Proceedings of Virtual Concept 2006
Playa Del Carmen, Mexico, November 26th – December 1st, 2006

3D Polygonal Models from CT Data for Medical Planning

Felix G. Hamza-Lup[1], Dan Lipsa [2]

(1) : Computer Science
Armstrong Atlantic State University
E-mail : felix@cs.armstrong.edu

(2) : Information Technology
Armstrong Atlantic State University
E-mail : dlipsa@cs.armstrong.edu

Abstract: As radiation treatment/surgery becomes increasingly available at various medical centers around the world, it becomes also the preferred choice for tumors treatment. Planning is a crucial part of the process because it can detect collisions between various components of the hardware delivering the radiation and the patient. Simulated planning requires a 3D model of the patient. This paper reports on the design and implementation of an on-the-fly conversion system of the patient CT (Coherent Tomography) data into a 3D representation. This work is complementary to the goal of creating a real-time 3D graphical simulator for an advanced radiation therapy/surgery system that improves the planning process supporting the decision making process as well as innovation in medical planning.

Key words:3D Modeling, Medical Planning, Radiation Therapy

1- Introduction and Background

Imaging techniques have become an important aid to diagnosis in the practice of modern medicine. Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) use a sampling or data acquisition process to capture information about the internal anatomy of a living patient. While the information is currently analyzed in 2D, with the advance of 3D displays, 3D models find an increasing number of applications into the medical field.

We are focusing on a medical subfield: radiation therapy. Radiation therapy is the careful use of high-energy radiation to treat cancer. A radiation oncologist may use radiation to cure cancer or for palliative purposes. About 50 to 60 percent of cancer patients are treated with radiation at some time during their disease [SN1]. Radiation destroys the ability of cancerous cells to reproduce, and the body naturally gets rid of these cells in time. A cancer patient may be treated with radiation alone (e.g. prostate cancer); however, sometimes radiation therapy is only a part of a patient's treatment. Patients can be treated with radiation therapy before surgery, enabling a less radical surgery than would otherwise be required.

Radiation therapy, involves sophisticated machinery as well as careful planning. Interactive Virtual Reality (VR) simulation combined with accurate 3D patient data obtained from CT scans and MRI will improve the planning process saving time and resources in generating the optimal treatment plan. The VR simulation helps in detecting collisions between various components of the machine delivering radiation. An accurate 3D model of a patient will enable detecting collisions between a machine delivering radiation and the patient, improving the radiation planning process.

Our focus is the design and implementation of an on-the-fly conversion system of the patient 2D CT into 3D polygonal models. This work is complementary to the goal of creating a real-time 3D graphical simulator for an advanced radiation therapy/surgery system [HD1] that improves the planning process showing how virtual reality can be used to support the decision making process as well as innovation in medical planning.

The paper is structured as follows: Section 2 provides the details of the CT to 3D data conversion. In Section 3 we present some of the open problems still under consideration and we conclude with future work in Section 4.

2- Patient 3D model from CT data

The issue we address is converting real-patient data to a 3D model to be embedded in a VR simulation. We convert on-the-fly a set of CT scans of a patient to a polygonal model of his/her body. The set of CT scans are stored using the Digital Imaging and Communication in Medicine (DICOM) standard (Fig. 1).

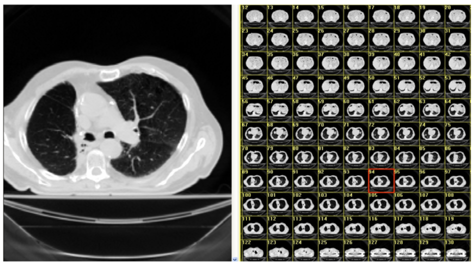


Fig. 1 Patient Torso CT Data Set (133 images)

As opposed to other types of image files, the DICOM file standard contains slice resolution, slice spacing and pixel size, all useful parameters in producing a realistic 3D polygonal model of a patient.

We process CT scans using algorithms from the Visualization Toolkit (VTK) [SM1], a software system for 3D computer graphics, image processing and visualization. The first processing step is to select from CT scans a volume that eliminates the table on which the patient is positioned. This operation reduces the number of polygons obtained in the final 3D patient model.

We apply the marching cubes algorithm [LC1] with a value that selects the isosurface of the patient's skin. We used the same value for the skin as in [L1]. The marching cubes algorithm checks if the corner values of a cube are above or below the isosurface value. If some corner values are above and some corner values are below then the isosurface obviously intersects the cube, and we can compute the intersection polygon by using a lookup table. The lookup table provides a very fast way to find the edges intersected by the isosurface based on what corners values are above and below the isosurface. The application of the marching cubes algorithm produces a polygonal model that includes the skin of the patient as well as internal organs (since the skin has the same pixel intensity as some internal organs in a typical CT scan). We have applied the marching cubes algorithm on a set of 133 CT scans of a patient torso. The number of polygons obtained (approximately 500,000) is to high for an interactive VR environment and since further optimizations are possible we decided to further reduce the number of polygons. We apply a decimation operation [SZ1] which reduces the number of polygons to approximately 100,000. Decimation works by evaluating the distance between each point and the average plane of the triangles using the point. If that distance is small, the point and all triangles using it can be deleted. Obviously the "hole" left has to be re-triangulated. Once re-triangulation is accomplished we apply a Laplace smoothing operation [F1] that modifies the position of each vertex to be an average of the neighboring vertices. We transform the polygons in triangle strips, obtaining about 30,000 triangle strips. At this stage the polygonal model still contains some internal organs of the patient as well as CT scan artefacts.

To obtain a "clean" polygonal model that contains only the skin of the patient (since we are interested in visual collision checks between the hardware and the 3D patient model in the VR simulation) we apply a polygon connectivity filter that further reduces the number of triangle strips to about three thousands. A challenge in applying polygon connectivity algorithm is specifying the connected surface. Choosing the maximum connected surface isolates the skin of a patient in most cases however in some situations pixels with same intensity are extracted from inside the volume. The result is illustrated in Fig.2.

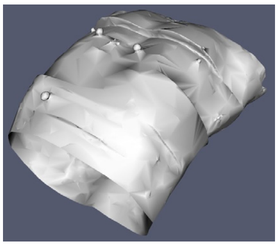


Fig.2 Torso Skin Model (3D) from CT Scans

In other situations, we need to explicitly specify the connected surface. For instance, the maximum connected surface might isolate internal organs instead of the skin or we might have two surfaces we are interested in, as it happens in the case of a concave object scan (e.g. through the legs of a patient).

2.1 Image Seed Connectivity Algorithm

A solution to the connected surface selection problem is to process CT images through an image seed connectivity algorithm. First we use a threshold algorithm that sets to zero all values less than the threshold (the skin CT value) and sets to 255 all values greater or equal to the threshold. This ensures that all values that are initially less than the threshold are set to zero. Image seed connectivity algorithm sets to zero all pixels connected to the user supplied seeds (which we set to the corners of the image) and it sets to 255 all other pixels. We consider all pixels with value zero that are connected to the seeds. This algorithm sets to zero pixels that are outside of the patient and it sets to 255 pixels that are inside. After this processing we can apply the algorithms in the previous section starting with marching cubes.

The solution is not perfect because wood grain artefacts can be seen in the generated image. The reason for those artefacts is that image seed connectivity algorithm changes the values of the pixels in the CT scans. So, when intersection points between the skin isosurface and a cube are calculated by the marching cubes algorithm, those are always going to be in the middle of the edges instead of the correct interpolated position. An image produced by inserting threshold and image seed connectivity algorithms before marching cubes is illustrated in Fig.3.

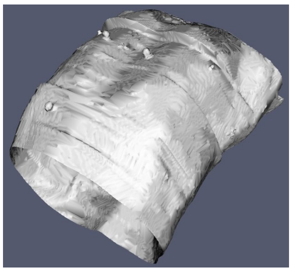


Fig.3 Torso Skin Model (3D) Using Image Seed Connectivity

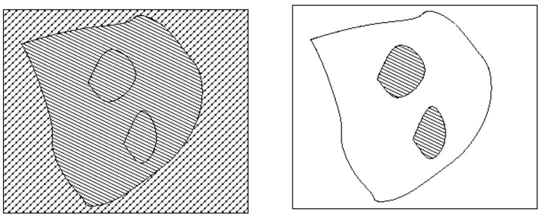
One can observe the surface of the 3D torso skin model from Fig. 3 is not as smooth as in the torso in Fig. 2., however the procedure for obtaining it is automatic.

2.2 Conversion Process Improvement

In automating the process of CT to 3D conversion two problems arise. The first one is eliminating from the CT scans the table on which the patient is positioned and the second is eliminating the wood grain artefacts which appear because of the threshold and image seed connectivity algorithms.

To solve the first problem we are investigating a generic image segmentation algorithm since the pixels intensity will be constant in all CT scans and the pixel dimension of the edge of the scan table is known.

A solution for the second problem is to modify the image seed connectivity algorithm in the following way: lets consider all pixels connected to the seeds that have value less than the threshold to be outside of the patient; we set to a maximum value all pixels not connected to the seeds that have value less than the threshold (see Fig 4b). Fig. 4a corresponds to our current processing, which sets all pixels outside a patient to a minimum value and all pixels inside a patient to a maximum value.



(a) (b)

Fig. 4 Seed Connectivity Algorithm Modification

The procedure eliminates internal organs from our 3D model. As a side effect however it also changes the values that determine the isosurface. In Fig 4b only pixels less than the threshold inside the patient are set to a maximum value. This enhanced procedure also eliminates pixels from the internal organs of the 3D volume but does not change the values of pixels that determine the skin isosurface.

3- Discussion, Open Problems

We have access only to CT scans from parts of the patient body (usually the part of the body that needs to be treated). What about the rest of the patient body?

An open problem is the generation of the full 3D patient body from incomplete CT data. In forensic science for example, the height and weight of a person can be deduced by analyzing the properties of the hip bones. Similarly, statistically analyzing the incomplete CT data we might be able to generate a 3D patient model that closely resembles the real patient. The full body 3D model could also be obtained by scaling a generic patient model based on the partial information from patient specific CT scans.

The importance of having these skin (surface) 3D models for medical applications is proven by the emergence of state of the art systems in the industrial sector. Vision RT™ [BM1] for example provides a means to extract in real-time surface info using a camera-pattern projector pair. We are currently investigating the possibility of embedding real time data into our VR simulator. However having deformable models in the simulation will significantly degrade the rendering performance and would be divergent to our ultimate goal of providing a web-based distributed VR simulator for medical physicists and practitioners.

4- Conclusion and Future Work

We presented a few insights of the automatic conversion of CT scan data to a 3D model of a patient. The next step is the combination of the 3D data into a VR web-based simulator using the X3D standard [WD1]. Our ultimate goal is to advance the quality of the radiation therapy process and consequently improve cancer patients' treatment and recovery.

5- Acknowledgements

We would like to thank Omar Zeidan at M. D. Anderson Cancer Center Orlando for his support related to the research.

6- References

[BM 1] Bert C., Metheany K., Doppke K., Taghian A., Powell S.N., Chen G.T. *Clinical experience with a 3D surface patient setup system for alignment of partial-breast irradiation patients*. Intl. J. of Radiation Oncology Biology Physics: 64(4):1265-1274, 2006.

[F1] Field D. A., *Laplacian smoothing and Delaunay triangulations*. Comm. in Applied Numerical Methods, (4):709-712, 1988.

[HD1] Hamza-Lup F., Davis L., and Zeidan O., *Web-based 3D Planning Tool for Radiation-Therapy Treatment*, Web3D 2006: 11th Intl. Symp. on 3D Web Technology, 2006.

[L1] Lorensen B., *Make Your Own Visible Woman*, Online www.crd.ge.com/esl/cgsp/projects/makevw, 2006.

[LC1] Lorensen W.E. and Cline H. E., *Marching cubes: A high resolution 3D surface construction algorithm*, SIGGRAPH '87: Proc. of the 14th Conference on Computer Graphics and Interactive Techniques, 1987.

[SM1] Schroeder W.J., Martin K. M., and Lorensen W.E., *The design and implementation of an object-oriented toolkit for 3D graphics and visualization*, Proc. of the 7th conference on Visualization '96, San Francisco, 1996.

[SN1] S. o. N. A. Radiological. *Radiation Therapy*, vol. 2006: Radiological Society of North America, Inc., 2006.

[SZ1] Schroeder W.J., Zarge J.A., and Lorensen W. E. *Decimation of triangle meshes*. Proc. of the 19th Conference on Computer Graphics and Interactive Techniques, 1992.

[WD1] Web3D Consortium, *What is X3D?*, vol. 2006, W. D. Consortium, Ed., 2006.