Interactive segmentation techniques of volume data sets using CT medical image sequences

S. Zimeras*[1] & G. Karangelis[2]

[1] University of the Aegean, Samos
[2] Medintec GmbH, Germany

Abstract

Image segmentation, is an essential step for many advanced imaging applications. Accurate segmentation is required for volume determination, 3D rendering, radiation therapy, and surgery planning. A problem, that occurs is that images are either over-estimated, with objects divided into parts or images are incorrectly segmented, with or more objects segmented as one object. An obvious direction, is the use of the manual methods. In this work we will present an effective semi-automatic method, based on the boundary tracking technique (Carlbom *et al.*, 1994), that improves the time when one or more structures are in use. The implemented algorithms can segment within a few seconds the complete volume of specific organs e.g. lungs, skin, spine. The only interaction of the user is to select the starting point in the region of interest and the algorithm will track the object boundaries in 3 dimensions. The above tool is already in use and involves applications of the InViVo family in ultrasound diagnostic imaging, interstitial brachytherapy and virtual simulation of external beam radiotherapy.

1 Introduction

Classically image segmentation denotes the technique of extraction of images structures (regions or objects) so that the outlines of these structures will coincide as accurately as possible with the physical 2D object outlines. Image segmentation approaches may be performed in one of these ways: **Manual segmentation methods** include pixel selection, geometrical boundary selection and tracing. Given normal image resolution, selection of individual pixels is clearly impractical and rarely used. **Fully automatic segmentation methods** are usually impractical due to image complexity and the variety of image types and interpretation. In addition, low contrast between structures generally causes many times robust automatic algorithms to fail. **Semi-automatic segmentations methods** combine the benefit of bath manual and automatic segmentation techniques. By supplying initial information about the region of interest, the user may guide an otherwise automatic segmentation procedure. Any remaining errors introduced by automatic segmentation methods may be corrected by manual editing. In this work, **a boundary tracking algorithm** (Karangelis *et al.*, 2001) was implemented for the segmentation part

2 Boundary tracking algorithm

Boundary tracking technique (BT) is a segmentation method that given one point along a region's boundary follows the boundary around the region until it returns to the original point. Assuming a constant boundary, this allows for considerable variation within the region without any effect on the segmentation. The advantage of the approach is that no assumptions need be made a priori about the boundary shape, which may vary from a straight line too much more complex shapes which are difficult to parameterize. First let us assume that the image with regions is either binary or that regions have been labelled using a specific threshold (white for the organ of interest, black for the background). The algorithm starts with an initial point. Different starting directions are defined until a sharp edge was found. Each boundary was tracked, keeping to the right part consistently. The tracking procedure stops only when all the boundary regions has been scanned. The algorithm traces the edges with detail providing high accuracy to the description of the contour shape. However, the final contour shape contains sharp edges giving an uncomfortable optical effect. Therefore, we decimate the original number of contour points about 40%, smoothing simultaneously the contour edge. The main drawback of the BT, is that is a binary approach and hence is very sensitive to gray value variations. If the threshold value is not selected properly then the system will fail to detect the appropriate organ shape. Most of the inaccuracies of the segmentation method require the user intervention to optimize the result. To overcome the limitation we calculate a secondary opacity volume from the original CT data based on the well-known approach from Levoy et al. (1988), that is very often used to visualize surfaces from scalar volume data in volume rendering.

3 Volume definition tools

Target volume and critical structure definition is a complex and time-consuming process in radiotherapy. The complexity varies for different anatomic sites. In CT-simulation and plan evaluation, both the physicists and radiation oncologists interact closely to subjectively identify the plan most appropriate for the individual patient. In order to reduce the investment of time and effort by the radiation oncology staff, several image analysis tools are integrated. The system allows the user to draw contours around the tumor, target and normal tissues on a slice-by-slice basis and provides, at the same time, a cross-reference to planar images. A function that significantly accelerates the contouring process is the linear interpolation between the original key-contours. The same principle ca be applied for defining structures in both planar planes, sagittal and coronal. The contour edit functions allow the user to move, scale and rotate an entered contour in addition to providing tools for rapid contour corrections and copying to inferior and posterior slice. Organs with large differences in there intensities can be segmented semi-automatically. In terms of user effort the only action required from the user is the selection of an initial point from the algorithm on the original axial slices. The complete 3D geometry of the organ will be traces automatically. Some of the common organs with high sensitivity factor and vital importance are the lungs, the spinal cord and the trachea (Zimeras and Karangelis, 2001; Karangelis and Zimeras, 2002a,b; Zimeras *et al.* 2002). In addition to those organs, the external body contour can be extracted in a similar manner. The contours that are generated semi-automatic can be manipulated and modified at the same manner as those defined manually. The user has the possibility to reconstruct the segmented organs as volumetric structures on the Beam's Eye View (BEV) and Observer's Eye View (OEV) images.

4 Computer assisted segmentation tool

The proposed contouring methods have been applied for a CT tomographic sequence of 8 bit gray scale images of a size 512x512 in which change the shape, and the orientation of the objects. For the visual comparison of the semi-automatic techniques, the EXOMIO virtual simulation package was used. Our CT-Simulator, can run on any low cost PC system under Windows NT or Windows 2000 operating system. The main part of the software is a 3D visualization system of medical volume data that has been developed over several years in Fraunhoder-IGD.

Due to the system design no special graphic card is needed and unlimited amount of volume data, in our case CT, can be imported into the system. This is an important issue since CT-Simulators must be able to handle large data sets, from 40 up to 150 slices, in order to produce high quality rendering images. The data used in this work have been acquired with a Siemens Somatom Plus-4 CT scanner, but the system can connect via network directly to any CT scanner that support DICOM-3 communication protocol. EXOMIO can display the imported volume data as original 2D CT scans, as orthogonal or oblique reconstructed planes.

For the segmentation process the contouring facilities includes: (1) Multi-organ contouring (up to 7 organs); (2) Contour definition in axial, coronal and sagittal planes; (3) Volume extraction from only three perpendicular contour planes (orthogonal interpolation); (4) Automatic extraction of the planning target volume from the gross or clinical target volume by applying 3D or 2D isotropic margins. Additionally the user can implement manual and semi-automatic segmentation. For the manual segmentation a discrete sampling approach is used; this approach is more precise and simpler to implement and because accuracy is a priority in medical images, the manual tracing algorithm incorporated into EXOMIO samples vertices directly. In order to speed the discrete contour drawing mode, the user may draw a smaller number of key contours on distinct slices while the intermediate contours are interpolated linear.

5 Discussion

The advantages of CT-based virtual simulation are well known and include the fact that target volumes, critical organs and structures can be effectively defined and displayed in multiple image planes (axial, coronal sagittal or oblique). Improved manual and automated contouring tools greatly simplify normal critical structure, tumor and target volume delineation. A direct interface to the treatment planning system permits efficient virtual verification. In CT-Sim is possible to display more information on the same screen such as (a) the beam's eye-view, where the Digital Reconstructed Radiograph is displayed, (b) the room view including a 3D model of the simulation or the treatment machine and (c) the observer's eye view, where the 3D surface reconstruction of the patient is shown. These images offer the user an overview of the simulation and treatment planning process. Furthermore, in virtual simulation one can observe larger parts of the patient's volume than on the conventional simulator where fluoroscopy is limited by the dimensions of the image intensifier (detector). According to our clinical experience the CT-Sim system could simulate all of the treatment cases, replacing completely the real simulator. The CT-Sim system has been easily integrated into our clinical radiotherapy routine. The modification required in the CT room was the installation of the laser installation in LINAC room. In addition, the flat CT table-top had to replace the original curved table-top.

Visualization of multileaf collimator (MLC) field is only possible with CT-Sim and this is most important because of widespread use of MLCs. CT-Sim also makes it possible, without the patient needing to be recalled, for verification to be repeated after changes to the treatment plan. Indeed, CT-Sim may eliminate the requirement for a conventional simulator for several treatment sites. All the main features of the classical simulator are available, software based, in EXOMIO. The validation of beam geometries in a classical simulator is only based on X-ray contrast between tissues of different densities such as bone, lung or a contract filled organ such as the bladder. In particular, CT based simulation enables accurate delineation of multi-field geometries, all necessary field matching and multi-planar field adaptation as shown in our results. These functions are not possible with classical simulation. In addition the CT based virtual simulation brings benefit for patient scheduling because it avoids the often experienced bottlenecks in patients workload flow within a department of radiology oncology. Finally 3D visual representation of the particular organ, in addition with the clinical examinations, could be a powerful tool to the doctors for diagnosis, medical treatment or surgery.

Acknowledgements: The authors would like to thank Prof George Sakas for the useful scientific help and comments about the progress of this work. Also many thanks to MedCom Company and Stadtishes Klinikum Offenbach whom provide equipments and medical data sets for the implementation of the above work. Finally the authors would like to thank the E.C. and the Marie-Curie Fellowship Association for this great opportunity to work with different people. This work was supported by a Marie-Curie Industry Host Fellowship Grant no: HPMI-CT-1999-00005.

References

I. Carlbom, D. Terzopoulos, and K. Harris (1994). Computer-assisted registration, segmentation and 3D reconstruction from images of neuronal tissue section, *IEEE Trans on Medical Imaging*, **2**, 351-362.

G. Karangelis and S. Zimeras (2002a). An accurate 3D segmentation method of the spinal canal applied on CT images *BVM 2002, Conference Proceedings, Springer-Verlag, Berlin, Germany, 366-369*

G. Karangelis and S. Zimeras (2002b). 3D segmentation method of the spinal cord applied on CT data, *Computer Graphics Topics, Vol 14, 28-29.*

G. Karangelis, S. Zimeras, E. Firle, Min Wang and G. Sakas, (2001). Volume definition tools for medical image applications, *4th MICCAI International Conference, Utrecht, Netherlands, M-A. Viergever, T. Dohi, M. Vannier (eds), Springer-Verlag, Lecture Notes in Computer Sciences 2208, 1295-1297.*

M. Levoy et al.(1988). Display of surface from volume data. *IEEE CGA*, **8**.

S. Zimeras and G. Karangelis, (2001). Semi-automatic segmentation techniques for CT medical data, *3d Caesarism Computer Aider Medicine, Bonn, Germany*

S. Zimeras, G. Karangelis and E. Firle (2002). Object segmentation and shape reconstruction using computer-assisted segmentation tools, *Medical Imaging 2002, San-Diego, USA.*