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Full Length Research Paper

Three dimensional nuchal translucency ultrasound segmentation using region growing for trisomy 21 early assessment

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Ultrasound prenatal screening has been proposed as a most effective technique for trisomy 21 early assessment. The current practice using B mode conventional ultrasonic images are restricted inter and intra observer variability. Therefore, we proposed three dimensional segmentation techniques for ultrasound marker, nuchal translucency (NT), as a replacement method to existing manual two dimensional NT thickness measurements. The developed generic computing algorithms are integrated with VTK and ITK open-sources libraries. Region growing was implemented with growth criteria and rendered by reconstructed multiplanar view. The findings have proven that the developed algorithm was able to produce consistent three dimensional NT segmentation.

Key words: VTK, ITK, ultrasound, region growing, segmentation, nuchal translucency.

INTRODUCTION

Trisomy 21 (British Down's syndrome) is a genetic condition in which there is extra copy of 21st chromosome resulting in abnormalities of fetus development. This deviate the development of normal physical body structure, functions, and often leads to mental retardation (Yu and Myoung, 2006; Snijders et al., 1998; Zosmer et al., 1999). Currently, the presence of Trisomy 21 can be detected manually by using three different methods, which are biochemistry blood tests, prenatal ultrasound screening and genetic confirmatory testing. The verified blood biochemistry markers for screening and diagnostic of trisomy 21 are the so called triple test of mother's blood, which includes PAPP-A (Pregnancy Associated Plasma Protein A), β-hCG (free beta human chorionic gonadotropin) and AFP (maternal alpha-fetoprotein). Based on previous researches, it has been recognized that the chromosomally abnormal pregnancy is associated with the abnormal level of biochemical markers. AFP is produced by fetus while PAPP-A and free ß-hCG are produced by placental trophoblast during pregnancy (Wee et al., 2010). In the first trimester, the PAPP-A level is, on average, low in Down's syndrome pregnancies (about half that of unaffected pregnancies). In the second trimester AFP levels is, on average, low (about three-quarters that of unaffected pregnancies) and free ß-hCG levels is, on average, high (about double that of unaffected pregnancies). Nevertheless, the drawbacks of these biochemistry tests are, very expensive, invasive and time consuming. Genetic testing is categorized into invasive method such as amniocentesis, chorionic villus sampling (CVS), or percutaneous umbilical cord blood sampling (PUBS). Only well trained or experienced O&G (Obstetrics and Gynaecology) specialists are permitted

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Abbreviations: PAPP-A, Pregnancy associated plasma protein A; **β-hCG,** free beta human chorionic gonadotropin; **AFP,** maternal alpha-fetoprotein; **NT,** nuchal translucency; **CVS,** chorionic villus sampling; **PUBS,** percutaneous umbilical cord blood; **VTK,** visualization toolkit; **ITK,** insight toolkit; **TCL,** tool command language; **GUI,** graphical user interface.

to execute the collection of biopsy through these invasive methods above. Due to its critical drawbacks in term of time usage, cost and potential miscarriage risk, it has always been considered as non-preferred technique during premature fetal screening and only been regarded for confirmatory testing at the last stage of clinical abnormalities screening (Wee et al., 2011; Wee and Supriyanto, 2010).

Ultrasound screening in first trimester of pregnancy provides the most effective way of trisomy 21 early screening. Particular assessment of ultrasound markers offer promising non-invasive method for fetal abnormalities detection, such as nuchal translucency, nasal bone, long bone biometry, maxillary length, cardiac echogenic focus and ductus venous (Hyett et al., 1995; Souka et al., 2001; Maj et al., 2010). Nowadays, measurement of NT thickness in the first trimester of pregnancy has been proposed as the most powerful marker in the early screening for trisomy 21, 18 and 13 (Nicholas et al., 1988; Abuhamad, 2006). However, the drawback of current ultrasound manual measurement technique is restricted with inter and intra-observer variability (Pandya et al., 1995).

Therefore, automation of three dimensional ultrasound markers segmentation and measurement are required to ensure the measurement in ultrasonic images can be less reliant on human operators. In this paper, we proposed the implementation of visualization toolkit (VTK) combining with insight toolkit (ITK) to segment three dimensional ultrasound markers. Generic computing of region growing technique was integrated with the multiplanar restructured ultrasound images. Throughout the functionality of VTK, the resultant three dimensional segmentation of NT can be visualized interactively within the rendering window.

The paper is organized as follows, we explained the features of ITK, and VTK mechanism and its implementation in C++ platform, and then we described the proposed three dimensional segmentation algorithms and its implementation in multiplanar ultrasound reconstruction. Finally, the performance of developed algorithms in three dimensional segmentation and conclusion was described.

MATERIALS AND METHODS

With the rapid build-up of medical informatics technology and development, the demand on various sophisticated medical equipment are increasing dramatically. Nevertheless, many developing countries such as Malaysia are heavily depending on imported medical equipment, needless to say, the costs are extremely high which in causing nonconductive treatment to the majority patients. This difficulty remains unsolved and limits patient category with only high income earners having easy access to benefits from high end medical technologies.

In recent years, many researchers worldwide are constantly working on an open-sources development platform for medical informatics, which includes powerful visualization toolkit, VTK and insight toolkit, ITK. They have been applied to medical image segmentation, three dimensional reconstructions, numerous medical image processing platform and filtering techniques.

Insight toolkit (ITK)

In 1989, the U.S. National Library of Medicine started conducting a visualization project on human internal imaging, they have developed a segmentation and registration package, as one of their project's tool, which became ITK later. Nowadays, ITK is an open source library which continues growing through maintains, exchange, and expands of users and developers worldwide.

It implements most of the segmentation and registration algorithms in either two dimensional or three dimensional images, and forms extensive class libraries which could reduce the duplication work done for developer worldwide. It is mainly used for image guided surgery, computer-aided diagnosis, surgery planning, radiation therapy and general medical care.

The object-oriented class library provided by ITK are written using ANSI C++ standard features, especially the module, which is based on the idea of paradigm programming. ITK also support the development of cross-platform environment for windows, UNIX, Linux and other platforms, it has been designed to encapsulate some common used algorithms for rapid and friendly developing. It is handled with pipeline mechanism designs, where various data types will be processed within appropriate class for data conversion and processing.

We can design and build our own processes using the pipeline mechanism, and thus different class of data processing, conversion or filters can be selected and connecting with the data channel. All of the classes and modules in ITK are scalable algorithms. Users can intercept their own class or module into the existing module, or replace, modify the existing class. Figure 1 shows the example ITK pipeline mechanism designs.

Although ITK was equipped with great image segmentation and registration features, it does not have visualization ability. Fortunately, this limitation can be countered by VTK, a specialization toolkit for visualization and rendering. The common characteristic between ITK and VTK is, they do not provide any user interface, and they are also not embedded as ready installation software. Without appropriate configure, compiling, and building using external tools such as Cmake, visual studio compiler or others, the library sources are not usable.

Visualization toolkit (VTK)

Visualization toolkit is also specially designed for use in pipeline mechanism; it can process almost all the structure type of data, and provides various type of data conversion or processing for a number of the corresponding classes. The most crucial issue in VTK image processing is about dealing with the structure of image data so that the correct method of processing can be chosen (Wee et al., 2011). VTK image data is classified into a number of categories. They are structural point, line grid, structured grid, unstructured points, polygon data and unstructured grids. And different filter will be allocated for each type of structure for processing.

Design and visual process can be built by user where different class of data conversion processing can be chosen and linked 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 visualisation result ultimately. In VTK, the characteristics of image data are separated as regular topology and geometry, where the data are arranged entirely by the origin,

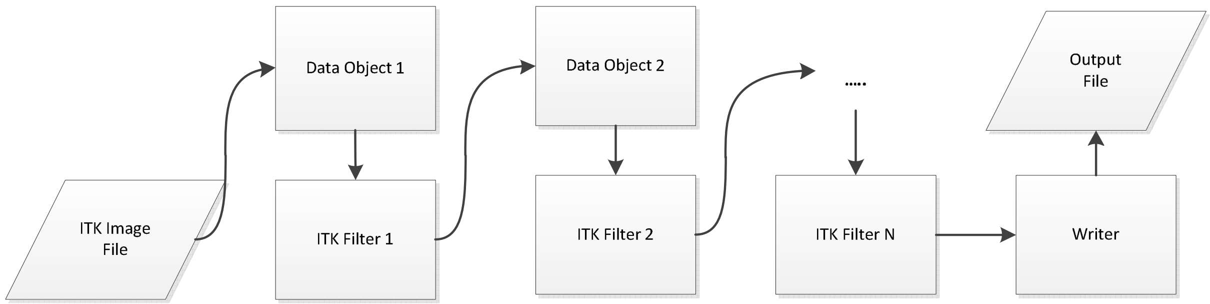

Figure 1. ITK data pipeline mechanism.

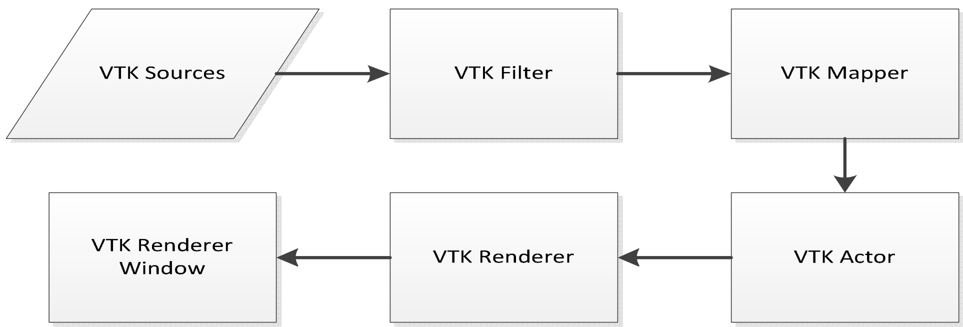

Figure 2. Data stream of VTK.

spacing, and dimensions parameters. Figure 2 shows the example of data stream in VTK processing channel.

It can be observed that, VTK source class object create a data source, then, VTK filter class or its derived class process the data source object. It follows by VTK mapper class or its derived classes mapped pixel data, and then the VTK actor class or a derived class represents a drawing entity. Finally, the image is rendered by the VTK renderer and displayed in VTK render window.

Interception ITK and VTK

In current studies, we proposed the integration of ITK and VTK in C++ programming language. It is a general programming language which is compatible with C language, support for data abstraction, object oriented and generic computing. The major features of this computation are including data encapsulation to reduce duplicative work, and systematic coding organization. It is more generalized in application such as server software, networking infrastructure, image processing, operating system, and other embedded devices which always require more stringent operating space.

Besides, for the implementation of VTK and ITK, there is another popular option for developer to build their own application, the TCL (Tool Command Language). It is another open-source dynamic scripted language, which is easy to configure, expand, testing, and having high flexibility to integrate with automation function. Normally, TCL is used together with toolkits as a higher level application development. The graphical user interface (GUI) tools provides more efficient and user friendly environment for user and developer to test, maintain, and expand their application over various compatible multi-platform scripting language, such as Windows, Mac, OS, Linux and other operating systems.

By comparing TCL or TK with C and C++ computing language, C++ having advantage including fast computing time, easier codes maintenance and less memory usage. Nonetheless, the disadvantage is the complicated debugging process, causing difficulty for any interception. Meanwhile, TCL and TK are easy to learn due to its simple nature computing, the testing or debugging process are simple and have good portability. However, by comparing to C++, it will consume larger memory footprint and slower computing time.

Figure 3 shows the interception of ITK and VTK using C++ language in current studies. By referring to Figures 1 and 2, we can observe that both toolkits are having dissimilar programming styles. To combine both of them and integrate in our application, ITK was utilized as data sources channel, and to perform three dimensional segmentation of ultrasound marker, as shown in Figure 3. The output of ITK will be transferred to VTK through image filter class, where the resultant three dimensional multiplanar-segmented will be visualized through interactive rendering window.

This designs shows the ideal utilization of both toolkit features, especially where ITK proving strong ability to read DICOM images, segment and registration, while VTK achieving great interactive visualization three dimensional rendering.

Segmentation of ultrasound marker

In three dimensional imaging systems, medical computed tomography will produce digital image data covered physical and internal body structures, such as human organ. In order to analyze the internal object interest in terms of their shape, form and its function, biological extraction from the restructured visualization is necessary. The process of these extractions is called medical

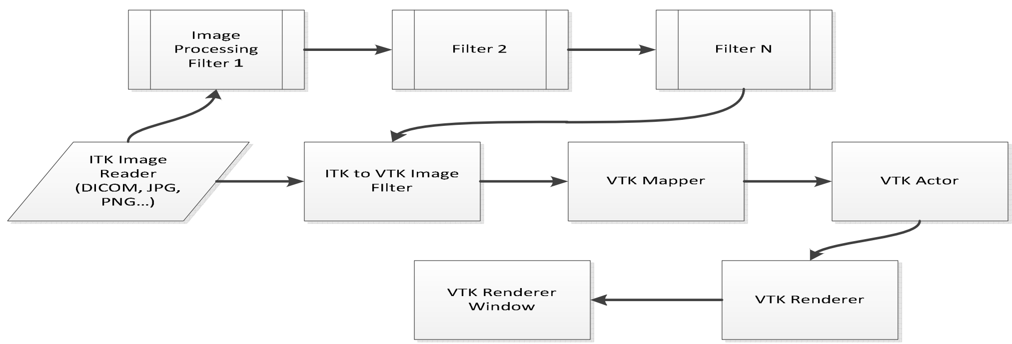

Figure 3. Algorithms realization of VTK and ITK data stream.

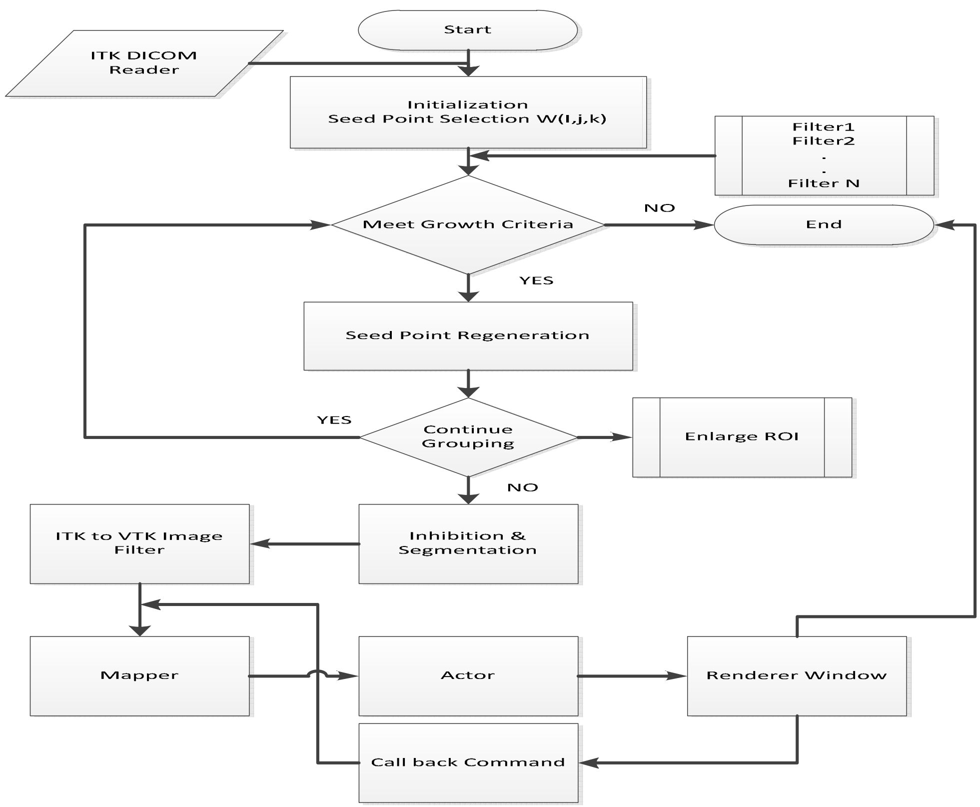

Figure 4. Flow chart of region growing algorithms.

image segmentation. Nowadays, medical image segmentation techniques are categorized into several methods, including but not limited to region growing, thresholding segmentation, watershed segmentation, fast marching, and level set segmentation.

The proposed technique in current ultrasound marker segmentation is region growing based on threshold boundary computation, where the fundamental of algorithm designs is a collection of similar pixels in nature together to form the interest regions. Figure 4 shows the algorithms process of region growing segmentation for ultrasound marker nuchal translucency.

The program starts with a seed point selection, it follows by interactive execution of grouping new seed pixels which meet the boundary selection. This continuous process will grow the size of initial seed point selection and forming the segmented region of interest, and it will only stop after no further pixel condition are met with the growth criteria. The growth criteria are determined by three key points, seed point selection, min and max computation, and growing threshold boundary factor. The overall algorithms processes are shown below.

Algorithm process

For each pixel, start from initial seed point P (*i, j, k*):

1. Define Seed Point Selection:

Seed (0) = *i*
Seed (1) = *j*
Seed (2) = *k*

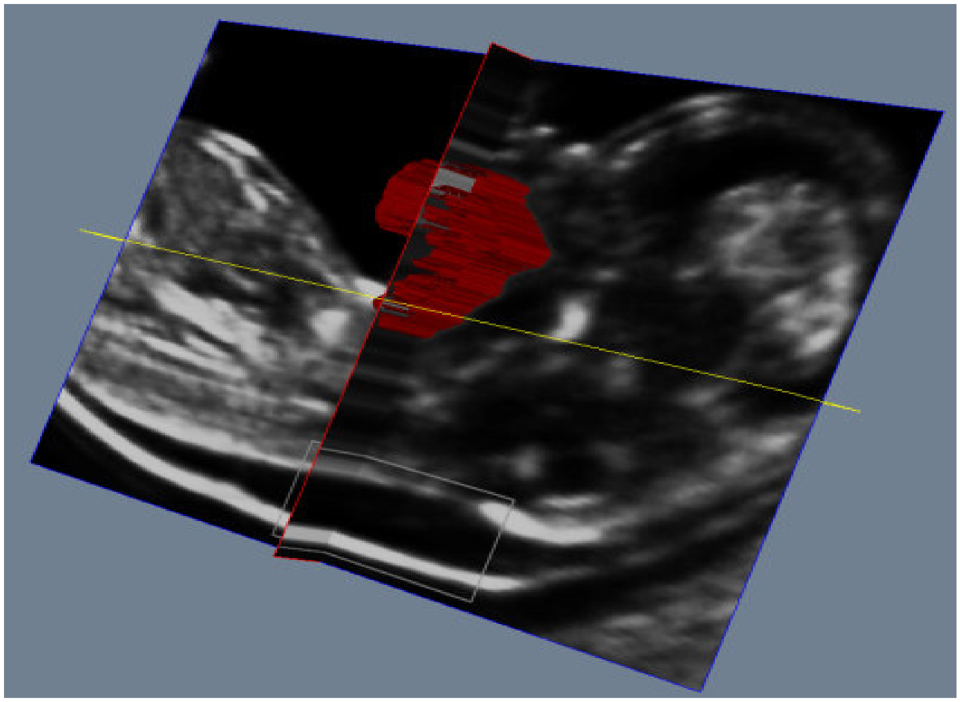

Figure 5. Simulation results of region growing segmentation on multiplanar reconstruction.

2. Image Min and Image Max Computation;
3. Growing threshold boundary factor:

$$I^{"}(i,j,k)=\begin{cases}1, & if \quad T_{\min} \le I(i,j,k) \le T_{\max} \\ 0, & else\end{cases}$$

Where, $T_{\min} = I_{\min} * \frac{Greyvalue \quad , P_{(i,j,k)}}{1 + Greyvalue \quad , P_{(i,j,k)}}$,

$$T_{\max} = I_{\max} * \frac{Greyvalue, P_{(i+n,j+n,k+n)}}{1 + Greyvalue, P_{(i+n,j+n,k+n)}}$$

4. Grouping, Enlarge ROI;
5. Transfer ITK to VTK image filter

RESULTS

Figure 5 shows part of the simulation results of multiplanar reconstruction for region growing segmentation. The cross-sectional images contain three different views, sagittal, coronal and orthogonal planes. Re-sliced Z image plane direction will be the orthogonal cross-section, X direction image plane will be the sagittal cross-section, and Y image plane direction will be coronal cross-section.

There are two ways to output the re-sliced volume data. The first method is extracting the volume data directly on the interest plane, where the data obtained is in VTK format. These kinds of data sources are not universal and it occupies large memory spaces. To overcome this limitation, the second option is to add VTK image reslice filter, to re-generate volume data and define the tangent plane. The data will be mapped by VTK volume ray cast class, and cut through add clipping plane class. The resulting slices can be saved in any ordinary image file.

Figure 6 shows the example simulation of ultrasound marker nuchal translucency using proposed algorithms. The resultant three dimensional rendering can be achieved and visualized in any orientation. The positions of cross-sectional plane are interactively controlled by user's mouse click. Figure 7 shows the close view of segmented NT marker, where the seed point selection is surrounded by fold thickness in B mode ultrasound images.

DISCUSSION

The seed point selection can be a single pixel, or it can be sub-pixel contained in a defined region. This seed point will be treated as initial representative point for growth criteria, which is determined by the measure between T_{max} and T_{min}. In fact, most of the growth criteria are based on evaluation of similarity degree within the seed point measurement. To stop the region growing, we can also replace our growing threshold boundary factor with others setting combination. The growth cessation by

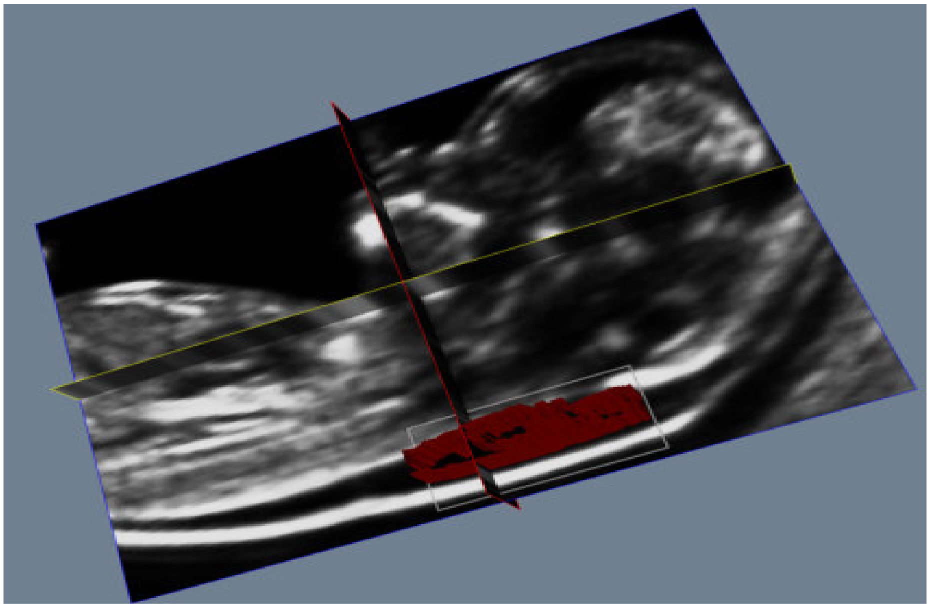

Figure 6. Nuchal translucency segmentation using region growing.

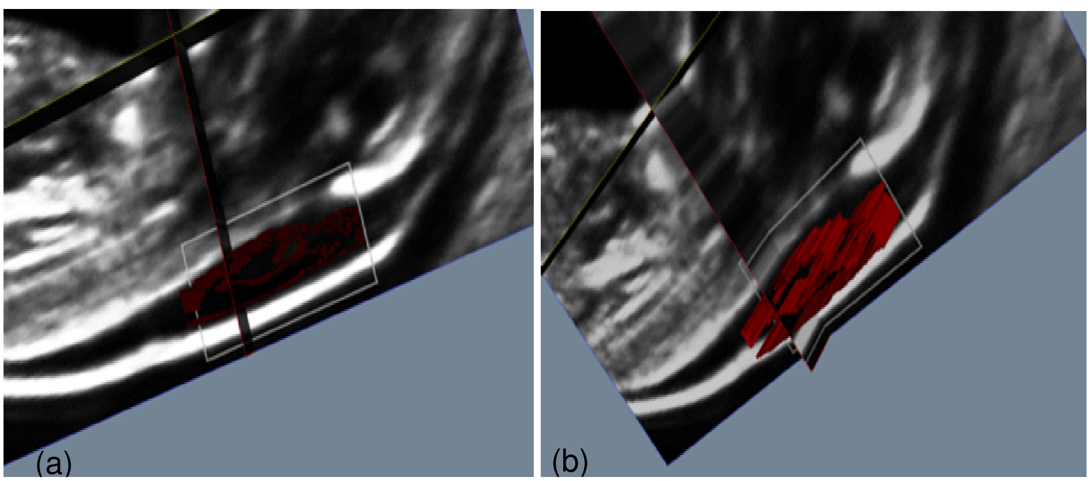

Figure 7. Interactive visualization of NT segmentation (a) front view (b) rotated view.

computed threshold boundary above can be changed, and it will influence the overall region growing performance.

Since the developed algorithms are object oriented program, we can simply replace the growth criteria to different methods without changing main program channel, for example, watershed segmentation. Watershed segmentation is a widely used mathematical morphology image segmentation method for medical image processing. It can locate the edge features in medical image accurately within simple and parallel processing. The drawback of this method is having high sensitivity of image noise causing deterioration of image gradient, which in turn create split shift of important image outline. For some noisy raw image sources, this method may prone to over-segmentation, producing large number of small areas segmentation due to its fine-grained detection.

Conclusions

Based on our findings, the proposed region growing algorithms integrated with VTK and ITK has proven an ideal protocol designs, in terms of each of their advancement in medical image processing. The desired ultrasound marker nuchal translucency can be segmented easily, and the results are promising with consistent performances.

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