

An automatic segmentation and reconstruction of mandibular structures from CT-data

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Abstract. In any medical data analysis a good visualization of specific parts or tissues are fundamental in order to perform accurate diagnosis and treatments. For a better understanding of the data, a segmentation process of the images to isolate the area or region of interest is important to be applied beforehand any visualization step. In this paper we present a method for mandibular structure surface extraction and reconstruction from CT-data images. We tested several methods and algorithms in order to find a fast and feasible approach that could be applicable in clinical procedures, providing practical and efficient tools for mandibular structures analysis.

Key words: Image Segmentation, Surface Reconstruction, CT-Data.

1 Introduction

In any medical data analysis a good visualization of specific parts or tissues are fundamental in order to perform accurate diagnosis and treatments. For a better understanding of the data, a segmentation process of the images to isolate the area or region of interest is important to be applied beforehand any visualization step. In this paper we present a method for mandibular structure surface extraction and reconstruction from CT-data images. We tested several methods and algorithms in order to find a fast and feasible approach that could be applicable in clinical procedures, providing practical and efficient tools for mandibular structures analysis. Some authors propose manual segmentation [2], histogram equalization [4, 5] or deformable models [6]. Those processes can be cumbersome and time consuming due to continuous manual intervention. In this paper we present a procedure to extract the contour of the main mandibular structures (lower or upper jawbone) from CT images. In order to provide a practical and efficient solution to the clinicians, we propose an automatic and fast segmentation method for surface extraction and reconstruction. Proposed method is implemented by using open source image processing libraries such as ITK (Insight ToolKit)[11] and VTK (Visualization Toolkit)[12]. The paper is structured as

follows. Section 2 gives a description and overview of the proposed method and some implementation details. Section 3 presents some obtained segmentation and reconstruction results. Finally, section 4 presents some overall conclusions and future work.

2 Methods

In order to obtain a fast and automatic method for mandibular structure segmentation and reconstruction, we propose an image processing pipeline based on three different steps:

- Image Pre-Processing.
- Image Segmentation.
- Surface Smoothing. All these steps are carried Following

2.1 Image Pre-processing

Our method is based on automatic multiple thresholding followed by a region-growing algorithm to extract the object of interest. During pre-processing, we apply an automatic thresholding in order to normalize the background noise into a single intensity value, see Figure 1. Depending on the nature of scanner device, the amount of noise can be very severe. For example, it is well known that Cone-beam CT scanners generates more noise, i.e, noisier images, than helicoidal CT scanners, mainly due to a lower signal to noise ratio [10]. A further step consists in resampling the dataset to speed up the automatic segmentation. In order to preserve the quality of low resolution images, we define a heuristic rule to resample the image depending on the original size of the image volume. The reduction in x and y space directions corresponds in each case to half the image dimension. For the z space direction we used an heuristic for resampling the image volume that depends on the resolution of the original image volume. When the image contains less of 50 slices, no resampling is performed. Otherwise, the downsampling factor is equal to 2 for 50 to 149 slices, 3 for 150 to 249 slices, and 4 for more than 250 slices.

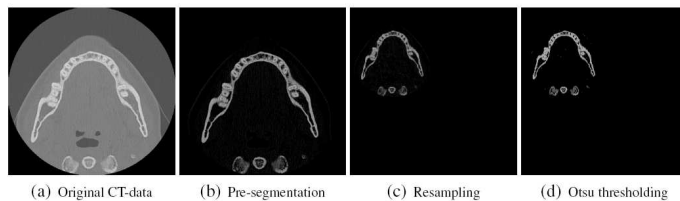


Fig. 1. Image Pipeline for Image Pre-processing and segmentation

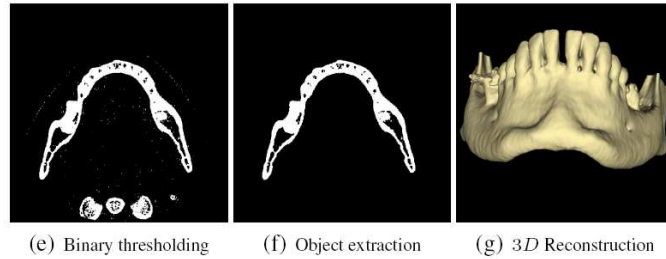


Fig. 2. Surface selection and Reconstruction

2.2 Image Segmentation

Once the image has been resampled, the multiple threshold method by Otsu [1] is applied to compute appropriate threshold values for segmentation process. Otsu method aims at selecting the thresholds by maximizing the between-class variance and minimizing the inter-class variance. Best results was achieved by using three threshold classes, one of them representing the mandibular structure. At the end of the segmentation pipeline we segment the objects with a binary threshold filter, using the values computed by the Otsu algorithm, resulting in a binary image mask. For the extraction process of the object of interest, we propose to use a region growing method [8]. The brightest point in the image is taken as the seed point of the region growing algorithm. The resulting object is defined as a single connected component containing the brightest points, see Figure 2. As seen in Figure 1 after thresholding and region growing were applied, more than mandibular structures can be generated, such as crowns of the other jawbone or parts of the spine. Therefore, a posterior step where the structure of interest is extracted must be accomplished. We simply select the largest connected component of the segmented image volume.

2.3 Surface Smoothing

In this section we present some experimental tests and results in order to find a fast and efficient way to smooth surfaces extracted from segmented images obtained with previously proposed method. Because of the internal structure of the data(image noise) and also because of the segmentation process itself, generated surfaces may presents some non desirable artifacts or surface noise. Therefore, a surface refinement or surface smoothing is desirable for a better reconstruction visualization. This enhancement step of the surface can be accomplished with two different approaches. One possibility is to modify the original image data before surface extraction is carried out, by applying filters directly on the images (Image Oriented Filters). Another approach is the use of some filters that acts directly on the noisy extracted surfaces (Mesh Oriented Filters). The main difficulty when dealing with signals extraction and signal filtering is to prevent the loss of important information. This is specially critical in medical

image processing. The aim of the filters we are searching for is to come closer to the real surface and reduce the artifacts generated by the segmentation and not only to have a nice looking result. We have defined the efficiency of a smooth or refinement filter as dependant on tree parameters:

- The time used by the filter.
- The resulting global aspect of the mesh.
- The precision of the filter.

The first parameter parameter can be evaluated by measuring the execution time needed by filter to process an specified data-set. The global aspect of the resulting generated surface can be estimated visually by showing the results to the experts and collecting their comments and opinions. In order to estimate the precision of the applied filter, we rendered several contours of the smoothed surface together with the corresponding contours of the original surface. We consider a smoothing

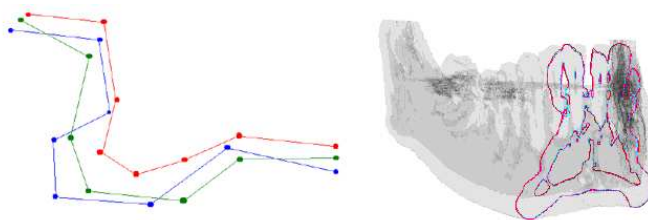


Fig. 3. Blue:Original Surface,Green:Precise surface, Red :Unprecise surface (Left). Iso-lines and a blended mandible model(Right).

filter becomes better and more precise when the average distance between the original reconstructed surface and the smoothed reconstructed surface decrease. To be precise, the filter should generate an "inside/out" surface from the original surface, see Figure 3.

Image Oriented Filters This type of filters are very common in Medical applications. In this type of approach the value of some image pixels are modified from the original value using the values of a certain quantity of their neighbours. We have tested the following filters implemented in ITK and VTK:

- `vtkImageGaussianSmooth` Filter.
- `itkBinomialBlurImage` Filter.

`vtkImageGaussianSmooth` implements a convolution of the input image with a Gaussian. This filter supports from one to three dimensional convolutions. The idea of Gaussian smoothing is to use this 1D distribution as a "point-spread" function, and this is achieved by convolution in the three directions of the space or volume. Since the image is stored as a collection of discrete pixels one need to

produce a discrete approximation to the Gaussian function before one can perform the convolution. The `vtkImageGaussianSmooth` internally computes the discrete Gaussian kernel. The only parameters that need to be set are the deviation value of the Gaussian filter, and radius factor which determines how far out the Gaussian kernel will go before being clamped to zero. At the beginning of execution, the kernel is filled in and normalized with the discrete value corresponding to the Gaussian function. Then the Convolution is applied to the image using the kernel in the three directions of the space. This filter gives a fast and



Fig. 4. Smoothed surfaces with different values of deviation parameter.

correct smoothed result. The filter does not respect the boundaries. Two closer surfaces can be linked or joined and the boundary might not be well preserved, as shown in Figure 4. The teeth seem to be joined and the space between them has almost been filled in. This issue can generate a loss of detail or resolution in the final surface. The approach followed by the `itkBinomialBlurImage` Filter is to compute a nearest neighbour average along each dimension of the space or volume. The process is repeated a determined number of iterations specified by the user. With a large number of iterations, the result of this filter will converge to the result obtained by the Gaussian filter presented previously, but execution time is much higher.

Mesh Oriented Filters In opposite to Image Oriented filters, these type of approaches work directly with a previously generated mesh or surface. These kind of filters are directly applied to the points (vertexes) of the 3D surface. The algorithms modify the position of some vertexes to obtain a smoother surface [9]. We have tested two implementation of this type of filters: `vtkWindowedSincPolyDataFiler` and `vtkWindowedSincPolyData`. `vtkWindowedSincPolyDataFiler` adjusts point coordinates using a windowed function interpolation kernel, relaxing the mesh, and therefore making the cells better shaped and the vertices more evenly distributed. The main parameter to be set is the number of iterations (or degree of the polynomial approximating of the windowed function). Through this parameter we can obtain different levels of smoothing, see Figure5. The filter is really powerful for smoothing the surface, but slightly modifies the geometry by globally scaling it. This can be non desirable in some context such as implant planning simulation, where precise size and anatomy coherence are mandatory.

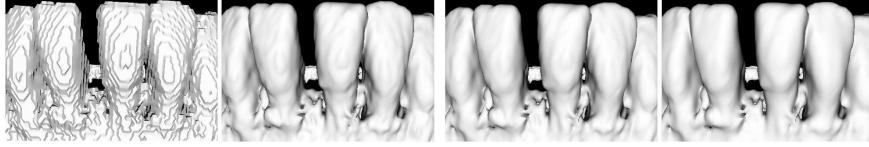


Fig. 5. Different iterations of `vtkWindowedSincPolyData` filter.

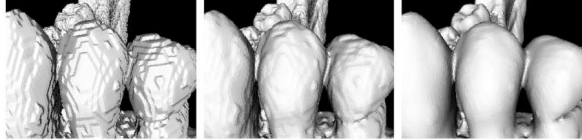


Fig. 6. Different iterations of `vtkSmoothPolyData` Filter.

Another Mesh oriented filter we have tested is `vtkSmoothPolyData` filter. This filter adjusts point coordinates using Laplacian smoothing. Similarly to the previous filter the effect of the filter is to relax the mesh, making the cells better shaped and the vertices more evenly distributed. The main parameter to be set is the relaxation factor which controls the displacement of each vertex during each iteration, see Figure 6.

3 Results

Proposed method was tested on 12 datasets of different resolutions and acquired by different CT devices. High-quality mandibular structures segmentation was obtained by all datasets, with accurate definition of the bone contours and removal of undesired objects. An average computational time of 10s per dataset is achieved on a standard PC (Intel Pentium 3.40GHz with 1GB of RAM). The resample filter allows to improve the calculation time by a factor of 4.74, while preserving a reasonably good quality of the image. Related with Surface Smoothing the `vtkSmoothPolyDataFilter` is definitely faster than all the others filters. Moreover, it provides a good approximation of the surface if the parameters are well set. The second interesting filter is the `vtkWindowedSincFilter` that is more powerful and closer to the original surface but it takes more time calculate the smoothed mesh. A good compromise for real medical application would be to use the `vtkSmoothPolyData` filter as the default one and use the `vtkWindowedSincPolyDataFilter` as an option to optimize the final surface.

4 Conclusion and Perspectives

We propose a method for reconstructing mandibular structures from CT-data images. The results of our automatic segmentation and reconstruction process

has obtained good results for all tested dataset. The computational time is mainly less than 10 seconds, which is a very promising result for a computer-assisted system without any interaction of the user. Automatic segmentation results are correct and execution time is moderate in a common PC. Moreover, this process must be accomplished only once. We are planning to extend current approach in order to be able to automatically segment other structures, such as dental nerves or teeth. Moreover, we want to extend the proposed method to be used in cone beam computed tomography (CBCT). It is known that these type of devices have higher and isotropic spatial resolution than conventional CT scanners, but higher noise, i.e, lower signal to noise ratio due to the low exposure. Therefore, other additional processing should be added to the proposed method, in order to accurately segment mandibular structures in noisier images such as those acquired with a CBCT scanner.

References

1. Otsu N.: A threshold selection method from gray-level histogram. *IEEE Trans. Syst. Man Cybern.*, Vol.9: 62-66, 1976
2. Enciso, R. Memon, A. and Mah, J.: 3D visualization of the craniofacial patient: Volume segmentation, data integration and animation. *Proceedings of the Conferences on Orthodontics Advances in Science and Technology*, 2002.
3. Lobregts, S.: Dental implant surgery: planning and guidance. *Medicamundi Vol.4*: 30-35, 2001.
4. Tognola, G. Parazzini, M. Pedretti, G. Ravazzani, P. Grandori, F. Pesatori, A. Norgia, M. and Svelto, C.: Novel 3D reconstruction method for mandibular distraction planning. *IST 2006 - In Proceedings Of International Workshop on Imaging Systems and Techniques*, 82-85, 2006.
5. Tognola, G. Parazzini, M. Pedretti, G. Ravazzani, P. Svelto, C. Norgia, M. and Grandori, F.: Three-dimensional reconstruction and image processing in mandibular distraction planning. *IEEE Transactions on Instrumentation and Measurement*, Vol.55(6): 1959-1964, 2006.
6. Lamecker, H. Zachow, S. Wittmers, A. Weber, B. Hege, H.-C. Isholtz, B. and Stiller, M.: Automatic segmentation of mandibles in low-dose ct-data. *International Journal of Computer Assisted Radiology and Surgery*, Vol.1: 393-394, 2006.
7. Krsek, P. Spanel, M. Krupa, P. Marek, I. and Cernocho, P.: Teeth and jaw 3D reconstruction in stomatology. In *Medical Information Visualisation - BioMedical Visualisation*, Vol.1: 23-28. *IEEE Computer Society*, 2007.
8. Gonzalez, R. C. and Woods, R.E.: *Digital Image Processing 2nd Edition*. Prentice Hall, New Jersey, 2002.
9. Taubin, G. Zhang, T. and Golub, G. H. Optimal Surface Smoothing as Filter Design. *Proceedings of the 4th European Conference on Computer Vision*, Vol.1: 283-292, 1996
10. Hashimoto, K. Kawashima, S. Araki, M. Iwai, K. Sawada, K. and Akiyama, Y.: Comparison of image performance between cone-beam computed tomography for dental use and four-row multidetector helical CT. *Journal of Oral Science Vol.48*: 27-34, 2006
11. Insight Toolkit(ITK), <http://www.itk.org>
12. Visualization Toolkit(VTK), <http://www.vtk.org>