities detection: nuchal translucency, nasal bone, long bone biometry, maxillary length, cardiac echogenic focus and ductus venous (Nicolaides et al., 1994; Cicero et al., 2003); However, the drawback of current ultrasound manual measurement technique is restricted with inter and intra-observer variability and inconsistency of results (Pandya et al., 1995; Abuhamad, 2005).

Besides, the utility of two-dimensional image plane invariably depends on the physical structure for the region of interest approach. Of most of the existing medical imaging systems, it is not trivial to generate the

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

Abbreviations: VTK, Visualization toolkit; **NT,** nuchal translucency.

best spatial orientation two-dimensional image directly (Lai et al., 2010a,b; Lai and Supriyanto, 2010; Supriyanto et al., 2010); the structures of positioning and scanning orientation are generally subject to the structure and other physical limitations.

In many occasions, it is crucial to identify and display the best two dimensional image plane from the three dimensional model. For instance, the best sagittal plane during the prenatal ultrasound screening is favorable for physician to access certain ultrasound markers: nuchal translucency, nasal bone, or ductus venous for Trisomy 21 assessment. This is of prime significance, since, current manual scanning method is restricted to acquire the correct scanning plane of 2 D ultrasound fetal images; if the ultrasound marker is not examined in an appropriate plane, the measurement would be shorter or longer than normal or worst, that is it does not exist. Also, if the tested images are not in the true sagittal view or coincide in the suitable plane, ultrasound markers might not appears in appropriate position. This difficulty remains unsolved in a few cases.

Therefore, three dimensional imaging has higher value for the clinical application. The three-dimensional medical image reconstruction and visualization has great significance in applications: the diagnosis of medical, surgical planning and simulation, surgery, prosthetic surgery, radiation planning and anatomy. Computer visualization of three-dimensional reconstruction is an important area of research, and hence, a number of foreign researchers in this area have conducted a lot of work previously, such as surface rendering, and volume rendering.

Currently, Visualization Toolkit (VTK) is an object-oriented, powerful visualization and graphics, image processing toolkit, providing more than 300 C++ classes (Wee et al., 2011); it has become the most prestigious visualization software development package as well as the ideal three-dimensional reconstruction system development tools. Therefore, in this study, the authors applied VTK and ray casting algorithms simultaneously to construct a crossed scalable platform for three-dimensional ultrasound fetal volumetric reconstruction.

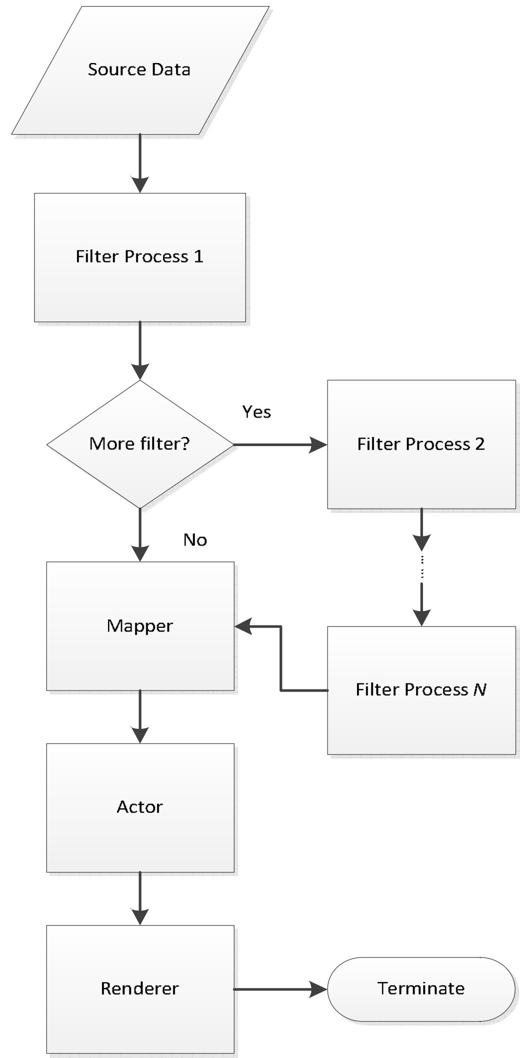


Figure 1. VTK pipeline mechanism.

EXPERIMENTAL SECTION

At present, conventional utilization of three-dimensional visualization tools consists of code executions that lead to drawbacks, like low efficiency and low computing speed. The three dimensional VTK implemented in this project is an OpenGL-based 3D graphics for image processing and visualization tool. The object-oriented technology adopted by VTK can be directly implemented with C++, TCL, Java or Python code; it can be operated in Windows, Unix or other operating systems independently. VTK is not considered as a system, in fact, it is merely a target object library which can be embedded in an applications program, or developed into our own basic functions based on the class provided. Since VTK is an open source and free software with strong three-dimensional graphics functions, that is, great architecture and high degree of flexibility and portability; it has been widely employed in the United States, Western Europe and other universities.

Despite the aforementioned advantages, its application is rarely reported in Malaysia, although, it has been very popular in Europe and America years ago. The present project attempts to reconstruct three-dimensional ultrasound images with VTK exploratory research and improve the performance of three-dimensional in terms of the visualization effectiveness. In this paper, several sets of data were used for surface rendering and volume rendering. The finding shows that VTK is a very useful visualization tools attributable to its great application, convenience and flexibility.

Figure 1 illustrates the principle of VTK pipeline mechanism design. In our case, our source data are multiple slices of two dimensional ultrasound images, which have to be converted into 3D voxel form. Scanned object in present studies is fetal phantom, with resolution 641 x 598 pixels using transabdominal 3.5 MHz ultrasound transducer. Collected DICOM file is stored in 8 bit, and digital unsigned characteristic with gray scale value (0 - 255). Maximum numbers of stored frames (256) are arranged in advance according to priority. Subsequently, Filter in VTK will process the data source object and its pixel data will be mapped by Mapper. Actor playing the rule to represent the drawing entity and the final

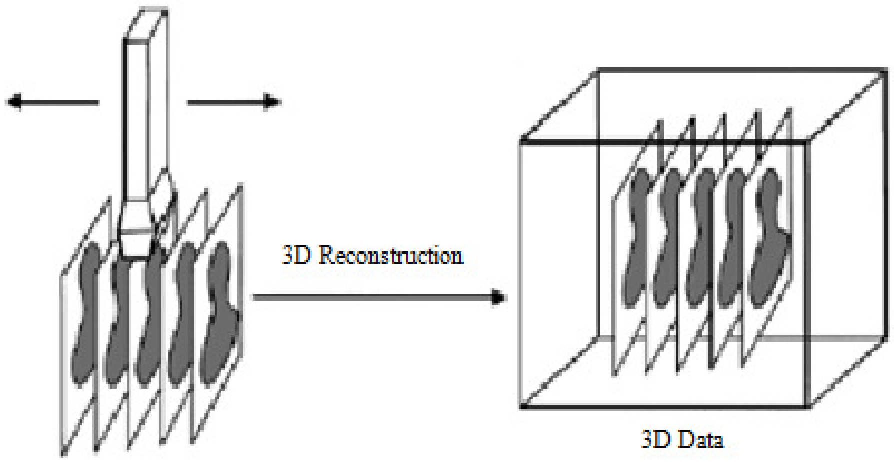


Figure 2. Fundamental concept for 3D voxel data forming.

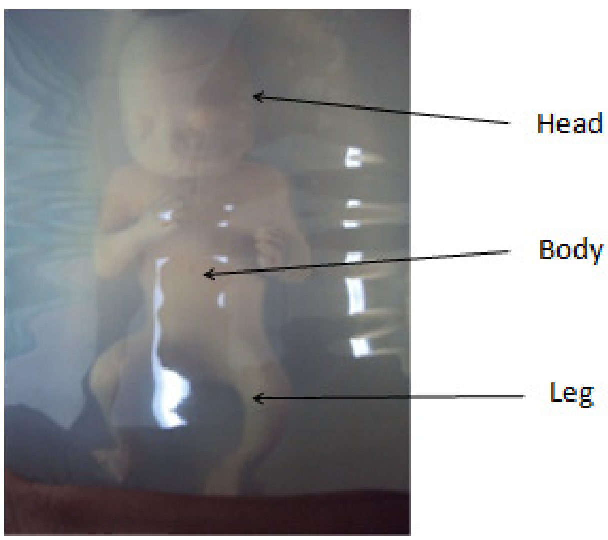


Figure 3. Ultrasound fetal training phantom, 20 weeks.

volumetric will be displayed by Renderer. The main purpose of three-dimensional reconstruction program is to display the overall three dimensional volumetric model, which provides comprehensive information on internal three-dimensional features; The fundamental idea is presented in Figure 2: arrange multiple slices of two dimensional ultrasound images in parallel position; adopt the rendering algorithm based on the lighting; shading model to display images. In computer graphics, adopting ray casting techniques, volume rendering algorithm has been now developed to a more matured stage.

Based on Figure 2, the principles of 3 D reconstruction are composed of two steps: firstly, 2D data slices need to be read and arranged exactly with the real spatial positions, the result is a data volume, and it can be saved in any memory of the computer; secondly, it follows by the rendering techniques in order to visualize data volume as 3D image.

In fact, for accurate data acquisition, the recording of 2D slices should co-operate with a position tracking devices (Gobbi et al., 1999; Gobbi et al., 2000; Gobbi and Peters, 2002), for example, the polaris optical tracking devices, magnetic polhemus tracking devices, or FASTRAK Tracking devices; these devices are used to record the exact position of ultrasound transducer during prenatal ultrasound. Together with each of their 2D ultrasound slices, the recorded Cartesian position data will be used to synchronize and form 3D data in voxel form.

Figure 3 shows ultrasound fetal phantom that have been utilized as the scanned object for the following simulation results. Figure 4 shows, the flow chart for the proposed volumetric rendering and measurement in three dimensional spaces.

In current studies, the measurement is conducted in 3 dimension spaces. For that reason, we have extended the Euclidean distance using Equation 1 below.

$$E(p,q)=\sqrt{(p_1-q_1)^2+(p_2-q_2)^2+\ldots+(p_n-q_n)^2}=E(q,p)=\sqrt{\sum_{i=1}^{n}(q_i-p_i)^2} \quad (1)$$

E denotes Euclidean distance between point q and p with the vector line $\left(\overline{qp}\right)$. In our case,

$$E(p,q)=\sqrt{(p_1-q_1)^2+(p_2-q_2)^2+(p_3-q_3)^2} \quad (2)$$

In actual computing, the sizes of voxel data spacing are in the form of P(x, y, z), or Q(x, y, z) that is to be defined. The recorded DICOM two dimensional ultrasound slices are 8 bit depth, with sample voxel spacing value equal to 0.195479. The re-sampled spacing can be calculated using equation below.

$$Spacing=\frac{S}{Ext-1} \quad (3)$$

Where *S* denotes the actual image size in mm scale, *Ext* denotes the number of pixels along *S* direction. With the assumption that the voxel extension for the restructured three dimensional ultrasound images are as V(1,1,3.58); the computing 3D distance can be calculated as follows.

$$L=E(p,q)\times\frac{0.195479}{3.58} \quad (4)$$

Where, *L* depicts the actual length (mm) for any two points in three

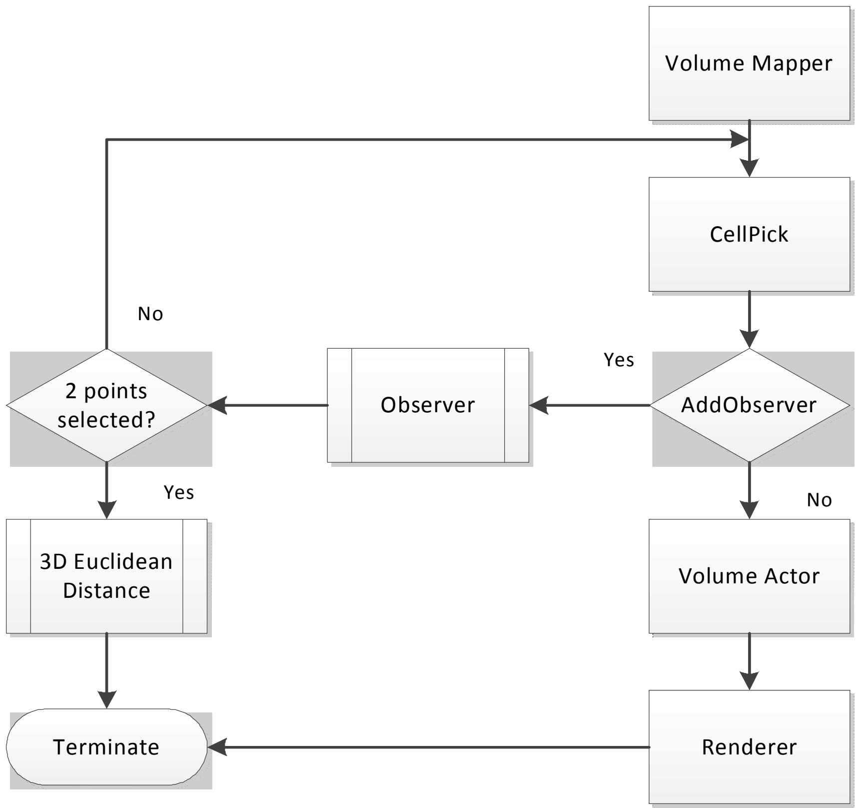


Figure 4. Ray casting flow chart incorporated with 3D measurement.

dimensional volumetric models. Figure 4 shows the computing process for the 3D Euclidean distance calculation.

For three dimensional Euclidean distance computation, using Equation 2, two worlds Cartesian coordinate are required to form vector line $(\overline{qp})$. The point picker in computer screen is only two dimensional coordinates which has no direct relation with the three dimensional objects, and therefore, conversion into world coordinates is necessary. The distinct difference between two dimensional coordinates and world coordinates is that the latter contains depth information, which reflects the depth of Z-coordinate spaces. As shown in Figure 4, computing Euclidean distance measurement is accomplished through CellPick widget. Observer will converts the CellPick data into geometrical and physical parameters in the rendering scene. The AddObserver acts as an external module to observe and reflect the real time data model status. Once CellPick updated its parameters, Observer will updates the data simultaneously through the interface connection established. The proposed system will send mouse and keyboard input messages to CellPick through command updating.

RESULTS AND DISCUSSION

Figure 5 shows part of the simulated three dimensional volumetric model using ultrasound fetal training phantom shown in Figure 3; the maximum number of two dimensional ultrasound slices is 255; within real time algorithm execution, the simulated model can be examined in any orientation.

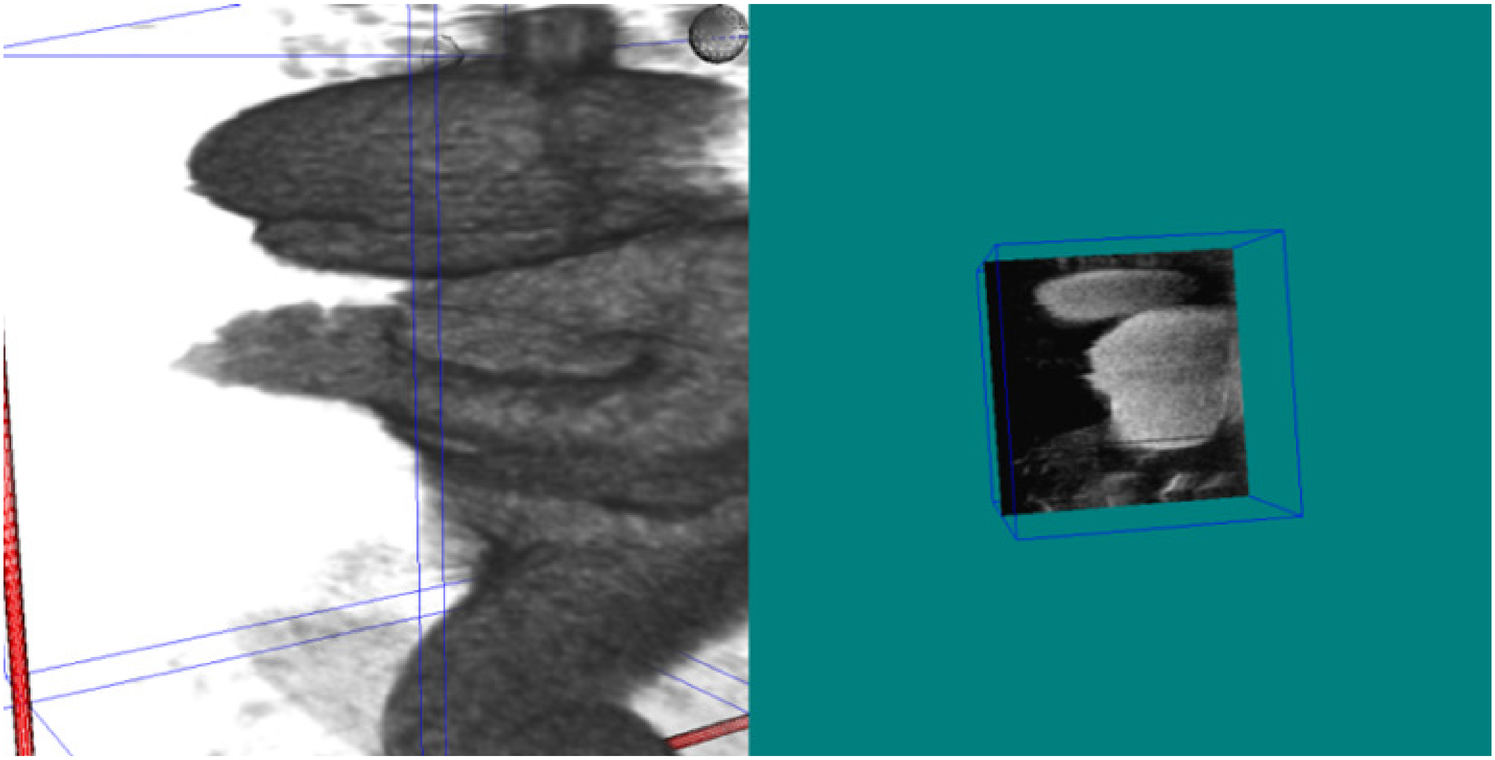
It can be observed that the skin or surface of restructured fetal phantom using raw ultrasound data consists of speckle noise, causing uneven ray casting in 3D rendering. Figure 6 shows the improved volumetric rendering after 3D anisotropic diffusion.

The improved volumetric rendering using 3D anisotropic diffusion has greatly enhanced the flat skin and provided more discrete surface edge; this is essentially important for the following three dimension distance measurement. Figures 7 and 8, shows the volumetric rendering using different luminance value in ray casting.

Figures 9 and 10, shows the execution of three dimensional Euclidean distance measurement; the resultant distance computation will only appear after two points were selected from the interactive window renderer.

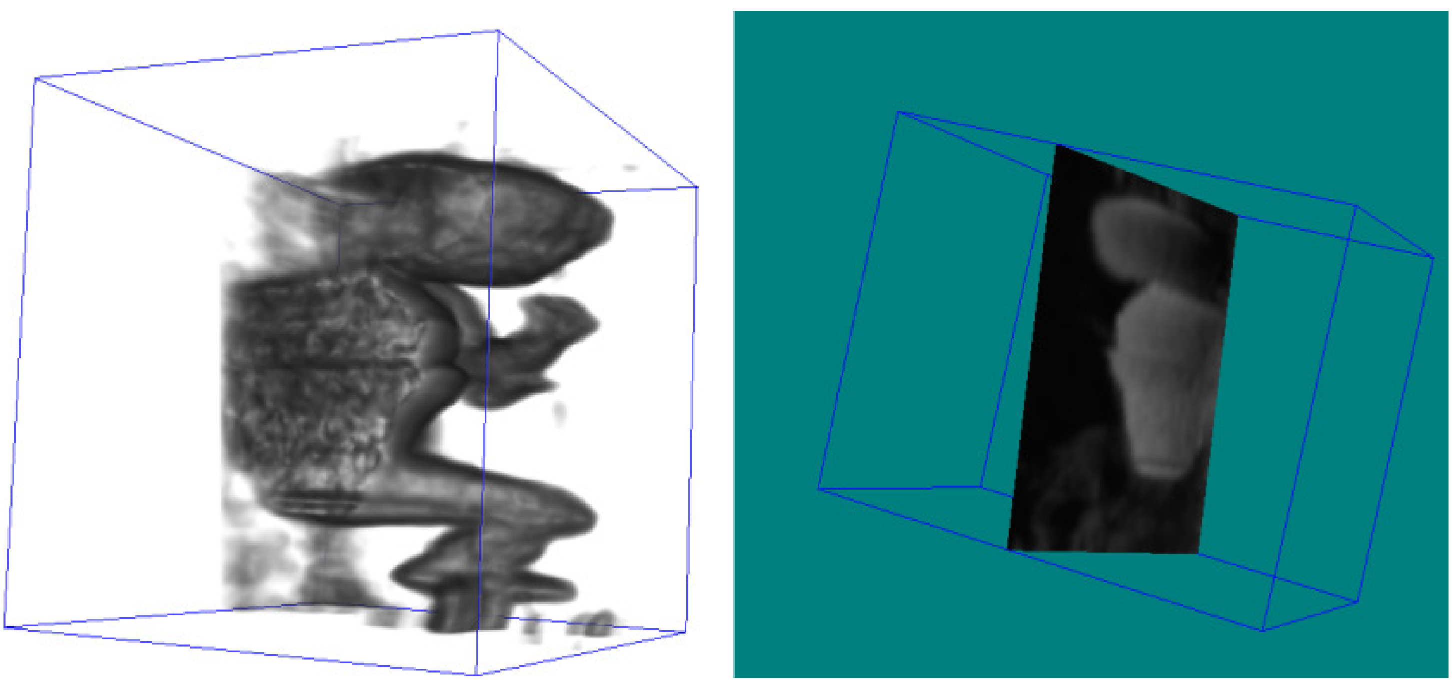
CONCLUSIONS

We have proposed an iterative computing for three dimensional ultrasound fetal reconstructions and its measurement. The selected two Cartesian points will be converted into 3 dimension spaces for Euclidean distance computation. Voxel spacing in mm scale for the re-sampled images must be defined in advanced before 3D



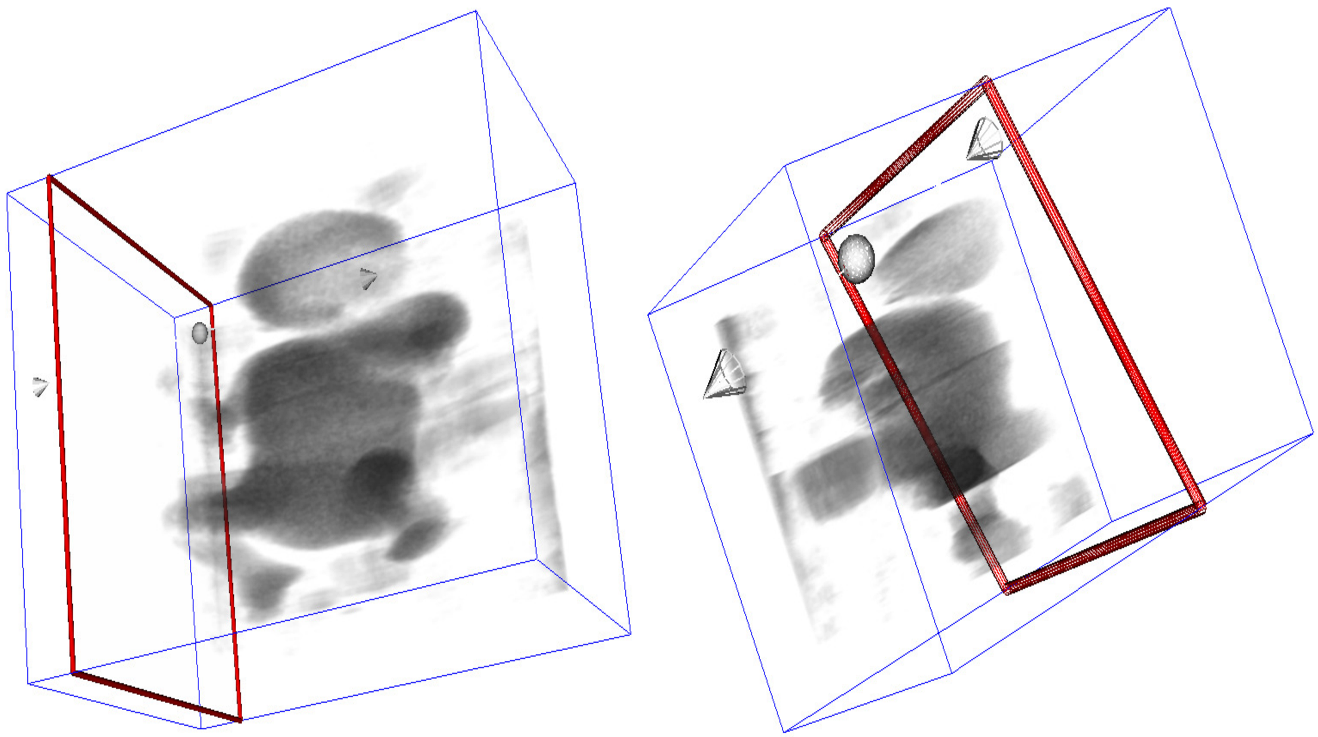
(a) (b)

Figure 5. Three dimensional fetal phantom reconstruction (a) volume rendering (b) sliced 2D view.



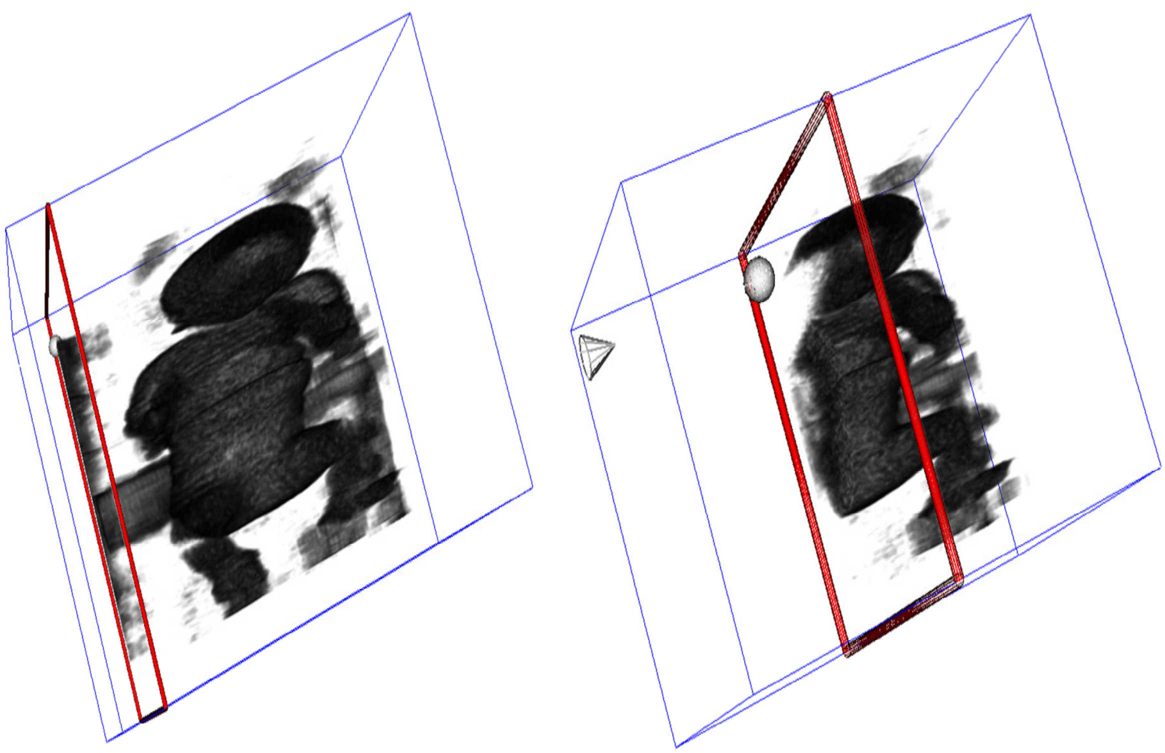
(a) (b)

Figure 6. Improved volumetric rendering using 3D anisotropic diffusion (a) diffused volume rendering (b) sliced 2D view.



(a) (b)

Figure 7. Low luminance in ray casting (a) full view (b) re-sliced view.



(a) (b)

Figure 8. High luminance value in ray casting (a) full 3D view (b) re-sliced view.

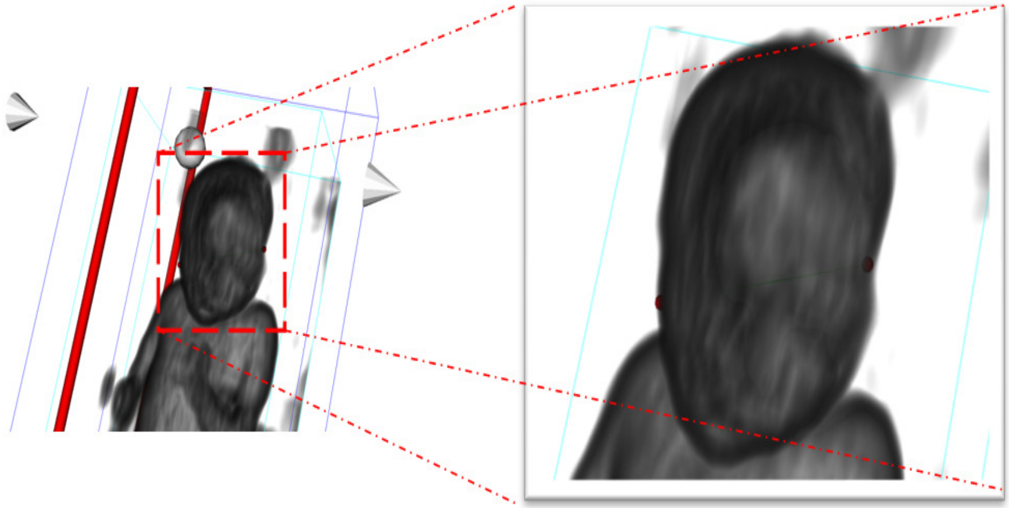


Figure 9. Simulated fetal phantom volumetric rendering with appropriate luminance.

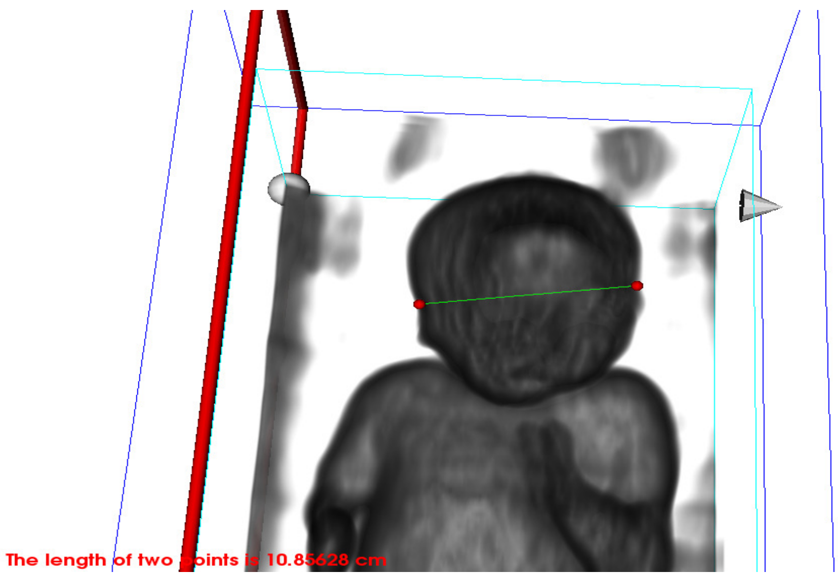


Figure 10. Three dimensional distance measurement.

computing measurement. Findings shows that proposed algorithms are able to provide consistent results.

ACKNOWLEDGEMENTS

Authors thank Prof Dr. -Ing Habil, Jens Haueisen and Dr Rer Nat Uwe Graichen for support and guidance throughout the project. Authors also thank DAAD (Deutscher Akademischer Austausch Dienst) for financial support to the student who conducted project at TU-Ilmenau, Germany. Authors also thank members of BMTI, Technische Universitat Ilmenau, Germany, for ideas and support to the project.

REFERENCES

Abuhamad A (2005). "Technical Aspects of Nuchal Translucency Measurement." Seminars in Perinatology 29(6): 376-379.

Celentano C, Di Donato NG, Prefumo F, Rotmensch S (2003). "Early resolution of increased nuchal translucency in a fetus with trisomy 18." Am. J. Obstet. Gynecol., 189(3): 880-881.

Cicero S, Longo D, Rembouskos G, Sacchini C, Nicolaides KH (2003). "Absent nasal bone at 11–14 weeks of gestation and chromosomal defects." Ultrasound Obstet. Gynecol., 22(1): 31-35.

Gobbi DG, Comeau RM, Peters TM (1999). Ultrasound Probe Tracking for Real-Time Ultrasound/MRI Overlay and Visualization of Brain

Shift. Proceedings of the Second International Conference on Medical Image Computing and Computer-Assisted Intervention, Springer-Verlag: 920-927.
Gobbi DG, Comeau RM, Peters TM (2000). Ultrasound/MRI Overlay with Image Warping for Neurosurgery. Proceedings of the Third International Conference on Medical Image Computing and Computer-Assisted Intervention, Springer-Verlag: 106-114.
Gobbi DG, Peters TM (2002). Interactive Intra-operative 3D Ultrasound Reconstruction and Visualization. Proceedings of the 5th International Conference on Medical Image Computing and Computer-Assisted Intervention-Part II, Springer-Verlag: 156-163.
Hulten M, Patel S, Westgren M, Papadogiannakis N, Jonsson A, Jonasson J,Iwarsson E (2010). "On the paternal origin of trisomy 21 Down syndrome." Molecular Cytogenetics 3(1): 4.
Hyett JA, Moscoso G, Nicolaides H (1995). "First-Trimester Nuchal Translucency and Cardiac Septal-Defects in Fetuses with Trisomy-21." Am. J. Obstet. Gynecol., 172(5): 1411-1413.
Lai Khin W, Arooj A, Supriyanto E (2010a). "Computerized Automatic Nasal Bone Detection based on Ultrasound Fetal Images Using Cross Correlation Techniques." WSEAS Transactions on Information Science and Applications, 1068-1077.
Lai Khin W, Supriyanto E (2010). "Automatic Detection of Fetal Nasal Bone In 2 Dimensional Ultrasound Image Using Map Matching." Proceedings of the 12th WSEAS International Conference on Automatic Control, Modelling & Simulation (ACMOS 2010): 305-309|455.
Lai Khin W, Too Yuen M, Arooj A, Supriyanto E (2010b). "Nuchal Translucency Marker Detection Based on Artificial Neural Network and Measurement via Bidirectional Iteration Forward Propagation." WSEAS Transactions on Information Science and Applications, 1025-1036.
Nicolaides KH, Azar G, Bryme D, Mansur C, Marks K (1992). "Fetal nuchal translucency: ultrasound screening for chromosomal defects in first trimester of pregnancy." BMJ., 304(6831): 867-869.
Nicolaides KH, Brizot ML, Snijders RJM (1994). "Fetal Nuchal Translucency - Ultrasound Screening for Fetal Trisomy in the First Trimester of Pregnancy." British J. Obstetrics Gynaecol., 101(9): 782-786.
Pandya PP, Altman DG, Brizot ML, Pettersen H, Nicolaides KH (1995). "Repeatability of measurement of fetal nuchal translucency thickness." Ultrasound Obstet. Gynecol., 5(5): 334-337.
Snijders RJ, Noble MP, Sebire N, Souka A, Nicolaides KH, FMFFTS Grp (1998). "UK multicentre project on assessment of risk of trisomy 21 by maternal age and fetal nuchal-translucency thickness at 10-14 weeks of gestation." Lancet, 352(9125): 343-346.
Souka AP Krampl E, Bakalis S, Heath V, Nicolaides KH (2001). "Outcome of pregnancy in chromosomally normal fetuses with increased nuchal translucency in the first trimester." Ultrasound Obstet. Gynecol., 18(1): 9-17.
Supriyanto E, Lai Khin W, Too Yuen M (2010). "Ultrasonic Marker Pattern Recognition and Measurement Using Artificial Neural Network." Proceedings of the 9th WSEAS International Conference on Signal Processing (SIP 2010): 35-40|120.
Tul N, Spencer K, Noble P, Chan C, Nicolaides K (1999). "Screening for trisomy 18 by fetal nuchal translucency and maternal serum free beta-hCG and PAPP-A at 10-14 weeks of gestation." Prenatal Diagnosis, 19(11): 1035-1042.
Wee LK, Chai HY, Supriyanto E (2011). "Surface rendering of three dimensional ultrasound images using VTK." J. Sci. Ind. Res., 70(6): 421-426.
Zosmer N, Souter VL, Chan CSY, Huggon IC, Nicolaides KH (1999). "Early diagnosis of major cardiac defects in chromosomally normal fetuses with increased nuchal translucency." BJOG: Int. J. Obstet. Gynaecol., 106(8): 829-833.