
An open-source GUI application for segment foetal ultrasound images

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Abstract: There are several commercial software for medical image dataset segmentation. However, most of them are expensive and not user-friendly. With our proposal of a new open-source software with a simple and specific graphical user interface (GUI), it is easy to segment a foetus from a 3D ultrasound medical image dataset. The segmented portion of images can be converted into a stereolithography (STL) file format for 3D print technologies in order to obtain an accurate physical reproduction of the model segmented. Despite the large number of segmentation algorithms available, this new GUI has three specific possibilities (threshold, region growing and Chan-Vese) in order to keep it simple and efficient. For the same reason, the GUI has just three noise filters available in order to reduce speckle. Besides GUI simplicity, a good segmentation quality was achieved. The main purpose of our proposal is to segment foetal 3D ultrasound images and to make this task quick, easy and efficient.

Keywords: 3D ultrasound images; GUI; level set; ultrasound image segmentation.

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1 Introduction

Ultrasound imaging is considered one of the most powerful techniques for medical diagnosis and is often preferred over other medical imaging modalities because of its non-invasive, portable, versatile and low-cost properties (Abd-Elmoniem et al., 2002). It is important to segment out cavities, different type of tissues and organs in the ultrasound image for effective and correct diagnosis. A fundamental problem in the field of ultrasound imaging is the speckle noise influence, which is a major limitation on image quality in ultrasound imaging. Imaging speckle is a phenomenon that occurs when a coherent source and a non-coherent detector are used to examine a medium, which is rough on the scale of the wavelength. The presence of speckle noise affects the human interpretation of the images as well as the accuracy of computer-assisted diagnostic techniques (Kim and Park, 2001).

Ultrasound is a sound wave with a frequency that exceeds 20 kHz. It transports energy and propagates through several means as a pulsating pressure wave (Suetens, 2009). It is described by a number of wave parameters such as pressure, density, propagation direction and particle displacement. The interaction of ultrasound waves with tissue is subject to the laws of geometrical optics. It includes reflection, refraction, scattering, diffraction, interference and absorption (Kyriacou et al., 2010; Jhang, 2009). Except from interference, all other interactions reduce the intensity of the ultrasound beam.

A 3D ultrasound system was first developed by Baba et al. (1989). A 3D probe and an ultrasound scanner, that displayed three orthogonal planes on a screen, were

developed and became commercially available in 1989 (Baba, 1992; Kuo et al., 1992). Three-dimensional data are usually acquired as large number of consecutive tomographic images through movements of ultrasound transducer array. A number of tomographic images obtained through 3D scanning must be constructed three-dimensionally into a 3D data set for further computer processing. This construction process involves interpolation and improvements of data quality by filtering (Guthart et al., 2015).

Several authors have been studying techniques of segmentation of ultrasound images. Furthermore, general methods for ultrasound image segmentation do not exist, and the segmentation strategies are application dependent. The automatic segmentation methods previously developed in the foetal imaging field focused on using segmentation as an intermediate processing step for estimating standard biometric measurements. Most of the methods attempted to segment the femur, head foetal or both. The methods were based on morphological operators, active contour models, Hough transform, deformable models or machine learning approaches (Noble and Boukerroui, 2006; Thomas et al., 1991; Shrimali et al., 2009; Hanna and Youssef, 1997; Pathak et al., 1997; Jardim and Figueiredo, 2003; Shan and Madheswaran, 2009).

This application was implemented using Python programming language. The libraries used to develop this software tool were Visualization Toolkit from Kitware, Scipy and Numpy. Figure 1 shows the interface software tool. Figure 2 shows the ultrasound systems operation and process of images reconstruction in ultrasound device.

Figure 1 Software interface (see online version for colours)

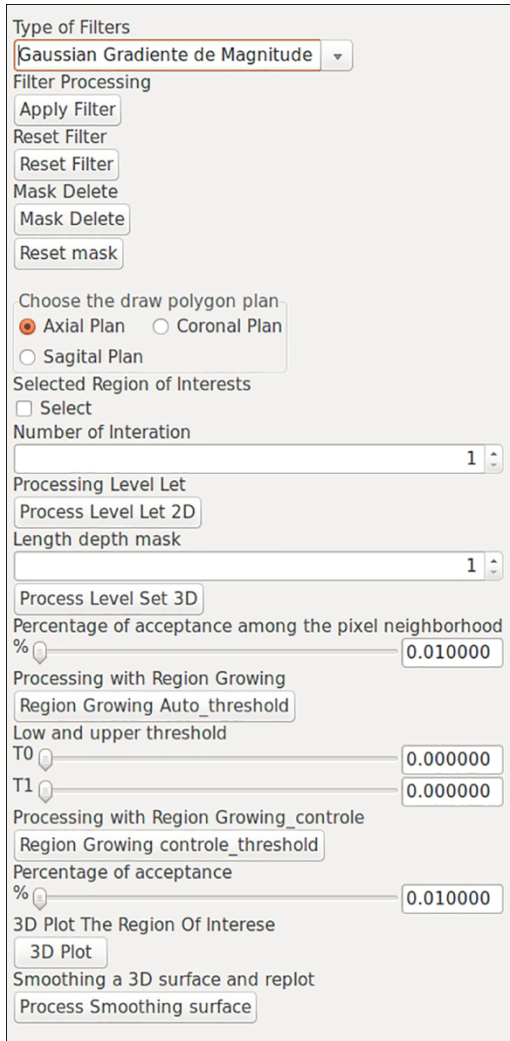
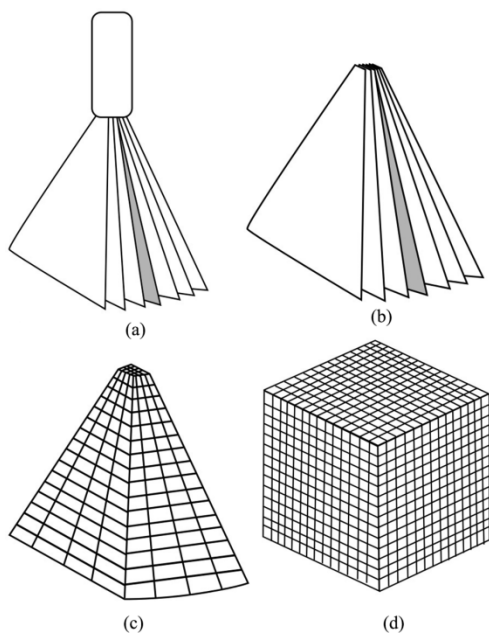


Figure 2 Acquisition process and reconstruction ultrasound image matrix. (a) 3D scanning by a 3D probe. (b) 2D images. (c) 3D data set. (d) Voxel volume



2 Methodology

The purpose of our work is to segment 3D ultrasound images and to create a 3D models of a foetus, in order to be printed using 3D printing technologies, also known as additive manufacturing. Our developed software follows the diagram of Figure 3. In input section, all the ultrasound images must be in digital imaging and communications in medicine (DICOM) format to be imported in our software.

Figure 3 Software diagram



2.1 Pre-processing

Nowadays, the ultrasound system is widely used as a diagnosis tool. However, one of its weaknesses is the poor quality of images due to the presence of speckle noise, which, besides affect the image contrast may in certain cases add spurious details and useless information for diagnosis and segmentation, resulting in errors for medical diagnosis (Stippel et al., 2005; Shrimali et al., 2008). Noise is a random signal that incorporates into the image during acquisition process, which becomes undesirable information that reduce image contrast, deteriorating form, size and contours of structures, even losing of details of perception (Arêdes, 2009). The speckle noise is a characteristic phenomenon in image that use coherent sources, such as optical and acoustic systems, as well ultrasound images, thus associated with any image acquisition technique. The speckle noise is a result of the interference between coherent waves (constant phase) generated by scattering of natural surface, which come out to make sensor or reflective structures having dimensions that go beyond the capacity of the acquisition system (Annadurai and Shanmugalakshmi, 2007; Coupé et al., 2009). To reduce this type of noise, several types of filters are used, such as:

- median filter
- bilateral filter
- Gaussian filter.

Median filter (Baxes, 1994; Loupas et al., 1989; Weiss, 2006; Bhadauria and Dewal, 2013) is widely used in order to smooth the noise speckles. This filter works as following: a kernel with dimension $n \times m$ is used to convolute, pixel by pixel, with the image to be filtered. Each pixel is replaced by the median value of their neighbourhood.

Bilateral filter (Tomasi and Manduchi, 1998; Weiss, 2006) is a non-linear filter image smoothing in spatial domain and also in colour domain. The intensity of pixel is replaced by a weighted average of neighbourhood pixels, with weights depending on difference in space and intensities between the central pixel and its neighbourhood. The pixel which are very different from the intensity of the centre, have lower weight, although they are physically close to centre of smoothing kernel, allowing to eliminate slight variations between pixel caused by noise.

The Gaussian filter is also widely used for smoothing images, i.e. with difference, they do not preserve the edges, since it does not consider the difference of pixel intensities. It takes two parameters, the size of kernel and a maximum standard deviation value (σ). Its behaviour is similar to low-pass filter, i.e. smooth images. The amount of the image that is smoothed is related to the standard deviation (σ), i.e. the larger σ , more the image is smoothed. They do not depend a lot on the size of kernel parameter. The larger the σ value, the greater the number of pixel whose value is not zero, which leads to the neighbourhood pixels to have greatest influence on each point by performing a large smoothing into the image (Tomasi and Manduchi, 1998; Coupé et al., 2009; Loizou et al., 2005).

During the pre-processing, the user can apply various filters (median, bilateral, Gaussian, etc.) to be able to improve the visualisation of the regions of interest.

2.2 Segmentation

Image segmentation is the process of separating a digital image into multiple segments. The goal of segmentation is to simplify or change the representation of an image into something that is more meaningful and easier to analyse (Barghout and Lee, 2003). Image segmentation is typically used to locate objects and boundaries in images. More precisely, image segmentation is the process of assigning a label to every pixel in an image such that pixels with the same label share certain characteristics (Barghout and Lee, 2003; Raut et al., 2009). Segmenting the region of interest in ultrasound image is not an easy task, due to the high level of noise and poor image contrast. So, in the proposed software, it is possible to apply three different segmentation algorithms in order to segment the foetus:

- thresholding algorithm
- region growing algorithm
- Chan-Vese algorithm.

Thresholding algorithm, in this method, the voxels selected are within a specific range. Our thresholding algorithm used two limits. A lower (T_1) and another upper (T_2). These values are entered by the user.

Region growing is a method of image segmentation based on pixel classification that is inside a determined range. This approach examines the neighbourhood pixels of initial seed points and determines whether the pixel neighbours should be added to the region or not (Kamdi and Krishna, 2012). Our software has implemented two types of region growing:

- Automatic threshold, the region expands if the difference between the actual voxel and its neighbours is above a given percentage.
- The region growing with control threshold (Kamdi and Krishna, 2012), it expands if the voxel is between a given lower and an upper value.

The Chan-Vese algorithm is an example of a geometric active contour model (He and Osher, 2007; Alvarez et al., 2012). Such models begin with a contour in the image plane defining an initial segmentation, and then it evolves its contour according to some evolution equation. The goal is to evolve the contour in such a way that it stops on the boundaries of the foreground region. There are various ways to define the evolution equation, but in this project, the Chan-Vese algorithm evolves this contour via a level set method (He and Osher, 2007; Alvarez et al., 2012).

2.3 Post-processing

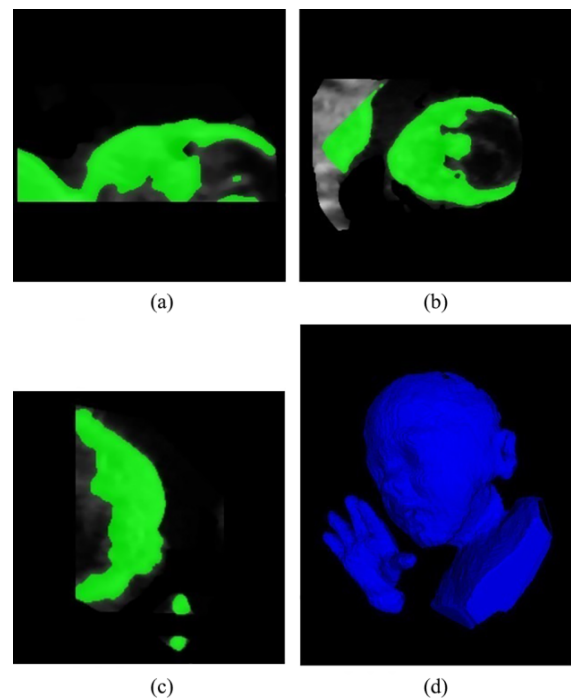
The result of segmentation algorithm is a mask indicating the selected object. It uses the marching cubes algorithm to generate mesh (Lorensen and Cline, 1987; Lorensen, 1995). After meshing, it uses also a decimation algorithm to reduce the number of triangles without losing the quality of mesh (Schroeder, 1997; Schroeder et al., 1992). In the end, model can be saved in STL file format to use in other applications.

3 Results and discussion

To analyse the software performance, three DICOM images of a foetal ultrasound have been used, with different periods of gestation. These images are showed in Figures 4 (34 weeks), 5 (28 weeks) and 7 (13 weeks). These images were performed using a GE ultrasound device. Figure 1 shows the interface software, with all of component operations.

Figure 4 shows the result achieved using Chan-Vese algorithm for segmentation of region of interest.

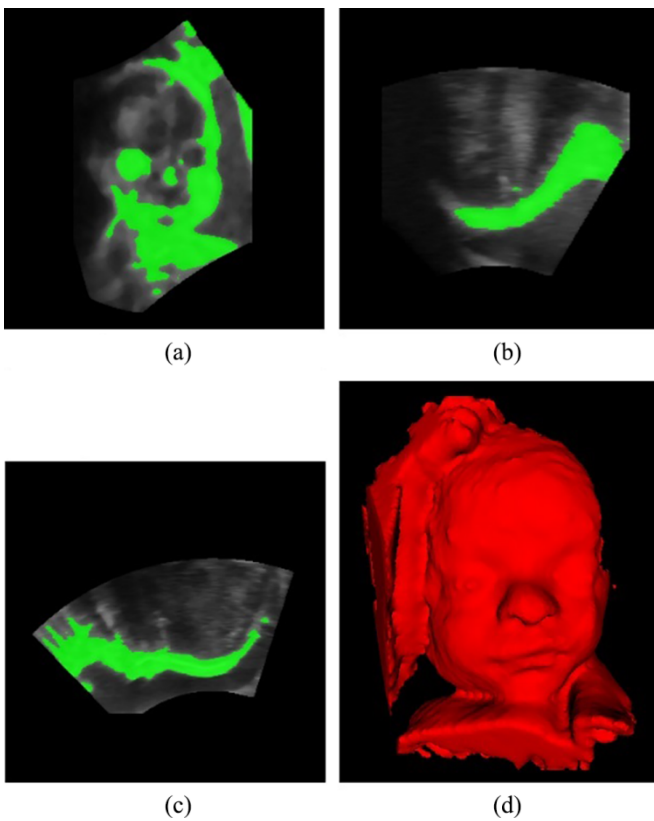
Figure 4 Median filter and segmentation by Chan-Vese. (a) Axial view. (b) Coronal view. (c) Sagittal view. (d) 3D model (see online version for colours)



As it can be observed in Figure 4, the 3D model of foetus was obtained using median filter, then it applied the Chan-Vese algorithm for segmentation and we managed to obtain good results. The algorithm can grasp well close to the contour delimiting the foetus. It can be clearly see the definition of fingers, mouth and ears of the foetus.

Figure 5 shows the result achieved using region growing with thresholding control algorithm in order to segment the region of interest.

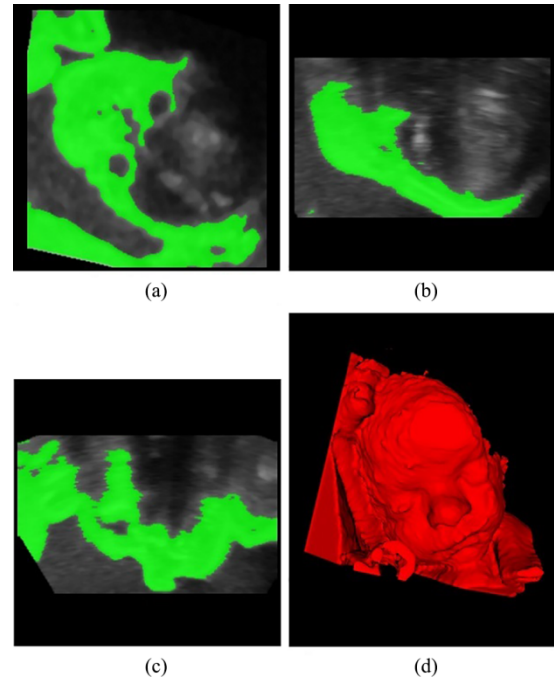
Figure 5 Median filter and segmentation by region growing with threshold control and applied mesh smooth. (a) Axial view. (b) Coronal view. (c) Sagittal view. (d) 3D model (see online version for colours)



As it can be observed in Figure 5, the 3D model of foetus was obtained using the median filter, and then applied to region growing algorithm with controlled thresholding. Then, it is refined the original surface mesh of foetus to export in STL file format. It was possible to keep the anatomical characteristics of foetus. Also, it is observed that algorithm cannot distinguish well the regions in contact with the mother's abdomen. It can be clearly see the definition of mouth, nose and eye. However, in the eyes region, there is always a loss of details using this algorithm.

Figures 5 and 6 used the same DICOM file. Figure 6 shows the result achieved using region growing with thresholding algorithm for segmentation of region of interest.

Figure 6 Median filter and segmentation by region growing with auto-threshold and applied mesh smooth. (a) Axial view. (b) Coronal view. (c) Sagittal view. (d) 3D model (see online version for colours)



As it can be observed in Figure 6, the 3D model of foetus was obtained using the median filter. Then, it applied the region growing algorithm with thresholding and 0.1% of acceptance among the neighbour pixels and then it refined the original surface mesh of foetus before export into STL format. It was possible to keep the anatomical characteristics of foetus. It is observed also that the algorithm cannot distinguish well the regions in contact with mother's abdomen. There is a lot of noise which is not eliminated in this 3D model.

Figure 7 shows the result achieved using the level set algorithm for segmentation of a foetus with 4 months of pregnancy.

As it can be observed in Figure 7, the 3D model of foetus was obtained using the bilateral filter. Then, it applied the Chan-Vese algorithm. It was possible to observe that segmentation depends strongly on the age of foetus. It means losing many anatomical details. Therefore, the algorithm does not distinguish the eyes, mouth and ears. This fact is associated with the bag containing the amniotic fluid surrounding the embryo is not yet suffering higher pressures due to the smaller size of embryo.

Figure 8 shows the result achieved from 3D model printing through the Selective Laser Sintering (SLS) additive manufacturing technique. To manufacture the segmented foetus, a Sinterstation HiQ SLS System from 3D systems was used. As it can be seen in Figure 8, 3D model, we managed to keep the anatomical characteristics of segmented foetus.

Figure 7 Bilateral filter and segmentation by Chan-Vese. (a) Axial view. (b) Coronal view. (c) Sagittal view. (d) 3D model (see online version for colours)

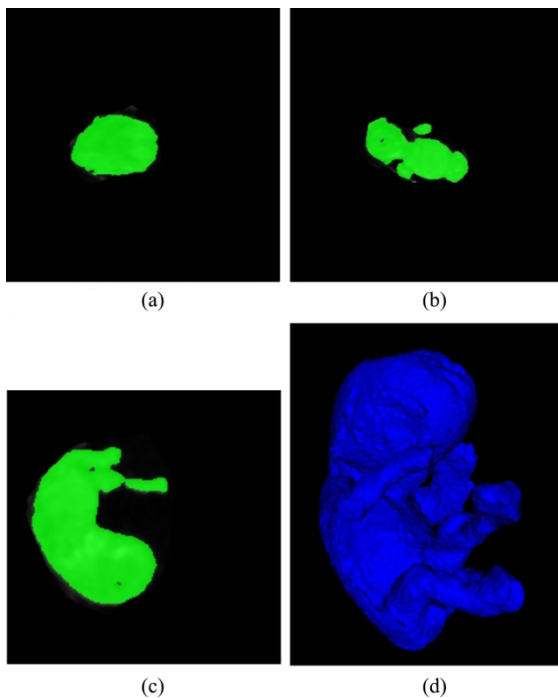


Figure 8 3D printed model (see online version for colours)



4 Conclusion

In this paper, we presented an interface application with intuitive methodology for segment ultrasound image to generate a 3D model for 3D printing.

Our application provides a simple and user-friendly interface. The outcomes achieved were satisfactory. Regarding all methods for segmenting ultrasound images, presented in literature, none of them are able to segment perfectly the ultrasound images, since those images are very noisy. In the case of foetus segmentation, they could not clearly distinguish the abdomen tissue of mother from

foetus tissue. It happens when the tissue foetus are very close to mother's abdomen walls.

In our application, we could achieve good results due to the possibility that this application enables making multiple image pre-processing before performing a final segmentation for generating the 3D model to be manufactured by a 3D printing technique.

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